Flinders University
Australian Industrial Transformation Institute

The Circular Economy

International Lessons and Directions for Australian Reindustrialisation

Lance Worrall, Hamish Gamble, John Spoehr

Australian Industrial Transformation Institute

July 2022

The Circular Economy

International Lessons and Directions for Australian Reindustrialisation

Australian Industrial Transformation Institute

College of Business, Government and Law
Flinders University of South Australia

1284 South Road
Clovelly Park
South Australia 5042

www.flinders.edu.au/aiti

ISBN: 978-0-6488941-8-6

CAT: AITI202209

Suggested citation:

Worrall, L, Gamble, H, Spoehr, J, 2022. *The Circular Economy – International Lessons and Directions for Australian Reindustrialisation.* Adelaide: Australian Industrial Transformation Institute, Flinders University of South Australia.

Contents

List of Figures

List of Tables

Executive Summary and Recommendations

Across the globe, nations are adopting policies to increase the level of circularity in their economies, that is, to decrease waste associated with single use models of resource exploitation, in favour of increasingly closed loops allowing valuable resources to be recycled and reused. Among the drivers for this shift toward greater resource efficiency are the need for carbon abatement and addressing other environmental limits including; long-term resource depletion and associated challenges to nations' ability to exercise self-determination; and the realisation that accompanying this shift are new growth and employment opportunities.

During the 20th century global consumption of raw materials grew at twice the rate of population growth as a function of industrialisation and urbanisation. Globally materials extraction doubled between 1990 and 2017 and will double again by 2060. This doubling is a function of economic growth. Efficiencies are evident with respect to resource use over past decades. Between 2000 and 2017 the G20 nations increased their resource efficiency by 40 percent. But these efficiencies are consistent with the forecast doubling. The critical issue is whether this growth in consumption can be met through a dramatic reduction in exploitation of virgin materials in favour of secondary materials. That is, through greater circularity: reduction of primary materials extraction in favour of secondary resources and increasing the duration of use of materials, and the reuse and recycling of products and materials.

Circular economy (CE) concepts seek a closed loop system not only to minimise waste and enhance sustainability, but also to keep resources in productive use for longer to enhance productivity. The focus is on reuse, repair, refurbishment, remanufacturing and recycling to create integrated production. It has three essential principles: to reduce or eliminate waste and pollution in production and use of the product; keep the product or materials in use for as long as possible; and regenerate natural systems. It takes responsibility for the full lifecycle of the resources. It implies a degree of self-sufficiency, effective sovereignty and onshore lifecycle processes. The CE is intimately connected to concepts of resource efficiency.

This is a proposal for application of CE principles to a national strategy with four planks: reindustrialisation, decarbonisation, value-adding and greater sovereign capability. The scope of the CE is vast, covering waste reduction and the closing of resource loops in spheres from household and municipal waste and avoidance of landfill to complex production systems using sophisticated materials and metals. Our concern with the CE's potential role with respect to the four planks determines a narrower concentration on industrial systems and metals over biological wastes and recycling of end consumer goods (although these definitely play a role in industrial systems).

This report is about industrial strategy and policy responses to CE practices and the roles appropriate to CE in achieving the generational project of Australia's reindustrialisation. Having a set of strategic purposes, we inquire into the 'decisive points' (Clausewitz 1832) at which CE concepts can contribute with greatest effect to reindustrialisation, decarbonisation, value-adding and greater sovereign capability. Hence, apart from a survey of CE definitions and a scene-setting description of the nature and extent of CE policies and practices internationally and in Australia, the paper does not consider the role of fiscal measures such as taxes on use of virgin materials or subsidies for secondary ones. Nor the theme, prominent in the literature, of green cities and city-based policies. Closing bio resource loops and household wastes are also largely bracketed out.

This analysis has an explicit strategic purpose: to determine where and how CE practice should be integrated into a national industrial strategy aimed at building onshore value chains in service of the four planks. What will be shown is that rather than opposition, there is positive interdependency between high levels of industrial capability and development and the capacity to develop closed loops of production and consumption and CE-like virtuous cycles.

The CE: Definitions and Benefits (section 2)

The CE is linked fundamentally to the concept of, and a concern with, resource efficiency. The CE sees potential for a system supporting a virtuous cycle in which there is recycling of highly valuable materials and products at the end of their specific product life. The system provides these valuable resources with many successive lives.

The linear economy, on the other hand, functions on 'take-make-dispose' principles. Raw materials are extracted, made into products, that at their life's end are disposed of. The materials and products in question have a single life and there is little or no attempt to extend their value through recycling, reuse, repair or remanufacturing.

Achieving greater circularity takes place in the three modes of:

- 'Closing' resource loops reduces materials extraction and wastes through recycling and secondary materials
- 'Slowing' the resource loop means longer-life products and improved reuse and repair opportunities
- 'Narrowing' the resource flow through expanded sharing practices and service models.

The survey reveals that circularity involves fundamental changes across many domains: new business models enabled by new digital technologies to extend product and material life, or recycle and reuse, and reduce waste in production; new active forms of government intervention through deliberate green procurement policies, Extended Product Responsibility laws, and so on.

CE benefits are surveyed and found to include reduced environmental impacts through resource conservation and use of clean energy; increased national resilience and security through reduced reliance on external sources for supply of critical materials; addressing resource depletion; and finding new sources of industrial growth, employment and innovation, together with increased sovereignty associated with integrated onshore value chains, and certain social benefits associated with the above. Various sources are examined estimating the quantity of economic, environmental and social benefit globally and on a nation by nation basis. They vary widely and it is sometimes unclear to what the entirety of these estimates are attributable. They are cited as indicative only. But almost all studies consider CE policies have a beneficial impact on growth and employment.

Lessons From International Experience (Section 3)

International experience and policies of nations and supranational bodies are surveyed to draw implied lessons about commonalities and differences and policies and actions that are effective. The survey clearly shows that the CE is a policy priority for many nations and supranational bodies, and that the CE is increasingly imbricated with national industrial policies.

A central lesson is of the critical importance of industrial processes to ‘Green Complexity’ (GC) and CE objectives. Not industrialised economies but rather ones biased toward extractive sectors and processes are furthest from sustainability and the CE. This is reinforced by two further international comparative studies summarised here.

Overall positive CE directions are most of all a function of positive and deliberate directional policies, particularly national policies. Enduring institutional commitments are critical. Higher performance is also correlated to levels of industrialisation and very high performance is observable in industrially leading countries with strong political, institutional and policy CE frameworks.

Evidence of policy commitment is found in facets such as adoption of legislation, national and supranational policies, programs, common frameworks, manuals, practice guides, directives, regulations, targets and timeframes. Positive policies include Green Public Procurement (GPP) and Extended Producer Responsibility (EPR). Most of all, higher performers deliberately articulate CE and green economy principles with industrial policies, and specific industrial and policy directions supportive of the CE and GC.

The CE in Australia: Australia’s Extractive and Linear Economy (Section 4)

As described in earlier papers (Australian Industrial Transformation Institute, 2021; Worrall, Gamble, Spoehr, & Hordacre, 2021) Australia has deindustrialised over the past quarter century, with almost the lowest manufacturing GDP share in the OECD, declining economic complexity or knowledge-intensity and the least manufacturing self-sufficient country in the OECD. Endowed with world-significant metals and energy sources required by a decarbonising world, over the past decade especially, Australia has chosen to lock itself into declining forms of resource extraction, failing to add value through onshore secondary processing, and failing to develop high-end product manufacturing opportunities related to these valuable endowments. Instead Australia overwhelmingly allows extraction of its resources for export in raw form for processing overseas. Our resources then reappear in the form of manufactured imports (often elaborately transformed and sophisticated manufactures).

Correlatively, Australia has a linear economy and lags badly on implementing CE practice. Not only does the nation fail to add value to its resources through secondary processing, relying on manufactured imports to a degree that questioned our capacity to meet the very basic needs of the population during the pandemic, it is also well behind other advanced nations in its capacity to recycle highly valuable materials and products at the end of their specific product life. These are resources with many successive lives provided a circular system exists to support such a virtuous cycle.

Australia lacks a national industrial policy and strategy. Correlatively, Australia is one of the worst performers on resource efficiency in the G20. Further key data on Australia’s CE performance are provided together with information on various state-based, research organisation (CSIRO) and legislative initiatives. The conclusion is that these are valuable but partial and fragmented, and that national leadership has been absent.

Bases for Australia’s Reindustrialisation, Decarbonisation and Greater Circularity (section 5)

As described in earlier papers (ibid.) there are four bases favouring Australia's reindustrialisation and accelerated decarbonisation, with net positive GDP and employment gains:

- Value adding through secondary processing to Australia's highly valuable metal resources and selected product manufacture
- Australia's vast endowments of renewable energy coupled with the requirement that green production must usually occur close to the energy source (renewable energy is expensive to transport)
- Digital technologies and new business models allowing short- to medium-run production and mitigating Australia's disadvantages in many areas of mass, economy of scale-based production, and
- The need highlighted most of all by the pandemic to hold certain key capabilities related to essential population needs onshore.

