Towards a Waste Free Future

TECHNOLOGY READINESS IN WASTE AND RESOURCE RECOVERY

Australian Academy of Technology & Engineering

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WASTE & RESOURCE RECOVERY

Report of a study by the Australian Academy of Technology and Engineering (ATSE)

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This report is dedicated to the memory of Ron Hardwick FTSE

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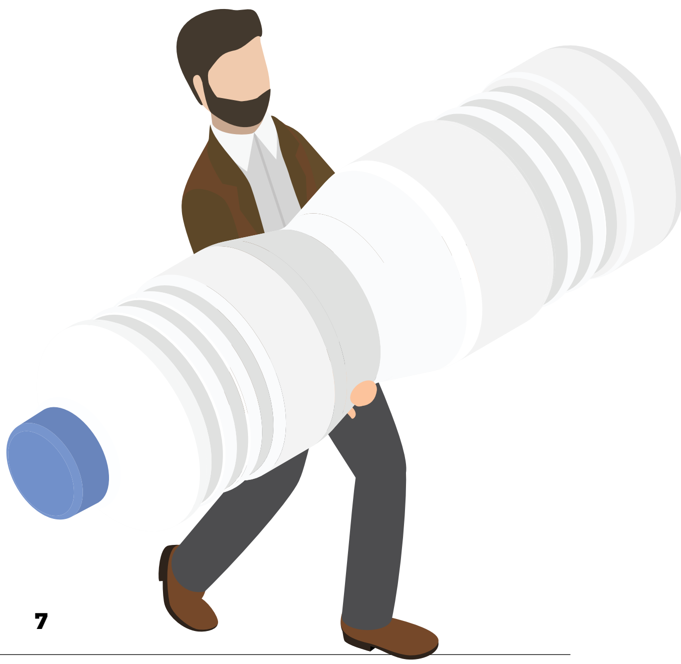



Australians create
2.7 tonnes of waste
per person per year

Executive summary

Australians create around 67 million tonnes of waste each year, which equates to 2.7 tonnes per person.[1] As our population increases, we generate more waste. New products and technologies are changing the way we use resources and manage materials. Supply chains and international markets are also changing, meaning more of our waste products and materials need to be processed in Australia. We need to do this efficiently and productively, and reduce the amount of material that goes to landfill. The need to transition Australia towards a more circular economy is now critical. Prolonging the life, functionality and value of products, components and materials will be key to achieving this.

A circular economy is regenerative by design and aims to gradually decouple growth from the consumption of finite resources.

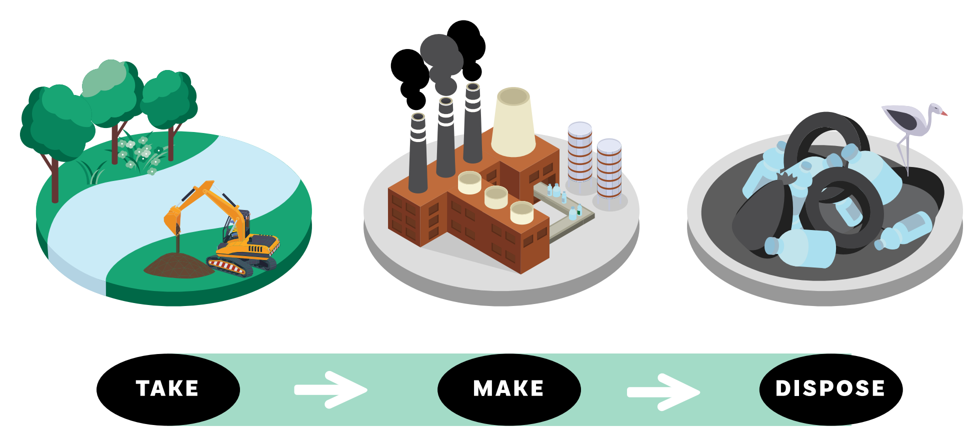
Ellen MacArthur Foundation[2]

The linear 'take, make, use and dispose' approach of global production and consumption — the driving force of today's global economy — is unsustainable. In 2017, 92 billion tonnes of resources were extracted globally, but only 8.6 billion tonnes were recycled — less than 9%.[3] If the current trajectory is maintained to 2050 we will need the equivalent of almost three planets to produce sufficient resources to satisfy global human consumption.[4]

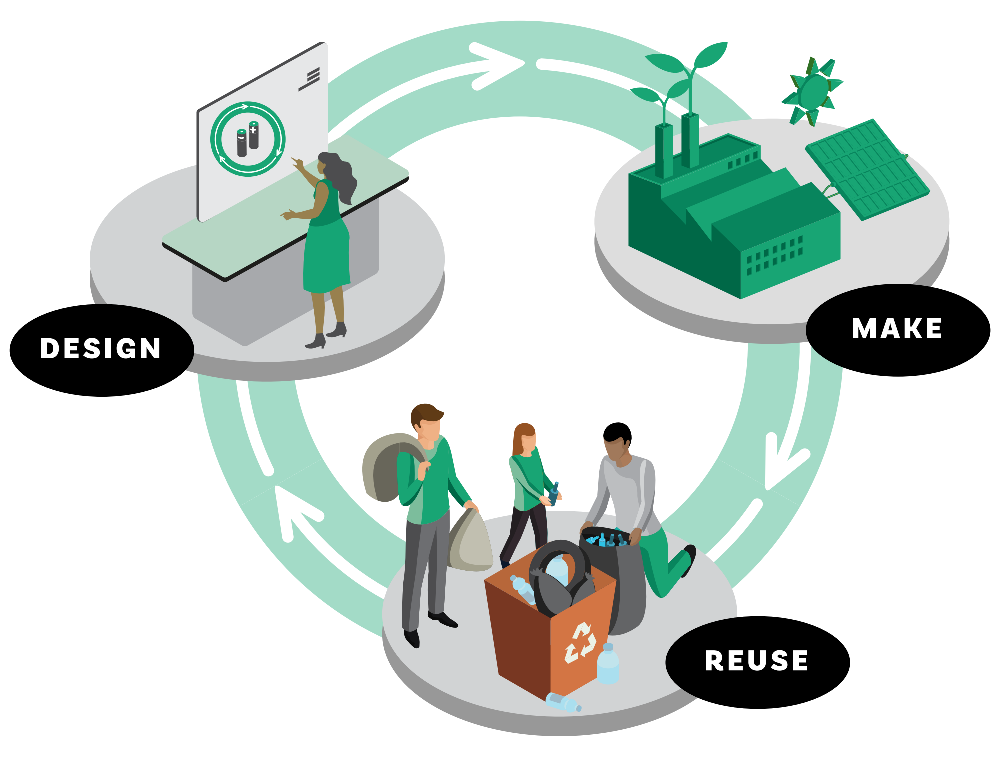
Humanity needs to reduce the consumption of finite resources by deliberately designing products, systems and infrastructure with the aim of creating less waste — and by reusing, recycling and recovering valuable resources. By changing the linear model of consumption to a more circular model, we can shift to a more sustainable course in which production continues to meet demand, supporting economic productivity while reducing our impact on the environment.

The economic argument for circular economy principles is well-established, driven by efficient resource use. New jobs are created, particularly in small and medium enterprises (SMEs), through increased innovation and entrepreneurship, and a growth in service-based work.[2] Circular approaches perform better in metrics based on the traditional triple bottom line (financial, environmental and social) in addition to supporting incidental benefits associated with increased collaboration, connectivity and improved supply chains between industries.

EXISTING THINKING — linear economy



NEW PARADIGM — circular economy



It is clear that moving to a more circular economy would have enormous benefits for Australia. It has been estimated that just a 5% increase in material efficiency in Australia could produce a $24 billion increase in the economy.[5] Currently we recover just 58% of materials that enter our waste streams — leaving about 27 million tonnes to go to landfill.[1] For every 10,000 tonnes of waste that is recycled, 9.2 jobs are created (compared with 2.8 jobs if the same amount of waste was sent to landfill).[6,7] The opportunity this represents for industry growth and job creation is enormous. Simplistically — if all the material currently wasted was to be recycled, this could create 35,000 jobs. One of the biggest challenges in the waste and resource recovery sector, however, is the lack of timely, accurate and consistent data. Estimations and outdated data make it difficult to quantify the opportunities and barriers for the sector.

The Australian Academy of Technology and Engineering (ATSE) sees enormous potential for technology to positively disrupt the waste and resource recovery sector in Australia, and support the transition towards a thriving circular economy.

ATSE is a Learned Academy of independent experts helping Australians understand and use technology to solve complex problems, including how to achieve sustainable development and advance prosperity. We bring together Australia's leading experts in applied science, technology and engineering to provide impartial, practical and evidence-based advice.

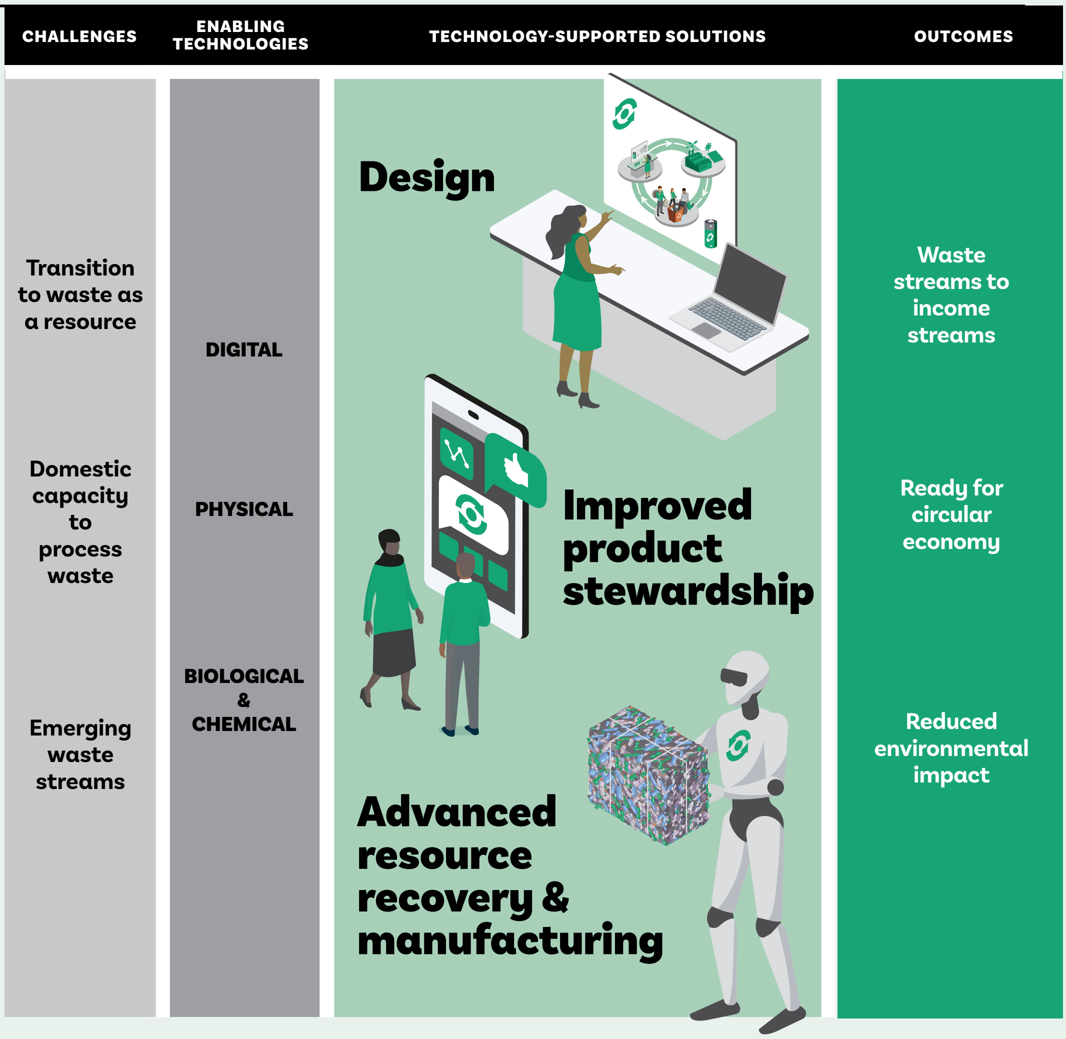
In this report, ATSE examines the readiness of the Australian waste management and resource recovery sector to adapt, adopt, or develop technologies to meet the challenges it will face in the decade to 2030, and identifies key actions to remove barriers and capitalise on opportunities. The overarching principles of the report are that materials have value at all stages of their lifecycle, and that Australia has a strong opportunity to maximise the value of materials in our manufacturing, retail and waste ecosystem for the benefit of the economy, society and environment.

This report is framed according to the waste management hierarchy, and presents concrete, technology-supported steps to shift Australia's economy, with an emphasis on avoiding waste creation, and re-using materials where avoidance is impossible. It proposes much-needed solutions focused on waste avoidance and reusable products — so that the majority of materials never even hit the waste stream. For those that do, we propose the employment of cutting-edge (and existing) technology to divert materials back into the economy at the highest possible value, turning Australia's waste streams to income streams, reducing environmental impact and stepping Australia towards a waste free future.

This report is part three of a major research project, supported by the Australian Research Council, identifying research and policy priorities to ensure Australia's technology readiness. The series is building a 10-year roadmap to prime Australian industry to maintain currency through technological change, and fully integrate new technologies to maximise economic advantage as well as social and environmental resilience. It highlights research priorities to guide decisions and ensure investment is appropriately focused to promote Australian industry competitiveness.

Technology is not the only solution, but it can support and guide systemic change. Data will continuously inform innovative design to avoid waste, and create more durable products that are reusable, repairable, and able to be remanufactured or disassembled once they reach the end of their usable life. Improved product stewardship will be underpinned by data and information systems, helping to track products and support consumers and investors to make decisions to avoid waste. Innovation in technology and engineering will help Australia improve our resource recovery, increasing the productivity of our resources and turning our waste material streams into income streams. Creation of innovative products will also create market demand for recycled products, generating new industries and jobs. Data and information will underpin the ecosystem, create a feedback loop for design and continuous improvement, make it easier to track our waste behaviour, and support informed decisions on an ongoing basis.

FIGURE 1
ATSE Project Framework — Technology readiness in the waste and resource recovery sector.



BENEFITS OF A CIRCULAR ECONOMY — SOUTH AUSTRALIA

South Australia has found that a more circular economy would deliver significant job creation and greenhouse gas reduction benefits compared to a 'business as usual' scenario for their state. According to Green Industries SA, this shift could:

- create an additional 21,000 full-time equivalent (FTE) jobs through material efficiency gains
- 4,700 FTE jobs through efficient and renewable energy gains
- reduce South Australia's greenhouse gas (GHG) emissions by 27% or 7.7 million tonnes of CO_2 equivalent.[8]

The current business model of the waste and resource recovery sector reflects Australia's linear economy and consumption model. This linear model does not preserve or increase the value of the materials. Given the lack of demand for non-virgin material in this model, the waste and resource recovery sector is challenged to recycle, repurpose or otherwise attempt to recover value from these materials.

Australia's domestic capacity to process all of our own discarded material requires attention following China's decision to cease importing Australian material and the Council of Australian Governments (COAG) agreement to ban the export of unprocessed glass, mixed plastics, whole used tyres, single polymer plastics, and paper and cardboard progressively from 2021.[9,10]

Almost all current recycling of masonry materials, organics, and glass recycling is undertaken in Australia, but in 2016-17, about 70% of plastic and 43% of paper and cardboard was exported for processing overseas.[11] In 2018-19, 4.4 million tonnes of waste was exported from Australia, including 1.4 million tonnes of waste plastic, paper, glass and tyres, representing 32% of total waste export tonnage.[12]

While this report is written with a global context in mind, its scope is limited to waste generated or managed in Australia. Its focus is guided by the findings of the *2018 National Waste Report*[11] and the volume and impact of waste it highlighted.

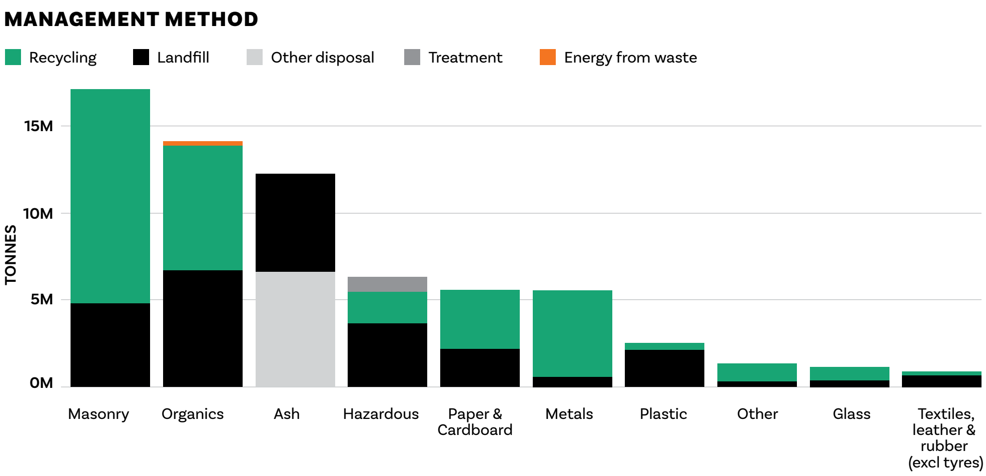


FIGURE 2
Generation and management of waste in Australia, 2016-17

Source: National Waste Report 2018

This ATSE report's central focus is on five key waste streams: masonry materials, organics, paper and cardboard, plastics and glass. These five waste streams are highlighted because these waste streams are generated in large volumes, or not yet recycled in high proportions. ATSE has also considered emerging waste streams such as e-waste, Li-ion batteries (LIBs) and solar photovoltaic panels (solar PV), as these streams are growing at an increasing rate with little planning in place for their end-of-life. End-of-life tyres are also included, given an upcoming ban on their export from Australia and our limited ability to process them onshore.

Ash has been excluded from scope because it is largely dealt with onsite. Hazardous waste has been excluded from scope because the stream is so complex and varied, it is impossible to address in a report of this nature. Metals have been excluded from scope because the majority are already recycled, and textiles are excluded because the volume of waste generated is relatively small.

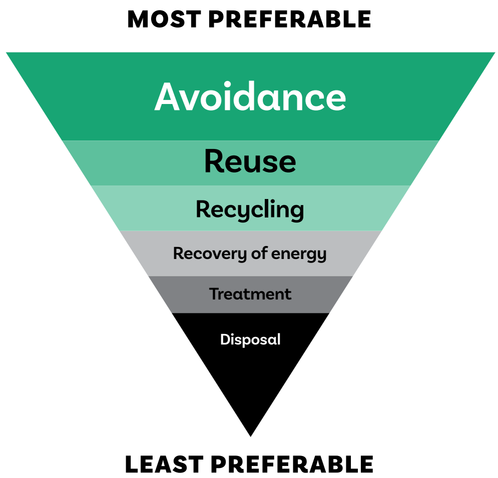
A growing renewable energy sector and digital economy bring with them e-waste, batteries, solar panels and wind turbine blades, all of which contain valuable recoverable materials. Currently, planning and infrastructure dedicated to their reuse or recycling are limited. These waste streams are growing exponentially, and are also more complex, containing rare metals and toxic materials in much higher quantities than current products.

To address these challenges, ATSE has surveyed existing and emerging technologies that could support the waste and resource recovery sector. ATSE examines how these technologies can be applied in three solution areas:

- **The role of design**
- **Improved product stewardship**
- **Advanced resource recovery and recycling**

These potential solutions follow the principles of the waste management hierarchy, reflecting the top four areas of avoidance, reuse, recycling and recovery. ATSE has not considered treatment and disposal in this report – although they are important in the waste management system, they do not contribute to the report's key objective of promoting the value in materials.

FIGURE 3
Waste management hierarchy
Source: National Waste Report 2018, Department of the Environment and Energy



ATSE conducted significant research and widespread consultations with stakeholders across Australia's waste and resource recovery sector, guided by an expert working group of ATSE's Fellows and industry and research experts, to rate each of the potential solution areas on five technology readiness parameters:

ATSE spoke with almost 100 stakeholders with an interest in waste and resource recovery, including from private enterprise, product stewardship organisations, industry peak bodies and associations, government stakeholders and researchers. A summary of results compiled from these consultations is presented below in Table 1 (page 16), and insights are explored in detail throughout this report.

Five key principles

ATSE's three solution areas are informed by the five key principles that Australia's National Waste Policy describes as underpinning waste management, recycling and resource recovery in a circular economy.[1]

1 Avoid waste.

Prioritise waste avoidance, encourage efficient use, reuse and repair.

Design products so waste is eliminated or minimised, they are made to last and we can more easily recover components and materials.

2 Improve resource recovery.

Improve material collection systems and processes for recycling.

Improve the quality of the recycled material we produce.

3 Increase the use of recycled material and build demand and markets for recycled products.

4 Better manage waste material flows to benefit human health, the environment and the economy.

5 Improve information to support innovation, guide investment and enable informed consumer decisions.

TABLE 1

Summary of ATSE's technology readiness assessment of the waste and resource recovery sector

SCALE	NOT READY	MORE WORK REQUIRED			READY
READINESS INDICATOR SCALE	○	◔	◑	◕	●

ASSESSMENT					
	Infrastructure readiness	Skills availability	Social readiness	Economic feasibility	Policy & regulatory readiness
Design	◔	◕	◑	◔	◔
Improved product stewardship	◑	◕	◕	◔	◑
Advanced resource recovery	◑	◕	◑	◔	◔

Overwhelmingly, stakeholders said that the availability of new and suitable technology in the waste and resource recovery sector was not the core barrier to technology uptake. Nor is workforce availability or skills, or societal readiness for change. The main challenge appears to be that Australia does not have the right economic, policy and regulatory frameworks to provide certainty and incentivise investment and innovation in a thriving waste and resource recovery sector.

Feedback from all parts of the sector is clear: economic and commercial feasibility and policy and regulatory readiness are the areas that require greatest improvement in order to enable the uptake and deployment of new technology for a waste free future.

There is also work to be done on maturing the sector's physical and digital infrastructure, which relies on the economic and regulatory settings for investment.

To create a thriving economy that values materials, Australia needs a national framework that includes long-term policy certainty, incentive-based measures, and consistency across jurisdictions and portfolios. The Australian, State and Territory governments must work together to lead a paradigm shift to waste avoidance, using targeted government investment and regulatory reform. Big data should be employed to inform decision-making, and a systems approach to resource recovery.

High scores in skills availability and social readiness suggest if these economic and policy frameworks are put in place, there is huge and immediate potential for innovation-driven growth in Australia's waste and resource recovery sector, which will generate new industries and jobs, and benefit the environment.

Based on our findings, ATSE has developed four key recommendations for focused, immediate, agenda-setting actions for government, industry and the research sector to employ technology to create a thriving and sustainable Australian circular economy, and work towards a waste free future.

Recommendations

RECOMMENDATION 1

A paradigm shift to design for waste avoidance

A paradigm shift in design principles can avoid creating waste altogether — designing a product to be reusable, to facilitate repair, upgrade, parts replacement, and trade-in for remanufacture.

Designers, manufacturers, retailers and consumers are faced with the reality that we must change consumption and waste habits, but inertia, policy uncertainty and market disincentives have led to slow progress. Government can tip the scales toward new and innovative business models, consumers can drive demand, and businesses must be required to shift.

To achieve this, ATSE recommends:

1. **The Australian Government accelerates the paradigm shift towards design for reduced waste by:**
   a. Targeting manufacturing grant programs and tax incentives toward innovative design for waste avoidance or minimisation (for example product as a service, and reusable products), and sustainable use of recycled content.
   b. Creating standards and certification systems for reused and remanufactured goods to build consumer confidence and promote the design of products with reuse and refurbishment in mind.
   c. Creating a legislated consumer right to repair products, starting with electronics.
   d. Ensuring all costs and regulations apply equally to imports and Australian products, to disincentivise 'free rider' or dumping behaviour.

2. **Manufacturers and retailers take advantage of circular economy principles to create more value from each unit of resource by:**
   a. Changing perspective to view waste as a design flaw, which if avoided will save material costs.
   b. Creating and marketing products as sustainable, high quality and durable, thus promoting these features to consumers as desirable characteristics.
   c. Designing products for recovery, and participating in product stewardship or extended producer responsibility schemes to retrieve valuable products and materials for reuse, remanufacture and sale of recovered materials.

3. **Research and development by Australian manufacturers and researchers prioritise alternative materials to make everyday products more durable, materials that can be sustainably produced, and innovative design for material and product reuse and remanufacture.**
   a. A co-operative research centre for advanced materials development could accelerate this work and provide new industries in Australia. More durable materials, self-healing materials, biodegradable materials and other innovative technologies could be commercialised and create an export industry.

4. **Consumers use their immense market power to demand quality, accountability and sustainable business practices from manufacturers and retailers.**
   a. Businesses provide transparent data and information about the sustainability and environmental impact of products and services, enforced by regulation if necessary.
   b. The Australian Government create national marketing campaigns aimed at changing consumer and industry behaviour to support the key principles of a circular economy.
   c. Social scientists prioritise research into measures to promote the integration of waste avoidance in consumer behaviour.

