Australia’s comparative and competitive advantages in transitioning to a circular economy

A report to the Office of the Chief Scientist

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Executive summary

A circular economy

recognises the scarcity and

value of natural resources.

A circular economy emphasises the design of products

and systems for reuse and recovery, aiming to establish

business models, production and consumption practices

that create a closed-loop system for resource utilisation.

While the approach is comprehensive, a circular economy

focuses on three key economic and industrial goals:

eliminating waste, maintaining and increasing the

value of materials and products through repeated use,

and conserving natural resources (see Appendix A).

Australia has considerable potential for a more

circular economy. Like many other countries, it can

unlock vast economic value while reversing the

substantial loss of natural capital.

• There are several industry sectors where Australia

could leverage its plentiful natural resources, including

critical minerals, renewable energy, and food, fibre

and feed. This report focuses on the potential of mining,

construction, manufacturing, agriculture and waste

management, and resource recovery.

• Australia’s strong foundation of a diverse and skilled

workforce and strong research and innovation

capabilities support these sectors’ comparative

advantages in maximising Australia’s benefits from

a more circular economy.

• Additionally, Australia’s proximity to Asian

manufacturing hubs and markets, supported by policy

and institutional frameworks conducive to investment,

further amplifies and reinforces the nation’s potential for

achieving favourable outcomes in a circular economy.

The five industries with the most potential

to advance a circular economy are mining,

construction, manufacturing, agriculture,

and resource recovery.

The inherent advantages in these sectors stem from

significant amounts of raw materials or products that can

be reused or recycled, as well as the potential for reducing

negative environmental impacts. There are identified

opportunities for product and service development within

these key sectors, each playing a crucial role in advancing

towards a circular economy.

• Mining opportunities exist in the repurposing of mining

rocks, tailings and closed mines. Novel mine‑tailing

beneficiation technologies are expanding, and smaller

enterprises can play a significant role in reducing

environmental impact if well supported.

• Construction opportunities include material production

or enhancements from mining, agricultural and industrial

by-products, prefabricated and modular housing,

cross‑laminated and recycled timber, low carbon

concrete, and regional resource recovery centres.

• Manufacturing opportunities are available in four

material sectors: lithium-ion batteries, e-waste, plastics,

and apparel and textiles.

• Agriculture opportunities would transform Australia’s

abundant agri-food by-products (such as grape marc)

into valuable chemicals and products, and feedstocks

for other processes using biological, chemical and insect

technologies. These advancements are underpinned

by Australia’s investment in synthetic biology and

biotechnology research, with examples of Australian

companies commercialising their innovations.

• Resource recovery opportunities (beyond those noted

above) lie in the abundant waste of our consumer

society, our capacity for technical innovation, and

the new Recycling Modernisation Fund. Harmonising

waste-management frameworks (education, regulation,

infrastructure, waste levies and planning pathways),

converting voluntary stewardship to extended producer

responsibility schemes, and mandating government

procurement of circular economy products and services

would further extend these opportunities.

To fully leverage these industry opportunities, Australia

can further develop its talent bank of ‘hard’ and

‘supporting’ skills. The hard skills include engineering

and digital capabilities, while the supporting skills include

the design, financial and regulatory expertise crucial to

facilitating and governing a circular economy. Workforce

diversity, a culture of innovation, and high educational

attainment are also essential components in this context.

• There is a shortfall in the engineering and digital skills

required for a circular economy. Although Australia

has seen growth in its tertiary-educated workforce,

there is high demand for these crucial ‘hard’ skills,

and they remain in relatively short supply, particularly

in regional areas.

• Policies are being developed to enhance industry-ready

training more effectively and accessibly, with a particular

focus on targeted immigration strategies. Further efforts

could also be made in the Vocational Education and

Training (VET) sector to upskill workers for roles in the

circular economy. This could involve offering more

short courses and micro-credentials co-designed with

industry players and implementing a ‘skills passport’

system to recognise and transfer accredited skills across

different industries.

While Australia has a significant comparative

advantage in innovation in mining and agriculture

and its professional service industry, ongoing strategic

investment is needed.

• Diverse professional fields exhibit Australia’s

comparative strengths, including material tracking,

accreditation, monitoring and evaluation, with expertise

in circular design, production, upcycling, and energy

recovery. Australia also excels in the field of reverse

logistics and has effective platforms to facilitate material

exchange between industries and businesses.

• Remarkable examples of innovation that either

enhance value or contribute to closing the loop are

found in various sectors, including construction, textiles,

furniture and homeware, plastics and polymers, metal

recycling, resource recovery and electronics.

• Australia’s private-sector and university-led innovation

hubs can spearhead greater research and development

(R&D) investment. Though these initiatives remain

relatively small by global standards, owing to Australia’s

remoteness and the smaller scale of businesses

embracing the circular economy, opportunities exist to

further extend the design and development of circular

economy related technologies. With R&D investment

falling to a 17‑year low in 2022, programs that link R&D

funding to mandatory participation in open innovation

networks could support more collaborative business

models in our relatively firm-centric industries.

Building on Australia’s diverse trading relationships, strong

opportunities exist for Australia to partner with other

countries, particularly in Asia and the European Union,

to create new demand for circular products and recycle

Australia’s end-of-life materials.

• Australia has strong and diverse trading partnerships

in manufactured goods, with opportunities to

increase trade with the EU. In 2021–2022, Australia

exported A$53.4 billion in manufactured goods, with

each of the top 20 exports having circularity potential.

These included advanced manufacturing goods to

the US, New Zealand, China, Hong Kong, Singapore,

Indonesia, the Netherlands, France, and the UAE;

and chemical materials to New Zealand, China, the

US, India, Japan and Thailand. Further trade with the

EU would accelerate Australia’s journey to a more

circular economy. The EU is leading the world with its

circular economy policy, such as its extended product

responsibility and digital product passport, making it a

future source for circular inputs and products.

• Australia might aim to retain the value of ‘end-of-life’

materials. In the same period, end-of-life materials

valued at A$4.36 billion were exported. Indonesia,

Vietnam, Bangladesh, Malaysia, Thailand, South Korea

and Taiwan were the top export destinations for plastic,

tyres, textiles and metals. Sweden is a potential partner

for commercial-scale chemical textile recycling, while

South Korea, Singapore, Canada, and Belgium are the

leading international partners for processing recycled

lithium-ion batteries.

However, offshore end-of-life processing may not be a

strategic solution in the long term, as the beneficiation

of these materials onshore could provide Australia

with a considerable boost to GDP and build Australia’s

reputation as a trusted supplier of high-quality secondary

materials for international industries. The Recycling

Modernisation Fund is also significantly boosting our

onshore recycling and remanufacturing capacity for

plastics, glass, paper and tyres.

To realise these opportunities, Australia will need to

strengthen and forge new international partnerships

to foster the purchase of Australian-made circular

products, help close the loops for end-of-life materials,

and supply circular inputs to domestic manufacturing.

Australia’s strengths for the circular economy lie in its

traditional world-leading sectors, diverse workforce,

emerging innovation ecosystems and international

trading relationships.

As yet, relatively few internationally-recognised

examples exist of how Australian companies leverage

these comparative advantages into competitive

advantages for their firms. Leveraging Australia’s

strengths, while closing the identified gaps,

would push Australia towards a more circular,

resilient and sustainable economy.

1 Introduction

In 2022, the world extracted and used over 100 billion tonnes of biomass, fossil fuels,

metal ores and non-metallic minerals, three times what it did 50 years ago, and on

a path to 160 billion tonnes by 2060. One-third of all extracted material is discarded

within a year (International Resource Panel, 2024).

Reversing this immense loss of natural capital and

economic value could unlock US$4.5 trillion of value

by 2030 (Lacy and Rutqvist, 2015). It would also address

50 per cent of climate change impacts, 90 per cent of water

stress and land‑use related biodiversity loss, and 30 per cent

of particulate matter health impacts. Doing so remains

critical for Australia both as an economic opportunity and

an environmental need.

Australia relies heavily on resource extraction and primary

industries for economic growth and global economic

participation. A circular economy may help foster new

industries and technologies and add to Australia’s role in the

global economy and its relationship with natural capital.

This report explores whether Australia may have comparative or competitive

advantages to assist in this potential transition. The following two questions

were the foundation of this research.

1 As international economies become increasingly circular,

what are Australia’s comparative and competitive

advantages in:

a. workforce capacity and capabilities

b. product and service development

c. research and innovation

d. economic activities.

2 Which countries represent valuable potential partners

to complement Australia’s strengths in the circular

economy, and increase the circularity of our material

supply chains?

The definitions of comparative and competitive

advantage continue to evolve in the economic

literature. We have adopted the following as being

most constructive to the present study:

• Comparative advantages: ‘Australia’s factors of

production (e.g., land, labour, and capital), and

other conditions (e.g., regulatory environment,

weather, policies, investments) that can be

used to efficiently produce goods and services

compared to others’. This is the area Australia is

generally strong in.

• Competitive advantages: ‘Australia’s ability to

generate products or services at lower cost or of

higher value than other countries, allowing it to

increase its global market share.’ This is the area

Australia needs to improve on.

Diagram showing the six elements Australia must focus on to enable circular economy, for a full description please contact Heinz.Schandl@csiro.au

MARKET DEVELOPMENTCONSISTENT GOVERNANCEZERO WASTE CULTUREMARKET DEVELOPMENTCONSISTENT CULTUREMARKET DEVELOPMENTCONSISTENT GOVERNANCEZERO CULTURERECYCLINGDESIGN ANDUSE ANDMANUFACTURECOLLECTIONRECYCLINGDESIGN ANDMANUFACTURECOLLECTIONEnablersMaterial flowCIRCULARECONOMYEnablersMaterial Australia’s economy has a strong potential to be more circular

The Australian economy has high material flows yet

relatively low circularity. Australia exports most of its

primary materials to other countries and imports most of

its consumer goods (Krausmann et al., 2015; Schandl et al.,

2019). In 2019, Australia’s material extraction stood at 2,587

million tonnes, of which 917 million tonnes were consumed

domestically, and only 39 million tonnes recycled, as shown

in Figure 2. This resulted in a circularity rate of 5.4 per cent

(Miatto et al., 2024), up slightly from 3.5 per cent in 2015

(Schandl et al., 2019). What we extract each year is

equivalent to digging up Hobart to a depth of 7.5 metres,

of which 2 metres is consumed in Australia.

Australia’s low economic complexity may also inhibit

a circular economy. Australia has been assessed as having

low economic complexity due to the large shares of primary

industries and service sectors in the national economy

(Harvard, 2023; Industry Innovation and Science Australia,

2023). The lack of economic complexity has not inhibited

Australia’s economic growth to date, as those sectors are

highly competitive in the global economy. However, it does

matter for its transition to a circular economy, as the

characteristics that define high economic complexity tend

to correspond with those needed for a circular economy.

Nonetheless, Australia has several valuable

comparative advantages in domestic production and

global trade that could enable circularity in many sectors

(Australian Trade and Investment Commission, 2023).