Decarbonisation provides Australia with its best prospects for reindustrialisation and value adding, for reasons previously stated, but for additional ones too. Decarbonisation substitutes metals for fossil fuels. Closing resource loops requires additional energy from green sources. Green-related products are more manufacturing-intensive.

The new national government's National Reconstruction Fund (NRF) is the most substantial economic initiative of the past decade, providing a positive directional policy focussed on priority sectors. It links explicitly reindustrialisation to decarbonisation to resource value-adding to associated product manufacture to greater national self-sufficiency in critical areas.

The Strategic Framework (Section 6)

The paper proposes a strategic framework for application by the NRF and the South Australian Hydrogen Jobs Plan, including the role of CE practices, concentrating on

- Industrial structures and processes, and
- Critical materials, especially metals, in a mission

"To reindustrialise Australia to drive accelerated decarbonisation, and increase dramatically domestic onshore value adding, and national sovereign capabilities and self-reliance".

This requires detailed analysis of designated individual value chains to identify the decisive points at which CE should contribute and become an embedded feature of an ambitious national industrial strategy.

Granted the NRF's significance, the analysis is concerned with those two streams in the NRF that explicitly link decarbonisation to reindustrialisation, renewables and resource value adding:

- 'Value-adding in resources through domestic processing (e.g., aluminium and lithium batteries) […]
- 'Renewables and low emission technologies (wind turbines, solar panels, lithium batteries, low carbon steel and aluminium, hydrogen electrolysers, etc.)'.

Sectors, products, materials, and energy sources (Section 7)

A 'vertical' analysis of these value chains is provided to assist in the definition of the 'decisive points' for strategy and policy. It is an analysis limited to indicating where to look for later definition and confirmation. Each value chain is then considered from the viewpoint of the relevance of CE to:

- Inputs to production, especially energy source (this corresponds to CE in the mode of closing resource loops)
- Production, including business model innovation, through-life issues, servitisation, digitalisation (this corresponds to slowing the resource loop through longer-life products and improved reuse and repair opportunities)
- End of product life, recycling and reuse (this corresponds to the closing resource loops mode of CE).

The analysis of industry verticals results in the following summary structure for the incorporation of CE practice into the generational project for reindustrialisation linked to accelerated decarbonisation and value-adding and greater sovereign capability, with these decisive points adopted for the purposes of incorporating CE into a comprehensive national industrial policy.

Recommendation 1: Adopt Sectoral Targets and Focal Points

That the following sectoral targets, aims, and policy ambitions be given priority consideration for later official adoption:

Sector	Product(s)	IP Objective(s)	CE Relevance	Decisive point(s) for securing IP Objective(s)
Critical Metals, Value-Adding, Secondary Processing.	Green Steel and Aluminium.	Vertically integrated onshore value chain.	Green electricity. Onshore recycling and reuse.	Securing green electricity. Onshore recycling and reuse.
	Other Critical Minerals (titanium, graphene, silicon, other).	Investigate.	Investigate.	Investigate.
Renewable Energy Products and Components.	Lithium-ion batteries.	Vertically integrated onshore value chain.	Recycling, reuse. Green energy source.	Attaining 'processed material and cell manufacturing' stage, and mass recycling and reuse.
	Wind turbines.	Onshore manufacturing of key selected components; capture more value chain elements over time as scale allows.	Use of green power in production. Generation of green power. Virtuous cycle.	Secure green electricity. Target towers and associated items initially to gain purchase over rest of value chain over time.
	Solar panels.	Onshore manufacturing of key selected components, with selective capture of other components over time as scale allows.	Virtuous cycle. Use of green power in production and generation of green power.	Green electricity close to silicon deposits. Target local production to at least solar module phase. Recycling and reuse of large hump of end-of-life panels this decade.

			Onshore recycling and reuse.	
	Hydrogen electrolysers.	Onshore electrolyser manufacturing industry.	Use of green energy. Generation of green power. Virtuous cycle.	Downward sloping cost curve, rising demand/scale. Decisive point is policy decision to support an onshore manufacturing capability (NRF, SA Hydrogen Jobs Plan, other state initiatives).
The Energy Source	Green Hydrogen.	Integrated onshore value chain, with progressive capture of upstream plant, equipment and technology areas, as scale grows.	Green energy to production, recycling and reuse.	Follow the downward cost curve for electrolysers. Develop capabilities for hydrogen storage and integration with natural gas network for transmission.
Value adding, Decarbonisation, Sovereign Capability, Reindustrialisation				

CE Policy Framework (Section 8)

The incorporation of CE into the agenda for reindustrialisation, accelerated decarbonisation, value-adding and greater national self-reliance, requires the following horizontal facets and the consideration recommendations related to the following.

Digital technologies and Industry 4.0

Recommendation 2: Promote Industry 4.0 Applications to the CE in NRF-Supported Projects

That, noting Industry 4.0 is integral to both the CE and the reindustrialisation, decarbonisation and value-adding objectives of the NRF, consideration be given to resourcing to ensure NRF-supported projects and businesses are comprehensively assessed for digital readiness and competence, together with use of digital technologies to build Australian industry participation and the onshore value chain, and the ability to apply CE principles as appropriate.

This should include enlistment and networking of the various intermediate organisations and living labs around the country to become more systematically articulated to the needs of the national strategy.

Business model innovation

Recommendation 3: Link Promotion of Service-Enhanced Business Models to Promotion of CE Practices in NRG-Supported Projects

That in connection with the NRF's recommended promotion of Industry 4.0, a focus also be placed on advice and assistance on adoption of new business models consequential to digital adoption and CE objectives. This should include consideration of updated legislation and requirements relating to Extended Product Responsibility (EPR) or Product Stewardship.

Strategic and Green Public Procurement

Recommendation 4: Commit to Sector-Focused and Targeted Use of GPP

That the Commonwealth announce its future intention to apply GPP principles following investigation of the appropriate design, scope and nature of a GPP program. This time-limited investigation and design phase would involve consultation with the states to help build scale, alignment and support. Focus sectors would likely include: construction and urban development, electricity grid renewal, and public transport. The roll-out of a GPP framework should be staged to reflect highest priority and beneficial impact, and to allow the gaining of knowledge and experience.

Recommendation 5: Commit to Targets for Application of GPP That Build Over Time

That the endorsed national GPP principles, programs and framework include time-based and progressive GPP targets in collaboration with the states for GPP expenditure as a proportion of total procurement.

Building Scale for Recycling, Reuse and Remanufacture

Recommendation 6: Build Scale for Recycling and Reuse Focussed on Batteries and Solar Panels

That consideration be given to a suite of measures targeted to build scale for a battery and solar panel recycling and reuse industry, to include consideration of an ambitious EPR/Product Stewardship initiative, use of deposit charges for disposal, and GPP involving deliberate use of secondary battery and solar panel materials, focussed R&D, and targeted investment attraction.

Recommendation 7: Set Targets and Aim for Scale by the End of the Decade

That the effort to build scale for recycling and reuse of batteries and solar panels be on measures that reach maximum effect by the end of this decade, and that the combination of measures eventually agreed be supported by time-bound targets.

A vision for the CE and Resource Efficiency

Recommendation 8: Adopt CE and Resource Efficiency Vision Statement With Time-Based Targets

That adoption of the above recommended directions be supported by an explicit statement of purpose, direction and intent in favour of the CE and resource efficiency. That statement should link the CE and resource efficiency to Australia’s reindustrialisation, decarbonisation, value-adding to national resources and enhanced sovereign capability, and include time-based targets.

South Australian Hydrogen Jobs Project

Recommendation 9: Identify Strongest Potential for Australian Industry to Supply Plant, Equipment and Technology to the South Australian Project and an Onshore Hydrogen Industry

That the South Australian government, in cooperation with the NRF and Future Made in Australia Office, assess potential for Australian engineers and manufacturers to gain a foothold in the upstream manufacturing of plant and equipment, engineering, process and services areas of the green hydrogen value chain, including electrolysers, as well as opportunities in through-life support.

Recommendation 10: Develop a Plan and Strategy for Australian Industry Participation

That the South Australian government develop an Australian industry participation plan and strategy for its hydrogen project and for the longer term growth of a vertically-integrated onshore hydrogen industry with a focus on technology and plant and equipment requirements. This would influence the later design of a national framework and dovetail with it. The strategy's scope would encompass local industry participation rules, processes and objectives, together with capability development including a focus on SMEs, targeted R&D and technology development, and linkages to adjacent industries to build scale, such as ammonia.

1 Introduction

This report is the third in an ongoing series of AITI papers intended to bring forward for public discussion urgent issues concerning Australia's future economic structure and development. This set of issues is connected to other society wide challenges, such as our capacity to positively respond to climate change. Critical to meeting these challenges are industrial policies aimed at providing direction and leadership to the development of the nation's economic structure. Such policies increase our self-sufficiency, making us less vulnerable to decisions by external trading partners committed to climate and other actions. Australia stands to benefit economically from climate action, but achieving those benefits depends upon economic leadership.