RECOMMENDATION 2

A systems approach to increase resource productivity and recovery

A systems approach acknowledges that all stakeholders in a product lifecycle have a role to play, facilitating greater resource productivity and creating demand for recovered materials.

A closed loop from design, to manufacture, retail, consumption and recovery has economic and environmental benefits for all stakeholders. Designers create efficiencies, manufacturers save on costs and expenditure on virgin materials, retailers can create customer loyalty through take-back schemes, consumers receive high quality products and services, and resource recovery is economic for the waste and resource recovery sector.

To achieve this, ATSE recommends:

1. **The Australian Government, in collaboration with State and Territory governments, sets an ambitious national resource productivity target — double by 2030.**
2. **The Australian Government sets basic design standards and specifications for Australian-made and imported products, requiring clear manufacturing specifications, including post-consumer recycled content.**
   a. These standards must be enforced through formal regulatory interventions, or bans of certain problematic materials.
3. **University curriculum includes exploration of how to measure full lifecycle impacts of products (including disposal), services, and infrastructure, and how to design to reduce these — particularly in engineering and industrial design.**
4. **Manufacturers adopt design principles of low material diversity, standard components, and non-destructive dismantling to reduce complexity and facilitate material recovery.**
   a. Product stewardship schemes to support and incentivise this shift, by facilitating resource recovery and enabling savings for manufacturers through reuse or sale of recovered materials.
   b. Plastics and packaging manufacturers to particularly focus on removing unnecessary complexities and using innovative labelling and sealing materials that reduce material diversity and thus facilitate efficient recovery.
   c. Designers and recovery facilities to collaborate on developing innovative methods to maximise the recovery of valuable materials in Australia.
5. **The waste and resource recovery sector, which has the assets and footprint to act as the supply chain in a circular economy, transitions towards supporting resource recovery, and material trading and product stewardship schemes.**
6. **Targeted grants and research funding to promote advances in reducing the energy usage of advanced resource recovery technologies, such as chemical recycling.**

RECOMMENDATION 3

Big data and analytics to inform decision making by policy-makers, businesses and consumers

Government and industry to leverage technology to improve information quality, quantity timeliness, and transparency.

Technology underpins decision-making by supporting the collection and analysis of vast amounts of data to inform design and product innovation, material and energy efficiency, maintenance cycles and end-of-life treatments. Big data analytics can also provide system level feedback on interventions to improve waste reduction, and measure progress toward targets. Collecting and sharing information, starting at the beginning of a product's life and throughout the stages of its use to the end of its first life, will inform better design, drive accountability, and greatly improve recovery and remanufacturing opportunities.

To achieve this, ATSE recommends:

1. **Interdisciplinary research into the potential and applications of smart systems and artificial intelligence in collecting, analysing, and learning from data about material flows.**

2. **The Australian, State and Territory governments accelerate and prioritise work on National Waste Policy Action 7.2,* to implement consistent national waste and material data and reporting, harmonised data classifications and definitions for reporting, and sharing arrangements across jurisdictions.**
   a. Data collection and sharing should be mandatory and transparent for manufacturers, waste and resource recovery businesses, and governments.
   b. Data collection and sharing should use the same meta-data parameters and units of measurement to support interoperability.

3. **Manufacturers and designers lead at-scale integration of technologies such as markers, sensors, and nanotechnology to facilitate the tracking of critical valuable materials from manufacturing to first use, re-manufacture and eventual deconstruction and reuse.**
   a. As these technologies reach scale, they should be leveraged to provide productivity gains and reduce regulatory burdens.

4. **The Australian, State and Territory governments work with the waste and resource recovery sector to make publicly available comprehensive, economy-wide and timely data to inform consumers, businesses and policy makers.**
   a. This information should be clearly available to consumers, for example through a database or labelling system, to provide information about the environmental and health impact of a product's lifecycle, promoting consumer awareness and sustainable consumerism.

** Commonwealth of Australia, National Waste Policy: Action Plan 2019. Accessed 12 October 2020.*
www.environment.gov.au/system/files/resources/5b86c9f8-074e-4d66-ab11-08bbc69da240/files/national-waste-policy-action-plan-2019.pdf

RECOMMENDATION 4

Targeted government investment and regulatory reform and policy certainty

A long-term policy and regulatory framework and targeted government investment will provide clear signals and create certainty for investment.

To achieve this, ATSE recommends:

1. **The Australian Government expands the $190m Recycling Modernisation Fund, adding a new stream and funding to target projects that address problematic waste streams and those with low levels of resource recovery — particularly soft plastics and organics.**
    a. The Australian Government to further set standards on the level and quality of resource recovery to be achieved through these grants, to ensure they are targeted at projects that will considerably accelerate Australia's ability to meet the National Waste Policy Action Plan's 80% resource recovery target.
2. **The Australian, State and Territory governments to drive demand for recovered materials in infrastructure, products and packaging, particularly those that are able to be processed back to virgin quality specifications, or can supplant virgin materials, by:**
    a. Amending regulations that classify high quality recovered materials as 'waste' to enable their incorporation into manufacturing, particularly packaging.
    b. Creating demand for recycled materials and de-risking infrastructure investment through mandated government procurement of recycled materials.
    c. Incentivise (including through the Modern Manufacturing Strategy) and support businesses to take materials out of the waste system as early as possible, or expand their use of recovered materials.
3. **State and Territory governments to drive economic demand and infrastructure investment in waste avoidance and resource recovery through:**
    a. Further landfill bans on problematic or high-value materials, such as unprocessed organic waste and e-waste.
    b. Ensuring landfill levies are set at a level that ensures recovery and sale of materials is competitive with disposal. Resultant levy funds should be invested in supporting innovative resource recovery projects.
    c. Investment in decentralised infrastructure to reduce the cost impact of distance, and create closed loops for distributed manufacturing in regional and remote areas.

Waste and resource recovery in Australia

MASONRY MATERIALS

Masonry waste contains mixed waste streams of asphalt, concrete, bricks, and rubble, as well as non-hazardous foundry sands, plasterboard and cement sheeting. It is largely derived from construction and demolition waste.

In 2016-2017, Australia generated 17.1 Mt of masonry waste, with a recycling and resource recovery rate of approximately 72% for mixed masonry waste.[11] This represents the second highest recovery rate of all waste streams in Australia, second only to metals.

Nearly all Australia's masonry recycling occurs onshore in materials recovery facilities (MRFs) that crush and extract aggregate and metals. The primary application for recycled masonry waste is in concrete aggregate as road base or hardstand, functioning to pack into a solid surface better than virgin aggregate. Other markets include the reuse of bricks, or brick-derived aggregates.

ORGANIC WASTE

Organic waste is any material which is derived from a natural or biodegradable substance, including food, garden organics, timber, and biosolids. Organic waste is the second largest waste stream in Australia by volume. In 2016-17 Australia produced 14.2 Mt of organic waste with a recycling rate of 52%.[11] Reducing and managing both gross and chemical contamination is the key issue to enabling higher rates of organics composting.[11] Additionally, as reported in 2018, 58% of Australian households have no access to kerbside collection of organic materials.[14]

When organic waste is buried, as in landfill, it undergoes anaerobic decomposition to produce methane and carbon dioxide, contributing about 2% to Australia's greenhouse gas emissions.[15]

Organic waste can be treated by anaerobic digestion (composting) to yield energy (biogas), water and fertiliser. Internationally, opportunities are being identified to add-value to organic waste by converting waste food into high value chemicals.

PAPER AND CARDBOARD

In 2016-2017, Australia produced 5.6 Mt of paper and card-board waste and had a recycling rate of approximately 60%.[11] Ninety-two per cent of local government authorities provide infrastructure for kerbside collection of paper and cardboard for households and small business.[11]

China's waste import restrictions have put pressure on Australia's onshore recycling infrastructure, as exports had accounted for around 43% of Australia's paper and cardboard recycling. The Australian Government has asked states and territories to partner with industry (and other states) to submit project proposals for new paper processing facilities.[16]

PLASTIC

In 2017-18 less than 50% of plastic put into the market was recovered in Australia – around 2.6 million tonnes.[17,18] Through the 2025 National Packaging Targets, Australian industry and government are working to ensure that 70% of plastic packaging is recycled or composted. Up to 70% of Australia's plastic waste had previously been processed offshore, but will shortly be banned from export.

Plastic waste is generally easy to separate and can be recovered in large volumes with relatively low contamination, making recycling and recovery of plastic one of Australia's highest potential industries. However, the current rate of contamination in the plastic waste stream is high, limiting its potential to date. As of 2018, only 10 Local Government Areas had municipal kerbside collections that can accept all types of recyclable plastic and plastic bags.[14]

GLASS

About 1.1 Mt of glass waste was generated in Australia in 2016-17.[11] Australia has reasonably high capacity for glass recycling, with approximately 57% of Australia's glass material recovered.[14]

Most recyclable glass material is sourced from co-mingled waste streams from either kerbside collection or through container deposit schemes. The material is then processed by one of Australia's six beneficiation plants in Melbourne, Brisbane, Sydney and Adelaide.[14]

Established markets exist for recycled glass, including construction aggregate, recycled aggregate in concrete, decorative glass aggregate, abrasives and filtration.[19] These are low-value products, however, and there is significant opportunity for further development of value-added products.

END-OF-LIFE TYRES

End-of-life tyres are those that are not reused or re-treaded. End-of-life tyres pose a significant challenge in terms of waste management. The proportion of tyres recovered locally is falling, the proportion being exported is growing, and stockpiles are becoming an issue.[20] In 2015, 51 million standard passenger car tyres entered the waste stream, and increase of 2.5 million from 2010.[20] Only 5% were recovered locally through recycling or energy recovery compared to 16%in 2009-10.

Each passenger car tyre contains rubber, steel, fibre, carbon and oil. During recycling, steel is recycled and tyres are shredded and crumbed for use in applications like high quality crumb or road repairs. The remaining tyres are used mainly for civil engineering projects such as fuel for energy recovery systems.

EMERGING WASTE STREAMS

Emerging waste streams include e-waste, batteries, and photovoltaic (PV) panels (solar panels).

E-waste, or 'electronic waste', includes mobile phones, computers, laptops, televisions, printers, electric car batteries and other electronic equipment. E-waste is the fastest-growing waste stream in the world, estimated at 48.5 million tonnes in 2018, and is environmentally damaging if it ends up in landfill – as almost 80% does worldwide.[53] According to the World Economic Forum, Australia is among the highest e-waste generating nations in the world; in 2016 we generated 23.6 kg of e-waste per capita.[21]

Some e-waste is already recovered and used in remanufactured products. Materials which can be recovered from e-waste include mercury, plastics, ferrous metals, aluminium and circuit boards, which can be sold to manufacturers for reuse in new electrical products.

TECHNOLOGY SUPPORTING RESOURCE RECOVERY FROM E-WASTE

In 2016, Australia's first state-of-the-art e-waste sorting technology was installed in Dandenong, Victoria. The BluBox technology can process up to 2,500 tonnes of e-waste per year, and is capable of dismantling electrical panels, saving 125 hours of labour per tonne of e-waste.[22]

Image source: wastemanagementreview.com.au

All other image sources: iStock and pexels

LITHIUM-ION BATTERIES (LIBS)

LIBs are also a fast-growing issue, as they are used to power devices in the exponentially growing consumer electronics market. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) estimates the quantity of discarded LIBs in Australia could grow from 3,300 tonnes in 2016 to up to 188,000 tonnes by 2036.[23] The Battery Stewardship Council is currently designing a consistent management approach for batteries in Australia.[24]

Batteries contain valuable metal components which can be recovered. Among these are zinc, cobalt, manganese, cadmium, lithium and rare earth metals. Despite the value of battery components, less than 3% of batteries in Australia are recycled, and more than 14,000 tonnes of batteries go to landfill each year.[25]

The Future Battery Industries CRC is looking at innovative pathways to mine, extract, refine and recycle battery minerals, metals and materials to produce battery grade products. It is also hoping to demonstrate feasible precursor production in Australia and pilot plant testing for battery manufacturing.

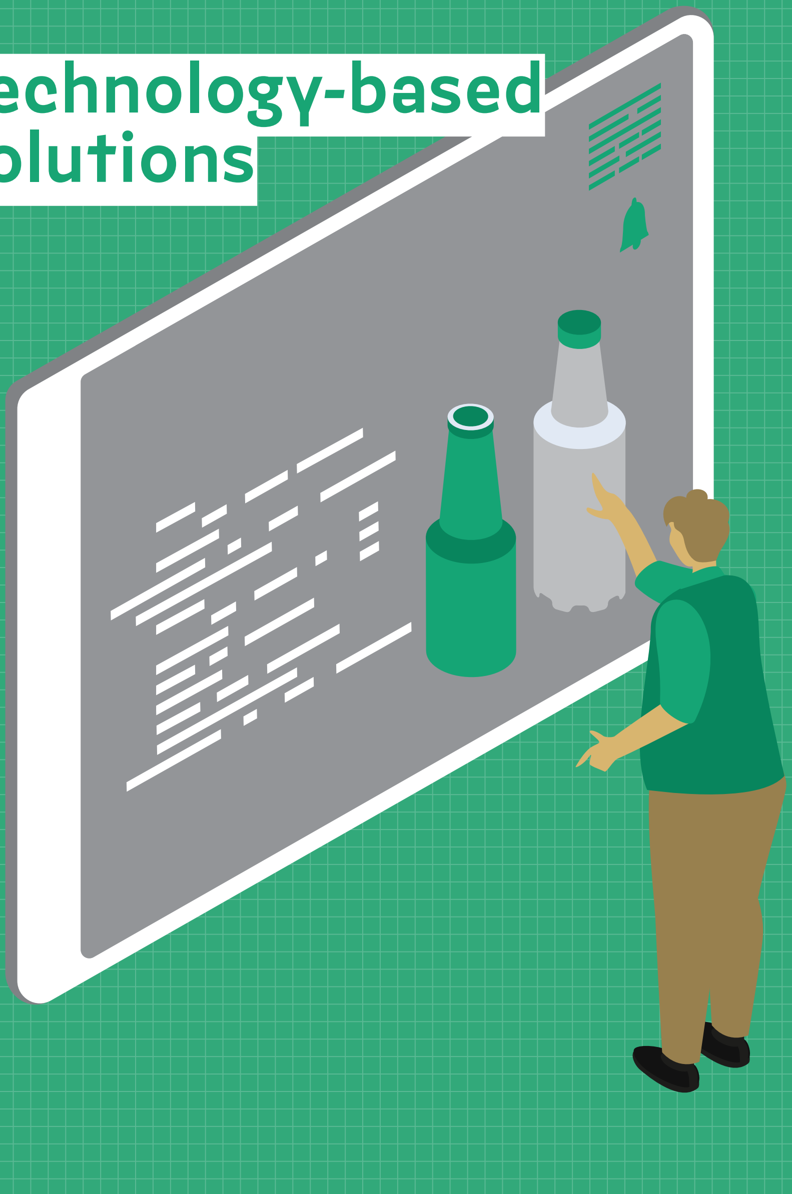
SOLAR PHOTOVOLTAIC (PV) PANELS

PV panels are another rapidly growing e-waste stream. More than 100,000 tonnes of solar panels and system equipment, many of them containing hazardous materials, will enter the waste stream by 2035.[26]

Compounding the issue is a lack of dedicated processing facilities in Australia that can recover valuable materials contained in PV products. The few solar panel recycling services in Australia can only recycle and reclaim a small percentage: up to 17% of a panel by weight.[26] The panel's aluminium frame and junction box are the components most easily recycled. The remaining 83% of a solar panel's materials (including glass, silicon and polymer back sheeting) are not currently recyclable in Australia.

Sustainability Victoria is leading development of a national approach to better manage PV products, in collaboration with other state and territory governments – as well as businesses and industry stakeholders.[26]

Technology-based solutions



Technology has enormous potential to support Australia's waste and resource recovery sector in the transition towards a circular economy.

ATSE's research and consultations have revealed an immense appetite for change in the sector. The paradigm is shifting internationally, and Australia must act decisively to remain competitive in waste and resource recovery. Our sovereign capacity to manage waste also needs support in order to cope with our growing population and a changed global supply chain in the wake of the COVID-19 pandemic.

There is also a powerful movement in consumer sentiment towards sustainability. This sentiment is not always directly matched by consumer behaviour – technology has the capacity to change through the provision of transparent and convenient information and product options that make sustainable consumption easy.

Opportunities will be created and innovation encouraged through policies that incentivise manufacturers and waste management and resource recovery organisations to apply strategies designed to shift waste-management services from a linear system towards more circular models.[27] At the same time, consumer awareness and increasingly higher rates of consumption are increasingly emphasising social and environmental impacts of complex global supply chains.[28]

Waste and pollution are not accidents, but the consequences of decisions made at the design stage, where 80% of environmental impacts are determined. By changing our mindset to view waste as a design flaw and harnessing new materials and technologies, we can ensure that waste and pollution are not created in the first place.[29]

Ellen MacArthur Foundation

Stakeholder consultations underscored the huge potential for innovation in Australia's economy to embrace design principles, improved product stewardship and advanced resource recovery, not just in the waste and resource recovery sector but in the manufacturing sector and more broadly. ATSE's suggested solutions can create new industry and employment, and elicit positive social, economic and environmental outcomes across many sectors. Technology can also support the waste and resource recovery sector to through this disruption, and accelerate the benefits of a circular economy for Australia.

Based on our research and consultations, ATSE has rated the readiness and potential of Australia's waste and resource recovery sector to adopt technology to improve design, product stewardship and advanced resource recovery. We have done this through the parameters of infrastructure readiness, skills availability, social readiness, economic feasibility and policy and regulatory readiness. The results are summarised in Table 1, and explored in detail throughout this section.

SCALE	NOT READY	MORE WORK REQUIRED			READY
READINESS INDICATOR SCALE	○	◔	◑	◕	●

ASSESSMENT	Infrastructure readiness	Skills availability	Social readiness	Economic feasibility	Policy & regulatory readiness
Design	◔	◕	◑	◔	◔
Improved product stewardship	◑	◕	◕	◔	◑
Advanced resource recovery	◑	◕	◑	◔	◔

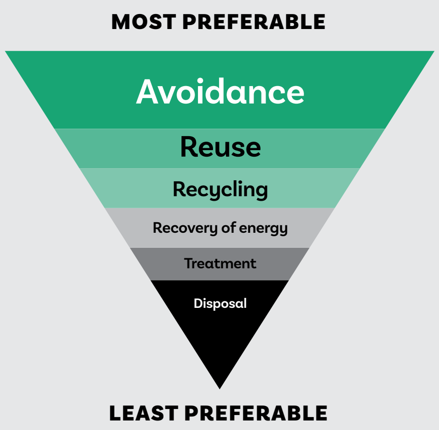
TABLE 1
Summary of ATSE's technology readiness assessment of the waste and resource recovery sector

Design

2018 NATIONAL WASTE POLICY		
PRINCIPLE 1 **Avoid waste** Prioritise waste avoidance, encourage efficient use, reuse and repair. Design products so waste is minimised, they are made to last and we can more easily recover materials.	**STRATEGY 1** **Waste avoidance** Deliver coordinated actions that help the community and businesses avoid and minimise waste, including through better design, reuse, repair, and sharing of products and services.	**STRATEGY 2** **Design** Design systems and products to avoid waste, conserve resources and maximise the value of all materials used at every stage of a product's life.

Design underpins the transformation of a linear system to a circular economy, where resources and materials are valued. A system-based approach uses the design phase to avoid the creation of waste, construct products for durability, reusability, and easy disassembly, and ensure materials are managed in accordance with the waste management hierarchy (see Figure 4).

FIGURE 4
Waste management hierarchy
Source: National Waste Report 2018, Department of the Environment and Energy



Designing products to be used multiple times, and giving them monetary value, is key to stopping them ending up in landfill.

The four main targets to achieve the change are:

- increasing material efficiency
- product life extension
- improving recycling efficiency, as well as the use of recycled content
- driving market demand for the used material.[30]

Design strategies that support these targets include:

- Modular design and standardisation of components
- Ease of assembly and disassembly with detachable connections and non-destructive dismantling
- Low material diversity, material recyclability and low toxicity
- Providing information for recyclers and disposal instructions for end users.

For the most part, today's product designs follow linear principles for the purpose of low-cost and high performance.[31] A paradigm shift in design principles can avoid creating waste altogether — designing a product to last 'forever' by creating ways to repair it, upgrade it, replace its parts, and trade it in for remanufacture once it is superseded.

Designing a product for reuse creates an entirely different business model, where the product never enters the waste and resource recovery system — or only does so after years of use. When it does, it's important that the product is easily remanufactured, or disassembled and recycled.

One emerging business model avoiding waste through innovative design, and supported by technology, is product as a service (PSS). PSS prioritises access to a product or service over ownership, through renting, lending or sharing. PSS increases economic incentives to design higher quality, longer lasting products that are easier to refurbish or recycle.[33]

Manufacturers retain greater control over the items they produce and the embodied energy and materials, thus enabling better maintenance, reconditioning and recovery. Customers also benefit, as they only pay for the service they require and use, and often receive a better service.[34]

For example, a PSS provider would rent a mobile phone with a communication services contract. The mobile phone has been designed for multiple use, with components to be disassembled and reused in the system. At the end of the contract, the phone would be returned to the PSS provider, refurbished, and upgraded. The whole system, including the use, repair, upgrade and end-of-life, is designed as a system delivered by the PSS provider.

PSS provides the unique opportunity for the rapid redesign of products, because consumers can provide data and feedback on the product's performance, which can be rapidly taken up by the PSS provider to promptly upgrade and adapt design modifications.[35] Application of new technologies such as artificial intelligence (AI) can magnify the competitive strength of circular economy business models such as PSS; by combining real-time and historical data from products and users, AI can help increase product circulation and asset utilisation through pricing and demand prediction, predictive maintenance, and smart inventory management.[36]

Product as a service business models are evolving through the application of technology to avoid the creation of physical products altogether — think Spotify replacing CDs, or Netflix replacing DVDs. The alternative is greater energy use, however, which must be considered in evaluating the environmental impact of these PSS models.

SODASTREAM

SodaStream is an at-home system that uses tap water to make sparkling flavoured water. The sparkling water-makers and reusable polyethylene terephthalate (PET) carbonating bottles are designed to avoid single-use plastics. Each water-maker comes with a plastic bisphenol A (BPA)-free reusable carbonating bottle or glass reusable bottle, and CO_2 cylinder. SodaStream has announced it wants to save 67 million bottles worldwide by 2025.[32]

Product Service Systems

ROLLS ROYCE AEROSPACE ENGINES

Rolls Royce has transformed an aerospace engine manufacturing model to a service model that delivers flying hours for clients. This aligns the goals for both Rolls Royce and the customer to be well functioning engines with little material or operational waste. Rolls Royce takes advantage of existing mechanical and engineering design knowledge and applies it in conjunction with big data analysis on engine performance. This enables Rolls Royce to perform predictive maintenance and identify isolated engine components for repair, minimising disruption and keeping engines flying for longer. This model also provides incredibly rich performance data for Rolls Royce to use in improving their engines.[37]

HP

HP's Instant Ink uses sensors to detect when printer cartridges need replacing and automatically organises for the replacement of the cartridge. In this service model, the consumer never runs out of ink and HP can secure a clean waste stream for refill or recycling. This model has reduced material consumption by 57%.[41]

PHILIPS LIGHTING

Philips' pay-per-lux intelligent service program installs and owns the entire lighting system within a building and contracts out usage of light to the consumer.[40] The product's lifespan is prolonged through Philips' supplied maintenance. When the customer needs to adapt or upgrade their fit out, Philips can recover and reuse their fixtures.

Image source: Atlas of the Future. atlasofthefuture.org

MICHELIN

Michelin Solutions provides fleet management to optimise the operation of commercial vehicles, and also includes price per kilometre tyre management. Using sensors connected to the Internet of Things (IoT), Michelin collects data on fuel consumption, tyre pressure, tyre temperature, speed, and location. This data allows Michelin to monitor, service, and change tyres on demand. It also provides the value-added service of advice to optimise fuel efficiency and operation.

For example, mining vehicles carry very large loads which can overheat tires very quickly, risking failure and downtime. Using IoT sensors and big data analytics, Michelin is able to empower drivers with real-time information on tyre temperature and the recommended optimal speed.[38]

Michelin also launched a suite of mobile apps in 2017: MyBestRoute (smart route planning), MyInspection (digitalises and standardises vehichle inspection), MyTraining (digital driver training) and MyRoadChallenge (rewards good driving practices).[39]

SHARE SHED AND BRISBANE TOOL LIBRARY

Provide a sharing platform for a wide range of products that people use only occasionally, including party supplies and decorations, sports and camping equipment, and various tools. This increases the productivity of items during their lifecycle and reduces the amount of new material being used.[43,44]

IKEA FURNITURE LEASING

IKEA is developing a subscription-based furniture leasing offer that enables the company to maintain ownership of the product to secure reuse as many times as possible before material and component recycling at the end-of-life, in response to customers' changing needs.[42]

Image source: IKEA. Annual Summary & Sustainability Report FY19 Ingka Group

Continued research and development into alternative materials used to make everyday products is also important in addressing the durability and longevity of products. For example, self-healing glass under development at the University of Tokyo's School of Engineering and the RIKEN centre could possibly be used in a wide range of products, such as screens for touch-screen devices.[45]

"The self-healing glass provides a longer-lasting, durable material which could double or triple the lifespan of something," said one of the material's creators, Dr Yu Yanagisawa. This innovative material promises to reduce the number of functional mobile phones being discarded due to cracked screens.