These include a well-educated and diverse workforce

with strong centres of innovation; abundant resources of

critical minerals, renewable energy, food, fibre and feed;

favourable policies and institutions for investment; and

proximity to Asian manufacturing centres and markets.

These advantages are implied in all our analyses

in Section 2, to which we add specific comparative

advantages for the identified sectors.

To pursue a circular economy, Australia must focus on

six key elements (Figure 1): three aimed at increasing

the circular flow of our materials (inner circle) and three

focused on enabling the changes needed to be more

circular (outer circle).

Key material flow strategies

1. Retain material through use and collection

2. Upscale and innovate recycling technologies

3. Innovate and collaborate in design and manufacture

Key enablers

4. Develop markets for secondary materials and the

products that use them

5. Streamline nationally consistent governance

6. Secure a national zero-waste culture

Figure 1 The six key elements that Australia must focus on to enable circular economy

Figure 2 Material flow account for Australia, 2019, in million tonnes

Source: Miatto et al., 2024

Material flow account for Australia for 2019 diagram, for a full description please contact Heinz.Schandl@csiro.au

BiomassFossil fuelsMetalsMetal oresGangue and tailingsNonmetallic mineralsOther products n.e.c.Balancing items

Imports ­­‑

Domesticextraction

­,

Domesticmaterial input

­,

Recycling ‑

Balancing items ‑

Exports

­,

Domesticmaterialconsumption

­‑

Energetic use ­,

Gangue and tailings ‑

Material use

­‑

Domesticprocessedoutput

­­­

Net addition to stocks +‑‑

Balancingitems

­‑‑

Air emissions

­‑­

Solid andliquid waste

­‑

Seeds andfertilizers ­‑

Units: MtAustralia, , material ows.

2 Industry opportunities

for a circular economy

Many industries are transforming how resources are used through a product’s life cycle.

CSIRO has reviewed these industries to identify those with comparative advantages

on which to build globally competitive products or services in a more circular global

economy. It has selected five industries – mining, agriculture, construction, several

manufacturing sub-sectors and waste management – as having the most potential.

For these industries:

• their successes demonstrate the value of cross-industry

partnerships and strong government commitment.

In particular, agricultural improvements that are helping

to create circular textiles and waste recovery initiatives

that are creating new construction materials

• they are achieving growth by tackling one link at a time

in their supply chains and seeing these advancements

spur on other important changes

• Australia has numerous comparative advantages that

will help grow the momentum of its circular economy,

including a well-educated and skilled workforce,

attractive climate investment and a stable

political environment

• leading the way is a growing list of globally competitive

firms and sub-sectors.

Selection of industries with promising

circular economy opportunities

This was based on economic activities that:

• produce large quantities of either raw materials or

circular economy products, able to be reused or

recycled within the circular economy

• currently have a high impact on the environment1 and an

opportunity to reduce that impact through adopting one

or more of the six key elements of a circular economy

(see Figure 1)

• have comparative strengths that can be leveraged.

Nineteen Australian and New Zealand Standard

Industrial Classification (ANZSIC 2006) industrial

divisions (ABS, 2008) were assessed according to the

selection criteria. The following five industry divisions

met the selection criteria:

• Mining – primarily involved in material extraction

• Agriculture – crop, fibre and livestock farming,

fisheries and forestry

• Construction – construction of buildings and other

structures, additions, alterations, reconstruction,

installation, and maintenance and repairs of buildings

and other structures

• Manufacturing – physical or chemical transformation

of materials, substances, or components into

new products

• Waste management – collection, treatment and disposal

of waste materials; remediation of contaminated materials,

including land; and materials recovery activities.

Each industry involves distinct circular economy enablers,

raw materials, products, services, economic opportunities

and comparative strengths that would reduce their

environmental impact (Ellen MacArthur Foundation, 2017);

see Table 1.

1 High environmental impact is considered in terms of material footprint, land use, water use, energy use, contribution to climate change (GHG emission)

and eutrophication, as per the Sustainable Consumption and Production Hotspots Analysis Tool (SCP-HAT).

Table 1 Summary of opportunities for Australian industries to accelerate circular economy

CIRCULAR ECONOMY

ENABLERS, MATERIALS,

PRODUCTS AND SERVICES

OPPORTUNITIES

COMPARATIVE STRENGTHS

Mining by-products

(CE Ob 2)

[Mining]

• Recovery of valuable materials

• Repurposing of mining by-products

• Sites for energy storage systems

• Abundance of mining by-products

• World-leading mining industry

• Mature mining by-product recovery technologies

• Leaders in the adoption of automation

• Strategic international partnerships and trade agreements

Circular buildings

and construction

(CE Ob 1, 2 & 3)

[Construction]

• Construction materials from mining

and agricultural by-products

• Recycling timber

• Modular housing

• Low carbon concrete

• Regional resource recovery

• Abundance of construction materials and by-products

• Skilled and culturally diverse labour

• Well established place-based co-innovation centres

(living labs)

Lithium-ion batteries

(CE Ob 2)

[Manufacturing]

• Designing for disassembly

and manufacturing

• Recycling

• Reusing lithium and other recovered

metals for energy storage

• Refurbishing commercial lithium‑ion

batteries for household use

• Global supply-chain advantages: Australia has nine of

the ten required lithium-ion battery mineral elements

• World-leading and demonstrated expertise in resource

extraction and processing (transferrable to metal recovery)

• High-tech engineering and substantial investments

into renewables research

• Low sovereign risk and strategic international partnerships

Plastics

(CE Ob 1, 2 & 3)

[Manufacturing]

• Developing bioplastics

• Advanced recycling of soft plastics

• Abundance of plastic waste and organic biomass

• Superior innovation in mixed plastic and dedicated

bioplastic research centres

• Supportive government policies

• Significant investment in recycling technologies

Apparel and textile

(CE Ob 1, 2 & 3)

[Manufacturing]

• Upcycling cutting waste

• Recovery of valuable materials

• Regenerative apparel

• Producing materials for art

• Apparel repair services

• First Nations apparel

• Abundance of cotton and wool to support regenerative

apparel, consistent with Australia as a globally recognised

leader in the natural fibre sector

• High innovation and R&D potential across the innovation

system, together with small medium enterprises (SMEs),

across natural and fossil-fuel based fibre types

• Closed loop resource cycling for regenerative agriculture

with pilot-scale/demonstrators in place at local scales

• World-first branding

• Strong, sustainable apparel education/skills expertise

across regions, with ‘clothing repair cafes’ active at

local scales, ready to expand/scale up

• An emergent and growing circular economy based

Aboriginal and Torres Strait Islander Apparel Sector,

including designers, practitioners, and SMEs

Agricultural by-products

(CE Ob 1 & 3)

[Agriculture]

• Valorisation of agri-food wastes

and by‑products

• Utilisation of organic biomass

as feedstock

• Insect technology

• Favourable conditions for food, feed and fibre from

abundant organic residues

• High investment in biotechnology

• Supportive industry policies

• High innovation in agri-food waste and by-product

utilisation

Waste management –

resource recovery services

(CE Ob 1, 2 & 3)

[Waste Management]

• Resource recovery services

• Materials for beneficiation

• Promoting best international practice

• Improving waste supply chain efficiency

• National Reconstruction Fund

• Abundance of by-product resource materials

Note: CE Ob 1,2,3 refer to circular economy objectives where CE Ob1 – Reduce use of natural resources; CE Ob2 – Maintain value of materials for as long as

possible; CE Ob3 – Reduce pollution and negative environmental impact.

2.1 Mining

There are opportunities within the mining sector to

repurpose common and often discarded material to benefit

other products and industries (key material flow circular

economy element – use and collection; key enablers element

– market development2):

• repurposing of mining rocks (waste rocks) to be used as

construction materials, rock fertiliser and mine void backfill

(Lebre et al., 2017; Solismaa et al., 2018; Tayebi-Khorami et

al., 2019; Simão et al., 2022; Thejas and Hossiney, 2022)

• repurposing mining tails to produce cement, ceramics,

and sand substitute (ore sand) (Kiventerä et al., 2016;

Peiravi et al., 2021; Liu et al., 2021; Golev et al., 2022)

• repurposing closed mines for energy storage systems

(Kinnunen et al., 2022)

• recovery of valuable minerals such as critical minerals

and rare earth minerals from tailings, slag, and laterite

(Peng et al., 2015; Saha and Saker, 2017; Dold, 2020;

Abaka-Wood et al., 2022; Makhathini et al., 2023).

Market drivers, comparative

and competitive advantages

Market drivers include adopting circular economy principles

(Guo et al., 2020) combined with increased demand for

sustainably sourced critical minerals (Araya et al., 2021).

Australia’s comparative advantages lie in:

• substantial mining by-products, with 620 million tonnes

of mine by‑products generated annually (Pickin et al.,

2023; Valenta et al., 2023)

• strategic international partnerships and trade

agreements (Australian Trade and Investment

Commission, 2023)

• highly skilled workforce in the mining sector

(Minerals Council of Australia, 2022).

These have supported competitive advantages in novel

mine-tailing beneficiation technologies (Minerals Council

of Australia, 2022), for example:

• NovaCellTM (Morgan et al., 2023; Han et al., 2023) –

enabling the flotation of valuable minerals at larger

particle size than current technology, allowing more

energy-efficient reductions, the effective recovery of

water, and the potential elimination of tailings dams.

• Viper Tailings de-watering technology (Whatnall et al.,

2021) – large-scale de-watering of mine tailings utilising

low energy and high production capacity.

• REFLUXTM Classifier (FLS, 2023a) – for de-sliming and

beneficiation of ultrafine iron ore particles.

• REFLUXTM Flotation Cell (RCFTM) (FLS, 2023b) – which

can operate at gas and wash water fluxes in an advanced

manner compared to other flotation techniques.

• Metso (Metso, 2023) – which provides tailing

management solutions, including mining wastewater

treatment.

International case study

EnviCore is a startup company based in Canada that

has developed a low-cost, energy-efficient technology

with the potential to replace 20 per cent of cement

used in construction. It does this by converting mining

tailings into supplementary cementitious materials,

reducing the need for cement mixers (EnviCore, 2023).

Transferrable learnings: Small-to-medium sized

enterprises can be supported to utilise mining

by-products and enhance the economic and

environmental impacts of the circular economy.

2 Refer to Figure 1 for additional information on the three key material flow strategies and three key enablers of the circular economy.

2.2 Construction

There are many opportunities in construction to repurpose

waste in other building elements, create products to reduce

environmental impacts, and replace single-use materials

with recycled materials to extend a product’s life cycle

(key material flow circular economy elements – use and

collection, design and manufacture, recycling; key enablers

element – market development):

• The production of construction material from mining

by-products can be transformed into masonry units for

construction (Cobîrzan et al., 2022).

• The production of construction material from

agricultural and industrial by-products, such as wood

shavings, can be transformed into wood foams to

increase their strength and performance and meet

required standards (Parece et al., 2020).

• Prefabricated houses manufactured and constructed

offsite are known to improve building quality and

reduce embodied and operational emissions and

construction waste.

• Cross-laminated timber (CLT) is an engineered

wood product used for prefabricated structural

applications, replacing concrete and steel to help

reduce environmental impacts.