Positive recognition of these points underlies two significant recent policy initiatives: the Federal Government's National Reconstruction Fund, and the South Australian Government's SA Hydrogen Jobs Plan.

The effort to achieve greater circularity in the economy needs to become a feature of a more ambitious future Australian industrial policy directed at a generational mission for reindustrialisation, decarbonisation, value-adding and greater sovereign capability.

Circular Economy practices, particularly those pertaining to industrial structures and processes, need to play a role both as ends and means of a national industrial strategy. This is the more so since the key to much of Australia's reindustrialisation and decarbonisation is in value adding to the nation's rich endowments of minerals and energy sources required in a decarbonising world.

Greater circularity will be an outcome of an ambitious industrial strategy, but it will also be an enabler or a means for that strategy. As circularity implies closing more resource loops onshore, scale is further built to supply affordable, reliable clean energy, which can be used for onshore processes including recycling, reuse and remanufacture, and for capture of other value-adding activities that today are mostly performed offshore.

This analysis considers where and how greater circularity can play a strong enabling role within Australia's industrial strategy. However, it will provide only an indication of areas where subsequent concentrated analysis should be applied to verify their suitability.

For the past decade Australia has lacked even the semblance of a national industrial policy or strategy. Recent developments nationally and at the state level (including South Australia) indicate greater ambition and a change of course.

The first paper in this series, 'Manufacturing Transformation: High-value manufacturing for the 21st Century' canvassed a range of key issues in Australia's reindustrialisation, whilst the second concerned advanced public procurement practices for innovation and industrial development.

We hope this paper stimulates discussion in support of greater circularity and an ambitious industrial policy for Australia's future.

Professor John Spoehr
Director, Australian Industrial Transformation Institute

2 The Circular Economy

The strategic purpose of this document is to pinpoint how and where CE concepts and practices could play a productive role in a national mission-oriented project with four planks: Australia's reindustrialisation and the decarbonisation of its economy, adding value to its mineral and renewable energy resources, and increasing national self-sufficiency and sovereign capability.

Our focus is selective and targeted, pertaining to priority industrial processes and value chains, together with key materials and metals. Ultimately the aim is to understand the decisive points at which CE practices could make the largest positive contribution to the four planks of the mission.

This section presents a summary of the case for greater circularity in the international economy, a distillation of the various definitions of the CE, the purposes fulfilled by greater circularity and its benefits. Later Australia's overall position is described with respect to the CE, particularly in the context of the nation's economic structure, which presently is defined by deindustrialisation and lock-in to declining forms of resource extraction.

2.1 The problem

During the 20th century global consumption of raw materials grew at twice the rate of population growth as a function of industrialisation and urbanisation. In the earlier-industrialising OECD nations there has been a partial decoupling of industrial production from previous high rates of resource consumption. Higher rates of resource consumption are largely accounted for by the newly industrialising countries of Asia (Bibas, Chateau, & Lanzi, 2021), although clearly certain countries in Eastern Europe, and others highly dependent on resource extraction, are less resource-efficient although not undergoing rapid industrialisation.

Globally materials extraction doubled between 1990 and 2017 and will double again by 2060 (OECD, 2020). This doubling is a function of economic growth. Efficiencies are evident with respect to resource use over past decades, but these are consistent with the forecast doubling. The critical issue is whether this growth in consumption can be met through a dramatic reduction in exploitation of virgin materials in favour of secondary materials.

Fundamentally, CE concepts are concerned to promote structural change in the economy by which the extraction of primary materials is reduced in favour of secondary resources, increasing the duration of use of materials (whether primary or secondary), and the reuse and recycling of products and materials, together form a closed (or nearly closed) loop through which waste is eliminated or radically reduced (Bibas et al., 2021).

Achievement of such structural change comes without compromising opportunities for future growth. Where decarbonisation decouples the economy from fossil fuels and not economic growth, the CE decouples the economy from extractive activities by opening new growth opportunities.

There are major qualifications to the idea of complete circularity, but it is important to put the strategic import and purpose of CE policies ahead of definitional dispute.

The CE is linked fundamentally to resource efficiency. The CE sees potential for a system supporting a virtuous cycle in which there is recycling of highly valuable materials and products at the end of their specific product life. The circular system provides these resources with many successive lives.

The linear economy, on the other hand, functions on 'take-make-dispose' principles. Raw materials are extracted, made into products, and disposed of at the end of their lives. The materials and products in question have a single life and there is little or no attempt to extend their value through recycling, reuse, repair, or remanufacturing. The business model is to maximise product sales as distinct from maximising product or material life, and the bundling of services with products, together with use of digital technologies to monitor product performance and prolong product life, in the CE. Increasingly, linear business models require the externalisation of environmental costs and consequences of high resource use. A comparison between the linear and circular economy is shown in Figure 1.

The CE on the other hand responds to four key challenges:

1. Reducing environmental impacts (including climate impacts) throughout the material and product lifecycle through clean energy and practices that extend material and product lifespan, such as 'recycle, reuse, repair and remanufacture'
2. Avoiding excessive reliance on external sources of supply of essential materials
3. Helping to address long-term resource depletion and associated problems of resource grade and quality, and
4. Finding new sources of growth, employment, and innovation, together with greater self-sufficiency and sovereign capability, associated with integrated onshore value chains.

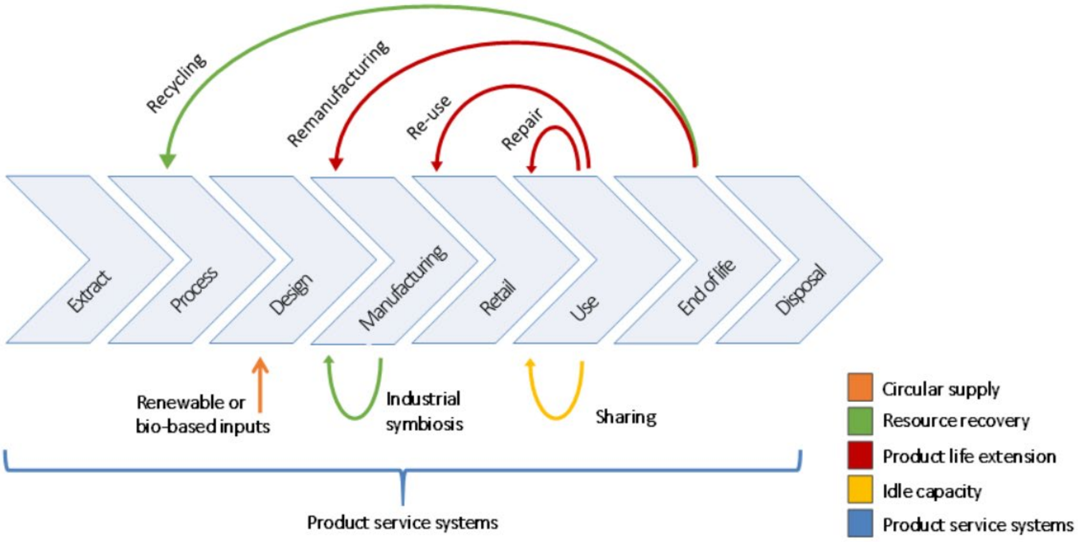
See Bibas et al. (2021); Bocken, Olivetti, Cullen, Potting, and Lifset (2017); Ekins et al. (2019); Lambert (2018); OECD (2020, 2021); PwC (2018).

Circular economy concepts seek a closed loop system not only to minimise waste and enhance sustainability, but also to keep resources in productive use for longer to enhance productivity. The focus is on reuse, repair, refurbishment, remanufacturing, and recycling to create integrated production, to reduce or eliminate waste and pollution in production and use of the product, and to keep the product or materials in use for as long as possible. It takes responsibility for the full lifecycle of the resources, and implies a degree of national self-sufficiency, effective sovereignty, and greater onshore lifecycle processes.

The key facets of circularity are illustrated in the graphic below. This depicts the theoretical model of a fully CE. The limits of that theoretical model and the possibility of achieving full (as distinct from greater) circularity are challenged by the important role of energy, the requirement for which increases with greater recycling, alongside the inevitability of energy losses (Roos, 2020), and that it will not be possible to reuse, or remanufacture, or repair or recycle everything. Current estimates for circularity levels achieved range from 6 percent of globally processed materials with high levels of waste, to 13 percent of EU materials processed (Ekins et al., 2019).

These points are important generally but not material, however, for this analysis which concerns the role CE could play in a comprehensive strategy for Australia's reindustrialisation and decarbonisation and adding value to its mineral and renewable energy resources, together with increasing national self-sufficiency and sovereign capability. Although it is important to survey definitions in the literature, and to arrive at clear specifications of meaning, our focus is strategic not taxonomic.

Figure 1: The Circular Economy closes material loops compared to the traditional linear economy



Source: OECD 2021

The CE divides into two streams: bio and industrial. Our discussion will focus explicitly on the industrial side, as core to the concerns with reindustrialisation, decarbonisation, value-adding and sovereign capability, together with resource efficiency and materials circularity.