Michelin are also developing new durable tyre technologies. Regenion is a new heavy truck tyre tread that self-regenerates, improving the longevity of tyres and reducing vehicle fuel consumption.[46] Tyres also use Powercoil and Infinicoil, which are new generation, robust steel cables with better endurance and stability.[47] These tyres can also be regrooved and retreaded multiple times.[48]

AI has also been used to develop completely new materials to meet desired specifications for more durable products. The European Space Agency's Advanced Metallurgy project used AI algorithms to analyse existing material and test new formulations.[36]

Design for recovery and recycling is also important where a product must be single use — such as in medical treatment or food packaging. Designing a product so that the material can be easily recovered makes economic and environmental sense. In a systems-based approach, a complementary regulatory regime will make landfilling valuable materials unattractive, and ensure it is cost-competitive to recover clean waste streams rather than use raw materials and a linear supply chain. Product stewardship schemes can support the retrieval and recycling of these products in clean waste streams.

One of the major barriers to remanufacturing and material recovery is the high costs and lengthy time of dismantling product components and materials. By integrating design for disassembly elements at the beginning of product development, businesses can improve revenue and reduce their environmental impact.

There are two methods of disassembly: conventional disassembly, and disassembly embedded design (with active disassembly).

Conventional disassembly involves the manual separation of most fasteners and components of a product. This manual process leads to high costs and extensive labour time.[49]

Disassembly embedded design consists of mechanism(s) that can be triggered to initiate the disassembly process. This can include a domino-like "self-disassembly" process, where when one or few fasteners are removed, the internal components of a product held together by locator features (such as catches and lugs) are prompted to disassemble from each other.

An emerging form of embedded disassembly design, called active disassembly, is a process by which external factors such as temperature, electric, mechanical pressure, or an electromagnetic stimuli can trigger the release of product components.[50] Active disassembly employs smart materials, for example, shape memory materials (alloys and polymers), thermally reversible adhesive sprays, and biodegradable layers.[51]

These smart materials are only triggered when the set temperature or mechanical force for its specific component is achieved. Shape memory alloys and polymers are also often reversible, and thus can be reused.[52]

This form of disassembly very efficiently supports recovery of materials, leading to minimal residual waste.

Infrastructure readiness

Australia currently has no nationally consistent framework, systems or infrastructure for design, and stakeholders did not provide significant feedback on Australia's infrastructure readiness. There is little conversation around design in Australia and limited understanding of how to support its integration.

There are three phases within a product's lifecycle that require appropriate design infrastructure: beginning-of-life, middle-of-life, and end-of-life.

Beginning-of-life processes relate to development, production and distribution. For designers, there are several methods and software tools available to help integrate ecodesign principles. Software tools for the life cycle assessment of products, including Simapro and GABi, can be used to determine the sustainability of materials, production processes, and design solutions. Software modules integrated in existing computer aided design (CAD) systems, such as Solidworks Sustainability and Autodesk Inventor integrated eco-materials assessment tool are also helpful. Additionally, the *Circular Design Guide* created by the Ellen MacArthur Foundation and Cradle to Cradle Products Innovation Institute includes a wide range of online-based tools, workshops and checklists that any person or company can use to understand, define, make and release circular products.[53]

Defining materials formulations and recording their inclusion in products is a key to unlocking change. Defining and using a set of pure materials stocks at scale streamlines flows of pure materials to create arbitrage opportunities that generate economic benefits and make investments in reverse cycle setups profitable.[54] A national database and mandatory reporting of materials in products would significantly accelerate Australia's reuse, remanufacture, recycling and resource recovery rates.

A different set of infrastructures are required for middle-of-life processes relating to a product's use, service and repair. Digital technology (5G, Internet of Things, sensors, digital product passports) is vital, and can be embedded into a product. Digital technology and data are especially critical in preventative maintenance, which is used to extend a product's life. The collection and management of data on a product's usage, performance, wear and lifecycle provides valuable information that can be used to maximise efficiency, reduce repair costs, and greatly facilitate the ability to remanufacture products.[55]

Product end-of-life management facilities can also greatly influence the recyclability rate of high value raw materials, as well as reduce contamination during disposal. To have an effective system, most, if not all, products need to be designed with a predetermined end-of-life value and require reconfiguration of supply chains and partnerships that enable product take-back schemes with value retention services. Collaborations between designer and recovery facility would lead to innovative methods to maximise the recovery of valuable materials in Australia.

CASE STUDY
IBM

BIG DATA AND ARTIFICIAL INTELLIGENCE (AI)

New technologies, including faster and more agile learning processes with iterative cycles of designing, prototyping, and gathering feedback, are needed for the complex task of redesigning key aspects of our economy.[36] AI can enhance and accelerate the development of new products, components, and materials fit for a circular economy through iterative machine-learning-assisted design processes that allow for rapid prototyping and testing.[36]

IBM has developed a prototype tool, called the 'Reuse Selection Tool', which collects data over the lifetime of products, data on product location and availability and cost of repair and reverse logistics. The Tool can then decide what the best next-cycle use is for a product.[56]

◕ Skills availability

Stakeholders indicated shortage of design skills was not a key barrier, rather a lack of implementation by industry. To transition from the current linear 'take-make-use-dispose' product consumption to a more sustainable circular model, there needs to be educational change across the value chain, from product designers and manufacturers to retailers.

Designers and engineers especially play a critical role in a product's life cycle. They have the ability to implement alternative solutions and influence positive change through the creation of more sustainable goods and services.

Australia is strong in engineering skills, evidenced by numerous research and manufacturing hubs around the country. However, training for engineers must look beyond the standard values of cost and performance and incorporate key eco-design principles: reduced material use, greater reparability, extended durability, and recoverability of critical materials at end-of-life.

There are currently skills gaps in eco-innovation across the globe. There are also too few educational programs available for the growing number of young and enthusiastic students interested in design and sustainability.

Design and the required skills are increasingly a priority for academic and research organisations. Australian higher education institutions are increasingly offering courses in sustainable product design and incorporating sustainable design units into industrial design, engineering and architecture courses.

More support is required for skills and training for digital manufacturing, remanufacturing and repair expertise. Partnerships between universities and industry would further accelerate innovative design solutions.

Similarly, school curriculums for engineering, industrial design, and graphic design courses should integrate Eco-design concepts into all processes.

Job types

Engineers (software, environmental, chemical, structural, mechanical, electrical, industrial). Designers (architects, product and urban designers). Research and development, technicians, sales and marketing, quality control and auditors, data scientists, chemists, analysts, project leaders, industry managers, and statutory planners.

Qualification types

Tertiary-based qualifications include bachelor degrees in engineering (software, environmental, chemical, structural, mechanical, and electrical), graphic design, architecture, mathematics, chemistry, information technology (IT), business and marketing. Technical and Further Education (TAFE) courses and, in some cases, apprenticeships.

Skills

Product design and life-cycle, CAD, computer skills, product quality and maintenance, health and safety practices, strategic and project management.

General employability skills in the design sector include strong communication, innovative, interpersonal, networking, leadership, analytics, organisational and planning ability.

◑ Social readiness

One of the key outcomes of ATSE's consultation regarding social readiness is that design and digital transformation are under-discussed. There is some awareness and slowly growing demand for sustainably-designed products, but the uptake and market for eco-designed products has been relatively slow. This is due to barriers at multiple levels; retailers, consumers, and designers, combined with the ongoing prevalence of linear business models of most companies and the current low cost of virgin materials. Stakeholders consistently indicated that awareness of the role of design in Australia is low.

There is also a collective dissonance between thought and action. Despite their expressed preferences, consumers choose to buy disposable products over sustainable products, typically due to lower costs, ease of availability and convenience. Additionally, with the rapid release of technology and trends, consumers prefer (or are encouraged) to purchase new products with the latest upgrades, resulting in the disposal of useable products as waste.

Some manufacturers recognise this as an opportunity to take back these products and refurbish them for sale, offering incentives to consumers to trade-in their previous model for a newer one.[57] Standardisation and certification of reused and remanufactured goods help to overcome consumer bias against used goods and promote the design of products with refurbishment in mind. Certification and labelling of remanufactured products or components that are widely recognised would increase buyer confidence.[55] The Australian Packaging Covenant Organisation (APCO) is currently leading efforts under the National Waste Policy Action Plan to incorporate information about the percentage of recycled content in packaging into the Australasian Recycling Label, to enable informed consumer choice.[13]

Consumers have significant power in influencing the transition to a more circular economy, and manufacturers respond to consumer sentiment. Consumers have driven change in the design of products all over the world, from how products are packaged, to how much energy they use, the materials that are in them, and even whether or not they are able to be legally sold. Consumers are also influencing the development of regulatory regimes such as a right to repair, which relies on design to enable products to be repaired, refurbished and remanufactured to extend their life.

The Australian Government committed to review and report on recommendations to introduce laws to improve consumers' 'right to repair' options by 2021 in the National Waste Policy Action Plan.[13]

Increasing the availability of information would assist consumers to make informed choices and drive the paradigm shift to a circular economy. Transparent, accountable business reporting on materials and sustainable practices would support consumers to choose products with potential for reuse and repair, and a plan for end-of life that enables the materials to be re-purposed.

RIGHT TO REPAIR

With electronic products filling almost every aspect of our lives, we are faced with a mountain of broken devices. Consumers are increasingly demanding repair services. Often, broken devices need to be sent to the manufacturer for a diagnosis of the issue and then, if possible, an extremely costly repair. Local repairers are frequently unable to repair devices due to inaccessibility of the device's software information or technology. In many cases, it is often easier, quicker and cheaper to purchase a new device than repair in addition to the expensive consumer costs, unfixable devices contribute to the mounting problem of e-waste.

A consumer movement dubbed the 'Right to Repair' began in Massachusetts in 2012. The Right to Repair movement shows that people are increasingly holding manufacturers accountable for the durability and sustainable credentials of their products.

Some small businesses will repair such products, but the catch for consumers is that if they repair their product at an unauthorised repair centre, the product's warranty will often be voided. Intellectual property and copyright laws restrict small businesses such as mechanics and electronics repairers from being able to access the information required to repair goods, and they have called for government regulation to permit a right to repair.

More than 30 states in the United States of America (USA) have now introduced Right to Repair Bills.[58] Europe has new standards for appliance durability, which include a requirement for manufacturers to supply spare parts for up to 10 years for some white goods.[59] These regulations also require manufacturers to make maintenance and repair instructions available to professional repairers.

To improve reuse and reparability, the National Waste Action Plan proposes Australian governments review and report on recommendations to introduce laws to improve consumers' 'right to repair' options by 2021 (Action 2.6).[13] The Plan also calls on all governments to support community-based reuse and repair centres, enabling communities to avoid creating waste (Action 2.7). The Australian Competition and Consumer Commission (ACCC) is also considering a mandatory scheme for manufacturers to supply independent car repairers with technical information.[60]

More products designed to be repaired, and regulations allowing a right to repair, would create a substantial increase in small businesses offering these services. In 2018, Sweden introduced a number of tax incentives and concessions for consumers to repair household items such as whitegoods rather than replacing them. This had the effect of reducing the cost of repair to the consumer by as much as 85% and stimulating jobs in the repair service industry.

Economic feasibility

Circular design has not been a focus for Australian manufacturers due to lack of market or formal incentives, or any requirements – including design standards. There is a perception that designing eco-products costs more, manufacturers would have to charge more for their products, and therefore consumers would buy a cheaper competitor's product.

However, as resources continue to become more precious, circular business models will gain an ever greater competitive advantage because they create more value from each unit of resource than the traditional linear 'take-make-dispose' model.[54] Minimising waste through efficient design will become more cost effective, and repairing products to resell will cost less than manufacturing from virgin materials. Customer loyalty can be earned through provision of quality products and good services, with customers only paying for what they use and need.

There is also an increasing corporate social responsibility imperative to design out waste, and produce sustainable products. Consumer demand will shift the economic feasibility of these technologies more and more in the decade to 2030 as the world's population increases and competition for resources increases.

The Australian Government has committed to identifying financial and other incentives that may assist key industries, including the waste and resource recovery industry, to transition to a more circular economy under the National Waste Policy Action Plan.[13]

Policy and regulatory readiness

Currently, there are no government regulations for the implementation of sustainable design principles in Australia. Stakeholders consistently told ATSE that there are currently no incentives or policy requirements for designing products for durability, reuse, repair or recycling, nor are there basic design standards and specifications for Australian made and imported products.

The design of a product and its resulting waste are separated in Australia's current perception, but should be conceptualised together. This could be accomplished by expansion of the *Product Stewardship Act 2011* (Cth), as well as extending producer responsibility to include regulations about product design and use of recycled content, including disassembly and recovery of components at the product's end-of-life stage. This would require clear manufacturing specifications to be enforced through formal regulatory interventions, or bans on certain materials.

Government regulation has a role to play in incentivising manufacturers to adopt eco-design principles and to create a level playing field where manufacturers are not disadvantaged by acting responsibly. For example, the European Commission has implemented Eco-design Directives through regulations designed to extend the life of many appliances by incorporating circular economy principles. Manufacturers are required to make appliances repairable and durable, and also provide replacement parts for up to 10 years, for some white good appliances, along with repair and maintenance instructions for professional repairers.[61]

Australian Governments have committed, through the National Waste Policy Action Plan, to delivering targeted programs to build businesses' capability to identify and act on opportunities to avoid waste and increase materials efficiency and recovery.[13]

The Australian Packaging Covenant Organisation, supported by governments and business, is also leading the phase out of problematic and unnecessary single-use plastic packaging through design, innovation or introduction of alternatives by 2025.[13] Similar targets could be used to address other problematic waste streams.

ENVIRONMENTALLY FRIENDLY PRINGLES©

In response to consumer concern, Kellogg is trialling a redesigned packaging for their Pringles© product in the United Kingdom (UK)to improve recyclability.[62] The current can design uses a combination of cardboard, foil, plastic and metal, which is unrecyclable though municipal recycling streams. The new recyclable design is 90% cardboard.

A simple video has been made to educate consumers. *Source: terracycle.com*

Improved product Stewardship

2018 NATIONAL WASTE POLICY		
PRINCIPLE 4 **Better manage material flows to benefit human health, the environment and the economy.** **PRINCIPLE 5** **Improve information to support innovation, guide investment and enable informed consumer decisions.**	**STRATEGY 4** **Product stewardship** Develop and implement partnerships across government and business to ensure ownership and responsibility for action to minimise the negative impacts from products, ensure the minimisation of waste and maximise reuse, repair and recycling of products and materials throughout their life cycle.	**STRATEGY 13** **Data and reporting** Continue to support consumers and manufacturers to make more informed decisions by improving national data and reporting on material flows, wastes and recycling, including economic aspects and reporting indices.

Product stewardship considers the entire lifecycle of a product, including the end of its useful life.[27] The concept of product stewardship, and extended producer responsibility more broadly, is central to a circular economy, in which all stakeholders in the lifecycle of a product – its design, manufacturing, sale, use, reuse or recycling, and ultimate disposal – act to minimise the negative environmental, economic, health, and safety impacts of the product.

The Organisation for Economic Co-operation and Development (OECD) defines extended producer responsibility as "an approach in which a producer's responsibility for a product is extended to the post-consumer of the product's life."[63] Extended producer responsibility provides an incentive to prevent waste at the source, promoting more environmentally sustainable product design and supporting the achievement of public recycling and materials management goals. Extended producer responsibility and product stewardships schemes can include take-back schemes, advance disposal fees, deposit refunds, and performance targets.

Consumers have a unique opportunity to drive the market towards products that are designed for sustainability and promote a more circular economy.[54] Consumers must consider the environmental impact of products when deciding which product to buy and how they ultimately dispose of them. They need to be aware of using products efficiently, safely, and take extra steps to recycle and or dispose of products accordingly. Consumer engagement must also be a priority when designing products as consumers are ultimately the primary users and disposers of products. Retailers also play an integral role as the access point between manufacturers and consumers. Local, state and federal governments all have responsibilities to provide leadership in coordinating and implementing clear, cohesive product stewardship legislation and schemes.

PRODUCT STEWARDSHIP IN AUSTRALIA

There are a number of voluntary product stewardship programs currently in place in Australia for plastic, tyres and some electronic products and one co-regulatory scheme (the National Television and Computer Scheme).

- Australian Packaging Covenant Organisation
- REDCycle
- Container Deposit Schemes
- National Television and Computer Scheme
- MobileMuster
- Tyre Stewardship Australia

Two proposed product stewardship schemes are currently under development under the National Waste Action Plan, for batteries (Action 3.4) and solar PV panels (Action 3.5).[13]

AUSTRALIAN PACKAGING COVENANT ORGANISATION

The Australian Packaging Covenant Organisation (APCO) is a coregulatory, not for profit organisation partnered with government and industry, established to administer the Australian Packaging Covenant.[64,65] The Covenant is part of a compulsory, co-regulatory product stewardship framework established under the National Environment Protection Council Act 1994 and the National Environment Protection (Used Packaging Materials) Measure 2011 to reduce the harmful impact of packaging on the Australian environment. Under this framework, obligations are placed on liable parties, which are brand owners in the packaging supply chain with an annual turnover greater than $5 million. There are three ways in which liable parties can acquit their obligations:

1. Become a Signatory to the Australian Packaging Covenant (these Signatories also become Members of APCO)

2. Submit to direct regulation by state and territory governments in relation to:
- The recovery of used packaging materials.
- The reuse, recycling or energy recovery of packaging materials
- Demonstrating that the recovered materials have been reused or exported
- Demonstrating that reasonable steps have been taken to advise consumers as to how the packaging is to be recovered.

3. Being part of an industry or sectoral arrangement that produces equivalent outcomes to those being achieved under the Covenant.

Images source: Australian Packaging Covenant Organisation. apco.org.au

REDCYCLE SOFT PLASTICS RECYCLING

REDCycle soft plastics recycling is a free voluntary program.[66] The program was implemented in 2011 to collect and process post-consumer soft plastics. The program works with Australia's largest supermarkets, Coles and Woolworths, and several major brands. REDcycle is partnered with Replas, Close the Loop and Plastic Forests to recover recycled materials into a new range of products.[66]

REDCycle collects and processes materials into a new range of products such as the bench above.[66]

Images source: RedCycle. redcycle.net.au

CONTAINER DEPOSIT SCHEMES

Container Deposit Schemes are legislated programs regulated by the Environment Protection Authority (EPA) at the state government level.[67] It is designed for beverage suppliers to be responsible for two things; firstly, to ensure a collection and recovery system is in place for their empty beverage containers, and secondly, fund the allocated 10 cent refund amount per returned drink container.

Container Deposit Scheme (CDS) in Belconnen, ACT.

Image source: ACT Container Deposit Scheme. actcds.com.au

Consumer video educating West Australians about container recycling.

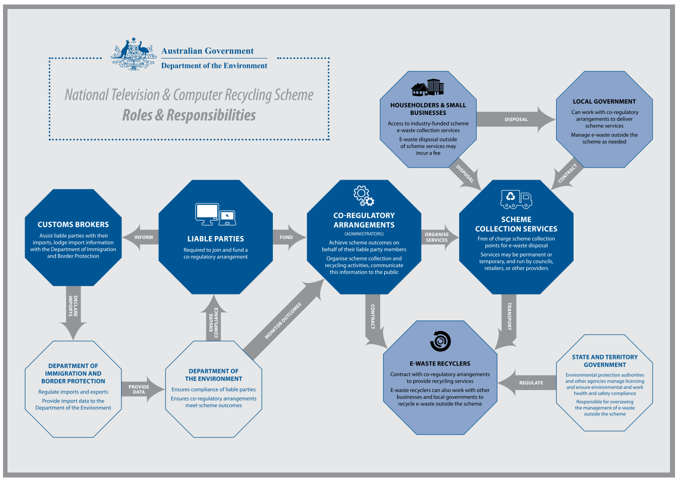
Image source: Containers for Change. containersforchange.com.au

A Return and Earn reverse vending centre (RVC) in Western Sydney, Parramatta, NSW.

Image source: Return and Earn. returnandearn.org.au

NATIONAL TELEVISION AND COMPUTER SCHEME

The National Television and Computer Scheme is currently the only co-regulatory scheme in Australia.[68] It is a well-established national scheme that provides households and small businesses with a free industry-funded collection and recycling service for televisions and computers. Under the scheme, the Commonwealth Government sets recycling targets and parameters which must be met by industry each year. Established in 2011, more than 1,800 collection services have been made available and 290,000 tonnes of TV and computer waste have been recycled.



National Television & Computer Recycling Scheme Roles & Responsibilities

Image source: Department of the Environment. environment.gov.au

MOBILEMUSTER

MobileMuster is the official voluntary free recycling program for the mobile industry.[69] Consumers can drop off mobile handsets and accessories at over 3,500 public drop off points at major phone retailers, including Telstra, Optus, Vodafone, and Samsung, or post them for free via a reply-paid satchel at participating Australia Post stores. Since its launch in 1998, the telecommunications industry has invested nearly $45 million, resulting in 1,500 tonnes of material being diverted from landfill.

Image source: Australian Mobile Telecommunications Association (AMTA). MobileMuster is an initiative of AMTA. mobilemuster.com.au

TYRE STEWARDSHIP AUSTRALIA (TSA)

Tyre Stewardship Australia (TSA) is a voluntary national scheme implemented by the government and tyre industry in 2014 to promote a resource stream from end-of-life tyres and reduce the environmental, health and safety impacts of disposed tyres.[70] The scheme aims to increase tyre recycling support new technologies, expand the market for tyre-derived products and reduce the number of end-of-life tyres ending up in landfill or illegal dumps. Tyre industry participants who apply for and gain TSA accreditation must commit to playing their part in sustainable end-of-life use for tyres.

Top left: Asphalt made using crumb rubber from old tyres laid on a busy Melbourne road as part of a major new trial and is in line with the State Government's Recycled First Policy, which aims to increase the use of recycled materials in construction projects.

Bottom left: Taurus Mats turn old four-wheel drive tyres into woven mats to create a safer, non-slip, surface for livestock in high traffic areas. They are made by weaving together used tyre treads and then fastening them with stainless steel bolts.

Above: The building of Australia's largest ever tyre-derived permeable pavement surface, in a car park operated by Mitcham City Council in South Australia, is a large-scale field test that will enable the impact of real-life traffic loading to be measured by a comprehensive set of mechanical and storm-water instrumentation; thus verifying the performance of the product under different traffic road conditions. Parameters measured include mechanical performance, mitigation of the surface surface run-off as well as impact of reduced pollutants flowing to waterways.

Images source: Tyre Stewardship Australia. tyrestewardship.org.au

CLOSED LOOOP & 100% RECYCLABLE PACKAGING

Fuji Xerox Australia has been awarded for their achievement of sustainability in the procurement and disposal of its packaging materials, leading to 100% recyclable packaging.[71]

In 2011, the company moved their recycling operation from Thailand to Australia so that all parts and consumables could be locally sorted, data captured and processed through recycling or remanufacturing within each capital city. This reduced the monetary and environmental costs of transportation; in 2015-16, b-double truck movements were decreased by 84,000km.

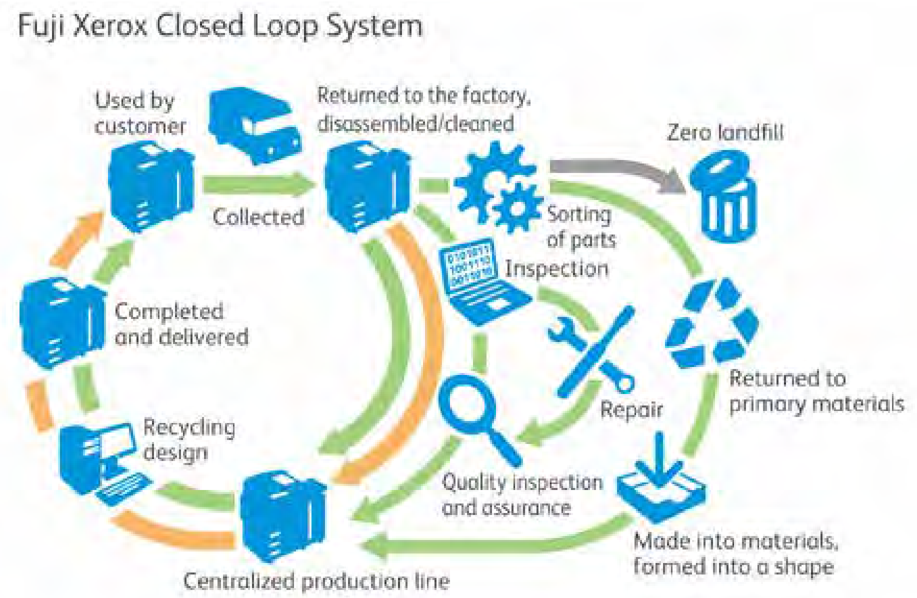
Fuji Xerox Australia have been using the material waste management hierarchy to reduce the amount of material in products by reusing and remanufacturing existing material. In 2015-16, Fuji Xerox Australia remanufactured 393 tonnes of materials at just one plant located in Rosehill. Collectively, they reached 91.6% of materials being recycled for reuse and 8.2% of materials directly reused from refurbished machines and remanufactured parts.