• Recycled timber can be used to make cross-laminated

timber, which has properties similar to pre-cast concrete

panels but is lighter in weight and has lower carbon

emissions (Carrasco et al., 2023).

• Modular housing enables easier disassembly at the

product’s end-of-life phase (Green Industries SA, 2022;

Minunno et al., 2020).

• Low-carbon concrete offers lower carbon

emissions to decarbonise infrastructure delivery

(Infrastructure NSW, 2022).

• Regional resource recovery centres would help increase

the production of construction materials and reduce

transport costs (Green Industries SA, 2022).

Market drivers, comparative

and competitive advantages

The construction industry currently enjoys high demand for

affordable and environmentally friendly housing (Horne et

al., 2023). The comparative advantages include:

• abundant raw materials that can be transformed for

construction, including mining by-products, timber,

and wool (Whittle, 2019; Pickin et al., 2023)

• robust and credible building rating systems such

as Green Star and NABERS, along with peak bodies

such as the Green Building Council of Australia

(Edge Environment, 2021)

• well established place-based co-innovation centres

(e.g., urban living labs) (CSIRO, 2023)

• a culturally diverse and skilled workforce due to

immigration policies that can bridge significant cultural

gaps in the Asia-Pacific market (Lim, 1997).

These have supported competitive advantages in constructing

high-rise multi-unit apartment buildings from cross-laminated

timber (see case study below), helping to stimulate the

industry using locally sourced raw materials and skills.

Local and international case studies

Next generation 5-dimensional building information

modelling (5-D BIM) is an emerging technology that

integrates design, cost, and schedule in a 3-dimensional

output enabling better designs and analysis of the

impact of changes to construction schedule and

material. The 5-D BIM is currently being promoted in

Britain, Singapore, and Finland (Agarwal et al., 2016).

Forté is Australia’s first mass‑timber high-rise

apartment building, constructed by Lendlease in 2012

in Victoria Harbour, Melbourne (Durlinger et al., 2013).

Transferrable learnings: The 5-D BIM case study show

that collaboration between architects and information

and technology specialists will be critical to driving

further circularity in construction. The Forté case study

indicates that Australia can utilise its natural resources

and innovation to build high-rise buildings and meet

the demand for affordable housing.

2.3 Manufacturing –

Lithium‑ion batteries

Better and more sustainable design of lithium-ion

batteries can enable an extension of primary life,

a second life and a more efficient recovery of metals and

materials (key material flow circular economy elements

– use and collection, design and manufacture, recycling).

The opportunities are:

• designing and manufacturing lithium-ion batteries

for disassembly to ensure they are structurally rigid and

open to automatic disassembly will ease the material

recovery at the end-of-life phase (Wu et al., 2023)

• recycling allows the recovery of reusable parts and

valuable metals (Chen and Ho, 2018)

• reuse of end-of-life electric vehicle batteries for

large and small-scale energy storage systems

(Baum et al., 2022)

• refurbishment of lithium-ion batteries for household

applications (Islam et al., 2022).

Market drivers, comparative

and competitive advantages

Global demand for electric vehicles leapt by 35 per cent

in 2022 alone and is forecast to continue (International

Energy Agency, 2020). Australia holds significant global

supply‑chain advantages:

• producer of nine of the ten minerals required to

manufacture lithium-ion batteries

• world-leading expertise in mining resource extraction

and processing, enabling quick response to global

consumer demands (Cordano and Zevallos, 2021)

• high-tech engineering skills for designing,

manufacturing and refurbishing lithium-ion batteries

• renewable energy sources that can be used to reduce the

production cost of lithium-ion batteries (Australian Trade

and Investment Commission, 2018)

• low sovereign risk, minimising the probability of

defaulting on its obligations, and high environmental

and labour standards.

Australia does not yet have internationally recognised

competitive advantages in lithium-ion batteries.

International case study

Redwood Materials is a US$3.8 billion

Nevada‑based startup offering services in

recycling, hydrometallurgical metal refining, and

remanufacturing of anode and cathode battery

components (Redwood Materials, 2023). It shows

that with substantial investments, small-to-medium

enterprises can offer services across the lithium-ion

battery supply chain. It shows that if Australia invests

more in lithium-ion manufacturing, small-to-medium

enterprises can offer services across the lithium-ion

battery supply chain.

2.4 Manufacturing –

Upcycling e-wastes

Waste generated from electrical goods (e-waste) are

valuable sinks of metals and materials (key material flow

circular economy elements – use and collection, recycling).

There are opportunities in:

• automated separation and disassembly of e-waste

• pulverising hazardous material increases the efficiency

of separating e-waste materials at the end-of-product

life phase (Tiwary et al., 2017)

• recovery of precious and base metals from e-waste

streams (Rene et al., 2021).

Market drivers, comparative

and competitive advantages

The drivers of demand for e-waste recycling

(Maximize Market Research, 2023) are:

• global surge in e-waste generation (53.6 million

metric tonnes in 2022)

• technological advances in material recovery

and recycling

• rising adoption of circular economy principles.

Australia has several comparative advantages:

• significant quantities of e-waste which can act as

resources (Pickin et al., 2018)

• well-established e-waste recycling scheme for some

e-waste (Dias et al., 2018).

These have supported competitive advantages in superior

e-waste innovation and large processing capacity.

For example:

• Mint Innovation which can process 3,000 tonnes of

circuit boards and recover valuable metals using green

chemistry (Mint, 2023).

• Microfactorie® technology that uses thermal techniques

to transform e-waste into valuable materials such as rare

earth metals (UNSW, 2023).

• Scipher Technologies can process 539,000 tonnes of

e-waste and solar panel waste (CEFC, 2022).

International case study

European Union’s (EU) extended producer

responsibility scheme requires electrical goods

producers in the EU to bear the cost of recycling

electrical goods in the EU. The rationale is that this

gives them a financial incentive to maximise product

lifecycles (ANZRP, 2015).

Transferable learnings: Australia has an extended

producer responsibility scheme, currently limited

to personal computers, computer accessories, and

televisions. Australia would benefit from expanding

the scope of products covered by its e-waste system

and promoting shared responsibility (ANZRP, 2015).

2.5 Manufacturing – Plastics

The opportunities for plastics are in (key material flow

circular economy elements – design and manufacture,

recycling; key enablers element – market development):

• developing renewable, non-toxic, biodegradableand compostable plastics (bioplastics) using organicfeedstocks such as sugarcane, seaweed, and algae(Berry et al., 2022; Payne et al., 2019)

• advanced recycling of plastics to break down difficultplastics into chemical building blocks for conversioninto new plastics (King et al., 2021).

Market drivers, comparative

and competitive advantages

Demand for renewable plastics is driven by the impending

Global Plastics Treaty (Recycling Plastics Australia, 2023)

which is intended to be negotiated by the end of 2024.

The comparative advantages for the Australian

industry include:

• abundance of plastic waste (2.63 million metric tonnesannually with 66 per cent recyclability potential) andorganic biomass (Pickin et al., 2023; Australian PackagingCovenant Organisation, 2021)

• expertise in processing and high-tech engineeringresearch (Australian Trade and InvestmentCommission, 2023)

• Australian Research Council’s Training Centre forBioplastics and Biocomposites enhances researchin plastic recycling (Centre for Bioplastics, 2023)

• supportive government policies (Australian PackagingCovenant Organisation, 2021)

• significant investments in recycling and resourcerecovery, such as the Recycling Modernisation Fund(RMF) Plastics Technology stream (DCCEEW, 2023a).

These have supported competitive advantages in mixed

plastic recycling. For example, Licella and BioLogiQ have

developed their high-tech Catalytic Hydrothermal Reactor

(Cat-HTRTM), a chemical recycling solution that can break

down mixed end-of-life plastics into oil (Licella, 2023).

Case study

The Australian Government has invested A$2.5 million

to develop a fit-for-purpose mobile plastic recycling

facility to process single-use plastics into valuable

products. Located in the Northern Territory, the

project will connect remote communities to a

global recycled plastic market (DCCEEW, 2023b).

These mobile recycling technologies and facilities can

help rural communities manage waste and enter the

global market.

2.6 Manufacturing –

Apparel and textiles

The opportunities to extend the life of textiles include

(key material flow circular economy elements – use and

collection, design and manufacture, recycling; key enablers

elements – market development, consistent governance):

• recovery of valuable materials, including biodegradable

fibres such as viscose and other cellulosic fibres

(Ma et al., 2020; Ruuth et al., 2022)

• reusing textile dye for art involves pulverising

textile waste into a powder that can be used in art

(Deakin University, 2023)

• regenerative apparel that produces apparel using fibres

sourced from regenerative farms rather than traditionally

resource-intensive fibres such as wool (Gueye, 2021).

Market drivers, comparative

and competitive advantages

Global environmental concerns are a key driver of

demand for regenerative apparel (Gueye, 2021).

Australia’s comparative advantages include:

• an abundance of cotton and wool as raw materials

that can be used for regenerative apparel and a

highly adaptive natural fibre industry in Australia

(Cotton Australia, 2023; Wiedemann et al., 2022)

• a world-first fashion industry trademark, the

Australian Fashion Certification Trademark, has been

launched to help identify Australian brands globally

(Australian Fashion Council, 2023)

• a National Clothing Product Stewardship Scheme for

textiles established to accelerate extending clothing

life and reducing textile waste at the brand/producer

levels of the value chain (Australian Fashion Council

and Consortium, 2023)

• an emergent and creative circular economy

transdisciplinary fibre and textile Australian ecosystem

tackling circularity in the textiles and apparel sector

(MacMillan and Payne et al., 2022).

These have supported a competitive advantage in separating

textiles. For example, a new ionic liquid (salt in a liquid state)

developed by Deakin University can separate different blends

of cotton-polyester, providing a breakthrough for recycling

textiles (Deakin University, 2014).

International case study

Worn Again Technologies is a unique solvent

capable of converting end-of-use polyester and

cotton garments into polyester pellets and cellulosic

pulp, developed in 2012 by a UK-based company.

The business has since secured funding through

partnerships to build a pilot plant with a 1,000 tonnes

capacity and plans to build a 50,000 tonnes capacity

plant by 2027 (Worn Again, 2023). The experience

showed the value of support mechanisms, extensive

R&D and strong partnerships to scale up and ensure

longevity in the market.

2.7 Agriculture – food, fibre

and feed

There are opportunities for transforming wastes and

by‑products for other industries, food sources and

economic benefit (key enablers circular economy

element – market development):

• Agri-food by-products can be transformed into

valuable food, fibre and feed (Papaioannou et al., 2022;

Isah and Ozbay, 2020; Hetherington, 2022). For example,

grape marc can be processed to extract natural

antioxidants, which is projected to see increasing

demand, with Asia-Pacific being a primary market

(Raju and Roshan, 2022).

• Organic feedstock uses by-products as feedstocks for

fermentation processes, such as synthetic biology,

to produce valuable products (CSIRO Futures, 2021).