2.2 Definitions and Overview

The survey below exhibits thematic consistency on keeping materials and products in productive use for as long as possible, the connection of CE to resource efficiency, and its essential character as an industrial system. This is relevant to a national mission for Australian reindustrialisation, decarbonisation, value adding and increased national sovereign capability.

Table 1: Selective survey of Circular Economy definitions

The Circular Economy is
"Viewed as a concept by some, a framework by others…A CE attempts to keep products, components, and materials at their highest utility and value at all times. The value is maintained or extracted through extension of product lifetimes by reuse, refurbishment, and remanufacturing as well as closing of resource cycles – through recycling and related strategies." Bocken et al. (2017)
"….an industrial system that is restorative or regenerative by intention and design…It replaces the 'end-of life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models". Ellen MacArthur Foundation 2013
…."an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations."

The Circular Economy is
Kirchherr, Reike, and Hekkert (2017)
…seeking "to extend resource life, for example: reuse, recycling, remanufacturing, servitization, repair, waste-to-energy, product longevity approaches, and the cascading of substances (i.e., the transformation of materials through various use phases)…..The CE "articulates (more clearly) the capacity to extend the productive life of resources as a means to create value and reduce value destruction." Blomsma and Brennan (2017)
…"one that has low environmental impacts and that makes good use of natural resources, through high resource efficiency and waste prevention, especially in the manufacturing sector, and minimal end-of-life disposal of materials". Ekins et al. (2019)
One seeking to maximise the value of materials and products in the economy, minimise material consumption and their environmental impacts, prevent waste and reduce hazardous components in waste and products. OECD (2020)
…"where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised, ….[contributing] to the EU's efforts to develop a sustainable, low carbon, resource efficient and competitive economy. Such transition is the opportunity to transform our economy and generate new and sustainable competitive advantages for Europe." PwC (2018)
Directed at " Increasing resource efficacy and moving to a more circular economy aims to maintain materials at their highest values and to keep products, components and materials in the economy for as long as possible, trying to eliminate waste and to reduce virgin resource inputs. Different processes of closing, slowing and narrowing resource loops can contribute to this aim in different ways.." OECD (2021)
"an essential condition for a resilient industrial system that facilitates new kinds of economic activity, strengthens competitiveness, and generates employment" Bastein, Roelofs, Rietveld, and Hoogendoorn (2013)

There is general agreement that that 'closing, slowing and narrowing' resource loops are the three key modes of circularity. **Closing** is a reduction in materials extraction and wastes through recycling and secondary materials, **slowing** means longer-life products and improved reuse and repair opportunities, and **narrowing** expands sharing practices and service models (OECD, 2021).

Circular business models serve the purposes of these three modes. The replacement of virgin materials inputs with renewable or recovered ones, recycling and reprocessing of wastes into secondary raw materials, discouraging waste from final disposal and reducing virgin extraction and processing helps to close resource loops. Product life extension models can slow materials flow through reuse, repair, or remanufacturing. Sharing models that intensify use of industrial equipment, transport equipment, and buildings especially, and service-enhanced production models, or Product Service Systems, including the role of Industry 4.0 and digitalisation, can assist with narrowing resource loops (OECD, 2021).

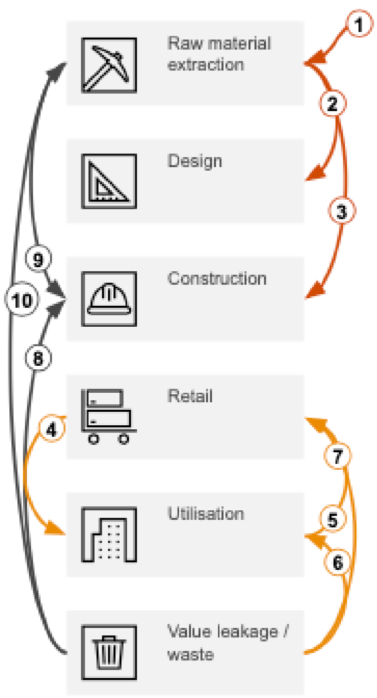
These imply changes in economic structure and new business models, from greater use of secondary materials to greater waste recovery for use in production of secondary raw materials, product life extension through reuse, repair or remanufacture, and greater bundling of services with product offerings (servitisation) (see: Bibas et al. (2021); OECD (2021); OECD (2018)). Vendors move from sole reliance on repeated one-off individual sales of a product, to bundling their products with services in the attempt to lock in customers and derive additional revenue. As more of their margin comes from services, so the vendor moves from a model of profit on sale to revenue over the use and life of the product.

Figure 2: Dimensions of the Circular Economy

3 principles and 10 corresponding strategies

Principles	Circular strategies	
Prioritise renewable inputs	1. Circular sourcing	Replace construction materials with renewable, bio-based, or recycled materials
	2. Sustainable design	Design infrastructure and buildings for disassembly
	3. Resource efficiency	Optimise usage of raw materials to minimise waste in the construction process (e.g. opting for prefabricated components or modular construction)
Maximise product use	4. Product as a service	Provide a service in areas that were traditionally sold as products (i.e. a developer pays a periodic fee for the use of a product rather than purchasing the product outright, for example modular facades)
	5. Sharing/ virtualising	Sharing or multi-purposing of assets (sharing of commercial and residential space through co-working and co-living)
	6. Usage optimisation/ maintenance	Increase the performance and efficiency of product to maximise its life span
	7. Reuse/ distribution	Purchase and sell second-hand materials
Recover by-products and waste	8. Refurbishing/ remanufacture	Remanufacture or refurbish existing buildings/ components for new usage, rather than down-cycling
	9. Recycling from manufacturing	Down-cycling waste or by-products from construction to be used for another product
	10. Recycling from consumption	Recycle discarded materials after demolition/ deconstruction

Infrastructure lifecycle



Source: PwC (2018)

2.3 The purposes and benefits of greater circularity

This subsection identifies the high-level purposes and potential benefits of CE from the literature. The overarching purposes and benefits of CE (also containing benefits), are:

- Reducing environmental impacts (including climate impacts) throughout the material and product lifecycle through clean energy and practices that extend material and product lifespan, such as 'recycle, reuse, repair and remanufacture'
    - Primarily environmental benefit, with major economic potential
- Avoiding excessive reliance on external sources of supply of essential materials, resulting in greater security of supply, resilience, and self-sufficiency

    - Economic, social and security benefit
- Helping to address long-term resource depletion and associated problems of resource grade and quality
    - Resource security and environmental and economic benefits
- Finding new sources of growth, employment and innovation, together with greater self-sufficiency and sovereign capability, associated with having integrated onshore value chains
    - Economic and social benefits enabling realisation of environmental and security benefits.

Table 2 shows the environmental benefits of greater circularity. Note, however, that some of these benefits may be qualified by assumptions used, especially about amounts of energy used for recycling (including transport), which will vary case by case. There is also a literature on 'rebound effects and the possibility that savings from CE are diverted into wasteful alternatives. This is a legitimate cautionary point for policy and strategy broadly speaking. It does not diminish the urgency or importance of CE, any more than that some free-riding countries avoid their climate obligations undermines the overall case for strong climate action. It is about the direction of the policy and strategy required.

Table 2: Environmental benefits of greater circularity

Environmental and resource benefits
Energy savings through recycling of high-energy products like steel, aluminium, cement and plastics, resulting in a large reduction of carbon emissions (Ekins et al., 2019).
Reduced extraction and use of virgin resources by keeping materials and products in productive economic use for longer.
Application of sharing models leading to more intensive use of buildings and vehicles.
The UN International Resource Panel (United Nations, 2020) finds a benefit of a 47 billion tonne (25 percent) reduction in materials extraction by 2050 from a 'towards sustainability' scenario over the historical trends baseline.

Table 3 shows the economic benefits estimated to result from increased circularity as identified in the literature. No claim is made here about the reliability or assumptions underlying any of these estimates. They are simply illustrative of modelling claims made by these sources. It is sometimes unclear to what extent claimed GDP increases are owed simply to CE resource savings, or to their combination with other factors, such as innovation-based assumptions.