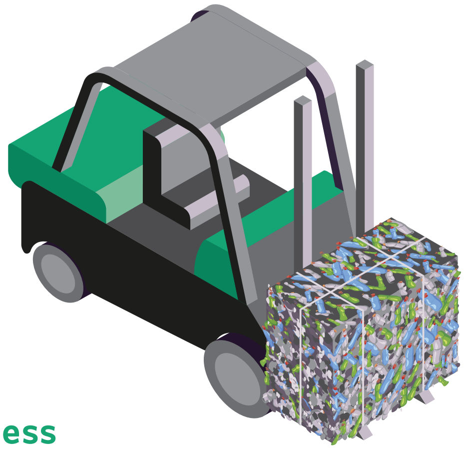
As a founding member of the Australia and New Zealand Recycling Platform, Fuji Xerox Australia is a reporting member that manages the collection of end-of-life devices from customers and delivery to recycling partner, Sims Recycling Solutions. The company also audits all downstream recycling partners to ensure safety, quality and environmental management systems adhere to high standards and achieve their zero waste to landfill commitment.

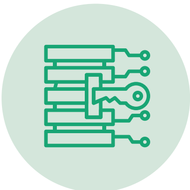
In the case of indirect channel sales in regional areas where 'zero landfill' recyclers were unavailable, Fuji Xerox Australia partnered with DHL logistics to track and monitor returns from every regional dealership. It also operates TechCollect, which is a free service available to all household and small business consumers of electronics to drop off and responsibly recycle all in-scope e-waste. Together, these initiatives have significantly increased uptake of e-waste materials for recycle or remanufacturing.

Fuji Xerox Australia is also employing a product service system to reduce the environmental impact of toner wastage. The company has developed a monitoring and reporting system of devices located at over 100 consumer sites, where it sends alerts when it identifies high wastage. After three years of its implementation, total toner cartridge distribution was reduced by 11%, which equates to eliminating 1,067 million black and white prints or 173 million colour pages.

Fuji Xerox Australia is part of the joint venture with Close the Loop and Downer Group to recycle toner waste into asphalt additive called Modified Toner Polymer (MTP). The MTP is added to asphalt to create TonerPave®. As of 2017, TonerPave® has been used on about 900km of Australian roads, which has had an estimated reduction of about 270 tonnes of carbon emissions due to the durability of its polymer.







◑ Infrastructure readiness

The key infrastructure for product stewardship, and extended producer responsibility more broadly, is collection points and markets. Also critical is the physical and digital infrastructure for tracking waste, and ensuring accountability of producers for waste arising from their products. In 2020 the Australian Government announced a $24.6 million commitment "to improve our national waste data so it can measure recycling outcomes and track progress against our national waste targets".[72] The details have not yet been announced.

There are some examples of tracking in Australia, such as the New South Wales (NSW) EPA online waste tracking tool.[73] This system helps industry to track hazardous waste. Online waste tracking reduces paperwork, makes it easier to comply with legislation and enables users to quickly and easily track a load of waste being transported from a waste producer to a receiving facility.

However, this system tracks logistical data rather than tracking waste - more work is needed to integrate waste data collection, recording, analysis and reporting across Australia. Innovative technology such as digital watermarks can be used to support accurate data.

There are significant data quality issues and comparing states and territories is difficult, as their systems have evolved largely independently.[74] Large volumes of data are currently collected across disparate sectors by various entities from industry and all levels of government, often manually.

Data and tracking technologies are essential for improved product stewardship. Successful integration of technologies such as blockchain, AI, Internet of Things (IoT) and nanotechnology on a large scale would facilitate the tracking of critical valuable materials from manufacturing to first use, remanufacture and eventual deconstruction and reuse. These technologies are also necessary to provide material and value chain transparency in the complex global supply chains of products.

Investment is required in a number of areas, especially in standardising data collection, sharing and communication. Improved information technology infrastructure is required to target and collate the extensive data and information being produced and then integrate into a common database accessible and used by all stakeholders to drive accountability and enhanced decision-making.

The Australian Government is leading work on implementing agreed national data and reporting improvements, harmonised data classifications and definitions for reporting, and sharing arrangements across jurisdictions under the National Waste Policy Action Plan.[13] This work is expected to be delivered by 2022 — acceleration would have significant benefits.

◕ Skills availability

Product stewardship and extended producer responsibility encompass many areas within the supply chain of a product, a vast range of skills and employment roles are involved. Transitioning to a circular economy will create a range of new employment opportunities, from jobs in the remanufacturing sector to roles in sustainable design.

ATSE's consultations revealed strong confidence from within the sector that the necessary skilled workforce is available for the transition toward a circular economy, although stakeholders indicated that there is somewhat limited understanding of product stewardship and extended producer responsibility in Australia.

The 2015 Action Agenda for Resource Productivity and Innovation identified tertiary degrees in sustainable design, business management, engineering, architecture and Information and Communications Technology (ICT) to be leading skill requirements for a future circular economy.[28] To maximise the opportunities these qualifications provide, universities must partner with industry and government to promote industry-led outcomes through supporting collaboration, work experience placements, research secondments, the dissemination of knowledge, and promoting industry relevant teaching and research outcomes.

In addition to formal education and training for a skilled workforce, standardised national educational programs are required to inform businesses and households of their responsibilities in product stewardship, such as when to return/recycle products instead of throwing out to landfill, and how to identify different types of waste. This will require a team of skilled personnel able to strategically and innovatively communicate these guidelines and policies to a variety of audiences and across a range of platforms.

Job types

Plant operators, labourers, technicians, sales and marketing, product designers, quality control and auditors, data scientists, engineers (software, environmental, chemical, structural, mechanical, electrical), chemists, logistics and analysts, IT, health and safety officers, industry managers. Social and behavioural scientists will also be needed.

Qualification types

Tertiary-based qualifications include bachelor degrees in engineering (software, environmental, chemical, structural, mechanical, and electrical), data and computer science, architecture, mathematics, chemistry, biology, public health, business administration and management, marketing, IT, and commerce. Senior positions may require additional postgraduate qualifications such as Graduate Diplomas, Masters and PhDs in relevant areas.

Apprenticeship-based or on-the-job training include licences for various heavy equipment (e.g. forklift, excavator, other machinery), site management, product quality and management, and other professional certificates (e.g. Professional Product Steward, and occupational health and safety regulations).

Skills

Computer skills, product quality and maintenance, health and safety practices, understanding of product life-cycle, storage and distribution procedures, supply chain assessment, strategic and project management.

General skills include strong communication, negotiation, research and analytics, interpersonal, collaboration, leadership, organisational and planning skills.

◕ Social readiness

Environmental and social costs are borne collectively rather than individually, so consumers tend to over-use waste disposal services when they do not directly pay for them. Ensuring that some of the costs of sustainable products are borne up front through product stewardship schemes will help to drive change in consumer behaviour.

Consumers are increasingly prioritising social responsibility when choosing products and services, based on their environmental impact and sustainability. Social awareness of waste has significantly increased across the community, businesses, and government.

Image source: The impact of the ABC's War on Waste. Prepared with the ABC by the Institute for Sustainable Futures, University of Technology Sydney. abc.net.au

The ABC's *War on Waste* TV series, which aired in 2017 and 2018, triggered country-wide social awareness and changes in consumer behaviours.[75] In a follow up study on the impact of the *War on Waste* series, the ABC found increased awareness and a surge in demands for eco-friendly products and services. In response some companies and institutions ended their use of single use plastics and introduced improved recycling schemes.

Consumer awareness of material management and its effect on the planet has been a driving force behind manufacturers, retailers and governments deciding to take responsibility and implement change. According to John Gertsakis of environment and sustainability firm Equilibrium: "Consumer appetite for stewardship schemes that meet a clear need and are also equitable in their coverage nationwide, is strong and ever-increasing."[76]

Most stakeholders consulted by ATSE indicated that they felt there is willingness to participate in voluntary product stewardship schemes in Australia, such as those that currently exist for computers and batteries. However, consumers are not fully engaged with responsible waste practices of repair and reuse. To enable positive consumer behaviour, consumers need information on how to use products efficiently and safely, and what extra steps they can take to recycle or dispose of products responsibly.

The introduction of online databases or labelling standards to provide consumers with information about the environmental and health impact of a product's lifecycle will support consumer awareness and promote positive consumer behaviour. Enabling the consumer to make better choices may incentivise manufacturers to design products for sustainability. With the rise of social media and the global information network, manufacturers and businesses stand to benefit from demonstrating extended producer responsibility to show corporate social responsibility.

Economic feasibility

There are many economic barriers to extended producer responsibility in Australia and few incentives for producers to take responsibility for the disposal or recyclability of their products. In the absence of voluntary or co-regulated product stewardship schemes, individual producers have no responsibility for the lifecycle or disposal of their products and few incentives to bear those costs. Stakeholders consulted by ATSE overwhelmingly believed that although Australia has the skills and technology to implement product stewardship schemes, it was unlikely to happen without regulatory push or market pull.

The United Nations Global Compact found that 99% of chief executive officers from large companies believe that sustainability is important to the future success of their business, but only 48% are actively implementing sustainability, with budget constraints seen as the primary obstacle.[77]

> **"The focus of the existing collection, recovery, reprocessing sector must transition from a "gate fee" model to a quality recyclate sale model, and this will involve shifting the entire focus of this sector from charging for public health protection services to one where the primary focus is on servicing the clearly stated objectives, need and obligations of the brands and manufacturers...the very essence of Product Stewardship."**
>
> Survey response – Mark Glover, Director, Ecowaste

Business model innovation is required, and a significant paradigm shift is needed for industry to move from the linear consumption model and invest in circular business practices. The mindset must change to 'polluter pays', with extended producer responsibility for products brought to market.

Retailers can consider investing in take-back schemes that enable consumers to return used products for recycling, thus establishing a closed loop for both the purchase and return of products. Manufacturers benefit from these schemes where incentives are given to consumers to trade-in their used products for a new product from the same brand. Increasingly electronic devices returned in this way are refurbished by the manufacturer and sold to consumers as certified refurbished devices.

The lack of financially sustainable markets for products made from recycled materials remains a significant issue in Australia. Several larger manufacturers are looking into sustainable operations using recyclable or recovered materials, but Australia's manufacturing capabilities have been greatly diminished due to increasing imports of cheaper products.

Another key barrier identified by stakeholders was inconsistency in the implementation of product stewardship schemes – the current variability adds cost and burden to businesses. National and consistent policy action is therefore necessary to create the institutions that can shape markets, and the incentives that can encourage businesses to participate, in order to ensure that product stewardship schemes optimise outcomes for both companies participating, and the Australian economy.

PROFITABLE CORPORATE SOCIAL RESPONSIBILITY

Apparel and footwear company VF Corporation is an example of profitable corporate social responsibility.[78] Sean Cady, VF Corporation's vice president of global sustainability and responsible sourcing, explains:

"We looked at the circular model, where waste becomes the feed for new products, and materials and products are kept in use as long as possible. We saw it as an opportunity to unlock a new revenue stream, engage with customers that might not otherwise be able to buy our products, and meaningfully minimalize our environmental impact.

"The resale of apparel in the US, for example, has grown 21 times faster than the general retail environment. We see rental becoming a first choice for consumers that care about the environment. We believe that circular business models are financially viable for retailers, especially those in higher-priced segments.

"Using waste as the raw material for new products just makes financial sense. When we get into rental, renewed or used products, there's a new market willing to pay a lower price for a slightly used North Face jacket that performs equally as well, or pay a rental fee for a piece of Kipling luggage they don't have the space to store.

"We see financial viability in areas of our business that are not necessarily replacing what a full-price consumer would pay."

◑ Policy and regulatory readiness

The *Product Stewardship Act 2011* was highlighted by many stakeholders as a key opportunity to drive greater implementation of product stewardship programs in Australia. The Act is currently in transition to a new regime and stakeholders indicated that there may be opportunity to expand definitions within *Product Stewardship Act* to encompass the principles of design, rather than its current focus on end-of-life and disposal.

By international standards, the policy environment governing waste and resource recovery in Australia is immature. This is attributable to a range of factors, including lack of alignment on priorities across key stakeholder groups, including governments and industry peak bodies.

For example, the European Union's Circular Economy Action Plan contains 54 actions involving all stakeholders across a product's supply and value chain. The United Kingdom (UK) is following the European Union (EU) Action Plan by implementing a legislative framework under the Circular Economy Package 2020.

Packaging producer responsibility regulations in the UK require participants in a supply chain, such as manufacturers, importers and retailers, to cover a proportion of the cost to recover waste materials equivalent to the amount of packaging put on the market. This is achieved through the purchase of packaging recovery notes from facilities that process waste.

Sweden's producer responsibility goes even further, covering recovered paper, packaging, waste electrical and electronic equipment, tyres, cars, batteries and pharmaceuticals. Producers are responsible for collecting and appropriately disposing of end-of-life products. Consumers too have greater responsibility in Sweden for sorting and disposing of waste appropriately.

The Australian context is complicated by the state and federal jurisdictions. A consistent approach to extended producer responsibility, including product stewardship, led by the Australian Government, could shape markets where product stewardship benefits and motivates manufacturers.

Gayle Sloan, Chief Executive of the Waste Management Association of Australia, said efforts to promote better use of recyclable materials with national and multinational companies are complicated due to the different regulations in each state/territory.[79]

"The Commonwealth Government is key … in standardising these approaches to give those involved with the waste and resource recovery industry … that there's certainty and long-term certainty around your investment," said Ms Sloan.

While the Act provides a framework for mandatory, co-regulatory (shared industry and government) and voluntary arrangements, there are currently no mandatory schemes in place under this Act. Both state and federal governments have indicated that expanding product stewardship programs is a priority. A major theme within the National Waste Policy Action Plan 2019 was to develop nationally consistent standards and specifications.

CASE STUDY

Paintback®

Image source: Paintback. paintback.com.au

MANAGING LEFTOVER PAINT

Paintback®[80], established in 2016, is a world-first industry driven initiative to responsibly manage leftover or unwanted paint and packaging. Diverting waste paint and packaging from landfill also minimises health and environment risks to the community.

Individuals can deliver unwanted paint to a Paintback collection site, where it is then transported to treatment and, subject to contamination, packaging recycling. The scheme is supported by a fifteen cents plus goods and services tax (GST) per litre levy on eligible products.

After return, the materials are repurposed:

- Solvent-based paint is used as fuel, replacing coal in high-temperature kilns that produce cement
- Water-based paint is dehydrated, reducing the volume dumped in landfill
- Steel cans are recycled into new steel products.

Paintback also invests in research on:

- Turning heavily contaminated plastic packaging into new plastic products
- Turning water-based paints into other useful products
- Recovering valuable material such as titanium dioxide from water-based paints
- Designing more sustainable packaging
- Finding and developing new uses for unwanted paint and paint packaging.

This non-profit organisation's goal is to ensure all paint and paint packaging in Australia is managed in a circular economy – that it is all reclaimed, turned into new products, or converted into energy. The program is driven by the nation's paint industry and the major companies that supply around 95% of all the architectural and decorative paint sold in Australia. Paintback recently reached 20 million kilograms of paint and packaging collected and treated from communities across the country, and aims to collect a further 45 million kilograms nationally over the next five years.

CREATING A CIRCULAR IKEA

Ikea has committed to becoming a circular business by 2030. It plans to make all its products according to circular principles – meaning products will only use renewable or recycled materials across their range, and all products can reused, refurbished or recycled.[81] Ikea started by mapping all its global waste materials, and defined a 'roadmap' for each material. For example, wood is the primary raw material used in Ikea furniture. To supply this, Ikea has been planting fast-growing, renewable poplar plantations in Slovakia since 2016. All textile products will be transitioned to recycled polyester. A recent collection of a bag, cushion covers and a tablecloth was made in part using PET plastic waste recovered from the ocean by Spanish fishermen in their fishing nets.[82]

For materials with no immediate solution, such as glue or a fire retardant coating for wood, Ikea are investing in research and development of sustainable alternatives.[81] New Ikea products are designed for circularity using nine design principles, for:

- An expected lifespan
- The use of renewable or recycled materials
- Recycling
- Minimal waste in production
- Standardisation and compatibility
- Adaptability and upgradability
- Care and repair
- Disassembly and reassembly
- Emotional connection.[83]

For existing products, Ikea is helping to extend their lifespan by operating a consumer buy-back scheme. People can bring used Ikea furniture that is still in good condition back in exchange for Ikea credit. The furniture is resold via the AS-IS department.[84] The scheme is projected to save up to 15,000 pieces of furniture from landfill each year.[85] Ikea has also trialled the refurbishment and resale of sofas in late FY19.[86]

A NATIONAL APPROACH TO PRODUCT STEWARDSHIP FOR SOLAR PV

To manage the lifecycle of solar infrastructure in Australia, Sustainability Victoria is leading development of a national framework of shared responsibility.[26] This will involve producers, retailers and consumers taking responsibility for the environmental and health related impacts of solar infrastructure across its lifecycle. The national working group is exploring three main options available through Australia's national product stewardship framework:

1. Industry-led

An industry-led product stewardship scheme is voluntary and would be led by Australia's PV sector. This means that industry would act voluntarily to reduce the impact their products have on the environment and human health. An industry-led and funded scheme would enable the industry to manage products without regulation – and can involve voluntary product stewardship accreditation.

2. Co-regulatory

Co-regulatory product stewardship schemes combine government regulation and industry action. Government sets the minimum requirements, while industry has some discretion about how these are achieved.

3. Mandatory

Mandatory product stewardship is a legal obligation where certain parties would be required to take certain actions in relation to a product. The scheme would be administered by the federal government. There are currently no mandatory product stewardship schemes in place in Australia.

In May 2019, the three options were assessed, finding that:

- Key stakeholders (including PV manufacturers, importers and industry associations) supported a nationally coordinated approach for managing PV system waste
- Solar panel waste is the fastest growing e-waste stream in Australia, with only limited recycling opportunities, and would benefit the most from a product stewardship approach
- Either a voluntary or co-regulatory approach for solar panels may be feasible and are likely to achieve the environmental, health and safety objectives of the *Product Stewardship Act 2011*, improve management of solar panels and increase the opportunity to reuse valuable materials.

The next step will be to analyse the potential impacts of voluntary and co-regulatory options.

Advanced resource recovery and recycling

2018 NATIONAL WASTE POLICY

PRINCIPLE 2
Improve resource recovery by improving material collection systems and processes for recycling, and improving the quality of recycled material we produce.

PRINCIPLE 3
Increase use of recycled material and build demand and markets for recycled products.

STRATEGY 5
A common approach
Implement a common approach towards waste policy and regulation, particularly in relation to national opportunities to support development of markets for recycling.

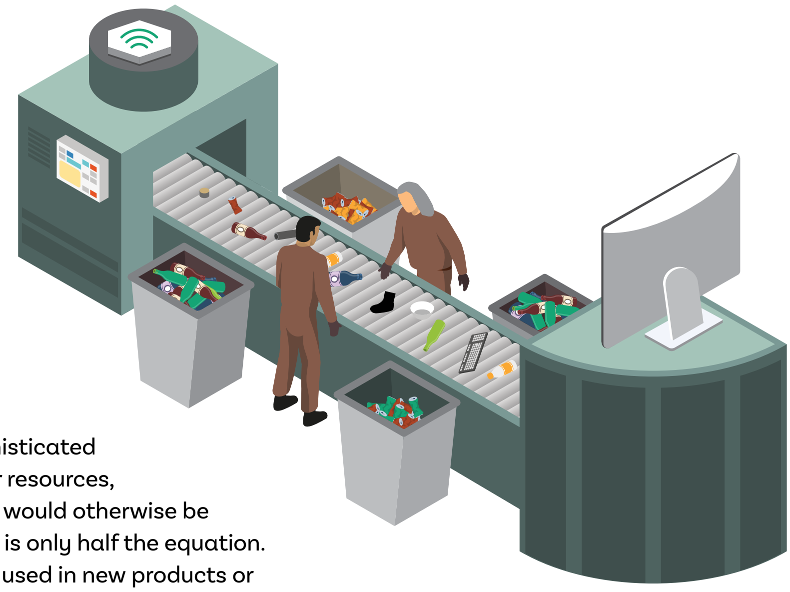
STRATEGY 7
Increasing industry capacity
Identify and address opportunities across municipal solid waste, commercial and industrial waste, and construction and demolition waste streams for improved collection, recycling and energy recovery, to deliver ongoing improvements in diversion from landfill, improved quality of recycled content and use of the waste hierarchy.

STRATEGY 8
Sustainable procurement by governments
All Australian governments consider environmental issues in their approach to goods and infrastructure procurement and promote demand for recycled materials and products containing recycled content.

STRATEGY 9
Sustainable procurement by business and individuals
Businesses and individuals in Australia take environmental issues into account when purchasing or manufacturing goods and services, and promote domestic demand for recycled materials and products containing recycled content.

STRATEGY 12
Reduce organic waste
Reduce organic waste, including garden and food waste, by avoiding their generation and supporting diversion away from landfill into soils and other uses, supported by appropriate infrastructure.

STRATEGY 14
Market development and research
All Australian governments and businesses generate and report information to support creating and maintaining markets for recycled materials, both domestically and internationally.



Advanced resource recovery uses sophisticated and innovative technologies to recover resources, materials and energy from waste that would otherwise be destined for landfill. Resource recovery is only half the equation. However, recovered materials must be used in new products or purposes before they can be considered 'recycled'.

Australia's resource recovery rate is currently around 63%, which is better than the United States at 49%, but well below Denmark at 94%t, Norway at 78%, and the UK at 75%.[11]

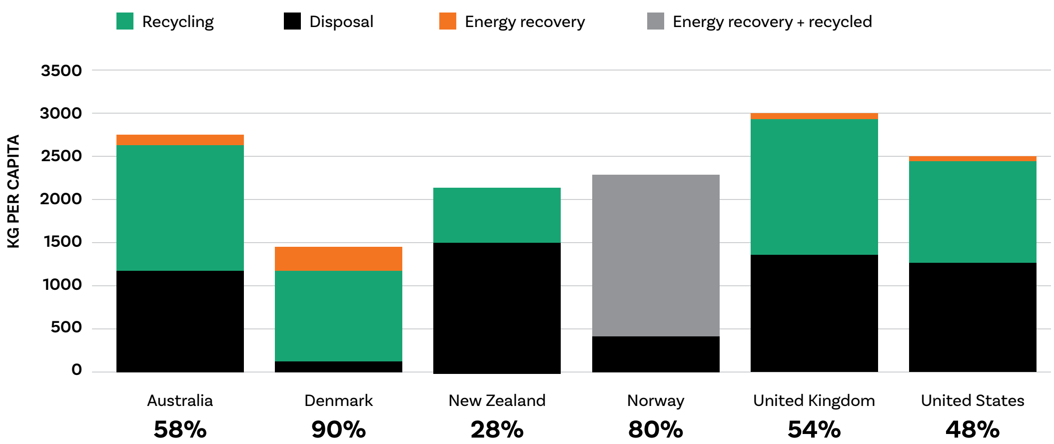


FIGURE 5
Australia's waste, recycling and engery recovery by volume, compared to other developed countries

Source: National Waste Report 2016. environment.gov.au

Australia's resource recovery target is set by the National Waste Policy Action Plan at 80% average resource recovery from all waste streams following the waste hierarchy by 2030.[13] This would mean an extra 15 million tonnes of material recovered per year.

Resource recovery rates are unevenly distributed across Australia's states and territories. In 2016-17, South Australia had the highest rate of resource recovery of all Australian states at 82%, followed by Victoria at 72% and New South Wales, 62%.[11] In 2017-18, 45% of waste in Queensland was recovered for other uses while 55% of waste was sent to landfill.[87] The Northern Territory had the lowest resource recovery of 15%.[11]

◑ Infrastructure readiness

Australia has infrastructure for advanced resource and material recovery for masonry, paper and cardboard, and metals. However, infrastructure is lacking in areas like plastics and organics, and infrastructure challenges differ across jurisdictions, and from metropolitan to regional areas.

DIGITAL INFRASTRUCTURE

Digital infrastructure is essential to track waste generation, recycling and resource recovery rates. Online platforms and digital infrastructure can also facilitate trade in recovered resources.