• Insect technology involves creating more valuable

and homogeneous biomass from agri-food waste

(Leni et al., 2021). The insect protein market is

expected to grow from US$288.38 million in 2023 to

US$348.97 million by 2028, at a compound annual

growth rate of 3.89 per cent (Mordor Intelligence, 2023).

• Regenerative agriculture. Biomass-based products

cycling back through the farm with regeneration of

soils, including diverting cotton fibre textile waste from

landfill to enrich cotton farm soils for fibre production

(CRDC, 2023).

Market drivers, comparative

and competitive advantages

Drivers of market demand (Kaza et al., 2018) include:

• global concern on food waste

• consumer shift from chemical to bio-based products

• technical advances in the utilisation of agriculture

• rising adoption of circular bioeconomy.

Comparative advantages in Australia include:

• climatic conditions that support various

agricultural products (Australian Trade and Investment

Commission, 2023)

• abundance of different agricultural by-products that

can be used as a feedstock across several sectors

(Robertson, 2022)

• high investment in synthetic biology and biotechnology.

For example, the Australian Research Council Centre of

Excellence recently invested A$35 million in synthetic

biology (ARC, 2023)

• supportive policies such as the AgriFutures 2023–2028

Australia and the Australian Insect Industry research

development and extension plan (Nolet and Lever, 2023).

These have supported competitive advantages in food

biotech, with innovative bioeconomy startups including:

• Farmed carbon3, which uses novel mobile microwave

pyrolysis technology to convert abundant rice straw

destined to be burnt by farmers into bio-bitumen and

biochar (Farmed Carbon, 2023). Microwave pyrolysis

technology is an alternative to conventional thermal

approaches and is more efficient with less emissions

(Ethaib et al., 2020).

• Nutri V4, where the whole of crop is utilised by turning

ugly but abundant waste vegetables into powders

(Nutri V, 2023). Waste vegetables are dehydrated using

an advanced process that retains essential nutrients,

vitamins and minerals to produce all natural, fibre-rich

and protein fuelled vegetable powders.

International case study

BioMADE is a non-profit organisation in the United

States with members from industry, research and

government seeking to enable domestic bio-industrial

manufacturing at all scales (BioMADE, 2023).

It shows that research collaborations can be used to

promote collaboration, innovation, and Australia’s

comparativeness in the bioeconomy.

3 https://www.farmedcarbon.com/

4 https://www.nutriv.com.au/

2.8 Waste management

and resource recovery sector

The opportunities within the waste management and

resource recovery sector include (key material flow circular

economy element – use and collection; key enablers

elements – consistent governance, zero waste culture,

market development):

• streamline policy, standards and practices across

Australia’s waste management and resource

recovery system

• implement international best practice of extended

producer responsibility schemes, green public

procurement, sustainable design standards and the

right to repair, and provide incentives that support a

circular economy

• provide waste management and recovery services

(Pickin et al., 2023)

• divert abundant waste by-products for beneficiation

(Pickin et al., 2023).

Drivers towards resource recovery

as a comparative advantage

Demand for improvements in the waste management

and resource recovery market is driven by:

• progressive new government regulations such as the

Recycling and Waste Reduction Act 2020 and waste

export regulations

• rising adoption of circular economy internationally and

at the Australian federal and state government levels

(Grand View Research, 2022).

It may make more sense to think of waste management and

resource recovery not so much in its own right, but as a

comparative advantage supporting other sectors. Promising

conditions for it to emerge as a comparative advantage in

Australia include:

• abundance of by-product resource materials generated

(Pickin et al., 2023)

• availability of R&D investments (DCCEEW, 2023c)

• supportive waste management frameworks at the

jurisdictional levels, creating consistency and certainty

through programs such as education, regulatory reform,

infrastructure, waste levies and planning pathways

(DCCEEW, 2023c)

• increased product stewardship, from voluntary

stewardship schemes to extended producer

responsibility schemes

• expanded green public procurement at all levels

of government, ensuring a minimum standard of

recycled material

• similar uptake of green procurement at the

industry level, with consumer information provided

on recycled content.

The $250 million Recycling Modernisation Fund

which is leveraging over $1 billion in total investment

(DCCEEW, 2023c) will accelerate this sector’s path to

being a comparative advantage.

As yet, there are no internationally acknowledged

competitive advantages in this industry.

International case study

Taiwan’s 4-in-1 Recycling Program was established to

reduce municipal solid waste, increase recycling, and

improve safety and efficiency in the recycling industry.

Under the program, manufacturers and importers

pay fees that subsidise recycling. This has helped

reduce waste from 1.14 kg per day per person in 1997

to 0.4 kg per day per person in 2011 (United States

Environmental Protection Agency, 2012). It shows

how extended producer responsibility schemes can

improve a range of outcomes in waste management.

3 Workforce capacity,

capabilities, and training

To capitalise on the sectoral opportunities described in Section 2, Australia will need

greater access to a broad range of both ‘hard’ skills (engineering and digital capability)

and ‘supporting’ skills (such as design, circular business models and regulatory

understandings) that enable the circular economy.

This section examines the available workforce data to

support those needs and the critical gaps that remain:

• On the one hand, Australia boasts a high standard of

education, research, workforce diversity and a culture

of innovation and entrepreneurship – all valuable for a

circular economy.

• At the same time, particular skills may be in short supply.

Engineering is a priority skill to shape a circular economy,

yet less than 3 per cent of the workforce has a formal

engineering qualification. Despite growth in the number

of workers with digital skills (up 66 per cent in the past

decade), demand outstrips supply across the economy.

• Access to both these skills and others, is unevenly

distributed across the country, with regional areas reporting

the most difficulty in meeting workforce requirements.

To fill this gap, Australia is developing policies to offer

more accessible and industry-ready education and training

programs and boost its intake of migrants with relevant

skills through targeted migration strategies.

3.1 The skills needed

for a circular economy

The skills identified as most important to a circular economy

are science, technology, data science, engineering, design,

professional services, trades and semi-skilled labour,

see Table 2. These skills will not only support core circular

economy jobs such as recycling and remanufacturing,

but they will also help advance the circular economy

through design, new business models, value-adding,

and the digitisation and tracking of material flows

and logistics (Bokkel et al., 2023; Burger et al., 2019).

Additional and diverse occupations will further support

the circular economy in areas such as education and

government services.

Table 2 Circular economy job descriptions

CIRCULAR JOB

ECONOMIC SECTOR

CIRCULAR ECONOMY ELEMENT

EXAMPLE INDUSTRIES AND ACTIVITIES

Direct jobs

Core sectors

Sustain and preserve what is already there

Repair services

Use waste as a resource

Recycling

Prioritise regenerative resources

Renewable energy

Enabling sectors

Design for the future

Industrial design and architecture

Incorporate digital technology

Digital technology

Rethink the business model

Renting or leasing activities

Team up to create joint value

Professional and networking associations

Indirect jobs

Indirect sectors

Education

Government services

Professional services

Circular economy jobs will require different education

and training. Core industries, such as repair, recycling and

recovery, may not necessarily need high education levels

(Burger et al., 2019). Many will require a general upskilling

of the workforce (Brown et al., 2021).

Meanwhile, circular economy-enabling industries such as

design, digital technology, business model development

and joint-value creation will require more skilled and

specialised labour (Burger et al., 2019). For example,

engineering skills are essential for developing and

implementing circular economy activities, while

digital skills will enhance artificial intelligence, digital

marketplaces, digital twins, material passports and

various scanning technologies (Cetin et al., 2022).

Key circular economy skills

Technical skills, including those for housing,

mobility, food, and energy (Burger et al., 2019).

Sustainability skills, including natural resource

management, resource efficiency, resource recovery

options, waste reduction and emissions reduction

(Blomsma and Brennan, 2017; Geissdoerfer et al.,

2017; Straub et al., 2023).

Digital skills, including data analysis and deploying

digital platforms or the Internet of Things (IoT) to

track materials usage (Kristoffersen et al., 2020).

Sustainability metrics and analysis skills, such as

life-cycle analysis and carbon and waste footprinting

(Moraga et al., 2019).

Systems and design thinking skills, including

biomimicry, modularity and adaptability to design

products for longevity, reuse, remanufacturing,

recycling, disassembly and recovery.

Circular procurement skills, including the correct

regulations, standards and certifications that govern

sustainable products (Hartley et al., 2020).

Entrepreneurship and innovation skills,

for new circular business models, such as

product‑as‑a‑service or creating value from

end‑of‑life materials.

Collaboration and networking skills,

for partnerships and business models to develop

circular supply chains (Lombardi and Laybourn, 2012).

Business leadership skills, to build a culture to

embrace circular practices and identify circular

opportunities (Hartley et al., 2020).

Note: Skills list informed by the Australian Academy of Technology

& Engineering, 2020

3.2 Australia’s workforce comparative advantages

Overview of Australia’s circular capabilities

Australia’s skilled labour force is anticipated to boost

circular economy opportunities. For example, in the two

decades from 2000 to 2020, the number of level‑one

qualifications (bachelor’s degree and above) has increased

from 25.6 per cent to 32.4 per cent (National Skills

Commission, 2021). Australia has a skilled engineering

labour force, although fewer than 3 per cent have formal

qualifications (Kaspura, 2019).

Meanwhile, digital skills have experienced tremendous

growth between 2013 and 2020, particularly in artificial

intelligence (Hope et al., 2022). Approximately 861,000

people now work in technology (Tech Council of Australia,

2022), which is still considered a shortfall given the demand

for these skills (Hope et al., 2022).

High-level education (bachelor’s degree and above)

statistics reveal that 97,676 postgraduate enrolments in 2019

were associated with the circular economy (Department of

Education, Skills and Employment uCube data hub, 2023).

Management, commerce and education courses had the

highest postgraduate enrolments, as shown in Figure 3.

Engineering and IT courses remain male-dominated,

while education tends to have more female enrolments

(Australian Council of Engineering Deans, 2022).

Promoting science, technology, engineering

and mathematics (STEM) education for girls will

help to improve the workforce gender balance

(The Treasury, 2023).

Figure 3 Circular economy related course enrolments by gender, 2019

Bar chart showing circular economy related course enrolments by gender in 2019, for a full description please contact Heinz.Schandl@csiro.au

­‑,­­­­,­­­‑,­­­­,­­­‑,­­­­,­­­

Natural andPhysicalSciencesInformationTechnologyEngineeringand RelatedTechnologiesArchitectureand BuildingAgricultureEnvironmentaland RelatedStudiesEducationManagementand CommerceNUMBER OF ENROLMENTSMaleFemale

Deepening Australia’s capabilities

To build its circular economy workforce capabilities,

Australia can draw on strong foundations in education,

research, workforce diversity and a culture of innovation

and entrepreneurship. This applies particularly to its

agricultural and natural resource sectors. Australia’s

labour market regulations also allow for flexibility, ensuring

businesses can innovate in response to changing conditions.

In addition, First Nations people offer unique contributions

for realising circular economy opportunities. Indigenous

businesses manage over A$10 billion annually and

employ over 70,000 workers. A total of 11,599 Indigenous

businesses are estimated to operate in Australia, including

3,688 Supply Nation-registered Indigenous businesses

(Langford, 2023). A significant proportion of these are in

industries related to resource recovery activities such as

construction and building maintenance, consulting, plant

and equipment, mining and energy, transportation and

logistics, and manufacturing.