Table 3: Economic benefits of greater circularity

	Benefits
Savings	Minimising lifecycle impacts links to cost minimisation and revenue maximisation (Roos, 2020) Net savings in materials consumption increases competitiveness. An Ellen MacArthur Foundation study found that CE transition in the EU would generate savings of USD 380 billion by 2025, which rise to USD 630 billion in an advanced transition scenario (Ellen Macarthur Foundation, 2012)
Innovation	Opportunities for technological, organisational and business model innovation, including powerful servitisation models that bring the producer and customer into a closer long-term relationship. This is referred to as product-service

	systems (PSS), in the CE literature but relates closely to servitisation, manufacturing as a service, or services-enhanced manufacturing (Ekins et al., 2019; OECD, 2019a, 2021). Opportunities to apply powerful digital technologies to new product and market development (Industry 4.0).
Growth	Estimates of a return to GDP from the implementation of CE practices vary. Lacy, Long, and Spindler (2019) identify a USD 4.5 trillion boost in global economic activity by 2030, whereas the Ellen Macarthur Foundation (2015, p. 33) estimates an increase of European GDP of 7 percentage points by 2030, and 12 percentage points by 2050. The UN International Resource Panel finds “implementing an integrated package of resource efficiency, sustainability, and climate policy actions results in net economic benefits globally from 2030 onwards, with global GDP 8 per cent above *Historical Trends* in 2060” (United Nations, 2020, p. 117). The European Commission estimates an additional 0.5 percent of GDP by 2030. A summary of multiple econometric studies by Ekins et al. (2019) finds some negative estimates, but most are positive, with GDP gains of less than 5 percent. Seven estimates are for GDP growth to be boosted by 5 percent, and 3 estimates for more than 10 percent. KPMG sees a $23 billion boost to GDP from the CE in Australia to 2025. This is derived from CE-related changes affecting three sectors: food, transport and built environment. The boost rises to $210 billion by 2047-8. (KPMG, 2020). PWC arrives at a near-$2 trillion boost to 2040 through a focus on four sectors: building, mobility, community and industry (Melles, 2021; PwC, 2018), whilst the Grattan Institute sees a cumulative benefit to 2040 to Australian industry of almost $1.4 trillion by the switch to renewable energy (Wood & Dundas, 2020).
Employment	Some country-specific estimates of aggregate employment gains exist, but overall, these analyses are more partial. One estimate is that “unemployment rates — compared to today — could be cut by a third in Sweden and the Netherlands, and possibly more, maybe even cutting unemployment in half — if some of the likely trade surplus gains would be used for investments domestically. In Spain the unemployment rate is likely to be reduced from the current over 20% to somewhere close to 15%, in Finland unemployment would be cut by a third, and in France by almost a third, provided that some of the likely trade surplus gains would be used for investments domestically” (Wijkman & Skånberg, 2015). The OECD (2021, p. 25) expects the CE to have “a small but net positive net effect on employment”, while an EC estimate is of an additional 700,000 jobs from the CE by 2030 (EC 2020). Certain other European estimates are higher than this (one as high as two million jobs by 2030).

	For Australia, high employment multipliers have been found from waste recycling, estimated at 9.2 jobs for every 10,000 tonnes recycled. In South Australia an additional 25,000 jobs in over five years through waste recycling was forecast (Levitzke, 2020; Otter, 2018). KPMG sees an additional 17000 FTE jobs nationwide as a result of CE initiatives pertinent to its three modelled sectors by 2047-8 (KPMG, 2020).

2.3.1 Social benefits

Although the CE literature often cites social benefits, including greater equality of opportunity and economic participation, there is reasonably little analysis of how the CE concretely advances these desirable social outcomes, and there are rather few case studies. Features of the CE that may favour greater social opportunity and some modest reductions in inequality include the CE's focus on production and innovation over extraction and consolidating and integrating onshore value chains and resource security with some level of self-sufficiency (over export of unprocessed raw materials and high import dependency for finished products). However, none of these features inherently make the CE more propitious to greater social equity. This will depend on how it is applied in different national and regional contexts, including the distinctive nature of their industrial policies and strategies. The importance of this issue is reflected in subsequent discussion of Australia.

Issues of sovereign capability and resource security loom very large in the Biden Order on supply chains (The White House, 2021). This is motivated primarily by national security, political and economic concerns. Nevertheless, a concern to ensure the capacity of an economy and society to meet the basic health, energy, food, defence, and other needs of a national population clearly involves a concept of the social good.

3 Lessons from International Experience

This section surveys international experience in applying CE policies, programs, strategies, and legislation and provides detailed country comparisons. It underlines the importance assigned to CE by national and supranational governments and institutions and reveals active and future-oriented policies operated at the regional and major city levels[1]. The survey also establishes the importance of national leadership, policy, and durable institutional commitments, and identifies the factors which give effect to the Circular Economy. For Australia, principal observations and suggestions will be provided, and the decisive points at which CE practice could contribute to Australia's reindustrialisation, decarbonisation, value adding, and achieving greater sovereign capability will be identified.

CE practice covers a vast spectrum from a focus on minimising landfill, through to largescale industrial systems and symbiosis. A central lesson is of the importance of industrial processes to GC and CE objectives. Economies biased toward extractive sectors and processes are furthest from sustainability and the CE, because they lack the capabilities needed for greater circularity. Their directionality and path dependency are misaligned to the future green economy. This point is critical for Australia.

Mazur-Wierzbicka (2021) analyses the 28 EU countries and classifies them into two groups according to the level and nature of their advancement toward the CE.

The groups divide into the high income industrialised 'old' EU countries (advanced) and more recent EU members mainly located in Eastern and Southern Europe with lower per capita incomes, lower urbanisation and less advanced industrial structures (slower adopters of the CE). The more advanced countries felt the impacts of excessive waste, resource constraint, pollution, etc., earlier and had greater capacity to deal with them than the less industrialised nations of Eastern and Southern Europe. Germany is the most CE-advanced EU country according to Mazur-Wierzbicka's analysis.

The key differentiators between advanced CE nations and developing CE nations are not the rates at which they generate waste, nor e-waste recycling rates, nor recovery rates from construction and demolition, although differentiation emerges with respect to recycling rates of municipal waste, packaging, and overall waste recycling, excluding major mineral wastes.

The key differentiators are:

1. the extent of private sector investment, jobs and value added related to the CE
2. patents relating to recycling and secondary raw materials use
3. extent of trade in recyclable raw materials
4. circular material use rates
5. the recycling of biowaste.

These differentiators imply a concern with industrial processes and CE as an industrial growth opportunity. The Circular Economy in fact describes industrial processes and structures directed towards the ends of resource efficiency and circularity. The connection underlined by Mazur-Wierzbicka between nations' industrial capabilities and their productive capacities related to the CE and the green economy are reinforced by the Green Complexity Index developed by Mealy and Teytelboym (2020).

[1] Analysis of regional and city level Circular Economy policies are omitted for space considerations.

Their approach is an analogue to that of economic complexity (Hausmann et al., 2013; César A. Hidalgo & Hausmann, 2009; C. A. Hidalgo, Klinger, Barabási, & Hausmann, 2007). Economic complexity is a synonym for the knowledge-intensity of an economy, asserting that 'what a country makes is what it knows'. The proxy used for assessing this level of knowledge-intensity is the basket of exports of each nation, analysed in a longitudinal series. Levels of complexity exhibit high path-dependencies. Generally, it is not possible to move from unprocessed commodity exporter to producer of sophisticated medical devices. Countries looking to diversify need to consider products adjacent to their current capability sets. The more complex an economy already is, the greater will be the spectrum of adjacent opportunities.

Applying a similar approach, Mealy and Teytelboym (2020) have developed an international data set of green products, to measure an individual nation's capabilities for green production. The data set consists of 543 green-related products and a further set of 57 renewable energy ones. The products are ranked according to their complexity, and nations' levels of Green Complexity (GC) are ranked in a Green Complexity Index (GCI). There is a strong correlative connection between nations with high economic complexity (and high industrial capabilities) and those with green complexity.

An additional measure identifies how much a nation's current industrial structure permits a transition to new green products. It shows that green products are higher in product complexity than average and that countries with a high GCI are likely to be lower emitters. The top 10 nations for green industrial complexity are: Germany, Italy, the USA, Austria, Denmark, China, the Czech Republic, France, Japan, and the UK. Australia has dramatically declined in both economic and green industry complexity (Hausmann et al., 2013; Mealy & Teytelboym, 2020, p. 7) to levels typical of a developing country. Australia is placed 80th for Green Complexity on the Mealy and Teytelboym (2020) 122 country index. Australia's capabilities are concentrated on resource extraction and are misaligned to the future green industrial economy.

Positive CE directions appear to be functions primarily of positive and deliberate directional policies, particularly national policies. Enduring institutional commitments are critical. Higher performance is also correlated to levels of industrialisation of the relevant national economy and high levels of per capita GDP, and very high performance is observable in industrially-leading countries with strong political, institutional and policy CE frameworks. Evidence of policy commitment is found in facets such as adoption of legislation, national and supranational policies, programs, common frameworks, manuals, practice guides, directives, regulations, targets and timeframes. Further, higher performers deliberately articulate CE and green economy principles with industrial policies, and specific industrial and policy directions supportive of the CE and GC (Aiginger & Rodrik, 2020; Rodrik, 2014).

Industrial economies have greater capacity to drive greater circularity through evolving and innovative industrial processes. An economic interest exists in the creation of new business models, products and services. By contrast, extractive linear economies lack the industrial systems and capabilities required for greater circularity and, as political economies, have often enlarged the power of political and economic interests opposed to policies and actions aimed at curbing their influence. This is critically important for understanding Australia's political economy and current position.

The deliberate imbrication of CE principles with industrial policy by high performers sees them promoting new service-enhanced business models and Extended Producer Responsibility (EPR) initiatives which extend the lives of materials, use of Industry 4.0 and digital technologies that extend product life, providing through-life performance monitoring and objective data on material and product history, and Green Public Procurement (GPP), to leverage powerful demand-side forces to create and shape future markets, by creating scale in target sectors and setting strong directions for their future development.