Australia's federated system is an impediment to digital infrastructure, with waste services delivered via local governments, individual industries and businesses recording data in different ways using different software, and based on varying definitions. The use of non-standardised systems is a key barrier to gaining a clear picture of Australia's capacity and potential for resource recovery. With better data capture and consistency, AI can help build and improve the reverse logistics infrastructure required to 'close the loop' on products and materials by improving the processes to sort and disassemble products, remanufacture components, and recycle materials.

Life-cycle analysis is another useful soft infrastructure tool. It can be used to determine the environmental impact of a product. It helps determine what part of the waste management hierarchy, including resource recovery, is the best practising environmental option.

Digital systems also enable materials exchange and sale in a closed loop system.

RESOURCE EXCHANGE

The Advisory System for Processing, Innovation & Resource Exchange (ASPIRE) is a spinout from CSIRO's Data61.[88] It is an example of a digital e-commerce platform which connects businesses to buy and sell waste to other businesses or recyclers, enabling exchange of resources for better economic and environmental outcomes. The ASPIRE platform extends beyond passive digital systems, where information is posted by 'sellers' online for potential 'buyers'. It goes one step further than a passive waste exchange by actively suggesting business to business collaborations. ASPIRE has been developed in response to manufacturing companies talking to their local councils about waste disposal costs.

Another example of the benefit of enhanced digital software was developed by the Local Government Association of Queensland. The association invested in development of a range of online data tools through its LG Sherlock project, one of which is a new waste analytics tool called Waste Detective.[89] Waste Detective tool uses the detailed data returns that councils provide to the Department of Environment and Science as the primary data source. The returns are required to be submitted monthly to the department by all Waste Levy councils. Participation in the LG Sherlock project is voluntary – and highly beneficial. The project has helped councils reduce energy bills by hundreds of thousands of dollars.

AUSTRALIAN CIRCULAR ECONOMY HUB

Planet Ark is also launching a government-funded platform in Australia in late 2020 to inspire and facilitate the collaboration and networking necessary for our transition to a circular economy. Planet Ark has created the Australian Circular Economy Hub and Marketplace with the aim of being Australia's leading platform to accelerate our transition to a circular economy. Planet Ark is currently seeking corporate partners and collaborators for the Australian Circular Economy Hub.[90]

Image source: Planet Ark. planetark.org

MODELLING WASTE FLOW — 'DIGITAL TWINNING'

'Digital twinning' is the creation and use of a digital model of a physical object or system.[91] Digital twins can be built using historical data and can use real-time information from sensors or similar from the physical object or system to mirror what is happening.[91]

Digital twins can safely model and experiment with waste flow and potential outcomes of interventions to improve waste management. This can save money on real life intervention implementation by maximising efficiency before deployment, anticipating risks, flagging potential unintended consequences and providing an opportunity to proactively address problems. A digital twin also allows industry and businesses to accurately monitor real-world waste systems, including waste streams and the health of machinery, in real time.[92,93]

Digital twinning can be applied to processes at every stage of waste management to support modelling of interventions. Digital twins can be used to model the outputs of waste systems, for a more accurate projection of the nature and volume of resources. This can give an element of certainty for businesses who can use recovered materials to produce new products and so increase demand for recovered resources.[94]

SMART WASTE MANAGEMENT SYSTEMS

Researchers, innovators, and start-ups are leading the way in development and application of a wave of smart technologies designed to improve the efficiency of waste collection, reduce greenhouse gas emissions, and capture more useful and granular data about waste. Smart systems incorporate sensors, automation, IoT, networks, data and software in order to describe and analyse a situation, and make decisions based on the available data in a predictive or adaptive manner, thereby performing smart actions.

Smart waste management systems facilitate more efficient disposal by consumers, and provide solutions for operational efficiency in the way waste material is collected and processed. Data collected by tracking and monitoring waste can be transferred to businesses in real time, which can then process waste in the most sustainable way rather than sending it to landfill. Such systems optimise efficiency of resources and costs to higher levels and create cleaner and more sustainable operations.

Adopting these and other smart technologies makes social, economic and environmental sense. They drive reduced costs and increased efficiency, as well as capacity of waste collection and materials recovery. Smart waste management systems can increase the capability of existing infrastructure, and make new infrastructure highly adaptable.

Australia has begun taking steps to adopt smart technological solutions for waste management which are designed to improve systems efficiency and reduce cost and emissions. The major barrier to improved digital infrastructure is the high cost of capital investment to install modern smart technology. This is especially challenging in regional areas.

Key infrastructure requirements for enabling smart solutions are a network of sensors, cameras, wireless devices and data centres (where sensor systems store their information), and platforms that allow sharing of information. Remote control pneumatic waste collection service networks and ICT are also critical in maintaining continuous communication with users and managing public services in real time to monitor, maintain and optimise waste collection requirements and activities.[95]

Some councils have moved to adopt waste management systems that reduce the physical footprint of necessary waste infrastructure. In 2018, Melbourne city council, for example, installed solar-powered waste compactors, cutting the physical footprint of public bins by 49%.[96]

Other councils across Australia are trialling or developing locally made smart bins. These intelligent waste management systems have embedded wireless ultrasonic fill-level sensors that detect how full the bin is. Then, through the Internet of Things, this data is sent to a cloud-based monitoring and analytics platform. On the basis of this data, waste collection services can optimise their routes and frequency.[97]

HOBART CITY COUNCIL

Hobart City Council recently completed installation of smart bins across the city.[98] They are connected to an IoT low-range network containing sensors which communicate data about bin fullness, fire hazards or odour. Though each bin costs approximately $200, they are forecast to reduce costs associated with maintenance and transport to empty low-volume bins.

Existing bins can be retrofitted with similar fill-level sensors to upgrade them to smart bins. The data collected from the bins can be combined with information on truck fleets to optimise route planning for collection, reducing vehicle movements and related costs, and at the same time automating billing and invoicing. Cloud based services are also available to store and share this data with other businesses, start-ups or companies who seek to use it for innovative solutions.

SMART WASTE TECHNOLOGY

- **SMART RUBBISH BINS**
  ROBIN tracks and sorts waste into categories, and gives points to the user through a Robin mobile app. The points can be exchanged for Miniwiz products or discount codes for partner stores.[99]
- **VODAFONE 'SMART WASTE COLLECTION'**
  Sensor on bin collection vehicles that can alert businesses and residents when the vehicle is passing so they can take the rubbish to meet the bin. These IoT-connected sims are also being used to guide trucks to previously missed bin collections, improving customer service and improving safety records.[100]
- **PNEUMATIC WASTE COLLECTION SYSTEMS AND AUTOMATIC WASTE COLLECTION SYSTEMS**
  Waste in bins is transported with vacuum and airflow via a network of underground pipes to a transfer station. The process can be totally automated and touch free.
- **BIN-E**
  AI-based object recognition to sort and compress materials collected. A touchscreen interface can guide users through the process. Sensors for fill level control which can connect to collection logistics.[101]

City of Melbourne's Clean Cube Solar Bins.
Image source: Smart City Solutions. smartcitysolutions.com.au

YOUNG AUSSIE INVENTOR

17-year-old Riu Fukazawa created a robotic waste sorting system for his year 12 project, which scans existing product barcodes to determine the correct disposal method.

When a user scans an object's barcode, a bench housing the standard two different types of household bins opens the appropriate flap to either the recycling bin or general waste bin under the bench.

Fukazawa's father Simon Monk tweeted about the invention, proud that he had created the sorting device himself using a battery powered barcode scanner and an Arduino circuit board.[103]

His Dad's comment: Of course, the real 'design' work here isn't what you can see or use, it's in the design thinking about using the existing barcodes already on the item. "Good design is obvious. Great design is transparent."

His Mum was not so impressed with his new viral status. She said: "how come, it's not even that amazing?"[102]

PREDICTIVE LOGISTICS AND ROUTE OPTIMISATION

There are a range of different models and techniques that can be used to compute optimal route, such as system dynamics or network theory.[104] Such optimisation offers a significant advance on current operations which work according to predefined schedules. Rigid processes are inefficient, considering the poor use of assets, workforce and fleet fuel consumption in collecting waste from half-full bins.

Optimising the use of waste collection vehicles and routes is essential to the efficiency of a smart waste system. Route optimisation includes consideration for time windows, heterogenous fleets and road conditions.[105] Waste can be collected from collection points when it is predicted that they will reach a certain threshold for volume, moisture, smell or other dimensions.

The use of big data and real-time monitoring to feed into predictive logistics and route optimisation has the potential for even bigger improvements such as predicting the most efficient speed, time of day and the amount of fuel needed to complete routes.[106] If waste collection can become more economical, it could potentially could be expanded to take-back services (reverse logistics) to increase reuse of materials.[107]

MECHANICAL RESOURCE RECOVERY

Material recovery facilities (MRFs) are the critical infrastructure for kerbside materials recovery and are a mixture of manual, mechanical and electronic processes. MRFs sort mixed waste streams to recover materials such as glass, plastics or metals, typically from the mixed recycling bin.

Most of the roughly 90 MRFs in Australia used manual sorting. They therefore lack the technical capacity to sort co-mingled, highly-contaminated municipal waste into many specific material types that have low levels of contamination.[14]

Australia currently has nine semi-automated MRFs and nine fully-automated facilities.[108] In the nine more modern facilities in Australia, optical sorting systems have replaced manual and mechanical sorting.

With recycling rates at just 12%, plastics may be 'low hanging fruit' for improving overall resource recovery rates. Where the value of plastics is too low for recycling, either in Australia or off-shore, processing into refuse-derived fuels offers an alternative. Like metals, plastics recycling has been affected recently by low commodity values and a relatively strong Australian dollar. Despite the China restrictions, strong global markets remain for plastic waste that is well sorted by type and free of contamination. Australia's plastics recycling rates could be improved with greater on-shore investment in plastics sorting and cleaning equipment to enable either on-shore or off-shore recycling.

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SHOALHAVEN RESOURCE RECOVERY CENTRE

A new resource recovery centre in the Shoalhaven region of New South Wales will enable 90% of mixed household waste to be recycled when it is built by 2021. Mixed waste material will be taken to the new facility for sterilisation, drying, and separation into various groups of recyclable materials. Residual material not able to be recycled would still be sent to landfill, but would be inert and therefore less harmful to the environment. Plastic, glass, metals and organics will all be separated and put back into construction aggregate, bricks and glass wool. Sterilised organic matter will be used for bricks, render, and potentially fuel for energy recovery.

Part of the design for these waste management centres is to make them less distasteful for residential neighbours, through reduced odour and limited traffic.[109]

ADVANCED SORTING TECHNOLOGIES

Advanced sorting technologies accurately sort waste into clean streams for efficient processing. Near-infrared spectroscopy measures light reflected off materials to identify, with great accuracy, the nature of those materials. X-ray fluorescence measures emitted wavelengths and energy released by materials after being energised by X-ray.[94] Floatation sort technologies use the density of different materials as the basis for separation. They may also utilise different surface wettability property of materials.[94]

To economically recycle large volumes of plastic waste, fast and accurate methods to sort plastics are essential. Spectroscopic sorting offers real-time sorting of waste streams without direct contact with materials or preparation the waste stream.[94] Near-infrared spectroscopy can also provide a quick snapshot of the composition of waste samples. Improved efficiency of machines (transmission devices and spectral collection) and creation of a database of polymer materials and their signatures would extend the ability of this technology to support recovery of a wider range of materials.[110]

MOBILE APP NEAR-INFRARED SORTING

In July 2020, trinamiX GmbH developed a new plastic sorting and recycling application for its mobile Near-Infrared Spectroscopy Solutions.[111] A portable handheld device combines data analysis with a mobile app to determine the diverse compositions of different plastics, improving recovery rates.

This technology is aimed at companies that need a flexible and mobile solution rather than a large, stationary sorting plant. Examples include recycling yards and plants as well as manufacturers of recycled products. “If valuable plastic waste can be classified and collected separately right where it is generated, the transportation costs to central sorting plants and thus CO2 emissions are reduced. In addition, pure plastic materials can be sold as resource,” explained Adrian Vogel, Manager Sales and Business Development Spectroscopy Solutions at trinamiX.

CHEMICAL RECYCLING

Chemical recycling recovers raw material from plastic by breaking polymer chains in recovered plastic waste down into monomer units. These monomer units can then be used to manufacture new polymers.[112] In this way, chemical recycling allows recovery of waste that cannot be recycled mechanically.[107] It can increase the lifecycle of materials and allow higher order uses for recovered plastics, reducing the pressure to produce virgin plastic materials.[112]

Chemical recycling uses chemical reactions based on the properties of plastics and specific solvents, such as methanol, ammonia and sulfuric acid, usually at high temperatures. Another approach uses pyrolysis to crack long polymer chains in polyethylene and polypropylene into short-chain hydrocarbons like diesel and naphtha. The resulting by-products can be used in fuel, or to manufacture polyethylene and polypropylene again.[113]

CHEMCYCLING™

CASE STUDY

BASF: ChemCycling™ products for food packaging: Fish box made of Styropor® Ccycled.

Image source: BASF SE. basf.com

BASF launched a project called ChemCycling™ in 2018, with the aim of manufacturing products from chemically recycled plastic waste on an industrial scale. ChemCycling™ is focused on plastic waste for which no high-value value recycling processes are established, including mixed plastic waste, plastics with residues or multi-layer food packaging. BASF has cooperated with technology partners who use pyrolysis to transform the plastic waste into raw material (pyrolysis oil). BASF can feed this oil into their chemical production Verbund at the beginning of the value chain, replacing fossil fuel-based feedstock. In the pilot phase, BASF presented prototypes of mozzarella cheese packaging, transparent refrigerator components and insulation boxes for sensitive applications. The first commercial products were launched in the German market in 2020.[114]

This technology represents a possible solution for problem plastics, such as contaminated or coloured plastics, which are unable to be recycled using existing technology.

Chemical recycling is not yet commercially viable at scale due to the amount of energy required, translating to high costs and greenhouse gas emissions.[107] Another major barrier to the widespread routine use of chemical recycling is the lack of a complete process that is efficient and environmentally friendly.[112] The development of efficient, highly selective catalysts that can be recovered and reused would assist in the technology's adoption.[112]

Chemical recycling may be commercially applied to many types of plastic if these obstacles can be overcome, as it has advantages over mechanical recycling. Chemical recycling can potentially recycle plastic polymers infinitely, at the same quality. Chemical recycling can also remove contamination such as dyes and food residue. If emerging technologies can support the commercial viability of chemical recycling, particularly reducing the amount of energy required, it could be a key element of a circular future for plastic.[107]

LOW ENERGY CHEMICAL RECYCLING

Loop Industries have developed a low-energy de-polymerisation technology that can handle a high level of plastic waste material contamination. Loop takes in waste PET and polyester plastic of all types, shapes and colours that would normally end up in landfills and the ocean. Through their patented low-energy depolymerisation technology, the waste plastic is completely broken down into its monomers: Dimethyl Terephthalate and Monoethylene Glycol — using low heat and no pressure.

Depolymerisation is the process through which waste PET plastic and polyester fibre feedstocks are broken down into their base building blocks. The monomers are then purified, removing all colouring, additives, and organic or inorganic impurities. These building blocks can be used to create new, virgin-quality PET resin and fibre.[115]

WASTE TO ENERGY

Waste to Energy (WtE) plants use thermal or biological processes to burn waste that cannot be recycled. They can generate heat, electricity steam or solid fuel.[14,116] Waste to energy can recover energy from lower order waste that may not be a candidate for recycling, replacing landfill as the final disposal option for residual waste.[117] This decreases the amount of land needed for landfill and reduces methane emissions from decomposing organic waste.[118] However, the emissions from waste to energy are problematic.

In 2016-17, Australia used two million tonnes of waste for WtE.[11] Australia's WtE rates have fallen over the past five years. The trend is partly attributable to reduced organics going to landfill, and poor reporting.

Australia currently has capacity for 620 Megawatts of electricity generation from small-medium scale technologies that accept homogenous and low risk feedstock, mostly landfill gas, wood waste fuels, waste oil or tyres, and agricultural waste.[119-121]

Construction on Australia's first WtE plan began in late 2018, a $668 million plant for mixed residual waste in Kwinana, Western Australia.[122,123] It is estimated that it will be able to divert approximately a quarter of Perth's post-recycling rubbish from landfill.[124] A second facility in nearby Rockingham has been planned, representing progression towards commercialisation for the sector in Australia.[125] Once both facilities are completed, it is projected that they will be able to process 700,000 tonnes of municipal, industrial and commercial rubbish per annum to produce 65 MW of power.[124,125]

EarthPower Technologies is Australia's first regional food waste to energy facility, located in Sydney's west. The EarthPower facility uses anaerobic digestion technology to convert food waste into combustible gas.[126] The gas is used as a renewable fuel source to produce green electricity and fertiliser. At full capacity, EarthPower can power over 3,600 homes.

Australian Paper, with French waste management company Suez, will proceed with Victoria's first WtE project. It will use kerbside rubbish to help power its Maryvale paper mill after completing the project's feasibility study.[127] The project will generate 225 MW of electricity, divert 650K tonnes of rubbish from landfill, and generate on average 1,046 jobs per annum during the three-year construction period. Once it is operating in 2024, it will employ more than 900 people.[127]

Other thermal infrastructure in Australia includes the high-temperature pyrolysis plant in Yarwun, Queensland. There, waste biomass and hydrocarbon materials are processed into crude oil which is then processed at an oil refinery into renewable fuel products.[128]

CATALYTIC HYDROTHERMAL REACTOR

Licella's Catalytic Hydrothermal Reactor (Cat-HTR™) platform intends to revolutionise how we approach a zero-waste economy and transition to sustainable renewable fuels and chemicals. Invented in Australia by Dr Len Humphreys, Licella's CEO, and ATSE Fellow Professor Thomas Maschmeyer. The Cat-HTR™ converts a wide variety of low-cost, waste feedstocks and residues into high-value products using water at near or supercritical temperatures. It can rapidly and economically transform a wide range of biomass, waste plastic and industry residues into a synthetic oil or biocrude to produce more sustainable fuels and chemicals.

For plastic, hydrothermal upgrading with the Cat-HTR™ has the significant advantage of being able to chemically recycle mixed plastic and multilayer plastic. For biomass, the Cat-HTR™ produces a stable biocrude which can be easily shipped, is not acidic and is miscible (blendable) with conventional oil. The Cat-HTR™ platform has been extensively tested, and conservatively scaled up, over the past ten years to its current commercial-ready module, located on the NSW Central Coast, Australia. [129]

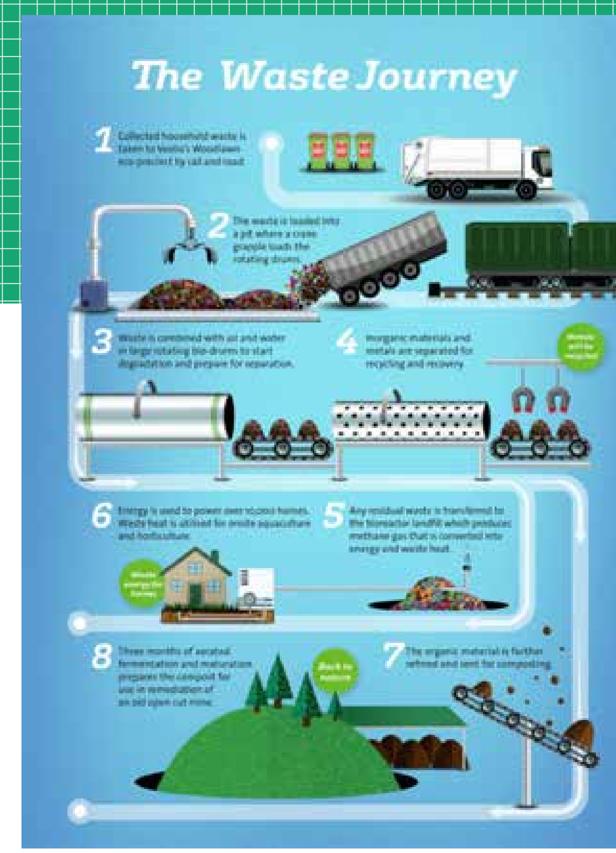
CASE STUDIES

Image source: Veolia.com

The towns of **PENRITH** and **LIVERPOOL** invested in a mechanical and biological waste treatment facility in an effort to cut the cost of sending waste to landfill. They treated 134,000 tonnes of waste per year, avoiding 55% being sent to the landfill. The advanced waste treatment plant, designed and operated by SUEZ, has increased the recycling of organic waste (15,506 tonnes recovered in 2015) that is used improve the soil and cut the community's costs.[130]

EARTHPOWER TECHNOLOGIES, located in Sydney, is Australia's first food to waste-to-energy facility since 2003. The bio-digestion of organic waste material — from industrial, commercial and residential sectors — are converted into methane and nutrient-rich fertiliser. Together with AB Muari Yeast, they divert 130 tonnes of waste from landfill, which saves $9,000 a year.[131]

WOODLAWN MECHANICAL AND BIOLOGICAL TREATMENT facility in Sydney will process up to 144,000 tonnes of waste per annum. Based on waste audit data, it is expected that approximately 50-60% of the waste received will be diverted from landfill.[132]



Skills availability

Matching available skills to emerging resource recovery jobs is key to accelerated industry development.[133] It is estimated that this lack of access to the right talent may have cost Australia about $3.8 billion in productivity and accrued $3.9 million in avoidable recruitment.[134]

Australia has a solid educational foundation on which to build an enhanced skill base for the sector, and stakeholders agreed that the university and TAFE systems offer advanced degrees and technical training in the skills needed.

Stakeholders reported that the waste management sector is knowledge-poor in the areas of materials science and processing. However, the current focus of the sector is how to move and dispose of waste. In order to gain value from waste, we must shift the national focus and skills base towards recycling, energy and materials recovery.

Skills required for a thriving advanced resource recovery sector range from materials science and process engineering, through to data analytics and market analysis.

Job types

The types of jobs required in the sector include process engineers, electrical engineer, engineering analyst, engineering and design supervisors, power systems engineer, resource conservation engineer, infrastructure engineer, occupational health and safety, project management, programmable logic controller technicians, supply chain project leaders, waste and resource recovery managers, risk engineers, implementation engineers, and occupational health and safety officers.

Also needed are energy analysts, energy managers, environmental waste consultants, carbon consultants, program analysts, and waste reduction consultants. Geo exchange designers are hired in many WtE projects, along with geothermal designers, equipment operators, mechanics, grid designers, and occupational health and safety officers.

Qualification types

Higher education qualifications required for these jobs include a Bachelor or Associate Degree in Science/Engineering – especially in materials engineering or design, chemical product engineering, industrial chemistry, technical certificate in instrumentation, controls or programming.

Degrees in chemical, electrical/electronic or process engineering, engineering geology, or geology with waste management, environmental management, agricultural specialist, microbiology, and biochemistry qualifications are also required for many WtE positions.

Skills

Essential technical skills include manufacturing, data analysis and interpretation, design, construction and commissioning. Also needed are skills in programmable logic control systems, selection and operation of plant and equipment.

Environmental legislation knowledge, along with skills in computer aided design, WtE and planning regulations, waste-management, selection and operation of plant and equipment.

General employability skills include computer skills, problem solving, analytical skills, communication skills (written and verbal), time management, and interpersonal skills.[135]

◑ Social readiness

There is generally high public support for resource recovery. Consumers are increasingly prioritising social responsibility by choosing products based on their environmental impact and sustainability.

Challenges exist around community acceptance of development of technologies that potentially generate nuisance such as smells, smoke, and noise, or where there is a perception of the risk of such nuisances. This is particularly relevant to WtE, but through regulation also impacts stockpiling and reuse of recovered materials.

In terms of the introduction of WtE infrastructure such as new environmentally sensitive incineration, it is clear that community acceptance and a social licence to operate will be key.[121] The location of infrastructure for resource recovery in many cases requires extensive planning and approval, often with requirements for demonstrated acceptance by local residents.

Community involvement offers an opportunity to build on expectations and public support for improved sustainability which, in turn, supports new infrastructure and innovations in resource recovery.[136] Determining the major drivers for acceptance in this space could provide key insights useful in developing community engagement programs and education.

A recent CSIRO survey found that the perceived benefits and value to society were key drivers of social acceptance in the waste sector, and that social acceptance and engagement are strongly motivated by understanding of societal benefits.[137]

Consumers overwhelmingly support the idea of minimising their environmental footprint by reducing the waste they send to landfill, but behaviour does not consistently correlate with this support. The use of new waste technologies to reduce contamination and increase sorting efficiency could help to close this gap between thought and action.

One factor contributing to the gap between consumer aspiration and consumer behaviour is the variation in approaches to kerbside recycling. Stakeholders indicated that inconsistency in kerbside collection practices and a lack of meaningful community engagement around waste were contributing to increased contamination and poor recovery rates of certain material streams.

Implementing new technologies – of all types – requires planning and consultation to ensure consumers and communities are engaged and willing to participate actively and appropriately. Behaviour change campaigns and better education on new initiatives, technologies and approaches would be beneficial.