Existing policies and programs by public, private and

charitable organisations are committed to growing the

Indigenous business sector, laying the foundations for

potential partnerships with circular economy industries.

Traditional knowledge of materials, such as bush products

and natural resource management, inspires innovation and

value-adding in the supply chain.

Risks of vocational and locational gaps

Despite the opportunities to upskill or reskill Australia’s

labour force for the circular economy, several challenges

remain. These include:

• Uneven regional employment – For more than 25 years,

a consistent 5-percentage point difference has remained

in the unemployment rate for different regions in

Australia (The Treasury, 2023). A systemic challenge for

First Nations people’s participation also extends to fewer

education, training, and employment opportunities in

remote and regional areas (Nicolaou et al., 2023).

• Employment contraction in manufacturing – With the

exception of food production, the manufacturing

industry has declined over the last 30 years (Productivity

Commission, 2003). However, the circular economy could

help improve business prospects for manufacturers.

• Modest engineering and digital skill capability

– Despite the growth of skills over the past decade,

Australia still lacks sufficient skill levels in engineering

and technology (Kapsura, 2019; Hope et al., 2023).

To fully understand the circular economy capability and

skills gaps in Australia more studies are required.

Table 3 Circular economy skills and workforce assessment

OVERALL

WORKFORCE

CAPACITY

CAPACITY

(LABOUR

SHORTAGES)

CAPABILITY

(SKILL GAPS)

TRAINING AND

UPSKILLING NEEDS

POTENTIAL FOR

CIRCULAR ECONOMY

SKILL DEVELOPMENT

AND TRANSFERABLE

SKILLS

Mining by-

products

Workforce

capacity and

capability exist if

priorities shifted

to secondary

processing

of mining

by‑products.

Capacity exits, though

requires allocating

labour to by-product

valorisation versus

primary processing.

Can draw on strong

mining technical skills

that already exist.

Training in circular

approaches and

secondary processing.

SMI UQ is offering

professional

development for

secondary processing

and repurposing.

TiME CRC is also

investing in training

and development.

Circular

buildings

and

construction

Residential sector

(low).

Apartment

buildings and

commercial sector

(high).

Trade skill shortages.

Skill gaps in residential

construction and

design for a circular

economy.

TAFE and vocational

education programs,

on-the-job training.

Learn from large

developers and

organise knowledge

transfer.

Lithium-ion

batteries

Workforce in

development

– supported by

Australia’s critical

minerals strategy

and battery

supply chain

connections.

Engineering and

digital shortages.

Design, engineering,

circular business

models, operators.

Greater capacity for

the design of novel

battery materials and

whole battery systems.

FBI CRC facilitates

university and VET

education pathways

to grow battery

industries.

Training relevant to

all critical minerals

production.

Apparel

and textile

Very limited in

manufacturing.

Global leaders

and expertise

in research

and design for

sustainability exist

in Australia but

lack a broader

workforce

capability.

Shortage in labour

for making clothes

onshore – yarn, fabric,

and garments – skills

‘dying out’.

The lack of

manufacturing

infrastructure further

limits labour capacity.

Design, repair, reuse,

circular business

models, and digital

skills to accelerate

upscaling.

Transition broker

training.

Circular business

models.

Apprenticeships and

traineeships in repair.

Repair and reuse

programs.

Intermediaries/

transition brokers

to accelerate the

transition.

Investment in

programs and

initiatives to support

front runners.

Agricultural

by-products

Agri-food

and fibre

Regional shortages

in skilled labour and

trades.

Processing, design,

digital skills in circular

business models,

value adding.

Particularly in regional

areas.

Transition broker

training – particularly

in regional areas.

TAFE and vocational

education programs,

on-the-job training.

Collaborations

with TAFE and local

employer groups to

develop circularity

related courses.

Resource

recovery

and

plastics

Capacity limited

by lack of

infrastructure

investment.

Technical skill

shortages are not a

key barrier; rather,

they are a lack of

circular economy

implementation

by industry.

Regional shortages

in skilled labour and

trades.

The lack of recycling

infrastructure limits

growth in workforce

capacity.

Design, processing,

circular business

models, advanced

recycling skills, market

development for

secondary materials,

digital and AI skills.

Focus on improved

product stewardship,

designing for

circularity, smart

waste management

systems, and advanced

resource recovery.

Education across

the value chain

is needed from

product designers

and manufacturers

to retailers, to

shift to a circular

model focusing on

reduced material

use, repairability,

durability, and

recoverability.

TAFE and vocational

education programs,

on-the-job training.

Opportunity for

workers to develop

transferable skills in

sustainability, which

will contribute more

broadly to their

employability in the

green economy.

Skills transferable to

any WMRR\* related

industry.

\*WMRR = Waste Management and Resource Recovery

3.3 Building circular economy skills

The following four areas would help to build circular

economy skills quickly and efficiently by tapping into

established resources.

Vocational educational and training (VET)

The VET sector and TAFE (Technical and Further Education)

colleges are well-placed to upskill workers in

sustainability transitions.

• Short courses and micro-credentials could be developed

to enhance the skills and capabilities needed to increase

Australia’s environmental sustainability, targeting locally

based industries (TAFE SA, 2023).

• Industries, sectors and educators could collaborate to

co-design relevant training programs as new skill needs

emerge, with governments providing support for access

to such programs (Brown et al., 2021). Funding to support

training for VET qualifications creates a pathway for First

Nations people into higher-level training and more highly

skilled jobs (Griffin and Andrahannadi, 2023).

• Green skills and digital skills could be a focus for VET

and TAFE courses, given their transferability to the

circular economy, different occupations and industries

(European Commission, 2020; Summerton et al., 2019).

• A skills passport would help recognise accredited skills

acquired during the employment process, given that

these skills are needed across many industries.

Migration

The professional, scientific and technical services needed

for a circular economy rely heavily on skilled migrant

labour. Australia could continue to pursue required skilled

migrants by promoting its comparatively high incomes,

and its support schemes, including the Migration Program

and Global Talent program, and its new Specialist Skills

Pathway aimed at making it easier to attract highly skilled

workers for industries such as green energy and technology

(Department of Home Affairs, 2023a, b, c).

Non-government organisations training

Non-government programs (NGP) offered by

non‑government organisations (NGO) and approved by

the Department of Employment and Workplace Relations

(DEWR, 2023), enable individuals to upskill and become

more employable through training and work experience

(DEWR, 2023). These could provide a valuable pathway for

individuals to enhance their circular economy skills.

Regional Australia initiatives

Many circular economy opportunities lie in industries

located in regional Australia, where workforce planning

and development has been identified as a strategic

priority (The Treasury, 2023). Many of these regions are

critical to Australia’s transition to a low carbon future

with the implementation of regional Renewable Energy

Zones. This presents opportunities to attract and retain

a skilled workforce to support a circular economy and

rural liveability as a priority (Houghton et al., 2023).

Growing relationships with First Nations businesses in

remote and regional areas will also prepare partnering

opportunities along the value chain.

Table 4 Number of jobs related to circular economy activities in 2022–23 (ABS, 2023)

CIRCULAR JOB

ECONOMIC SECTOR

INDUSTRIES AND ACTIVITIES

EMPLOYED

PERSONS

IN ‘000

(FULL-TIME

EQUIVALENT)

Direct jobs

Core sectors

Repair service

210.1

Agriculture, mining and construction

1,639.3

Electricity, gas and waste services

115.7

Enabling sectors

Digital technology

314.9

Renting or leasing activities

70.7

Indirect jobs

Indirect sectors

Education

776.3

Government services

431.1

Professional services

814.8

Total

4,372.9

Table 5 Percentage growth of digital skills in Australia (2013 to 2020)

DIGITAL TECHNOLOGY SKILL

% GROWTH

Artificial Intelligence (AI)

4,412

IT Automation

3,817

Internet of Things (IoT)

3,645

Application Programming Interface (API)

780

Machine Learning (ML)

724

Natural Language Processing (NLP)

537

Distributed Computing

516

Data Visualisation

482

Software Development Methodologies

450

Big Data

384

4 Research and innovation

Most waves of 21st century innovation will support the circular economy, with real

breakthroughs in biotechnology, nanotechnology, health, new materials, energy

generation, transmission, storage and electromobility.

Australia has made several inroads in research and

innovation to drive a circular economy, with private-sector

and university-led innovation hubs drawing on the many

innovations to emerge through the waves of digitalisation

and automation.

However, the scale of these initiatives remains small by

global standards, owing both to Australia’s remoteness

and the limited scale of businesses that might embrace

the circular economy. Opportunities exist for more

strategic leadership among Australian manufacturers

and for government incentives to support the design and

development of circular economy technologies.

4.1 Infrastructure for innovation

Overall, Australia’s innovation ecosystem (its institutions,

human capital, research, infrastructure, and market

sophistication) was ranked 25 out of 132 countries in the

World Economic Property Organisation’s 2022 global

innovation index (WEPO, 2022). Australia was marked down

in market and business sophistication, which suppressed

the nation’s creative, knowledge and technology outputs,

leading to underperformance by the world’s 13th biggest

economy. Australia’s public investment in R&D is low by

international comparison, both in absolute value and share

of GDP, and is falling (The Treasury, 2023). While progress is

being made at the design end of innovation, less is evident

at the production end, where more industrial symbiosis

may be needed.

Several of Australia’s innovation hubs support circular

economy innovation, including the Sydney Startup Hub,

the University of Sydney’s Sydney Knowledge Hub, the

Melbourne Connect innovation hub and the RMIT Activator.

Several other Australian universities have created similar

innovation districts or hubs. They typically focus on a mix

of high-tech development, commercialisation of research

and support for entrepreneurs. Government initiatives play

their part, too, with resources such as funding, networking

events and educational programs to help promote

key industries (Nnanna et al., 2012).

There has been only a slow uptake of business-to-business

resource sharing platforms for production and no strong

examples of co-located industrial symbiosis, eco-industrial

parks, hubs and eco-industrial towns (King et al., 2020).

This creates a significant opportunity for regional and

secondary cities to achieve economies of scale as shared

resource recovery hubs. Recycling capabilities and end-

of-life waste management are improving with policy,

government funding and co-investment. However, there

needs to be greater co-located manufacturing capability

to realise the value. Again, some businesses are reusing

end‑of-life materials within their own operations

(for example, in the building sector and in sewerage),

but more innovative shared infrastructure and business

models are needed.

4.2 Innovation in design for

circular materials, products,

and processes

The principles of design for a circular economy are the

longevity, renewability and recyclability of products and

materials. Designers opt for non-toxic, renewable, or

recycled materials that have minimal environmental impact.

They pursue modularity and adaptability, allowing for easy

repair or upgrade of products and prolonging their useful

life. Products are designed to consume as little energy as

possible through their life cycle. Service-based business

models allow products to be leased or shared rather than

owned, maximising usage and reducing disposability

(Den Hollander et al., 2017).