Between 2000 and 2017, G20 nations grew in resource productivity by 40 percent (OECD, 2021). Partial decoupling of GDP and growth from resource extraction are evident as past and future trends. This is clearest in industrially mature economies, whilst the newly industrialising and urbanising countries account for major growth in global resource consumption which will double by 2060. The issue is whether this doubling of consumption can be met through radically reduced use of virgin resources and replacement by secondary ones.

Global trade in waste rose 30 percent between 2003 and 2016, and follows the pattern of high export by developed countries such as the US, Germany, France and Japan, with principal importing countries being China, India and Turkey (OECD, 2021). Rates of recycling are highest for glass, paper and metal packaging, as these are relatively easy to recycle (OECD, 2021).

A further observation is the vast breadth of CE practice. Much of the literature is concerned with recycling of household and municipal waste and avoidance of landfill, more than with the industrial implications and processes which will be our primary focus in later sections. The broader literature often emphasises the problems of plastics and bio-wastes, with focus on cities as both the source of much of the challenge as well as having the infrastructure, resources and complexity to meet those challenges. Without underplaying the importance of these, some of the literature suggests that certain areas achieve salience in part (but clearly not entirely) because they are easy to measure (e.g., tonnes of waste).

These observations point to broad key success factors. The setting of targets together with ongoing monitoring and benchmarking are critical. However, no clear overall picture emerges of key success factors, of what works and what does not, at greater specificity. This could be researched further.

3.1 Description of CE in selected nations and supranational organisations[2]

Table 4 identifies the current key features of CE practice in nations and supranational organisations, with a focus on institutional forms and commitments to give effect to CE initiatives, and to explicit policy recognition of their connections to broader societal challenges.

[2] The literature is vast. In addition to sources cited in the bibliography and in the table below, particularly those from the EU, OECD and the Biden supply chains order, this survey relies upon principally: Brears (2018); Eisenriegler (2020); Ekins et al. (2019); Ghosh (2020); Lambert (2018); Mao, Li, Pei, and Xu (2016); Matthews and Tan (2016); Mazur-Wierzbicka (2021); OECD (2019b, 2020, 2021); Otter (2018); Sillanpaa and Necibi (2019); The Warren Centre

Table 4: National and Supranational Circular Economy Policy Statements (selective survey)

Nation or body	Policies	Comments
Belgium	Towards a Belgium as Pioneer in the Circular Economy, 2014	21 measures focussed on sharing and repairing, and sustainable waste management, increased recycling
Canada	Dialogue on Plastic Waste: Online consultation for moving Canada toward zero plastic waste, 2018	Policy of zero plastic waste through lifecycle approach digital. Active NGOs
China	Law for the Promotion of the Circular Economy, 2008 Circular Economy Policy Portfolio, 2017	Leading non-OECD nation on CE. 11th and 12th Five-Year Plans support CE strongly. Emphasis on industrial symbiosis, reuse and industrial parks (which account for 50 percent of industrial production)
Denmark	Advisory Board for Circular Economy, Recommendations for the Danish Government, 2017	27 recommendations for Denmark as a CE on four themes: value chains, design and production, consumption, and recycling
European Union/European Commission	European Green Deal 2019 Closing the Loop – An EU Action Plan for the Circular Economy, 2015 For a Cleaner and More Competitive Europe - A New Circular Economy Action Plan, 2020	Highly ambitious, with CE integrated into future vision for Europe's economy and society Policies are strongly directional and aimed at solving several society-wide challenges together Production of directives, guidance, resources, regulations, common templates and standards, helping to shape future markets EU deals with CE from all viewpoints: fiscal measures (taxes and subsidies), regulation, industrial policy, research and development and innovation, regional coordination, urban development, Emphasis on active policies aimed at shaping and accelerating market development for advanced products and services and solutions Advocacy of new business models, Green Public Procurement, Extended Producer Responsibility, etc Targets on plastics, landfill, resource efficiency Green Deal links with industrial policy and "the green and digital transformation"
Finland	This is how we create a circular economy in Finland	Highly ambitious, aiming to be global leader in CE by 2025. Roadmaps and key target areas. Led by Finnish Innovation Fund, SITRA. Produced world's first CE roadmap: policy actions, key projects and pilots
France	Circular Economy Roadmap of France, 2018	France is a leader. Roadmap aims to halve landfill and completely recycle plastics by 2025. Contains 50 measures toward a CE centred on themes of production, consumption, waste and community action and engagement. Also a 30 percent reduction of resource consumption in relation to GDP by 2030 (compared to 2010)
Germany	2012 statute promoting CE and resource efficiency	Germany is early adopter and CE leader. Comprehensive recycling plan. In the early 2000s it adopted an economic goal of separating growth from

Nation or body	Policies	Comments
	German Resource Efficiency Programme (ProgRess) 111	materials use. Adoption in 2012 of a statute promoting CE and resource efficiency Aims at making production depend less and less on primary resources and expanding CE. 4-yearly progress reports and updates to the German parliament
Italy	Towards a Model of Circular Economy for Italy, 2017	Highly developed CE indicator monitoring framework. Strong public education. Strategy oriented to five parameters: production, consumption, waste management, secondary raw materials, and competitiveness and innovation
Japan	Law for the Promotion of Efficient Utilization of Resources, 2000 4th Fundamental Plan for Establishing a Sound Material-Cycle Society, 2018	High rates of metals recycling, together with recovery and recycling of electronics; low landfill rates. Sustainability practices partly determined by Japan's industrialisation and resource scarcity
OECD	Numerous policy statements including: Towards a more resource-efficient and circular economy, 2021 and OECD, Ekins et al, 2019 Re-Circle: Resource Efficiency and Circular Economy Project (OECD 2018)	Analysis of/advocacy for CE policies at the macro- (fiscal, tax and subsidy, regulation), and meso- and micro-levels - covering industrial and urban policies, waste recycling, nations, regions, cities, neighbourhoods. Manuals, guides, templates, regulations, etc. OECD Re-Circle: Resource Efficiency and Circular Economy Project (OECD 2018): qualitative policy analysis and quantitative modelling
Spain	Strategy for Circular Economy in Spain, 2020	Targets and initiatives to effect a 30 percent reduction in national resource consumption and a 125 percent cut in waste generation (compared to 2010). Successive three-year action plans under the Strategy help keep the focus on practical measures and achievement of targets
The Netherlands	Government of the Netherlands, A Circular Economy in the Netherlands by 2050, 2016 Opportunities for a Circular Economy in the Netherlands	A leader in CE. Priorities are biomass and food, plastics, manufacturing, construction, and consumer goods interim target to halve primary raw materials use by 2030, through high value use of existing raw materials, replacement of fossil fuel-based raw materials by sustainable and renewable inputs where possible, and new processes and products and corresponding industry restructuring
UK	Waste and Resources Action Plan (WRAP) Building a Britain for the future Industrial strategy: building a Britain fit for the future.	UK advanced in resource efficiency but no national CE policy although CE is one of four key planks of its industrial strategy Building a Britain for the future Waste and Resources Action Plan (WRAP) since 2000 CE directions are acknowledged in the UK 25-year Environmental Plan and the forthcoming Resource and Waste Strategy
United Nations	UN 2030 Agenda for Sustainable Development	Sustainable Development Goals (SDGs) promoting • Inclusive and sustainable economic growth, employment and decent work for all (SDG 8)

Nation or body	Policies	Comments
		○ Decoupling of GDP growth from materials use and environmental degradation (SDG 8.4) • Sustainable consumption and production patterns (SDG 12) ○ Sustainable management and. Natural resource efficiency (SDG 12.2) • Conservation and sustainable use of oceans, seas and marine resources for sustainable development (SDG 14) ○ Prevention and reduction of marine pollution, including marine debris (SDG 14.1)
USA	Sustainable Materials Management Action Plan Resource Conservation and Recovery Act (RCRA) Sustainable Materials Management Program Strategic Plan for Fiscal Years 2017-2022 Biden100-Day Executive Order 14017 on 'Building Resilient Supply Chains, Revitalising American Manufacturing and Fostering Broad-Based Growth' (The White House, 2021)	The 2017-202 five-year plan focusses on the built environment, organics recycling and reducing packaging. Further areas of priority are sustainable electronics management, lifecycle assessment, and international collaboration on sustainable materials management The Biden 100-Day Executive Order 14017 focusses on resource efficiency and recycling of critical materials from the viewpoint of increasing US industrial soveriegn capability and reducing dependence on vulnerable supply chains Many NGOs active, together with large cities' waste reduction and elimination strategies

4 The Circular Economy in Australia

4.1 Australia's extractive and linear economy

Over the past quarter century Austr alia's economy has undergone deindustrialisation. This has made it more reliant on extractive industries and less capable of adding value to its endowments of high-value resources. Australia is dependent on exports of unprocessed raw materials that are transformed offshore and reappear as high-value manufactured imports. Australia's capabilities are centred on extractive export industries, missing vast opportunities to develop industries based on value-added resources needed in a decarbonising world. While nearly half of the world's supply of iron ore, and thirty percent of all unprocessed ores were exported from Australia in 2019, less than half of one percent of global iron and steel, and processed metals, are sourced from Australia. These features of economic structure and relatively unsophisticated industrial processes reinforce lower performance with respect to GC and the CE.