GREEN STEEL[138]

OneSteel, an Australian based steel manufacturer has been working in close cooperation with the Sustainable Materials Research and Technology (SMaRT) Centre at the University of New South Wales on developing innovative technologies to use waste materials such as end-of-life tyres and plastics as alternative carbon units in steelmaking.

"Our range of research projects suggest that the potential for sourcing waste as raw materials for industrial production is considerable, and the extent of such opportunities is as broad as the range of materials containing hydrogen and carbon" said ATSE Fellow and SMaRT Centre Director Professor Veena Sahajwalla.[138]

Economic feasibility

In order to increase rates of recycling and resource recovery, it must be more economically attractive than landfill. Appropriate levies for depositing waste in landfill will increase the competitiveness of products designed with circular principles.[54] The key barrier acting against increases to landfill levies is a political aversion to new or increased taxes and a concern that these levies may place further economic strain on struggling industries. Increasing these levies is the strongest available policy mechanism to promote the economic viability of resource recovery in Australia, a message echoed by many stakeholders consulted for this report.

The Victorian Government is leading investigation into options to harmonise waste levies across Australia through government treasuries to encourage best practice waste management, under the National Waste Policy Action Plan.[13]

Currently in Australia, only metals, paper and cardboard have sufficient market value to outweigh the costs of collecting and processing the materials, and thus drive resource recovery. Recovery of all other waste streams is somehow subsidised – kerbside collection and gate fees by ratepayers, for example, or container deposit schemes by consumers. According to Mike Ritchie of MRA Consulting Group: "The bottom line is that if we want higher recycling rates then that comes at a cost to the economy and at a cost to someone. The question is who should pay and how much?"[121]

Market conditions must be created to ensure that resource recovery is both environmentally and financially viable. These are usually generated through Government signals, such as targets or regulation.

Targets can facilitate a more integrated assessment of business models as well as technological innovations. Targets can help innovators to promote their role as drivers of change and market shapers, as their achievements can be better measured and clearly communicated to investors and policy-makers. Resource use targets could help set reliable objectives, monitor performance and report at both company and country levels.[139]

Targets are helpful as a 'safety check' for business and policy decisions, and act as a strategic guide to more systemic innovations. According to the World Economic Forum, setting targets for smart and sustainable use of natural resources is the next big frontier in understanding how to reach a liveable future – and how to be economically competitive in it.[139]

In Australia, the Renewable Energy Target (RET) provides financial incentive for production of renewable energy.[140] Of that energy, 7% is provided from biogas, which can be produced from landfill or anaerobic digestion. The RET has driven infrastructure investments at landfill sites to generate renewable energy from landfill emissions.

The alternative to targets is regulation, through landfill bans and mandatory processing requirements. This is the European model, and has driven their high resource recovery rates. Strong EU legislation around plastics design and recycling has driven up the value of plastic feedstock, for example, providing a market pull and environment for investment in new technologies for waste management to meet the new EU circular economy directives. A similar approach may be effective in Australia, along with a substantial boost in the availability of facilities for source separation and advanced resource recovery. Australian Governments undertook to explore a legislative framework to prevent the landfilling of recyclable material in the 2019 National Waste Policy Action Plan.[13]

Australian Governments also committed to developing new markets for recycled products and materials, building industry capacity and supporting manufacturing of recycled content products through the National Waste Policy Action Plan.[13]

CASE STUDY
UNSW Sustainable Materials Research and Technology (SMaRT) Centre.

Image source: SMaRT. smart.unsw.edu.au

MICROFACTORIE® TECHNOLOGIES

Through its microrecycling science, the UNSW Sustainable Materials Research and Technology (SMaRT) Centre has and is developing numerous innovations that reform waste streams destined for landfill into new, value-added materials and products. Using its Microfactorie® technologies, this is a new industrial concept involving engineered modules to transform difficult waste usually considered to be non-recyclable, into new 'green products and materials' for advanced manufacturing.

One Microfactorie® module can reform waste plastic into filament as a feedstock resource for manufacturers and other users who do 3D printing. Another Microfactorie® module can reform textiles and glass into very smart-looking ceramics for the built environment. And an e-waste Microfactorie® module can extract valuable and precious metals and critical materials. These Microfactories® are based at UNSW and collaborations are underway for industrial take up of this technology.

UNSW SMaRT Centre Director, and ATSE Fellow, Professor Veena Sahajwalla said: "Imagine being able to recover from electronic waste all of the critical materials and precious metals like cobalt, gold, palladium and platinum, and others, for use as feedstock in manufacturing. These technologies can reduce the need for virgin materials as well as all the associated environmental and economic costs, while creating new and local supply chains to boost Australian manufacturing."

"Australia currently exports waste plastic and imports filament, so imagine that we could instead be processing the plastic here and using it productively, as well as exporting it as a value-added material to other countries. I see the need for a new alignment of recycling and manufacturing, which would be a major boost to developing circular economies, where materials are kept in use for as long as possible, thus creating greater sustainability and better economic outcomes."[143]

The economic viability of resource recovery also relies on markets for recovered material. That, in turn, requires a strong local manufacturing and re-manufacturing sector or viable export opportunities. Industry is generally risk averse in relation to making the large infrastructure investments necessary to change material recovery practices significantly. Development of a strong market will require both increased investment in technologies needed to produce recovered materials and increased demand for them. There must be growth in manufacturing industry and more supportive institutions to support use of recycled, rather than virgin, materials.

Sustainable procurement is also needed to boost demand. This involves government requirements or incentives for the use of recycled or recovered products and materials in infrastructure, along with the purchase, by all levels of government, of products containing recovered or recycled materials.[141]

The Australian Government is strengthening the Commonwealth procurement guidelines to enable any procurement undertaken by a Commonwealth agency to consider environmental sustainability and the use of recycled content when determining value for money. Using purchasing power, they hope to generate demand and encourage innovation.[142]

The impending bans on the export of certain types of unprocessed waste material will likely make material recovery more commercially viable for these waste streams, although for some streams, such as plastic, landfill will remain a cheaper option. Corresponding landfill bans should be considered for these problematic streams to promote recovery, with the longer-term aim of designing out problematic waste streams.

The waste export bans will result in significantly increased volumes of waste materials available for processing on-shore, meaning that the waste and resource recovery sector will need to invest in new machinery, equipment and technologies to manage this increased load. Lead times for equipment purchased internationally are expected to be up to 18 months from order to delivery, due to high global demand for new waste management technology. Australia would therefore benefit from investment in domestic research to develop material processing and remanufacturing technologies that suit local conditions and support local industry.

The Australian Government has flagged support for innovation in the waste sector to boost recycling and meet targets. In response to the growing concerns around management of plastic waste, in February 2020 the Federal Government announced $20 million of funding for nine Cooperative Research Centres Projects (CRC-P) aimed at reducing plastic waste and boosting plastic recycling.[144]

Difficulty scaling-up existing markets is also a barrier to the economic viability of resource recovery. According to a recent survey, for instance, plastic re-processors have indicated that running costs related to energy and wages grew at challenging level during the 2017-18 financial year.[17] While there is a domestic demand for most processed scrap polymers, especially in the building sector, the local buyers are still too limited in volume to compensate for the closure of overseas markets such as China.

There are international models which could be considered. Spain, for instance, has a highly successful scheme in which the government established an institute to undertake applied research into how to transform waste to valuable products.[145] Other models from comparable nations include the Catapult Centres in the UK, Finland's Strategic Centres for Science, Technology and Innovation, and the Fraunhofer-Gessellschaft network of institutes and research facilities in Germany.[146–148]

CASE STUDY

PACT Group.

Image source: PACT Sustainability Review 2020. pactgroup.com.au

2025 END OF WASTE TARGETS

Since 2018, PACT Group has been pursuing three 2025 End of Waste Targets: to eliminate all non-recyclable packaging it produces; to find solutions to reduce, reuse and recycle all single use secondary packaging in supermarkets; and to offer 30 per cent recycled content across its packaging portfolio.

PACT Group's sustainability division converts significant volumes of plastic waste into recycled plastic resin, recycled slip sheets and underground cable covers.[149] This area of the business is focussed on the product life cycle and closing the loop – meaning they make it, take it, reflake it and remake it. This provides a complete and returnable packaging solution, reducing environmental impacts and generating efficiencies for PACT's customers.

In March 2020, PACT Group pledged to work collaboratively with government and like-minded partners to invest over $500M in existing and new facilities over the next five years.[150] Their stated vision is to include 30% recycled content across their product portfolio by 2025. Across the business, this would be the equivalent of keeping nearly 2 billion plastic containers out of landfill.

PACT is also building a new recycling plant in Albury-Wodonga, in conjunction with Cleanaway Waste Management and Asahi Beverages. It is anticipated the facility will recycle the equivalent of around 1 billion 600ml PET plastic bottles each year. The bottles will be used as a raw material to produce new bottles plus food and beverage packaging in Australia to help close the loop on recycling. This will see the amount of locally sourced and recycled PET produced in Australia increase by two thirds – from around 30,000 tonnes currently to over 50,000 tonnes per annum, according to Pact Group.[151] Other major environmental benefits it will deliver include reducing Australia's reliance on virgin plastic, the amount of plastic waste sent overseas and the amount of recycled plastic Australia imports. The facility will be part powered by solar energy.

◔ Policy and regulatory readiness

Policy and regulation can be mechanisms to incentivise resource recovery, and several states are well on the way to implementing reforms which would support their own recycling and resource recovery capabilities. Overall, however, stakeholders indicated that the regulatory frameworks must change to support 'clean' recovered materials.

Current regulations often treat them as 'waste', which attracts more onerous regulation than virgin materials, meaning they are not able to be used in food packaging, for example.

The development of national standards for the quality and use of recycled content was a consistent recommendation from stakeholders. The *National Waste Action Plan* includes a number of actions to develop standards to avoid waste, facilitate the use of materials throughout the lifecycle of products, increase life cycle potential and promote the use of recycled content.[13] The development of these standards and specifications should cover all waste material streams, with priority given to those for which standards and specifications could quickly and significantly increase resource recovery rates. In preparation for the waste export bans, nationally consistent definitions and specifications for some waste and recycled commodities have already been developed.[13]

Stakeholders also indicated the need for a harmonised approach to data collection on waste generation, movement and processing. We lack a clear picture of national waste activities due to inconsistency in data collection – to waste terminology and reporting requirements vary from state to state. Without a clear picture of waste activities nationally, it is more challenging to build a case for the adoption of technologies which might otherwise fill a critical gap in resource recovery capabilities.

As part of the National Waste Policy Action Plan, Australian Governments have committed to exploring better aligned reporting systems, agreed national classifications, and standard definitions for data and reporting, as well as national recycling surveys, to improve the quality and availability of information.[13]

South Australia is arguably the leader in resource recovery policy in Australia, with a Waste and Resource Recovery Infrastructure Plan that provides a clear guide for future waste and resource recovery infrastructure needs across the state to support a resource efficient economy. The plan provides information to assist in informing investment decisions, identifies potential infrastructure needs for specialised and problematic waste streams and considers soft infrastructure supporting the waste and resource recovery industry development. South Australia has a dedicated agency – Green Industries SA – overseeing this work and promoting the circular economy, resource efficiency and the conservation and recovery of scarce resources.[8]

Victoria is encouraging resource recovery. Infrastructure Victoria has set a number of goals and actions to support the recovery sector, including:

- Stable end markets for recycled products for ongoing sustainability
- Strengthening the end markets for materials and improving the quality of feedstock for processors
- Initiatives to disincentivise the use of virgin materials in production, or promote the procurement of products made from recycled materials.[152]

To boost the use and create demand for recycled and reused materials in construction projects across the state, the Victorian Government launched *Recycled First* in March 2020.[153] The program incorporates recycled and reused materials that meet existing standards for road and rail projects.

The Victorian Government will also introduce a container deposit scheme, aimed at reducing litter and waste going into landfill, and creating new Victorian jobs.[154] The government will design and deliver the scheme in close consultation with councils and industry so it can begin by 2023. Further, the state will establish a new dedicated authority governing the state's recycling system and holding waste service providers to account. An education and behaviour change campaign will support the rollout of the initiatives.

Western Australia has committed to reducing waste and supporting a circular economy to increase resource recovery across the state. The Western Australia Waste Authority released the *Waste Avoidance and Resource Recovery Strategy* in 2019. It outlines the state's approaches towards increasing resource recovery and reducing the volume of waste going to landfill in order to support a transition to a circular economy.[155] The Strategy's priority actions for 2019-20 included implementing a new waste data and reporting system, establishing a recycling infrastructure support program, and identifying priority resource recovery and waste avoidance investment targets.[155]

New South Wales provides funding for business recycling, organics collections, market development, new waste infrastructure, research and development. The NSW Government has invested $24 million to improve kerbside separation of food and garden organic waste.

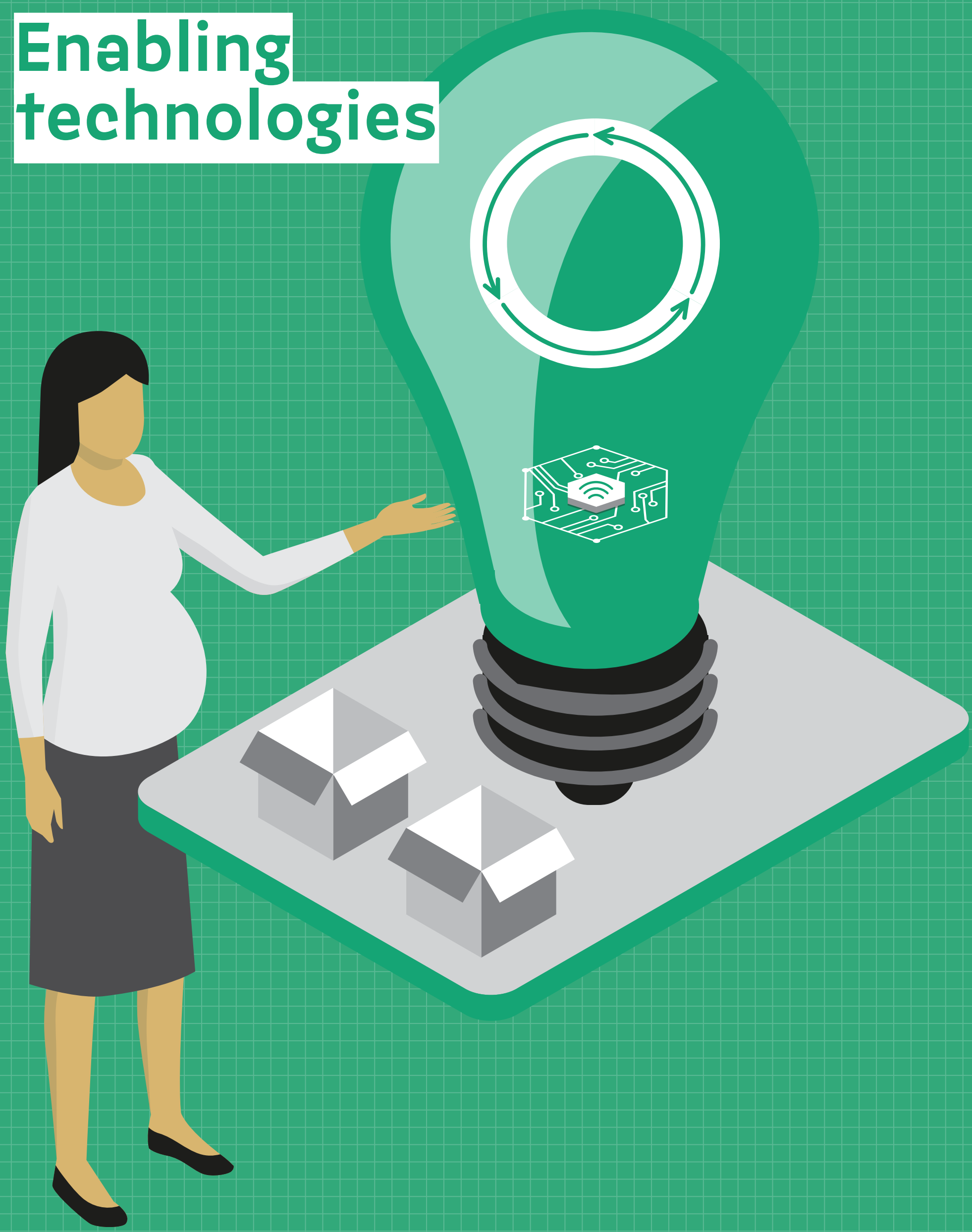
Queensland has set ambitious targets for 2050 to divert 90 per cent of all waste from landfill, with 75% recycling rates across all waste streams. It also seeks to divert 25% of municipal solid waste from landfill by 2050.[156] In 2018 the Queensland Government announced a $100 million three-year investment program, *Resource Recovery Industry Development Program*, designed to position the state as a world leader in resource recovery. The program provides funding for projects initiated by local governments, businesses and not-for-profit organisations that employ resource recovery technologies throughout their supply chain.[133]

The National Waste Policy Action Plan contains actions that could also help to drive sustainable procurement by businesses and individuals, including encouraging the adoption and publication of procurement policies, and setting targets and incentives.[13]

National Waste Policy
Action Plan 2019.

Image source:
environment.gov.au

Enabling technologies



Design, improved product stewardship, and advanced resource recovery and recycling are underpinned by existing and emerging technologies. This section explores some of the key technologies and their potential applications in the waste and resource recovery sector.

- **Digital technologies** can quantify and track material as it moves through the system. Smart technology can then make accurate predictions to inform planning, optimise logistics, and automate processes.
- **Physical technologies** can more efficiently sort and process materials, optimise logistics, and increase resource recovery productivity. They can handle materials and transform them to new products or energy.
- **Biological and chemical technologies** have the potential to transform materials and return value into a circular economy.

While many of these technologies hold great potential to positively disrupt our waste and resource recovery sector, key challenges include the very high amount of energy required for many of them, and the resulting expense and generation of greenhouse gas emissions.

DIGITAL TECHNOLOGIES	PHYSICAL TECHNOLOGIES	BIOLOGICAL & CHEMICAL TECHNOLOGIES
Big data analytics	Automation	Bioenergy technologies
Artificial intelligence and machine learning	Robotics	Biodegradable plastics
Intelligent assets and the Internet of Things	Fluorescent markers	Microbiological technology
Sensor networks	Urban mining	
Mobile apps and devices	Nanotechnology	
Blockchain and digital product passports	Materials science	
Digital watermarks	3D printing	

DIGITAL TECHNOLOGIES

Digital technologies are based on computer sciences, electronics and communication technology.

Big data analytics

"Big data" is a term used to describe data sets with high volume, high velocity, and/or high variety. It goes beyond the size and complexity of data that humans could traditionally manage and analyse.[157,158]

Big data analytics can find relationships that otherwise may not be apparent with datasets of smaller size or variety, creating the potential to be highly responsive, analysing or adjusting as data points continue to accumulate in real time.

Big data can provide information on how consumers use products and product performance over the product's lifecycle. This is the best available approach to optimising product use and understanding how an individual product can best fit into a circular economy.[159] At an individual product and a system level, big data can aid understanding of how waste is being generated, managed and recycled, as well as source and final destination. Big data analytics can also help to provide system level feedback on specific outcomes of interventions to improve waste management.

ROLE OF DESIGN	Designers can make use of big data to improve their product designs based on historical data on production, maintenance and failure.[159] Information on available materials including mechanical properties, durability and recyclability in target markets can also be collected into a durable design tool, incorporating crowd-sourced feedback from recyclers and consumers. Such a big data library can be used by designers when choosing materials, and also support something like a standardised 'recyclability index' for products, as a transparent way for consumers to choose products with sustainability in mind.[56]
IMPROVED PRODUCT STEWARDSHIP	In ideal circular economies, materials are cycled on the same or at a higher level in the waste management hierarchy. There are multiple considerations that determine what is possible in a product's next cycle, such as its condition and the current market situation. Big data analytics on product and consumer use would have the ability to build the most efficient decision-making model for choosing the next cycle for a product at its end-of-life.[56]
ADVANCED RESOURCE RECOVERY	Big data analytics could help to improve the efficiency of processes to collect, extract and reuse resources from waste by understanding how energy is used in those processes. Using historical maintenance data on products can help to determine the degradation status and remaining value of the components for recovery.[159]

What is its potential in the next ten years?

In waste management, the application of big data analysis techniques could offer improved efficiency in data analysis, enabling insights into waste collection, management and recycling systems, and delivering waste reports much quicker than has been possible in the past. This would enable decision-makers to use the most current information to guide action.[160] Waste collection routes could be decided based on information in real time, rather than historical data.

The $24.6m investment announced by the Australian Government in July 2020 to improve national waste data creates the potential to immediately set up digital infrastructure to generate valuable and usable big data in the waste and resource recovery sector. This would support more detailed understanding of the waste lifecycle and allow agile assessment and prediction of the impact of new management systems. The availability of good quality big data may also attract data scientists and other innovators to encourage accelerated research and development in waste management and resource recovery.

Artificial intelligence (AI) and machine learning

AI is a collection of interrelated technologies that can mimic human problem solving, learning, perception, understanding, reasoning, and awareness of surroundings.[161,162] Machine learning (ML) is a subset of AI where computers can 'learn' to perform tasks without explicit instruction.[163]

AI can be used to optimise many different processes within the current waste management system.[161] It can be used to automate the classification of waste materials, predict the fill levels of bins, to optimise waste collection schedules and routes, and to predict maintenance of waste infrastructure and processing equipment.[163] AI can also be used to forecast waste generation, to model waste behaviour and patterns.

ROLE OF DESIGN	AI can be used to increase the scale and scope of design improvements and remanufacturing potential. AI can analyse vast amounts of data on previous designs and begin to make suggestions in the design of new products, including in material selection, and even perform creative work. AI can then provide continuous feedback on design decisions.[36,41] It also presents possibilities in bespoke design (for example, products individually tailored for a specific person).[164]
IMPROVED PRODUCT STEWARDSHIP	AI can be used to support sophisticated data analysis and tracking, and can predict when preventative maintenance may be needed, instead of waiting until major faults occur.
ADVANCED RESOURCE RECOVERY	AI and ML have been successfully applied to automate sorting of mixed waste streams, from municipal solid waste to construction and demolition material.[36] AI can also be trained to optimise recycling infrastructure for separate waste streams, such as automatically adjusting conveyer belt settings to accommodate materials of different shapes and sizes.[36] The ability to predict parameters and outputs of recycling processes will support optimised processing, capture and use of materials. For example, predicting the amount of biogas or energy that is produced as a by-product of landfill that may be harnessed as a resource. Simulating and modelling waste conversation processes can help to identify the optimal approach.[161]

What is its potential in the next ten years?

The Ellen MacArthur Foundation, in collaboration with Google, identified three high potential circular economy opportunities that AI can accelerate:

- designing circular products, components, and materials
- operating business models
- optimising infrastructure to ensure circular product and material flows.[36]

Costs from all aspects of waste management can also be incorporated into analyses to create economic predictions and cost-effective recommendations.[161]

AI and ML are only as good as the data available, however. To use these technologies to their current capacity, first it is necessary to improve the collection of a sufficient quantity of good quality data from diverse sources across the waste management system.

Intelligent assets and the Internet of Things

Intelligent assets are "physical objects that are able to sense, record and communicate information about themselves and/or their surroundings".[56] This definition incorporates objects connected to the Internet of Things (IoT), a network of appliances and devices that are connected to each other and to the internet.[165]

IMPROVED PRODUCT STEWARDSHIP	IoT will underpin data exchange on transaction, rewards and usage along the entire length of the global supply chain.[41] This is important to a smooth running circular economy where material and products pass through multiple hands and processes in order to be reused and recycled, including reverse logistics.[56] IoT can connect products with people, enabling a sharing economy where product use can be maximised over their lifetime.[56]
ADVANCED RESOURCE RECOVERY	The IoT can be used to improve recovery and reuse/repurposing of assets that are no longer in use.[56] For example, items connected to the IoT can send notifications when they break down, alerting the company to schedule a pick-up to repair and disposal.[106]

What is its potential in the next ten years?

As connected devices become the norm, the network of the IoT will continue to expand its reach and expand its potential. If more segments of the waste journey could join the IoT, the potential for monitoring aspects such as location, equipment performance and nature of materials could improve efficiency across the board.[165] The IoT can also be combined with automation and robotics, which have great potential to improve our capacity and quality of waste management systems.

Having an IoT enabled waste infrastructure can help improve the efficiency of waste collection, by using sensors to accept clean waste streams or indicate when bins need to be emptied and potentially, trigger automated emptying, which is already operational in Songdo, South Korea.[166] Similarly, connected sensors and equipment could improve waste treatment and disposal through automated sorting.[167] Collecting data throughout the process would also feed into richer big data sets that can be used to evaluate and improve systems for continual system evaluation and improvement. It is important that product stewardship is considered in the design, use and end-of-life management of IoT devices.