Innovations that pursue these principles are becoming

more common in the sectors prioritised in Section 2

(see Table 6), but they are few and business-as-usual

generally prevails. Examples often sit at the interface of

chemical, biological and engineering disciplines and involve

digital opportunities as well. For example, the development

of membrane technology for industrial applications mimics

the functionality of membranes in biological processes at

the ANU Centre for Entrepreneurial Agri-Technology and

the UNSW Centre for Membrane Science and Technology

(Voicu and Thakur, 2023).

Table 6 Assessment of Australia’s circular economy innovation capacity for key opportunities

OVERALL

INNOVATION

CAPACITY

DESIGN FOR

CIRCULAR ECONOMY

LOOP-CLOSING

DIGITAL INNOVATION

BUSINESS MODEL

INNOVATION

Mining

by‑products

High

Mine planning is

designed for net

positive impact.

Use of by-products as

building aggregates.

Material passports

and material

characterisation,

provenance.

From extraction to

material supplier

(virgin and

secondary).

Circular

buildings and

construction

Medium

Modular, prefabricated

buildings and

components, long

building lifetimes.

Use of recycled

materials and

end‑of‑life separation

and reuse of materials.

Building scorecards,

material passports,

measurement of

embodied materials,

waste, and emissions.

Vertical integration

with material

and component

suppliers, Waste

Management and

Resource Recovery

sector.

Lithium-ion

batteries

High

Sustainable

battery design and

manufacturing.

Use of recovered

materials for new

batteries.

Material passports and

automated separation

and dismantling.

Domestic value

adding.

Plastics

Medium

Design for extended

use and disassembly.

Advanced recycling.

Recycled content

standards and

traceability.

Apparel and

textile

High

Natural fibre tech and

high-tech polymers

for extended use

and designing out

pollution.

Clothing Product

Stewardship

textile-to‑textile

loops; fibre and

component separation

technologies.

Textile and apparel

digital twins and

supply chain logistics

optimisation.

Textile and clothing

SMEs in partnership

with STEM and

place‑based

partners.

Agricultural

by‑products

High

Maximising use of

pre- and post-farm gate

primary resources and

household biomass.

Whole-of-animal

and whole‑of‑crop

utilisation,

i.e., innovative uses

of different parts of

organisms.

Digital-based decision

support tools for

bio-based resource

upcycling and

‘real time’ biomass

resource mapping at

granular scales.

Agri-food and fibre

SMEs in partnership

with STEM and

place‑based

partners.

Waste

management

and resource

recovery services

Medium

Depending on

manufacturing and

design (not in control

of the sector).

Depending on

collection and

separation system.

Sensors, AI and

robotics for

identification

and separation.

Vertical integration

of waste

management and

resource recovery

with upstream

sectors.

4.3 Innovation for value adding

and closing the loop

In a circular economy, ‘value-adding’ means exploring

ways to maintain or increase the value of products,

components and materials. ‘Closing the loop’ means

ensuring that products and materials circulate within

the economy at their highest utility, rather than being

downcycled into lower-value applications or sent to

landfill (Geissdoerfer et al., 2017). Various businesses

embrace these principles across Australia

(Collins et al., 2023), including:

• Construction and building sector

– e.g., Mirvac and Close the Loop.

• Apparel and textiles

– e.g., Adrian Ramsey Design House and Spell.

• Furniture and homeware

– e.g., Koala.

• Recycled plastics and polymers

– e.g., Replas and Plasma.

• Metal recycling

– e.g., Sims Metal Management.

• Waste management and resource recovery

– e.g., Visy and Cleanaway.

• Technology and electronics

– e.g., Substation33.

4.4 Opportunities for

digital innovation

Digitalisation helps industries implement circular

economy principles through better resource management,

efficiency and supply chain transparency. Various digital

technologies can help transform manufacturing and

supply chains, as highlighted in Figure 4 (Culot et al., 2020;

Oztemel and Gursev, 2020). However, the uptake of digital

innovation in Australia has been restricted by its relatively

small domestic market, geographic isolation, and a

manufacturing landscape dominated by small and medium

enterprises, which has slowed the rollout of necessary

standards and governance frameworks (Mason et al., 2022).

Digitisation is also critical to building strategic leadership

among Australian manufacturers. Currently, businesses are

tilting towards vertical rather than horizontal integration.

Combined with a decline in digital comparativeness,

this trend is diminishing potential gains such as advanced

production planning and supply chain management

(Mason et al., 2022). Researchers have identified the

need for Australia’s circular economy to draw on open

innovation, horizontal integration and robust investment

in digital skill-building (Hizam-Hanafiah and Soomro,

2021; Messeni Petruzzelli et al., 2022). One potential

way to address this is to tie R&D funding to mandatory

participation in open innovation networks.

Figure 4 Digital technology innovation supporting a circular economy

Diagram showing the digital technologies supporting a circular economy, for a full description please contact Heinz.Schandl@csiro.au

DigitaltechnologiesAdvanced

roboticsDigital

integrationBig dataInternet

of thingsArti

cial

intelligenceAugmentedrealityAdditive

manufacturingCloud

computingCybersecuritySimulation

4.5 Business model and supply

chain innovation

Circular business models are designed to intensify, narrow,

slow, close or even dematerialise resource loops while

delivering value. They can take many different forms

(Geissdoerfer et al., 2018; Lewandowski, 2016; Lacy and

Rutqvist, 2015). Embracing circular business models entails a

dedicated commitment to open innovation and investment

in capacity building. This encompasses both tangible and

intangible assets, such as digital technologies and supply

chain management systems, as well as initiatives for

business process improvements, leadership development,

and comprehensive training programs

Though there are some green shoots, Australian businesses

are limited in their adoption of circular economy business

models. The circular economy requires strong alignment

across entire supply chains (Planko and Cramer, 2021),

with new ways of creating, delivering and capturing value

that depends on collaboration. Yet, Australian business

models tend to be firm-centric. While circular economy

concepts are now reflected in some corporate business

strategies (Australian Institute of Company Directors, 2019),

there is no solid evidence base to understand this trend.

If intangible assets such as product design, business process

re-engineering and network formation are vital to business

innovation and circular business models, the Australian

System of National Accounts does not consider them

(Commonwealth of Australia, 2019).

The likelihood that Australian businesses will adopt

more circular business models depends on the political,

economic, social, technological, legislative and

environmental context (Lewandowski, 2016; Roos, 2014).

In this regard, Australia has several advantages:

• professional service industry that has established

capacity to support information and data management

technologies for material tracking, monitoring and

evaluation, and accreditation

• R&D sector that supports innovation in circular design

and production, waste avoidance and reduction,

upcycling, recycling, and recovery as energy

• reverse logistics and platforms that support material

exchange between industries and businesses.

In many circumstances, however, the value of circularity and

the social and environmental costs of current linear models

are treated as externalities and not incorporated into

short-term business decisions in a comparative marketplace

(Barrett and Makale, 2019). Pricing these externalities

through regulation would establish both an incentive and

a level playing field. However, the social licence for that

regulation is remote, particularly when placed against

cost-of-living concerns. However, as the unsustainability of

the current markets in housing, mobility, food and energy

(for example) become more apparent, there may be more

interest in circularity initiatives and investments.

5 International partnerships

for a circular economy

As countries worldwide shift to a circular economy, the focus moves from creating

new materials to reusing, repairing, remanufacturing and recycling existing ones

(van der Ven, 2020). This change will transform global trade, especially regarding

material exchange (Barrie and Schröder, 2022).

To date, Asia has been a favoured Australian export

destination for recycling various end-of-life materials,

including tyres, textiles and plastics. Apart from masking

what had been a low extent of circularity in the Australian

economy, this practice has since become subject to

stringent new regulations.

This section identifies the international partners that

would complement our strengths and close loops on our

material supply chains by processing end-of-life materials,

purchasing Australian-made circular products, and

supplying circular inputs to Australian manufacturing.

As more trading partners adopt policies promoting the

circular economy, Australia must build its reputation as a

trusted participant in global circular value chains.

International partners are also essential to boosting direct

foreign investment in industry opportunities for a circular

economy, acquiring skilled workforce and technologies,

and sharing policy insights on how to accelerate the circular

transition in Australia (see Appendix B).

5.1 Leveraging existing

partnerships for circular

manufactured goods

Australia exported A$53.4 billion in manufactured goods

in 2021–2022 (Department of Foreign Affairs and Trade

(DFAT) 2023). The main buyers of the top 20 exports are in

Asia, Oceania, North America, Europe and the Middle East

(Table 7). Any of these manufactured goods could become

a circular product by meeting one or more of the three

circular economy objectives: eliminating waste, preserving

and enhancing the value of materials and products

through multiple uses, and conserving natural resources

(see Section 1).

While Australia exports to the global market, its circular

products could be particularly attractive to markets

that set a strong policy for sustainable consumption.

For example, the EU’s Second Circular Economy Action Plan

includes adopting eco-friendly designs and introducing

Digital Product Passports (DPPs) (Weick and Ray, 2022).

Australia could access new sustainable markets by

ensuring Australia’s manufacturing exports meet these

circular standards and can pass DPP requirements.

Australia’s circular products may also find comparative

advantages in Oceania, due to proximity and several

free‑trade agreements.

Section 2 explored potentially valuable circular product

opportunities involving manufacturing lithium-ion batteries

and bioplastics, construction materials, upcycling mining

by-products, e-waste, agricultural by-products, and textiles.

Australian companies must build their capacity to navigate

the relevant international standards, some of which may

not yet exist for secondary materials and products made

with secondary materials. Furthermore, the markets for

some of these new circular products need to be developed.

While waiting for such changes to come to fruition,

Australia could prioritise trade partners and circular

products with established systems already in place.

Table 7 Australia’s top 20 manufactured good exports ranked by 2021–2022 value (in A$ thousand), and top 3 destinations for each

line item

MANUFACTURED GOODS

2019–20

2020–21

2021–22

TOP 3 EXPORT DESTINATIONS

684 Aluminium

3,760,536

3,828,480

5,816,671

Japan, Republic of Korea, United States

682 Copper

3,432,884

4,233,152

4,497,597

China, Malaysia, Taiwan

541 Pharm products (excl medicaments)

3,631,359

2,210,074

2,298,229

United States, China, New Zealand

764 Telecom equipment and parts

2,498,951

2,210,034

2,205,291

New Zealand, United States, Hong Kong

(SAR of China)

874 Measuring and analysing instruments

2,043,363

1,956,500

2,125,425

United States, United Kingdom, China

872 Medical instruments (incl veterinary)

1,709,344

1,468,689

1,999,720

United States, Netherlands, New Zealand

542 Medicaments (incl veterinary)

2,911,754

1,961,013

1,577,643

New Zealand, China, United States

686 Zinc

1,302,306

1,522,183

1,507,868

Taiwan, China, Vietnam

792 Aircraft, spacecraft and parts

2,354,448

1,672,101

1,338,714

United States, Singapore, France

553 Perfumery and cosmetics (excl soap)

1,070,573

1,082,503

1,212,840

New Zealand, China, United States

533 Pigments, paints and varnishes

986,995

874,244

1,097,118

India, China, New Zealand

752 Computers

975,483

916,355

1,093,071

New Zealand, United States, United Arab Emirates

784 Vehicle parts and accessories

920,365

1,010,040

1,078,197

New Zealand, United States, United Arab Emirates

522 Inorganic chemical elements

613,730

580,541

1,033,164

Japan, China, Thailand

685 Lead

800,523

939,798

1,007,502

United Kingdom, United States, Philippines

641 Paper and paperboard

884,436

761,035

935,957

New Zealand, United States, China

592 Starches, inulin and wheat gluten

664,838

683,760

821,861

United States, Japan, China

728 Specialised machinery and parts

799,265

737,052

808,276

United States, Papua New Guinea, New Zealand

772 Electrical circuit equipment

631,715

683,821

718,349

New Zealand, United States, Indonesia

897 Jewellery

679,822

753,419

688,831

Singapore, Hong Kong (SAR of China),

New Zealand

Data source: DFAT publication ‘Composition of trade Australia’, Last updated: November 2023 using ABS International Trade in Goods, Australia

(September 2023 data).