The consequences of Australia's deindustrialisation are that Australia now has virtually the smallest manufacturing sector as a proportion of GDP amongst OECD nations (Australian Industrial Transformation Institute, 2021) contributing around half the average for OECD countries (and having the lowest manufacturing self-sufficiency (the highest import-dependency) of any OECD nation (Stanford, 2020). Australia's level of economic complexity has declined, reflecting a significant reduction in knowledge-intensive manufacturing capabilities (Hausmann et al., 2013). Australia's current international complexity ranking is 86th of 133 countries, below the oil-dependent stares of Qatar and UAE, and has fallen 31 places since 1995. Australia ranks 80th for Green Complexity with Australia's declining Green Complexity now resembling that of oil states, with high national income levels (Australian Industrial Transformation Institute, 2021; César A. Hidalgo & Hausmann, 2009; Stanford, 2020; Worrall, 2022a, 2022b, 2022c, 2022d; Worrall et al., 2021).

These issues were dramatized during the pandemic, which exposed the lack of essential industrial capabilities associated with an advanced economy, and an inability to provide services and products required for resilience and sovereign capability. Sovereign capability is fundamentally about ensuring a degree of self-sufficiency and security for a nation and avoiding the vulnerability of external dependency in key areas of national interest. The nation lacks several of the capabilities to do what it needs to be able to do in several domains critical to the well-being and security of the population: national defence, population health, security of energy and essential materials, food, and environmental sustainability including climate abatement and response (Worrall et al., 2021).

Australia today not only fails to add sufficient value to its immense high-value natural resources: it is also well behind other advanced nations in its capacity to recycle highly valuable materials and products at the end of their specific product life. These are resources with many successive lives provided a system exists to support such a virtuous cycle. Australia exports unprocessed minerals, imports them as sophisticated high-value products (e.g., titanium-based medical devices), and later must either send them offshore for recycling, or consign them to landfill (Australian Industrial Transformation Institute, 2021).

Secondary processing to add value to our raw materials and the energy and industrial processes required by decarbonisation are major openings for manufacturing and reindustrialisation. These linkages have been recognised explicitly in the announcement of a National Reconstruction Fund (NRF) as a key economic plank of the recently-elected federal government. This emphasis needs to be complemented with a focus on the CE. Australia's inadequate industrial structure is owed in part to the fact that Australia has lacked a national industrial policy and strategy, a lack to which the NRF is an important response.

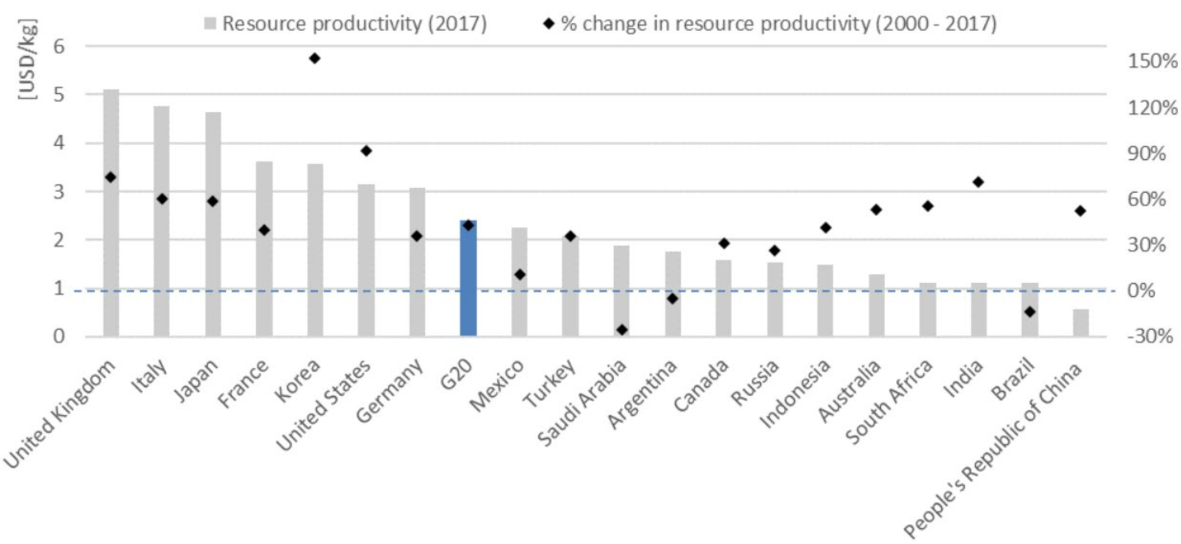
4.2 Overview of current position

4.2.1 Resource efficiency: Australia in international perspective

Resource productivity is linked to the level of industrial capability of a nation, with later industrialising countries, or those reliant on resource extraction tending to have lower levels of resource efficiency. G20 resource efficiency increased by 40 percent between 2000 and 2017. Material consumption to 2060 will rise absolutely in most large G20 nations due to population and economic growth, despite these efficiency increases. Fast growing newer industrialisers like China have major increases in materials use, and likely progressive efficiency gains over time. As a deindustrialised extractive economy, Australia lags in resource efficiency.

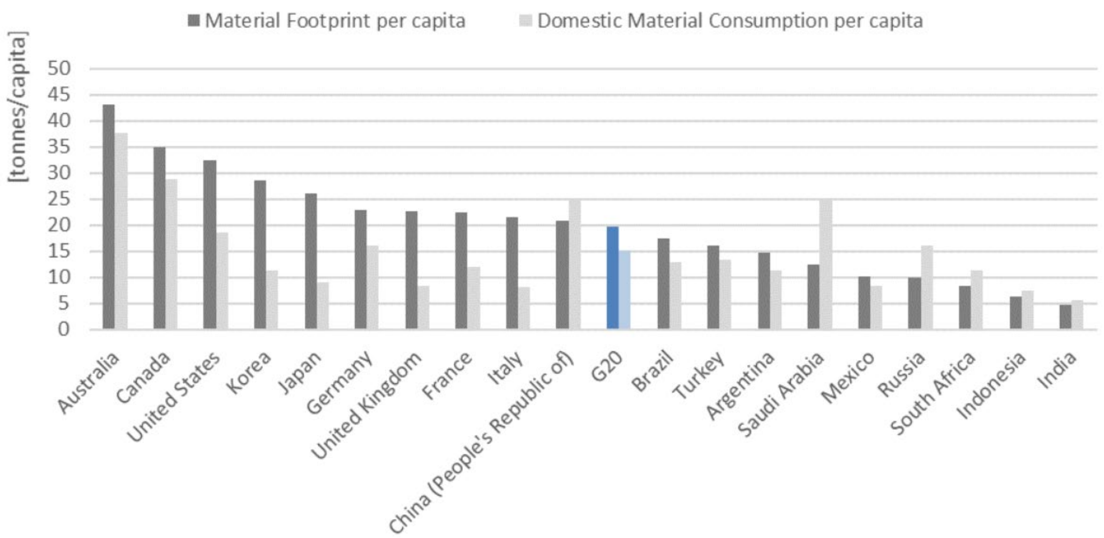
Figure 3 shows resource efficiency as the ratio between GDP and the total materials used in an economy. It shows Australia as a relatively poor performer behind even other resource-based economies and only marginally in advance of some new industrialisers. Australia is well behind the leading countries of the UK, Italy, Japan Korea, the US and Germany. Australia's low resource productivity, combined with our high material footprint and domestic material consumption per capita as shown in Figure 4, highlights the link between overreliance on extractive industries and the lack of industrial processes and capabilities for greater efficiency and circularity.

Figure 3: Resource productivity



Source: OECD (2021)

Figure 4: Material consumption



Source: OECD (2021)

The linear character of Australia's resource use is illustrated by Schandl et al. (2020). Australia's heavy reliance on landfill and underdeveloped recycling capacity has led to large waste exports. In 2019 Australia exported 4.4 million tonnes of waste, with 1.4 million tonnes of this comprised of plastic, paper, glass, and tyres. These exports were largely banned by Chinese edict in 2018.

Australia's recycling capabilities in plastic, paper, glass, and tyres, are limited as shown in Table 5. To meet the demands for recycling of these products, Australia would need to improve its recycling capacity by 150 percent.

Table 5: Australian recycling capabilities

Material	Domestic recycling	Landfill	Virgin inputs and imports
Plastic	4%	65%	96%
Paper	33%	25%	66%
Glass	36%	38%	64%
Tyres	14%	31%	94%

Source: Schandl et al. (2020)

4.2.2 2018 Senate inquiry

In 2018 the domestic and municipal recycling sectors were disrupted by the China's decision to ban the former practice of wholesale export of waste to China. The adjustment has been fraught by slow progress in growing domestic capacity. The decision led to an inquiry by the Senate Environment and Communications References Committee (*Never waste a crisis: the waste and recycling industry in Australia*, 2018). The report summarised key trends including a rise in generation of waste from 57 million tonnes in 2006-7 to 64 million tonnes in 2014-15. This rise was in line with population growth and entailed a minor per capita reduction. Less solid municipal waste was being generated per capita, whilst commercial industrial and construction waste were increasing. Over the period the quantity of materials recycled increased significantly.