Sensor networks

Sensor networks consist of multiple sensors distributed across a geographic location. The sensors send data to a central node or base station.[168]

Wireless sensor networks allow communication over large distances in an energy-efficient way, such that whole systems can be continuously monitored.[105] Sensors have the capacity to measure different dimensions of useful information, such as ultrasonic sensors for waste levels, moisture sensors for wet waste and gas sensors for smell and toxic gases.[169]

Sensor networks have already been trialled and/or deployed to improve waste management in smart cities in Australia including Geelong and Adelaide.[170,171] A sensor network can be monitored from a central location, or from local nodes.[170] For example, a driver could use a tablet to see information sent from sensors in public smart bins or traffic congestion from road sensors, and use this information to plan their routes efficiently to stop only at bins that need emptying.[171] A sensor network would also contribute valuable real-world data which can be used for AI/ML applications to improve modelling and better inform evidenced-based decision making.

IMPROVED PRODUCT STEWARDSHIP	Sensors could be incorporated into products to support service models. They could be used to monitor use in refillable consumer goods, such as smart detergent bottles that will automatically order a refill or exchange when getting low.[41] Sensors are also essential for products that require active monitoring of systems, such as solar panels. Sensors can send alerts when maintenance is required, prompting early maintenance to prevent product failure, decrease inconvenience and increase product life.[165,171]
ADVANCED RESOURCE RECOVERY	Sensor networks support efficient resource recovery. This may allow sorting and collection of waste by specific materials, helping to minimise contamination.

What is its potential in the next ten years?

The implementation of sensor networks into existing waste systems and integration of the sensors into the IoT will increase data availability useful for future infrastructure planning. There is also the potential for automation of optimal route searching and notifications for maintenance or overflow.[172]

Potential applications include control of material flow to ensure clean waste streams or weight measurement to estimate the cost of disposal. At scale, this would also allow organisations to accurately plan waste collection logistics. Knowing the exact volume of waste to be collected allows routes to be optimised for each vehicle in the fleet.[41]

SMART FRUIT

Sensors can be used in combination with AI/ML to accurately sort fruit and vegetables based on quality properties such as firmness and acidity, directing the fruit and vegetables to the optimal use. It has the ability to do this very quickly, reducing processing time and so extending shelf life and reducing food waste.[173]

Above video still: Amazon Fresh Machine Learning – Using Algorithms to Sort Fruit
Image source: Amazon. aboutamazon.co.uk

Mobile apps and devices

Mobile applications (apps) are software and/or programs designed for use on mobile devices such as phones and tablets. Both help people to access services.[175] Apps may be designed for consumers or organisations (for example, for use by authorities or companies responsible for waste management).[175]

Mobile apps can facilitate interactive communication between waste management authorities and individuals to communicate information, collect feedback, and involve the community in decision making. They're already being used to deliver successful recycling campaigns, improve services and infrastructure and influence individual recycling attitudes and behaviours.[174] Within organisations, apps may be used to support administration or resolve specific management problems such as cost benefit analysis, or sizing of waste treatment facilities.[175]

ROLE OF DESIGN	Mobile apps can be used to house and deliver information and databases to empower good design choices.
IMPROVED PRODUCT STEWARDSHIP	Mobile apps can connect consumers and businesses, and support reverse logistics. Container deposit schemes operating in some Australian states and territories use digital wallets in smartphones and mobile apps.

What is its potential in the next ten years?

Mobile apps are best put to use as part of a bigger waste and recycling policy and plan. To make the most of their potential, we must first increase understanding of the potential benefits of mobile apps, and support their development.[174] Apps that help connect consumers with excess resources such as solar electricity have been suggested as a way to reduce environmental impact and manage electricity bills.[176] As Smart Cities and the IoT develop, so will the potential to link consumers directly to useful information to support lower-waste behaviour, such as real time alerts to the availability of specialist material collection points.[177]

A number of Australian recycling apps already contain information about what can be recycled through local council collections, identify places nearby that handle specialist recycling, and link hospitality to people in need to manage leftover food.[178] Mobile apps could also be used to organise and pay for on-demand waste collection, or at a basic level to view the local schedule for waste collection.[174,179]

Blockchain and digital product passports

Blockchain is a system in which a record of transactions is maintained across several computers that are linked in a peer-to-peer network. Blockchains provide a permanent, transparent, safe, and public way of recording transactional data.[180,181]

A blockchain 'digital passport' for products could aid in identification, processing, and accountability. They have the potential to increase recycling by identifying material composition and recycling details for correct sorting into waste streams.[182] One consumer-facing application is the use of blockchain-secured digital tokens to reward people who return waste to recycling centres. Consumers are able to track how their returned waste has been recycled and reused.[180]

ROLE OF DESIGN	Incorporating blockchain into system and product design can facilitate accurate and reliable tracking of materials. A unique digital passport for products (and parts within products) can contain valuable information including material details, how products can be disassembled, and where products should go next in the waste management hierarchy. Blockchain and digital passports may also be used to facilitate service-based models by tracking past-use data.[41]
IMPROVED PRODUCT STEWARDSHIP	Blockchain, in conjunction with IoT, can be used to track products over their lifecycle. This increases the chance of recovering products at the end of their life and repurposing, reusing components or recycling.[183] It also aids accountability for product stewardship by identifying the origin, transactional history of the product and where to products go. This could support trust in second-hand markets and also aid enforcement of product stewardship regulations.[41]
ADVANCED RESOURCE RECOVERY	Blockchain could allow easy identification of component materials in products, supporting recovery of resources via urban mining for example.[183]

What is its potential in the next ten years?

Blockchain could underpin a global waste material trading system. The ability to track materials and products through a supply chain has the potential to pressure suppliers at each level to take some responsibility for the product at its end-of-life, and makes regulation much easier.[180]

Digital watermarks

Digital watermarks are optical codes, about the size of postage stamp, that can be created within the pixels of the design or by tiny variations in the surface texture of plastic. Using the small changes to the existing design means that no extra material is needed to deliver a digital watermark.[184]

Digital watermarks can be read by cameras, including existing barcode scanners and smartphones, as a way of tagging and identifying items. The unique code can be linked to a database storing information about the product, including its material make up and product origin. This system has the benefit of being able to carry information on multiple properties of the product and can be updated with product changes and as new processing technology evolves.[184]

Digital watermarks can be read by optical sensors/cameras and sorted into clean material streams based on the product information by automated robotic arms or air streams. It can also be implemented at a consumer level, allowing sorting at the point of collection by smart bins.

ROLE OF DESIGN	Digital watermarks can deliver real-time information to manufacturers and recyclers on recycling rates for individual products. This could be used to inform the design of products, collection and recycling processes.[184]
IMPROVED PRODUCT STEWARDSHIP	Digital watermarks can identify products for return, facilitating reverse logistics. Since digital watermarks can be accessed using a smartphone, they can also be used to engage and inform consumers.[184]
ADVANCED RESOURCE RECOVERY	The accuracy of digital watermarks mean they can be used in manufacturing to obtain higher yields from material recovery.[184]

What is their potential in the next ten years?

Proof-of-concept has been established, although industry views on the feasibility and cost-effectiveness have been varied.[184] Scaling up digital watermarks for widespread use and processing ability will depend on stakeholders agreeing on common identification and data governance systems.

DIGITAL WATERMARKS

Digital watermarks are optical codes covering the surface consumer packaging. They can carry a wide range of attributes such as manufacturer, SKU, type of plastics used and composition.

Image source: Procter and Gamble. pg.com

PHYSICAL TECHNOLOGIES

Physical technologies work with the basic properties of materials and energy.

Automation

Automation is the creation and application of technology to automatically monitor and control the production and delivery of products and services.[185] Automation covers a broad range of technologies including robotics, sensors, telemetry and communications and electro-optics.[185]

Processes may be automated at many points in waste management systems, including for sorting, processing and quality assurance. Smart bins incorporating sensors can automatically compress waste, decreasing the frequency of collection.[166] Several processes can also be automated at waste-to-energy plants to increase efficiency.[186]

What is its potential in the next ten years?

Automation could revolutionise manufacturing to reduce waste. Automation of waste sorting can continue to be improved through the integration of AI and deep learning.[187] Automation of new construction and manufacturing processes with less waste can help to decrease construction waste, which accounts for around 40% of waste in Australia.[188]

Robotics

Robotics is the design, construction and application of machines that can complete physical tasks.

Industrial robots are the main class deployed in waste management. For example, robotic gripper arms are used to sort waste as it passes on a conveyer belt with the help of different sensors. The robot is programmed with software that controls both the arm movements and the identification of the waste materials for picking.[189]

Robotics can increase waste processing capacity through the ability to work faster and with minimal down-time.[190] Used in conjunction with sensors and AI/ML, robotics reduces the need for manual sorting. Robots have been developed with the ability to sort materials from mixed waste streams, allowing them to be collected together and thereby simplifying the logistics of waste collection.[189] In some cases, sorting that was previously too difficult or dangerous, such as sorting construction and demolition waste, can be completed by robots.[189]

Using robots can significantly increase the amount of waste covered for recycling from similar volumes of waste. Robots can help with material flow management as waste comes into processing plants, thus creating optimal conditions for sorting.[189] Robotics can also support end-of-life processing by disassembling products to recover useful material, such as precious metals from smart phones and electric cars.[189,191] The use of robotics at Carl F (Sweden) saw a 25% increase in recyclable material. In Helsinki, robots at Remero increased waste utilisation from 70% to 90%.[190]

What is its potential in the next ten years?

Current robotic technologies can sort waste that is ready to recycle, and is relatively 'future proof' in this respect, as robots can be 'trained' to recognise new materials.[189] The Danish Institute of Technology is working on a robotic-based system that uses AI to sort batteries in electrical devices, picking up individual batteries but also any devices that might contain batteries.[189] There are still limitations such as considerable sorting still to be done after detection, so the development of "cobots" (collaborative robots) that allow robots to work with people in the same work environment is increasingly important.[189]

Fluorescent markers

Fluorescent markers can be used like an invisible barcode to identify materials, especially plastics that are difficult to differentiate and sort into clean material streams.

Fluorescent material is printed onto a label or packaging sleeve, or added as a coating. Materials can be used in different combinations to create different 'codes'.[192] Under ultraviolet light, the fluorescent marker lights up to be read by a sensor, and the product can be air-propelled into the correct stream.[193] The marker can be removed during recycling, leaving the material ready for its next life.

Fluorescent markers can be used to identify products that use multiple layers of different materials and black coloured polymers, both of which limit near-infrared sorting. Near-infrared sorting is not sensitive enough to differentiate between polymers that are very similar.[193] Being able to sort polymer materials accurately into their different types and previous uses is essential to be able to recycle food-grade polymers. Fluorescent markers are able to differentiate a bleach bottle from a milk bottle made from the same polymer type.[193]

ROLE OF DESIGN	Design can reduce material complexity (i.e. make a product entirely from a single kind of material) to increase the ability to recover pure, high-grade material.
IMPROVED PRODUCT STEWARDSHIP	Fluorescent markers could allow reverse logistics to be combined with other waste collection by being able to identify very specific products for return and processing. This would allow brands to establish their own 'closed loop' system of product use and return.[194]
ADVANCED RESOURCE RECOVERY	Fluorescent markers could be read by sensors in smart bins to sort waste at the source. Specific polymers can be recovered with up to 95% purity, which increases the quality and options for material recovery.[193]

What is its potential in the next ten years?

Fluorescent marker technology has been trialled in materials recovery facilities and is ready to be implemented using existing near-infrared sensor technology.[193] The application of this marker technology could increase plastic packaging recycling rates from a maximum of 30% to up to 80%.[192] It could also be used to recover and reuse plastics used in automotive and chemical industries.[195]

Urban mining

'Urban mining' is the extraction of resources from existing products and infrastructure once they are no longer useful.

Waste streams such as e-waste and motor vehicles contain valuable raw materials, such as precious metals, base metals and plastics.[196] Overall, e-waste is richer in metal than land-mined ores.[197] Urban mining aims to recover these materials through various metallurgy extraction techniques.[198]

Raw materials obtained through urban mining can be reused to repair or replace components in existing products, in new products, or on-sold.[199] This has the two-fold advantage of reducing the volume of waste material sent to landfill and the subsequent environmental effects, and increasing the sustainability of finite resources.

ROLE OF DESIGN	Smart design plays a key role in the ability to recover valuable raw materials such as precious metals, or separating individual metals from alloys. Designs that use recovered materials, or materials that can be recovered, rather than newer materials will also increase demand for recovery. However, there is also a maximum number of times that metals can be recovered. Designing products for longevity is also key.[199]
IMPROVED PRODUCT STEWARDSHIP	Promoting urban mining as a valuable part of a circular waste economy would tap into a large reserve of e-waste being held by consumers.[199]
ADVANCED RESOURCE RECOVERY	It has been suggested that urban mining of copper and gold from e-waste streams could be more cost-effective than traditional mining of ores.[200]

What is its potential in the next ten years?

Increased coordination between the mining and recycling sectors will support a new, circular economy for metals.[199] Traditional metal processing may not be efficient for urban mining. New technologies are needed to be able to extract valuable metals from e-waste. The development of flexible and mobile solutions will also be key to increasing the viability of urban mining. Currently, the cost of transportation of e-waste to processing sites limits the value of resource recovery.[199] Maps of urban mines that show data locating market inputs, stocks in use and waste flows will help business and government to track resources and target mining efforts.[196]

Nanotechnology

Nanotechnology employs materials with at least one dimension less than 100 nanometres.[201]

Because they are so small, nanomaterials have increased reactivity with, and selectivity for, reactions and contaminants. Their large surface area makes them effective for the adsorption of pollutants from liquid waste streams. In membrane filtration and separation, nanomaterials can be used to make nanocomposite membranes. Nanomaterials can also undergo chemical reactions that conventional materials cannot. Nanomaterials may be used in photocatalysis, a process that degrades organic contaminants in waste.[201]

Nanotechnology is a promising alternative to conventional liquid waste treatment technologies, offering simpler treatment steps and lower energy, cost and time requirements.[201] Similar processes involving nanotechnology could also be used to treat contaminated soil and air from industrial processes.[202]

ROLE OF DESIGN	Using nanotechnology in composite materials can produce material that is lighter, smaller and more environmentally friendly. This material has the potential to last longer and for parts be repurposed. Biodegradable plastics that easily decompose can also be made using nanotechnology.[203]
IMPROVED PRODUCT STEWARDSHIP	Nanomaterials could be used in building products to improve performance, resilience and longevity. For example, nano-engineering of aluminium, steel and asphalt in highway and transportation infrastructure.[204] Lubricants and engine oils incorporating nanomaterial perform very well and can extend the life of moving parts.[204]
ADVANCED RESOURCE RECOVERY	Nanomaterials could be used as 'markers' on different polymers, thus supporting separation of the polymers into clean waste streams.[205] Nanotechnology can target very specific contaminants to remove pollutants from waste water and gas so that it can be reused.[203] Nanotechnology can also be used in waste-to-energy facilities to increase the efficiency of heat exchange.[205]

What is its potential in the next ten years?

Nano-bioengineering of enzymes will enable conversion of biomass (e.g. wood chips, corn stalks) into ethanol for fuel.[204] Nanomaterials are still expensive to produce, limiting potential for widespread commercial application until this challenge is overcome. There is also a question over how to handle nanomaterial after it is no longer useful.[202] The effect of nanomaterials on health and the environment requires further characterisation.[201]

Materials science

Active disassembly allows self-disassembly of products through the use of smart materials or structures in the product that can be activated using one or more external stimuli such as temperature, magnetic force or pressure.[206]

Active disassembly device(s) are implemented during the design and assembly stages of production. Materials that can be used in the devices include alloys and polymers, thermally reversible adhesive sprays and biodegradable layers. Shape memory alloy or polymers can be designed to spontaneously reverse back to their initial shape and change their mechanical properties on exposure to a specific circumstance using active disassembly devices.[206] Thermally reversible adhesive sprays can be used to bond parts in products instead of welding, riveting, screwing or traditional adhesives. At room temperature, thermally reversible adhesive sprays are stable, but can be decomposed by manipulating to a predetermined temperature.[207]

Active disassembly can improve recovery opportunities by reducing costs associated with manual disassembly and maintaining the quality of recovered product components.[206] Active disassembly has been investigated for electronic and automotive sectors, in which products need to be both lightweight and strong.[206,208]

ROLE OF DESIGN	Materials science applications give designers more options to facilitate the dismantling of their products, by using different characteristics to suit different product architecture and materials.[206]
IMPROVED PRODUCT STEWARDSHIP	Active disassembly can decrease the cost, time and difficultly of dismantling products for repair.[206]
ADVANCED RESOURCE RECOVERY	Active disassembly can be introduced as a step in the recycling process of e-waste by increasing the quantity of precious materials that can be recovered.[206]

What is its potential in the next ten years?

Active disassembly can provide a generic fastening solution for diverse disassembly problems. The next phase of active disassembly application will be determining the economic viability in product/large assemblies that require a large disassembly force.[206]

3D printing

3D (three-dimensional) printing, or additive manufacturing, is the process of joining materials, usually layer by layer, to make objects from 3D model data.[209]

3D printing can build exact and complex parts and products from digital designs using almost any materials, including metals, ceramics, polymers, clays and organ tissue. It produces less waste compared to conventional machining as it is able to use only the exact amount of material needed to make the product.[210]

ROLE OF DESIGN	3D printing has made design and production accessible to everybody.[210] It provides an opportunity to design and produce very specific and complex parts from 3D models that would allow consideration of how a product could be dissembled and each part could be repurposed. Design for additive manufacturing also allows exact numbers of product to be ordered and produced.[210]
IMPROVED PRODUCT STEWARDSHIP	3D printing could be used to remanufacture products at their end-of-life, or to manufacture specific parts in small batches for repair.[210,211] 3D printing can also consolidate parts by being able to print a single complex unit without separate parts that need to be joined. For example, General Electric was able to use additive manufacturing to redesign its Catalyst aircraft engines from 855 components to just 12 titanium 3D-printed components, without losing any functionality. This can lead to lighter, more durable, better performing products due to fewer seams and tighter tolerances.[210]
ADVANCED RESOURCE RECOVERY	Plastic waste streams, such as water bottles, can be recycled for use in 3D printing filaments. For example, the Million Waves Project is a non-profit project that collects ocean plastic, recycles it into filament, and uses it to 3D print prosthetics.[212] In 3D printing of metals, metal powder used as the raw starting material is not commonly recycled, despite evidence that there is little effect on the mechanical properties of the material. Some companies are investigating new sieving solutions for metal powders, and also developing approaches to reforming scrap metal into powder.[210]

3D PRINTING

3D scanner and printer making a replacement part.

Image source: iStock

What is its potential in the next ten years?

Using advanced simulation software to anticipate behaviour of materials will behave during the printing process will also improve the efficiency of 3D printing and reduce failed prints.[210] To maximise the utility of 3D printing in a circular economy, materials such as metals that have greater potential to be recycled, should be prioritised.[209] 3D printing also has the potential to boost local manufacturing using nearby sources of recycled plastic waste.[213]

BIOLOGICAL AND CHEMICAL TECHNOLOGIES

Biological and chemical processes to manage and transform waste materials.

Bioenergy technologies

Bioenergy is energy produced from organic matter (known as biomass).[214] Biomass can be converted to heat, electricity, biogas and liquid fuels.[215]

Bioenergy supplied half of all renewable energy used worldwide in 2017.[215] Its use is projected to grow, accounting for 30% of the growth in renewable energy between 2018 and 2023.[216] There is opportunity to harness waste streams to provide feedstock to produce bioenergy that is cost effective compared to traditional and other renewable energy sources.[215] Other applications for bioenergy include direct heat, transport fuels and bioproducts used as starting material to make clothing, detergents, bitumen and concrete.[215,217]

IMPROVED PRODUCT STEWARDSHIP	Bioenergy technologies can contribute to 'resource stewardship': using residual food waste, agricultural and industrial waste.[218] Waste streams that are candidates as feedstock for bioenergy present a higher order waste management option than landfill. Bioenergy remains lower on the hierarchy of waste management than avoidance, reuse or recycling.[219]
ADVANCED RESOURCE RECOVERY	Bioenergy offers a way to extract resources that cannot be reused in other ways, such as wastewater, agricultural, forestry and industrial waste.[215] Gases generated in landfill and sewage treatment can be collected and used to generate bioenergy.[214]

What is its potential in the next ten years?

The global use of bioenergy is likely to increase in the next decade, using a number of different feedstocks.[220] Australia uses bioenergy at a much lower rate compared to other OECD countries (ranked 19 out of 24 in bioenergy contribution), so there is large scope to increase local capacity.[217] The use of diverse feedstocks and bioenergy technologies, including various waste streams, also has the potential to grow to ensure sustainable supply and maximise efficiency of conversion. This could be supported by big data to monitor and understand feedstock types and volumes.[217]

Plastic cup from BioPak that can be composted using industrial processes through the BioPak Compost Service.
Image source: iStock

Biodegradable plastics

Bio-based plastics are plastics that can be produced from renewable materials such as sugar, corn and soy. Bio-based plastics are considered to be biodegradable because they are designed to biologically degrade to organic compounds through the action of microorganisms and enzymes.[221,222] Biodegradable plastics may also be made from petrochemicals with biodegradable additives.[223]

Examples of biodegradable plastic include a plastic material that has a finite usage life before catalysts auto-trigger biodegradation, developed by Polymateria.[224] Teysha Technologies has also developed a plastic that degrades in water in an effort to ameliorate concern about plastics pollution in oceans.[225]

After use, biodegradable plastics become post-consumer waste. Small amounts may be recycled with non-biobased counterparts but large amounts should be separated to avoid contamination.[221] Biodegradable plastics in clean waste streams can also be mechanically or chemically recycled.[226]

ROLE OF DESIGN	Biodegradable plastics can be used in products designed to transit through a circular system, that traditionally has components that are not recyclable, such as sealant films.[227] Product design could also take advantage of new advanced biodegradable plastics.
IMPROVED PRODUCT STEWARDSHIP	Biodegradable plastics offer consumers and manufacturers an alternative to renewable resources that return to organic materials after use.
ADVANCED RESOURCE RECOVERY	Using biodegradable plastics develops industrial composting as a waste management stream and frees up capacity in other processing methods. Composting also returns useful products to the soil.[221]

What is its potential in the next ten years?

The global trend towards biodegradable plastics is increasing due to consumer awareness and government regulation. The challenge is to ensure the large scale collection of clean waste streams of biodegradable and compostable plastics to ensure they are effectively processed.[222] More research is needed to determine the conditions for safe composting.[221]

Microbiological technology

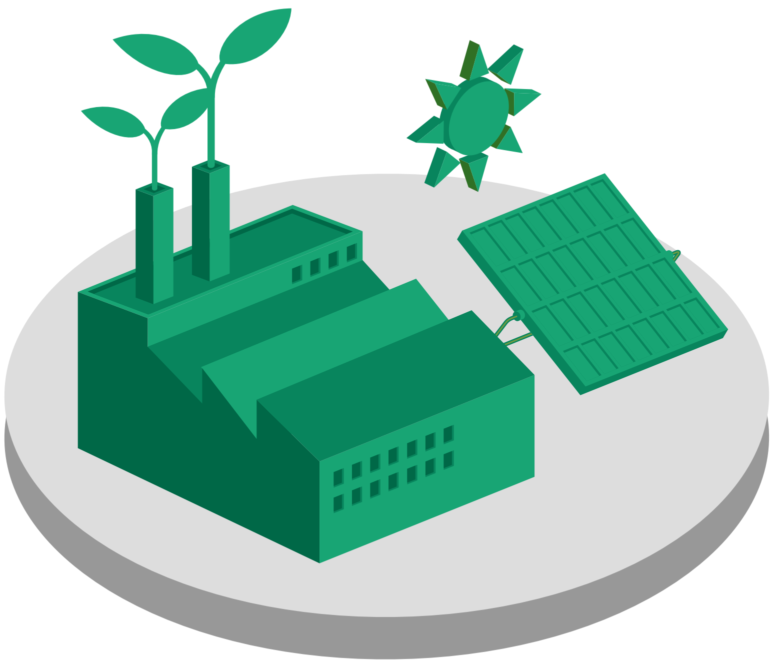
Microorganisms can be used to remove pollutants because their enzyme systems have the potential to transform waste compounds into less toxic compounds.[228]

Bacteria are used to digest microbes in wastewater, forming biofilms which can be separated out of water to be reclaimed. The remaining biofilm can be digested again to produce biogas, which can be burned for energy.[229]

ADVANCED RESOURCE RECOVERY	Microbial waste treatment can be effective to degrade organic waste more effectively – degrading a wider range of compounds, taking shorter time, working in a wider range of conditions and producing less by-product.[228]

What is its potential in the next ten years?

Microbial fuel cells use biofilms to convert organic matter (including wastewater) into electricity. At the current stage of development, the cells cannot generate enough power to be a practical source. New bacterial strains engineered to optimise the energy generating reactions are being developed.[230] Although in early stages, basic research has identified the first new strain of bacteria that feeds on polyurethane to break it down, which could extend the application of microbiological technology beyond organic waste processing.[231]



Conclusion

Throughout consultations for this project, ATSE consistently heard that the availability of new and suitable technology is not the core impediment to technology uptake in the waste and resource recovery sector. Nor are there major issues with workforce availability and skills, or societal readiness for change.