Note: Manufactured Goods use UNCTAD (United Nations Conference on Trade and Development) Standard International Trade Classifications.

https://unctadstat.unctad.org/EN/Classifications/DimSitcRev3Products\_Official\_Hierarchy.pdf

5.2 Investing in onshore

beneficiation of end-of-life materials

Asian countries are the main trading partners for Australia’s

end-of-life materials. In 2021–22, Australia exported

4.41 million tonnes of end-of-life materials valued at

A$4.36 billion5 (Lin et al., 2023). The top seven recipients

of end‑of‑life plastics, tyres, textiles and metals were

Indonesia, Vietnam, Bangladesh, Malaysia, Thailand,

South Korea and Taiwan (Du et al., 2023; Lin et al., 2023).

Plastics, tyres and textiles have relatively low recycling

rates compared to other waste streams in Australia,

given the lack of dedicated recycling infrastructure for

these materials (Pickin et al., 2023; Schandl et al., 2020).

Future collaborations with Sweden could also be explored,

given Renewcell’s pioneering new commercial‑scale

chemical textile recycling plant (Santi, 2023).

In 2019, 80 per cent of Australia’s recycled e-waste yielded

only scrap metals as a low-value export. Australia still

depends on international partners for end-stage

recycling (Van Yken et al., 2021; Islam and Huda, 2020).

South Korea, Singapore, Canada and Belgium are the

leading international partners for processing recycled

lithium‑ion batteries (Battery Stewardship Council, 2020).

China, Indonesia and Japan are the main recycling

partners for TVs and computers collected under the

National Television and Computer Recycling Scheme

(Van Yken et al., 2021). Australia’s e-waste sent to landfills

is a lost economic opportunity. Alone, battery storage

and photovoltaic solar waste are estimated to be worth

between A$603 million and A$3.1 billion (Bontinck et al.,

2021; King and Boxall, 2019).

Processing more end-of-life materials may build Australia’s

reputation as a trusted supplier of high-quality secondary

materials for international industries. Doing so requires

upgrading recycling infrastructure and promoting R&D

in material recovery technologies. Australia’s efforts to

increase onshore recycling capability have accelerated since

various government acts, funds and action plans were

introduced. These include:

• National Waste Policy Action Plan 2019 – setting a goal

for an 80 per cent average recovery rate from all waste

streams by 2030.

• Recycling and Waste Reduction Act 2020 – regulating

the export of scrap plastics, glass, paper and tyres that

have not been converted to value‑add materials.

• Recycling Modernisation Fund – boosting investment

to increase the recycling and remanufacturing

capacity for plastics, glass, paper and tyres to/by an

anticipated 1.13 million tonnes annually by July 2024

(Pickin et al., 2023) (Table 8).

Table 8 Projected additional onshore resource recovery capacity funded through the Recycling Modernisation Fund

(kilotonnes per year)

MATERIAL TYPE

REMOTE AND REGIONAL AREAS

METROPOLITAN CENTRES

TOTAL

Glass

130

197

327

Material recovery facility

30

124

154

Multi-material facility

7

3

10

Paper and cardboard

0

239

239

Plastics

55

239

293

Transfer stations

1

0

1

Tyres

5

84

89

Total

228

885

1,113

Source: National Waste Report 2022, Pickin et al., 2023.

5 Historical values are inflated based on the annualised consumer price index.

Figure 5 Sankey diagrams of scrap plastics (a), tyres (b), textiles (c), and metals (d) showing originating Australian state

and international destinations

Source: https://www.dcceew.gov.au/environment/protection/waste/how-we-manage-waste/data-hub/waste-export-data-viewer

Sankey diagrams of scrap plastics, tyres, textiles, and metals showing originating Australian state and international destinations

, for a full description please contact Heinz.Schandl@csiro.au

a

b

c

d

5.3 Ensuring that imports embody

circular economy principles

Australia can promote environmental sustainability and

foster responsible procurement by prioritising circular

economy business inputs and consumer products among its

imports. A strong Australian circular economy supply chain

will require policies, guidelines, standards, infrastructure,

and bilateral agreements with major trading partners.

Of the top 10 suppliers of manufacturing inputs to Australia,

China and the United States are the leading partners and

have differing degrees of regulation on circularity (Table 9).

On the one hand, China’s Circular Economy Promotion Law

and its recently launched 14th Five-Year Plan for Circular

Economy Development highlight potential avenues for

Australia to procure more circular inputs.

As a nation, the US lacks a comprehensive national policy,

although individual states, including New York, California

and Colorado, have championed localised circular economy

policies and initiatives (Smol, 2023). Meanwhile, the EU’s

Second Circular Economy Action Plan prioritises extended

producer responsibility and the use of secondary materials,

making it a competitive future source for Australia’s quest

for circular inputs.

Table 9 Australia’s top 10 manufactured parts imports ranked by 2021–2022 value (in A$ thousand) and top 3 sources for each line item

IMPORTED MANUFACTURED PRODUCTS

2019–20

2020–21

2021–22

TOP 3 SOURCES

764 Telecom equipment and parts

15,230,342

14,465,586

15,524,730

China, Vietnam, United States

723 Civil engineering equipment and parts

4,452,859

5,360,360

6,182,941

United States, China, Japan

778 Electrical machinery and parts, nes\*

3,952,642

4,618,086

5,291,775

China, United States, Republic of Korea

893 Plastic articles, nes

4,098,874

4,376,399

4,757,794

China, United States, Malaysia

598 Miscellaneous chemical products, nes

1,483,067

1,452,744

4,016,768

China, United States, Republic of Korea

699 Manufactures of base metal, nes

3,068,315

3,292,414

3,904,100

China, United States, India

784 Vehicle parts and accessories

2,955,558

3,358,826

3,695,881

China, United States, Thailand

741 Heating and cooling equipment and parts

3,134,628

3,529,027

3,675,323

China, Thailand, Italy

744 Mechanical handling equipment and parts

2,782,500

3,198,994

3,598,231

China, Germany, United States

728 Specialised machinery and parts

2,715,502

3,000,053

3,273,907

China, United States, Germany

Data source: DFAT publication ‘Composition of trade Australia’, Last updated: November 2023 using ABS International Trade in Goods, Australia

(September 2023 data)

\*nes = not elsewhere specified.

As Australia’s import criteria increasingly shift to embrace

principles of circularity, it will seek goods that contain

secondary materials, are designed for ready maintenance

and servicing, and include easy disassembly and

manufacturer take-back in its business model. The EU’s

Second Circular Economy Action Plan resonates with these

principles, fostering durability, reusability, repairability and

upgradability (Smol, 2023; European Commission, 2022).

The Plan is already helping regulate how packaging,

batteries, construction and food are manufactured.

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Appendix A –

Data, methods and concepts

A.1 Data and methods

This section presents the data sources and methodological

approach taken to inform this report. The research team

used a combination of literature review (peer reviewed

and grey), basic existing databases, and key informant

interviews to collect and analyse data. The literature review

involved systematic searches of papers indicating research

on the circular economy in Australia over the last five

years (via databases such as Scopus and Google Scholar).

Grey literature was obtained from official government

reports (e.g., Australian Strategic Policy Institute Limited,

Department of Industry, Science and Resources), trusted

global reports including regional government websites

(e.g., OECD reports, Ellen MacArthur Foundation,

UNEP, Association of Southeast Asian Nations (ASEAN),

Asia‑Pacific Economic Cooperation (APEC), and industry

reports (e.g., IBISWorld, Australian Packaging Covenant

Organisation). Data was analysed from public sources

such as the Australian Bureau of Statistics, DCCEEW’s

National Waste Report and the Australian Research Council

Grant Connect Database. Key informant interviews were

undertaken targeting major players in key circular economy

industries, including the private sector and scientists with

domain and regional knowledge.

A.2 Concepts

‘Circular economy’ and ‘Industrial ecology’

A circular economy based on industrial ecology thinking

is a concept that aims to create a regenerative and

sustainable economic system by mimicking natural

ecosystems. It integrates principles from both the circular

economy and industrial ecology, two complementary

approaches that focus on reducing waste, conserving

resources, and minimising environmental impacts.

Industrial ecology is a systems-based approach that

draws inspiration from ecosystems, where waste from

one organism becomes a resource for another. It seeks to

create industrial systems that function more like natural

ecosystems, optimising resource use and minimising waste

through interdependent relationships among industries and

processes. By considering the broader interactions between

different economic sectors and their impacts on the

environment, industrial ecology aims to enhance the overall

efficiency and sustainability of industrial activities.

When combined, the circular economy and industrial

ecology principles offer a powerful framework for creating

a more sustainable economic system. Key features of a

circular economy based on industrial ecology thinking can

be thought of as key principles and include:

• Resource efficiency: Maximising the efficient use of

resources, including raw materials, energy, and water,

to reduce waste and decrease the environmental

footprint of industrial processes.

• Closed-loop systems: Designing products and industrial

processes to enable materials and components to be

reused, refurbished, or recycled, thereby minimising

waste generation and the need for new raw materials.

• Ecosystem thinking: Emphasising a holistic approach

that considers the interconnectedness of industries,

supply chains, and environmental impacts to identify

synergies and opportunities for resource exchange.

• Biomimicry: Drawing inspiration from nature’s design

principles to create innovative and sustainable solutions

replicating natural systems’ efficiency and resilience.

• Collaboration and networks: Encouraging collaboration

among industries, businesses, governments, and

other stakeholders to share resources, knowledge,

and best practices to optimise resource use and reduce

waste generation.

• Product life extension: Encouraging the design of

durable products that can be repaired, upgraded,

or remanufactured, extending their useful life and

reducing the demand for new products.

By adopting a circular economy based on industrial ecology

thinking, societies can move towards a more sustainable

and regenerative economic model that not only minimises

environmental impacts but also fosters economic growth

and innovation. It requires a collective effort from all

stakeholders, including businesses, policymakers, and

consumers, to transform the way we produce, consume,

and manage resources.

Appendix B – International

partnerships additional information

This appendix elaborates on two additional ways

international partnerships can enhance Australia’s

competitive and comparative advantages in its transition

to a circular economy: boosting circular Foreign Direct

Investment and sharing learnings and innovation to

accelerate the circular transition.

B.1 Boosting circular Foreign

Direct Investment (FDI)

Linking FDI to circular economy outcomes ensures that

investments facilitate sustainable growth and responsible

resource management. To position Australia as a prime

destination for ‘green investments’, it could revise FDI

guidelines to favour circular economy-oriented projects,

organise international investor summits, and offer tax

benefits or incentives for circular economy-compliant FDI.

In 2021, the dominant sectors for Australia’s US$770 billion

in FDI (United Nations Conference on Trade and

Development, 2022) were mining, real estate, finance

and insurance6, with less FDI in sectors central to the

circular economy such as manufacturing, electricity

and construction (Figure B.1). In terms of total foreign

investment7, the leading investors are the United States,

United Kingdom, Belgium8 and Japan (Table B.1) and

circular economy deliverables are not yet pivotal in

their investments. However, the US Inflation Reduction

Act (IRA) and the European Green Deal offer fresh

avenues to promote circular economy narratives into

new foreign investments.

Figure B.1 Foreign direct investment by industry in 2022

Source: Based on ABS catalogue 5352.0. Prepared from table downloaded from https://www.dfat.gov.au/trade/trade-and-investment-data-information-and-

publications/foreign-investment-statistics/uropeian-industries-and-foreign-investment

Bar chart showing foreign direct investment by industry in 2022, for a full description please contact Heinz.Schandl@csiro.au

­%

%

­%

%

­%

%

­%

%

­­­­­­­­­­­­­

Financial &

insurance

activitiesWholesale& retail

tradeTransport& storageElectricity,

gas &

waterInformation& comm-

unicationPROPORTIN OF SHARE %

INVESTMENT A$ BILLION

INDUSTRY

% of totalMining &

quarryingOther/

Unallocat-edProfessional,

sci & tech

activitiesManu-

facturingConstruct-ionRealestateactivities

6 FDI is when an individual or entity from outside Australia establishes a new business or acquires 10 per cent or more of an Australian enterprise, and so has

some control over its operations.

7 Total foreign investment is broader than FDI and includes portfolio investment, financial derivatives and other investment.

8 The majority of total investment from Belgium is portfolio investment liabilities in the form of debt securities (Belgium hosts a major clearing house and

depository for euro-denominated bonds and other securities, Euroclear).

Australia and the US have entered into the Climate, Critical

Minerals and Clean Energy Transformation Compact

(‘the Compact’), to dovetail with the IRA and bolster

both nations’ manufacturing prowess in renewable and

clean energy (Prime Minister of Australia, 2023). The IRA

earmarks US$369 billion for hydrogen, green technology

manufacturing, green metals, and clean energy generation

(DFAT, 2023), and the Compact sets milestones for clean

energy supply chains, critical mineral sourcing, and battery

innovations. Australia can tap into IRA funds to supplement

its A$40 billion pledge for renewable energy capability9,

including A$20 billion in the Rewiring the Nation Plan and

A$1 billion in the National Reconstruction Fund (DFAT, 2023).

This investment may enable Australia to carve niches in the

value chains of seven net-zero economy opportunities10

(DFAT, 2023; Advanced Manufacturing Growth Centre, 2022).

For example, Box 1 sets out the potential and repercussions

of Australia’s participation in the global battery value chain,

including magnifying demand for secondary materials and

paving the way for reuse, remanufacturing, repurposing,

and recycling within the renewable and clean energy sector.

The circular economy is a core tenet of the European

Green Deal, which has a €1 trillion Investment Plan and

€100 billion reserved for a Just Transition Mechanism

spanning 2021–27 (Smol, 2023). If Australia can forge

stronger trade and investment alliances with the EU, it may

access FDI into digital technology, digitisation, recycling,

building renovation, low-carbon transport, and sustainable

food – priorities identified in the European Green Deal.

Table B.1 Top 20 countries investing in Australia between 2020 and 2022

RANK IN 2022

A$ BILLION

% OF TOTAL

ECONOMY

2020

2021

2022

1

United States

926

1050

1,092

24.1

2

United Kingdom

770

722

1,007

22.2

3

Belgium (a)

409

394

359

7.9

4

Japan

265

258

257

5.7

5

Singapore

116

122

149

3.3

6

Hong Kong (SAR of China)

139

124

133

2.9

7

Canada

64.7

75.5

99.6

2.2

8

Luxembourg

107

92.4

89.0

2.0

9

Netherlands

84.4

88.3

87.6

1.9

10

China

81.2

91.4

85.1

1.9

11

Switzerland

61.9

69.5

74.1

1.6

12

New Zealand

68.4

69.1

72.2

1.6

13

France

42.9

43.4

54.0

1.2

14

Germany

46.9

48.6

52.5

1.2

15

Bermuda

42.4

42.5

45.4

1.0

16

Ireland

37.6

40.4

38.5

0.9

17

India

np

27.8

34.5

0.8

18

Norway

25.6

28.3

30.1

0.7

19

Republic of Korea

31.1

29.8

28.1

0.6

20

Virgin Islands, British

25.4

23.5

23.0

0.5

Other economies

669

665

720

16

All economies

4,014

4,104

4,531

100

Based on ABS catalogue 5352.0. Last Updated: May 2023. Table downloaded from: https://www.dfat.gov.au/trade/trade-and-investment-data-information-

and-publications/foreign-investment-statistics/statistics-on-who-invests-in-australia

Note: Foreign investment includes direct investment, portfolio investment, financial derivatives and other investment. (a) The majority of total investment

from Belgium is portfolio investment liabilities in the form of debt securities (Belgium hosts a major clearing house and depository for euro-denominated

bonds and other securities, Euroclear). np = not published.

9 A large-scale local hydrogen industry could generate A$50 billion in additional GDP by 2050 and create more than 16,000 jobs in regional Australia.

An additional 13,000 jobs could result from the construction of the renewable energy infrastructure required to power the production of green hydrogen.

10 The seven priority areas are: value-add in agriculture, forestry and fisheries; transport; medical science; defence capability; and enabling capabilities;

renewables and low emission technologies; and value-add in resources.

Box 1: Example of strategic partners to

expand Australia’s participation in the

battery value chain

By expanding Australia’s participation further

down the global value chain for batteries, including

the capability to reuse, refurbish and recycle

batteries, could almost double the economic gains

between now and 2030, resulting in A$7.4 billion in

value‑added and around 34,700 jobs (Future Battery

Industries Cooperative Research Centre (FBICRC) 2021).

Increasing recycling of e-waste from 54 per cent to

80 per cent and high efficiency recycling systems

would result in an additional A$440 million worth

of materials recovered, 0.34 million tonnes of

e-waste being dismantled for high-value recycling,

creating local jobs, and saving 2.5 million tonnes of

CO2e emission (Bontinck et al., 2021). Batteries will

be critical to transitioning the Australian energy

system to low carbon over the next decade, with

battery sales expected to reach US$133–151 billion

by 2030 (World Economic Forum, 2019; Roskill, 2020).

With growing demand, the value added from battery

reuse, refurbishment and recycling will likely increase

substantially over the next decade.

Australia has a competitive advantage in supplying

about half of the world’s lithium market and being a

major supplier of other critical metals (FBICRC, 2021).

The position as a key supplier of critical energy

minerals provides leverage for negotiating strategic

international partnerships with countries that either

have (e.g. China, Chile, Japan and South Korea) or

are developing capability further down the value

chain (e.g. United States, Germany, the UK, Finland

and Canada) (FBICRC, 2021). However, the committed

investment between 2018 and 2021 in battery

manufacturing (A$130 million) and integration and

services (A$103 million) pales in comparison to the

investment in battery material extraction and refining

(A$3,850 million). More investment is needed to build

capability further down the value chain if Australia

is to realise the benefits of reusing, refurbishing and

recycling batteries.

B.2 Learning from advanced

circular economy countries

Countries like the Netherlands, Finland, and Japan

have been progressing a circular economy agenda, and

their experience can offer valuable insights into policy,

regulations, programs and innovations to increase

circularity in their economies. Australia could engage in

international forums, bilateral workshops and exchange

programs, and import successful pilot projects from these

countries, adapting them to the Australian context.

Australia’s 17 free trade agreements (Table B.2) encompass

frameworks for skilled workforce exchanges and funding

avenues for collaborative international research. Such

partnerships can accelerate Australia’s acquisition of

advanced skills and technologies for a more active role in

the global circular value chains.

Table B.2 List of free trade agreements in force

Australia–New Zealand

Singapore–Australia

Australia–United States

Thailand–Australia

Australia–Chile

ASEAN–Australia–New Zealand

Malaysia–Australia

Korea–Australia

Japan–Australia

China–Australia

Peru-Australia

Comprehensive and Progressive Agreement for

Trans‑Pacific Partnership

Australia-Hong Kong and associated Investment Agreement

Indonesia- Australia Comprehensive Economic

Partnership Agreement

Pacific Agreement on Closer Economic Relations Plus

Regional Comprehensive Economic Partnership

Australia-India Economic Cooperation and Trade Agreement

Source: https://www.dfat.gov.au/trade/agreements/in-force

Regional platforms like the ASEAN and the APEC

are also now promoting the circular economy.

The ASEAN Framework for Circular Economy and the

APEC Sub‑committee on Standards and Conformance

(ASEAN, 2021; APEC, 2021) provide opportunities for

Australia to partner for collaborative projects, push

standards harmonisation and exchange innovation.

Other initiatives that Australia might consider for its circular

economy journey include:

• China’s Circular Economy Promotion Law catalyses

resource efficiency, particularly in high-tech and

export‑focused manufacturing. Yet areas such as

construction and agriculture lag behind (Bleischwitz

et al., 2022). More robust policy evaluation, surveys,

accountability measures, and independent oversight are

essential (Domenech and Bahn-Walkowiak, 2019).

• Taiwan’s ambitious 5+2 Major Innovative Industries Plan

champions research and innovation in recycling and

resource recovery.

• South Korea’s Act on Resource Circulation of Electrical

and Electronic Equipment and Vehicles underscores a

design-for-recycle ethos, ensuring easy accessibility and

reusability of components rich in critical minerals and

building domestic stockpiles.

• Chile’s Circular Chile by 2040 vision was developed

inclusively, with a myriad of stakeholders from the public

and private sectors, NGOs, academia, and the general

populace (Ellen MacArthur Foundation, 2022).

• The EU’s Waste Electrical and Electronic Equipment

Directive surpasses Australia’s National Television and

Computer Recycling Scheme regarding product and

population scope (Van Yken et al., 2021). Producers must

shoulder the responsibility of collecting and treating their

end-of-life products, enabling the EU to achieve the highest

global e-waste recycling rate in 2019 (Baldé et al., 2020).

In summary, Australia has a wealth of global experiences

to draw upon. By meticulously analysing these global

best practices and integrating them with domestic

strategies, Australia can design a bespoke, effective,

and accelerated pathway towards a circular economy.

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