The key barrier seems to be that Australia does not have the right policy, regulatory and economic frameworks to support technology investment and innovation in the waste and resource recovery sector.

The current lack of economic feasibility is clearly a critical barrier to the transformation of the sector, with its roots in a lack of long-term policy and regulatory settings. Policy and regulatory regimes are also inconsistent across the nation, and do not incentivise sustainable practices. Incentives to drive investment in infrastructure, which are largely dependent on the economic, policy and regulatory settings, are lacking.

Australia's skills and social readiness for technology-based solutions in the waste and resource recovery sector are high, indicating an opportunity for the country to move ahead quickly with the right economic and policy settings. However, behaviour does not always align with this sentiment — highlighting the need for more social research and actions to design consumer behaviour change.

Other key themes that emerged in ATSE's research and consultations include the need for:

- A shift in consumer behaviour, to drive the market towards a circular economy
- Standards, specifications and certifications throughout the manufacturing, retail, waste and resource recovery system, to drive a shift in business models and uptake of recovered materials
- Data collection and consistent reporting requirements to improve effectiveness, accountability, innovation and technology uptake in the waste and resource recovery sector
- Targeted and prioritised policy and regulatory interventions to drive investment and provide clear signals to the market
- Measures to ensure circular principles of avoidance, reuse, repair, remanufacture, recycling and resource recovery are economically competitive with landfill.

Australia is already making significant efforts towards addressing many of these issues, particularly through the National Waste Policy and the associated National Waste Policy Action Plan. While the principles of the National Waste Policy follow the waste management hierarchy, the strategies that sit under it are weighted towards recycling and recovery, which means these strategies will not on their own be sufficient to drive the shift towards a circular economy. Similarly, the National Waste Policy Action Plan's measures are heavily weighted towards waste collection and recycling, rather than avoidance, reuse, repair of remanufacture. The Plan's ambitious and admirable goals will not be achieved unless new strategies are employed to support design for waste avoidance and improved product stewardship. In particular, goals for 10% reduction in waste generation per person, increasing resource recovery to 80%, and halving organic waste sent to landfill, will be difficult to achieve without focusing on avoidance. Committing to this paradigm shift will require short-term investment for much longer-term and significant gains, and can be accelerated through the innovation and technology detailed in this report.

The most powerful actor in the sector, though, is without doubt the consumer. ATSE hopes that this report and the information and ideas contained within in excite consumers to demand quality, sustainability, innovation and accountability from their products and services, leading to better outcomes for Australia as a whole — and a waste free future.

Appendices

Appendix 1

A SHIFT IN AUSTRALIA'S WASTE AND RESOURCE RECOVERY POLICY

Attitudes towards waste have shifted in Australia, triggering a significant period of policy change for the waste material, recycling and resource recovery sector. Global attitudes and markets are also changing, prompting substantial policy responses.

January 2018 — China National Sword Policy

In January 2018, China announced a 'National Sword' policy, restricting the types of recyclable material China would accept from overseas. The policy stated that only material with a contamination rate of 0.5% or less would be accepted. Australian shipments regularly exceeded this level. Other large importers such as India and Malaysia have also stopped accepting highly contaminated recyclable material.

2018 — Australia's National Waste Policy[1]

The 2018 National Waste Policy recognises that Australia's views on waste and resource management have shifted to recognise the value of resources and embodied energy in waste, and that there is a growing desire to see our resources recaptured and recirculated within our national economy. The policy also recognises that different policy and regulatory regimes across Australia are hindering effective action, and that businesses that operate in national markets would benefit from co-ordinated approaches. The Policy provides a framework for collective action by businesses, governments, communities and individuals until 2030.

Overarching principles:

- **Avoid waste**
- **Improve resource recovery**
- **Increase use of recycled material and build demand and markets for recycled products**
- **Better manage material flows to benefit human health, the environment and the economy**
- **Improve information to support innovation, guide investment and enable informed consumer decisions.**

2019 — National Waste Policy Action Plan[13]

The National Action Plan presents targets and actions to implement the 2018 National Waste Policy. These targets and actions are intended to guide investment and national efforts to 2030 and beyond. This plan is intended to complement and support the implementation of national packaging targets developed and agreed by Australian businesses and industry through the Australian Packaging Covenant Organisation, and the separate policies committed to by each state and territory jurisdiction. It also aims to address impediments to a circular economy for waste in Australia and support businesses and households to realise the full value of recyclable materials and work towards more sustainable use of resources.

Targets*

1. **Ban the export of waste plastic, paper, glass and tyres, commencing in the second half of 2020**
2. **Reduce total waste generated in Australia by 10% per person by 2030**
3. **80% average resource recovery rate from all waste streams following the waste hierarchy by 2030**
4. **Significantly increase the use of recycled content by governments and industry**
5. **Phase out problematic and unnecessary plastics by 2025**
6. **Halve the amount of organic waste sent to landfill by 2030**
7. **Make comprehensive, economy-wide and timely data publicly available to support better consumer, investment and policy decisions**

*All measured against the baselines in the 2018 waste report

The Australian Government has pledged $35 million to implement commitments under the National Waste Policy Action Plan. So far, no specific breakdown has been provided of how the investment will be distributed. The Government is still working on identifying the highest-impact interventions across each of the targets.[72,232]

Cooperative Research Centres and Projects:
Cooperative Research Centres (CRC) grants provide funding for medium to long-term, industry-led research collaborations, including the the Fight Food Waste CRC.[233,234]

CRC-P Grants provide funding for short-term research collaborations of up to three years.[235] The program provides matched funding of between $100,000 and $3 million to develop a product, service or process that will solve problems for industry. Past and current rounds have included a targeted portion of funding for waste reduction-focused projects:

- On 9 February 2020, the Hon Karen Andrews MP announced nine successful projects as part of the $20 million 'plastics waste reduction and plastics recycling' priority delivered in Round 8 of the CRC-P program. These funded projects are expected to deliver innovative solutions to reduce plastic waste and boost plastics recycling nationwide and will be completed within the next three years.
- Announced on 20 August 2020, CRC-P Round 10 looked to address four waste streams: plastic, glass, paper and tyres. The projects supported through this round are to give consideration to overcoming challenges unique to Australia's circumstances, particularly these four waste streams that are subject to upcoming export bans, and present challenges for recycling.[236]

2 March 2020 — National Plastic Plan[237]
Key announcements made at the National Plastics Summit in early 2020, included large commitments from industry on how they will address plastic waste. Solutions, discussions and ideas generated at the Summit will be used to develop the National Plastic Plan. The Australian government has indicated that this plan will be delivered by the end of 2020.

13 March 2020 — Waste export bans[238]
In March 2020, COAG made the decision to implement the first target of the National Waste Policy Action Plan, and progressively ban the export of plastic, paper, tyres and glass waste from July 2020. Due to COVID-19 restrictions, these bans are now expected to commence in January 2021.

Phasing out exports of waste plastic, paper, glass and tyres. Response strategy to implement the August 2019 agreement of the Council of Australian Governments. March 2020.

FIGURE 6

Updated timetable — waste export ban implementation.

Image source: Department of Agriculture and the Environment.[10] environment.gov.au

2020 — Australian Recycling Investment Plan[12]

The government has committed to build a stronger industry through a $167 million Australian Recycling Investment Plan. The Plan focuses on creating the right investment environment to commercialise new technologies, prevent pollution from entering our oceans and create valuable new products. It includes funding to support the manufacturing of lower emissions and energy-efficient recycled content products, new product stewardship schemes and new and innovative solutions to plastic recycling. It also includes funding for research on new ways to incorporate recycled plastics in manufacturing and construction.

The $167 million committed includes:

- $1.6 million for a new circular economy hub (Planet Ark — launching 2020[90]) matching sellers of recyclable materials with buyers
- $20 million Product Stewardship Investment Fund, aimed at supporting the national target of recovering 80 per cent of resources from waste material by 2030
- $100 million Australian Recycling Investment Fund, administered by the Clean Energy Finance Corporation (CEFC): the CEFC provides debt and/or equity finance to eligible larger-scale commercial and industrial projects which use clean energy technologies to support the recycling of waste plastics, paper, glass and tyres[15]
- $20 million for Cooperative Research Centre grants to find new and innovative solutions to plastic recycling and waste
- $16 million to combat plastics and other waste in oceans through the Pacific Ocean Litter Project.

July 2020 — Recycling Modernisation Fund[72]

The Government committed $190 million to a new Recycling Modernisation Fund (RMF) that is projected to generate $600 million of recycling investment and drive a billion-dollar transformation of Australia's waste and recycling capacity. The Government expects that more than 10,000 jobs will be created and over 10 million tonnes of waste saved from landfill to make useful products.

The RMF is intended to support innovative investment in new infrastructure to sort, process and remanufacture materials affected by the upcoming waste export bans, including mixed plastic, paper, tyres and glass. Commonwealth funding is contingent on co-funding from industry, states and territories.

Funding will be provided to the states and territories through National Partnership Agreements. The allocation of funding to specific projects is the responsibility of state and territory governments, that will assess their jurisdiction's major gaps in local reprocessing capacity.

6 July 2020 — National Waste Data Visualisation Platform[232]

The Minister for the Environment announced $24.6 million for the creation of the National Waste Data Visualisation Platform. This will measure recycling outcomes and track progress against national targets, thus providing a better understanding of waste in Australia.

9 July 2020 — Product Stewardship Investment Fund[239]

This fund comprises $20 million to ensure that manufacturers, retailers and industry groups take greater responsibility for the entire lifecycle of the products they produce and sell.

Grants of up to $1 million were available for individual applicants to accelerate work on new industry-led product stewardship schemes, or to improve the rates of recycling across new and existing schemes.[240]

7 August 2020 — Entity to drive food waste reduction[241]

The Australian Government announced $4 million in seed funding to create a new independent entity that will be responsible for driving food waste reduction in Australia. The new body will support change in all parts of the farm-to fork food supply chain — from farmers, food manufacturers and wholesalers through to retailers, hospitality, households and food rescue organisations, as well as create new jobs in food innovation. A key responsibility of the new entity will be to implement a voluntary commitment program for industry. The new body will be partnered with the Australian Government, but it will act independently to lead Australia's food waste issues and solutions.

1 October 2020 — Modern Manufacturing Strategy[242]

The Australian Government announced as part of the 2020-21 Budget that it will invest $1.5 billion in a Modern Manufacturing Strategy. Recycling and Clean Energy has been identified as one of the six priority areas for growth and a sector of comparative advantage and strategic imperative under the Strategy.

The Strategy will be supported through three key initiatives:

- **Modern Manufacturing Initiative**: $1.3 billion to encourage more private investment and support large projects to build scale, connections and capabilities of local manufacturers, enabling them to shift up the value chain and grow
- **Manufacturing Modernisation Fund** round two: $52.8 million for a second round
- **Supply Chain Resilience Initiative**: $107.2 million to identify and address supply chain vulnerabilities for critical products.

Product Stewardship Amendment (Packaging and Plastics) Bill 2019[243]

The *Product Stewardship Amendment (Packaging and Plastics) Bill 2019* was intended to amend the Product Stewardship Act 2011 to establish a mandatory product stewardship scheme for manufacturers, importers and distributors of consumer packaging and certain single-use plastics, as well as prescribing targets, prohibitions, design requirements, labelling requirements, and financial contributions in relation to packaging and products identified under the scheme.

The Bill was referred to a Senate Committee for inquiry in September 2019. Disruptions related to COVID-19 mean that the Committee is not required to report until 2021. However, the *Product Stewardship Act 2011* is now intended to be superseded by the Recycling and Waste Reduction Bill 2020.[244]

The Recycling and Waste Reduction Bill 2020[27]

The Recycling and Waste Reduction Bill 2020 will introduce bans on the export of waste glass, mixed plastics, whole used tyres, unprocessed single polymer plastics, and paper and cardboard. The Bill will also establish a new national framework for the waste and recycling sector and encourage companies to take greater responsibility for the waste they generate. This Bill will incorporate the framework of the existing *Product Stewardship Act 2011.*

The Bill will establish three regimes related to product stewardship, each one designed to encourage or require manufactures, importers, distributors and other persons to take responsibility for their products.[27] These schemes will be established through the making of rules, after the legislation is in place.

Significant elements of the legislative framework, which will also be determined following the passage of the legislation include:

- the kind of waste material to be 'regulated waste material' for the purposes of the new regime, the regulation of waste material exports, as well as the conditions that will apply to the export of waste material
- the accreditation of voluntary arrangements
- the scheme for the management of co-regulatory arrangements, including who is a liable party and the outcomes and matters to be dealt with by co-regulatory arrangements
- the requirements for mandatory product stewardship.

Appendix 2

LIST OF CASE STUDIES

CASE STUDY	DESCRIPTION
Amazon	Smart Fruit: Sensors can be used in combination with AI/ML to accurately sort fruit and vegetables, based on properties such as firmness and acidity.
ASPIRE	The Advisory System for Processing, Innovation & Resource Exchange (ASPIRE) platform facilitates resource exchange, matching business with potential remanufacturers, purchasers or recyclers.
Australian Paper and SUEZ	Victoria's first waste-to-energy project.
BASF	BASF launched a project called ChemCycling in 2018, with the aim of manufacturing products from chemically recycled plastic waste on an industrial scale.
Bin-e	An AI-based object recognition functionality to sort and compress collected materials in bins.
Cleanaway	Blubox processing technology supports resource recovery from e-waste, including flat panel displays, smart phones, tablets and laptops.
Container Deposit Schemes	Designed to ensure collection and recovery of empty beverage containers, reducing litter and facilitating cleaner waste streams. Provides a refund per returned container.
Earthpower	Australia's first regional food waste-to-energy facility. Earth Power is designed to process five most common food waste streams for the production of energy and nutrient rich fertiliser.
Fuji Xerox Australia	Fuji Xerox Australia have been using the material waste management hierarchy to reuse and remanufacturing existing material. TonerPave is an example of a successful program to recycle toner waste into and asphalt additive. TechCollect is another initiative supporting e-waste recycling.
General Electric	General Electric was able to use additive manufacturing to redesign its Catalyst aircraft engines from 855 components to just 12 titanium 3D-printed components, without losing any functionality. This can lead to lighter, more durable, better performing products.
Geoscience Australia	National Waste Management Database – data on locations of waste infrastructure.
Green Industries SA	Green Industries SA is a dedicated agency to promote circular ecomony, resource efficiency, and the conservation and recovery of scarce resources. The agency also oversees the South Australian Waste and Resource Recovery Infrastructure Plan.
Hobart City Council	As part of the 'connected Hobart' strategy, Hobart is using smart bins connected to IoT network to communicate data about bin fullness, fire hazards and odour.
HP Instant Ink	HP's Instant Ink uses sensors to detect when printer cartridges need replacing. In this service model, HP can secure a clean waste stream for refill or recycling, and the consumer never runs out of ink.
IBM	Prototype Reuse Selection Tool collects data over the lifetime of products to determine best next-use cycle.
IKEA	IKEA is using recycled material to manufacture furniture, starting buy-back programs, applying circular design to new products, and engaging in research and development for new sustainable/recyclable materials. IKEA is also testing furniture leasing in 30 markets during 2020.
Kellog's UK	In response to consumer concern, Kellogg is trialing a redesigned packaging for Pringles in the UK. The new recyclable design contains 90% cardboard which is widely recyclable.
LG Sherlock	After completing an extensive review into available waste data in QLD, LG Sherlock developed a new waste analytics tool called Waste Detective. The tool provides local councils with the opportunity to develop their waste management system and has helped them safe hundreds of thousands of dollars in energy bills.
Licella	Catalytic Hydrothermal Reactor (Cat-HTR™) platform converts a wide variety of low-cost, waste feedstocks and residues into high-value products.
Loop Industries	A low-energy de-polymerisation technology that can handle a high level of plastic waste material contamination to create new, virgin-quality PET resin and fibre.

Melbourne City Council	After a successful pilot in 2017, the city of Melbourne started replacing their existing public litter bins with solar powered compactors in high use areas of the central city. In 2018 they had installed 397 of these compactors, and intended to install another 772.
Michelin Solutions	Michelin Solutions provides fleet management to optimise the operation of commercial vehicles. Using sensors connected to the IoT, Michelin can monitor, service and change tyres on demand. They are also developing a new heavy truck tyre treat that self-regenerates.
Million Waves Project	The Million Waves Project, in partnership with GreenBatch makes 3D printed upper limbs from reclaimed ocean plastic. The group also works with e-NABLE to provide to provide prosthetics templates and to connect recipients.
Miniwiz	Smart rubbish bin, named Robin, that tracks and sorts waste into categories and gives points through a mobile app.
MobileMuster	Voluntary free recycling program for the mobile phone industry.
NSW State Government	NSW EPA online waste- tracking tool.
Pact Group	Pact is a dynamic manufacturer of packaging and other products operating in Australia. Since 2018, the group has been pursuing three 2025 End of Waste Targets: to eliminate all non-recyclable packaging it produces; to find solutions to reduce, reuse and recycle all single use secondary packaging in supermarkets; and to offer 30 per cent recycled content across its packaging portfolio.
Paintback	Product stewardship scheme to manage leftover and/or unwanted paint and packaging. Paintback diverts waste paint and packaging from landfill.
Phillips Lighting pay-per-lux	Phillips' pay-per-lux intelligent service program installs and owns the entire lighting system within a business. You don't have to buy any lamps or lights and only pay for the light you consume.
Planet Ark	Planet Ark is launching the Australian Circular Economy Hub (ACE Hub) with the aim of being Australia's 'one-stop-shop' for circular economy inspiration, education and implementation.
Polymateria	Polymateria uses a new technology to ensure plastic can fully biodegrade in the natural environment. When applied, their proprietary formulation triggers a chemical transformation that breaks carbon chains faster, ensuring biodegradation.
Recycling Robot by Riu Fukazawa	Riu Fukazawa invented a recycling robot as part of a Year 12 project to sort plastics for recycling using the existing barcode.
REDCycle	Free soft plastics recycling program, working with Australia's largest supermarkets to recover recycled materials into new ranges of products.
Rolls Royce Aerospace Engines	Rolls Royce has transformed an aerospace engine manufacturing model to a service model. They actively manage the lifecycle of their engines to achieve maximum flying availability, while collecting massive amounts of data.
Share Shed and Brisbane Tool Library	Share Shed is a sustainable alternative to buying items that are only used occasionally. The program offers a monthly membership for people to borrow up to five items. The Brisbane Tool Library operates in a similar way, allowing people to borrow tools and other equipment.
Shoalhaven Resource Recovery Centre, NSW	Projected to be able to recycle 90% of mixed household waste.
SMaRT Centre at UNSW	Through its microrecycling science, the UNSW Sustainable Materials Research and Technology (SMaRT) Centre is developing numerous innovations to reform waste streams destined for landfill into new, value-added materials and products.
SodaStream	Sparkling water makers and reusable PET carbonating bottles designed to avoid single-use plastics.
Teysha Technologies	Teysha developed a new technology that creates a wide range of polymers to meet the growing demand for sustainable plastics. The company focuses on natural products to create plastic that degrades in water.
trinamiX	Mobile Near-Infrared (NIR) Spectroscopy Solutions to support plastic sorting.
Tyre Stewardship Australia (TSA)	National tyre product stewardship scheme to promote a resource stream from end-of-life tyres.
University of Tokyo's School of Engineering and the RIKEN centre	Self-healing glass that provides a longer-lasting, durable material to increase product lifespan.
Veolia	Mechanical and biological treatment facility in Woodlawn, NSW.
VF Corporation	The company adopts a circular model approach, where waste becomes the feed for new products.
Vodafone 'Smart Waste Collection'	Sensor on bin collection vehicles that can alert business and residents when vehicle is passing so they can take the rubbish to meet the vehicle.

Glossary of terms

Aggregates
Materials or structure made of a combination of fragments of several separate elements mass.

Circular economy
The Ellen MacArthur Foundation defines a circular economy as "an economy that is restorative and regenerative by design and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles and decoupling growth from the consumption of finite resources. It is conceived as a continuous positive development cycle that preserves and enhances natural capital, optimises resource yields and minimises system risks by managing finite stocks and renewable flows."[56]

Closed loop economy
An economic model in which materials, components and products are circulated in closed loops, and nothing is wasted. Materials, components and products are instead channelled to different processes depending on their remaining properties and characteristics.

Cloud based services
Information technology tools that are provided over the internet, offering remote resources as a service.[245]

Digital infrastructure
The technology, equipment and systems that provide linkages, networks and pathways to connect people and communities with data, products and services. Similar to power, water and roads infrastructure, digital infrastructure allows information and data to travel around the world and underpin our social and economic lives. It includes the mobile network, data centres and high-powered computer facilities.[246,247]

Digital revolution
The digital revolution, known as the 'third industrial revolution', saw the uptake of electronics and information technology to automate production.[248]

Feedstock
The raw material used to supply or fuel a machine or industrial process.

Fourth industrial revolution
The fourth industrial revolution is characterised by the fusion of physical, digital and biological technologies. It focuses on augmented reality, machine learning, AI, 3D printing and robotics.[248,249]

Infrastructure pipeline
A set of infrastructure projects in early development and construction stages prior to project commissioning, typically presented as a sequence of proposed investment opportunities over time that support long-term development objectives.[250]

Linear economy or linear model of consumption
A 'take, make, dispose' model, where raw materials are collected and transformed into products that are used until they are discarded as waste that does not return any further value.[56]

Non-virgin material
Material that has been used before or recycled.

Organic waste
Wastes derived from material that was once living, excluding petroleum-based materials.

Product stewardship
"Product stewardship is an approach to managing the impacts of different products and materials. It acknowledges that those involved in producing, selling, using and disposing of products have a shared responsibility to ensure that those products or materials are managed in a way that reduces their impact, throughout their lifecycle, on the environment and on human health and safety."[251]

Recycling

Converting materials, which would have otherwise been disposed of, into new materials.

Remanufacture

Refurbish (a used product) by renovating and reassembling its components, or using the components
to make a new and different product.

Reprocessing

Converting recovered materials into new products.

Resource recovery

Making use of a waste material, including recycling of waste matter and recovering energy or other
resources from waste.

Resource productivity

Resource productivity is the value that can be generated per unit of material use.[252]

Resource recovery ecosystem / Resource recovery sector

Resource recovery is the extraction or separation of materials from the waste stream to return valuable material or energy through processes such as recycling, composting, and waste-to-energy generation.[253] The resource recovery sector is made up of all companies that are involved in the collection, transfer, sorting, and processing of waste.[254]

Reuse

Reallocation of a product or material without reprocessing or remanufacture.

Reverse logistics

The process of moving goods from their typical final destination back to a location for the purpose of capturing value (through reuse, remanufacturing, refurbishment, parts harvesting or recycling), or for proper and safe disposal.[56]

Supply chains

A supply chain refers to the network of suppliers that move products from the raw components all the way to delivering the final product to the consumer.[255]

Systems thinking

A holistic approach to viewing, identifying and solving problems, where parts and components of a system, their interactions and interrelationships are analysed individually to see how they influence the functioning of the whole system.[256]

Waste lifecycle

The entire life cycle of waste material, from the generation of waste through to its collection, processing, use, reuse, recycling, materials and energy recovery and disposal of any residual waste.[257,258]

Waste material flows

The transformation, movement and storage of physical waste.[259]

Waste streams

Flows of specific waste types or from specific site or industries.[260]

List of abbreviations

3D	Three-dimensional
AI	Artificial intelligence
ACCC	Australian Competition and Consumer Commission
APCO	Australian Packaging Covenant Organisation
ASPIRE	Advisory System for Processing, Innovation & Resource Exchange
ATSE	Australian Academy of Technology and Engineering
BPA	Bisphenol A
CAD	Computer-aided design
CEFC	Clean Energy Finance Corporation
CEO	Chief Executive Officer
CO2	Carbon dioxide
COAG	Council of Australian Governments
CRC	Cooperative Research Centres
CRC-P	Cooperative Research Centre Projects
CSIRO	The Commonwealth Scientific and Industrial Research Organisation
EPA	Environment Protection Authority
EPR	Extended Producer Responsibility
EU	The European Union
E-waste	Electronic waste
FTE	Full-time equivalent
GST	Goods and services tax
ICT	Information and communications technologies
IoT	Internet of Things
IT	Information technology
LIB	Lithium-ion batteries
ML	Machine learning
MRF	Material recovery facility
MTP	Modified Toner Polymer
NSW	New South Wales
OECD	The Organisation for Economic Co-operation and Development
PET	Polyethylene terephthalate
PSS	Product as a service
PV	Photovoltaic
RET	Renewable Energy Target
RMF	Recycling Modernisation Fund
SCRI	Supply Chain Resilience Initiative
SMaRT	Sustainable Materials Research and Technology
TAFE	Technical and Further Education
TSA	Tyre Stewardship Australia
UK	United Kingdom
USA	The United States of America
WtE	Waste-to-energy

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