The Committee called for institution of an Australian CE, and a move from an export recycling industry to an onshore waste processing industry – using waste to make new products domestically. It heard evidence in favour of mandating use of recycled materials in manufacturing and of Germany's policy against waste exports and favouring instead reprocessing within the nation's borders. It discussed the significant investment in infrastructure and processing facilities required were Australia to adopt such a policy. The Committee canvassed various industrial reuse and recycling opportunities.

The Committee considered there was a clear lack of national leadership and absence of partnerships with industry of the type needed to lead market development through a stronger National Waste Policy, materials and product stewardship schemes (elsewhere called Extended Producer Responsibility), infrastructure investment, and use of advanced procurement to accelerate and guide market development (including consideration of mandating of recycled materials in government projects).

The Senate committee heard evidence from the waste recycling industry that the Commonwealth had tried frequently to shift its responsibilities for national coordination to the states and territories. Effective policy requires active collaboration between all three levels of government.

The Committee reported more favourably on state-based programs, whereas national policy was more limited. Reported activities include updating the National Waste Policy in cooperation with the states and territories (the last one having been from 2009). This endorses CE principles. In 2017 the latest National Food Waste Strategy was released, with an objective of halving food waste by 2030. Australia's main product stewardship act dates from 2011. Like Extended Producer Responsibility, product stewardship aims at influencing decisions relating to the whole materials and product cycle, focussing on design, materials selection, use by the owner, and end of life reuse or disposal to maximise economic and environmental benefit. It aims to internalise through-life costs, including disposal. Australia's product stewardship legislation seems limited, focussed on end of product life more than the whole product life-cycle. While recycling industry submitters to the Senate inquiry were positive about the schemes established under the 2011 Act, many saw the case for expansion of product stewardship principles. All current Australian product stewardship schemes are voluntary, not mandatory.

In 2019 COAG agreed a timetable to ban export of waste plastic, paper, glass and tyres and to develop a CE strategy for them that would lead to increased capacity to produce high value products from recycled materials. This led to the development by the CSIRO of its Circular Economy Roadmap for plastics, glass, paper and tyres (Schandl et al., 2020).

4.2.3 Attempts to increase circularity

The Senate report considered national leadership to be inadequate to support the scale, direction and velocity of CE market development required. Attempts to increase circularity have often been high quality, but are as often fragmented and sub scale.

Australia has lacked a national industrial policy. This is cause and consequence of Australia's failure: to take advantage of opportunities to value-add to its highly significant energy and mineral resources; to utilise its structural advantage as a renewables-rich nation to re-shore energy-intensive large-scale production; and to use the economic opportunities of decarbonisation to build new industry clusters and value chains.

In the absence of national industrial policy the powerful linkages of reindustrialisation to CE and GC cannot be maximised and there are fewer opportunities to embed CE principles as drivers for future industrial development.

Although existing initiatives are valuable, they are fragmented, instead of being articulated to a positive directional industrial policy that would be the vehicle for maximising these linkages. Although they are to a degree involved in changing industrial processes to greater circularity, their focus remains primarily on recycling and reuse of consumer items and biowastes, and the avoidance of landfill. These are vital; the point is that they should be broadened and supplemented in the ways indicated in later sections. CE should become a lever of a comprehensive national industrial policy.

4.2.3.1 CSIRO

The CSIRO has devised a CE roadmap for plastics, glass, paper and tyres arising from a 2019 COAG meeting responding to China's decision to ban imports of these wastes in 2018 (Schandl et al., 2020). The impediments to greater circularity were identified as being:

- Loss of potential material through inadequate design, consumption and collection, such that they are not able to be recycled
- Lack of reprocessing capacity (including limited market development and scale)
- Failure to lead the development of end markets for secondary materials
- Lack of consistency across jurisdictions
- Lack of overall system-wide capability.

Six high-level strategies are supported towards a CE:

- Retain rather than dispose of material through use and collection: improve collection and sorting
- Upscale and innovate recycling technologies: increase capacity and investment in recycling of plastics, paper and tyres, and foster regional recycling (hubs, precincts, etc.)
- Innovate and collaborate in design and manufacture: design in circularity, build circularity into industry and innovation programs
- Market development for secondary materials and products: government and corporate procurement encouraged to use secondary material, especially in construction, and promote business model innovation
- Streamline nationally-consistent governance: harmonise waste policies, regulation, levies and fees, standards for recycled content in products, plastics, construction, etc., and streamline compliance
- Build a national zero-waste culture: awareness, labelling and product disclosure, set targets, etc. Also, promote industry participation and policies such as materials and product stewardship.

The roadmap nominates priority actions and goals for 2022, 2025 and 2030 which include:

- Plastics: development of sorting technology and market development and leading government procurement using recycled plastics. By 2030 and 80 percent plastics recovery rate and recycling at commercial scale. From 4 percent recycling in 2018 to 50 percent in 2030
- Glass: sorting at collection to avoid contamination. By 2030 80 percent recovery, with use of virgin material falling under 20 percent of input. From 33 percent recycling in 2018 to 65 percent in 2030
- Paper: Australia recycles 39 percent of paper and cardboard, so the emphasis is on increasing this as well as reducing single use paper products. Early need to deal with paper contamination at kerbside collection and harmonised standards, to achieve an 80 percent recovery rate by 2030 and solutions for recycling of low-grade product, with complementary reductions in use of virgin inputs and a modest increase in recycling
- Tyres: early adoption of mandatory tyre stewardship with bans on tyre disposal by 2025, together with market-developing procurement policies and incentives for recycled

material use. Achievement of 100 percent recovery by 2030, together with industrial ecology platforms, reverse logistics and innovation parks.

4.2.3.2 States and territories

In the absence of national policy, states have become the de facto leaders, together with larger municipal bodies. State- and Territory-based actions and initiatives are summarised in Table 6 below.

Table 6: State and Territory based circular economy and waste policy frameworks

State or Territory	Policy or Policies	Targets and Comments
ACT	ACT Waste Management Strategy. Applies landfill levy, and landfill bans to TVs and computers.	Targeting waste generation at less than population growth; waste sector to be carbon neutral by 2020; double recovery of energy from waste.
NSW	Strategy for waste avoidance and resource recovery. Landfill levy. 20-year waste strategy. CE Policy document released in 2019. CE Innovation Network under auspice of Chief Scientist. 2017 Container Deposit Scheme (CDS).	Targets for reduction of municipal solid waste, commercial and industrial, and construction and demolition. Targets for reduced waste per capita, and various regional targets. The CE policy outlines principles guiding government on CE, including minimising consumption of finite resources, decoupling growth from resource use, designing out waste and pollution, keeping materials in use for as long as possible, resource efficiency, and create new CE jobs.
NT	No landfill levy but a CDS.	Waste Management Strategy for 2015-2022, but no specific targets.
Qld	Landfill levy from 2019. Waste avoidance and resource productivity strategy to 2024. Work is occurring on development of a CE platform.	Targets for reduction of waste per capita and to landfill. Targets to increase various recycling categories.
SA	Landfill levy. 5-year waste strategy. Green Industries Act, 2004 – establishes board, fund, and oversees functions of Green Industries SA. 2017 report of Creating Value, the Potential Benefits of a Circular Economy in South Australia.	Reduction targets for waste to landfill and per capita. Landfill bans on hazardous materials, most e-waste, whole tyres, etc. SA was first to introduce a CDS in 1977. First jurisdiction to quantify CE benefits.

State or Territory	Policy or Policies	Targets and Comments
	Global Leadership Program on Circular Economy.	
Tas	Voluntary landfill levy. Waste and resource management strategy.	CDS to be implemented by 2022. Waste and resource management strategy, but no quantitative targets.
Vic	Landfill levies. State-wide Waste and Resource Recovery Infrastructure Plan – CE principles. Resource Recovery Infrastructure Fund.	No numerical targets in Plan. Increased bans on hazardous substances and e-waste to landfill.
WA	Waste levy. State-wide Waste Strategy (2019).	Strategy targets are ambitious: • 10% reduction to landfill by 2025 and 20% by 202030 • Material recovery by 70% by 2025 and 75% by 2030 • Only 15% of waste to landfill by 2030 • Residual waste to waste to energy by 2020

Sources: Levitzke (2020); Otter (2018)

5 Bases for Australia's reindustrialisation, decarbonisation and greater circularity

Section 4 outlined Australia's current underdeveloped position regarding the CE. This is largely attributable to the nation's deindustrialisation and overreliance on extractive industries. Australia has become locked into excessive dependence on declining forms of resource extraction a decarbonising world cannot use. Australia's linear economic processes owe much to the absence (indeed the repudiation) of ambitious industrial policy, leadership and strategy, particularly over the past decade. A feature has been the previous national government's failure to support Australia's immense advantages in making the low carbon transition through reindustrialisation.

This transition can be achieved with inclusive direction-setting leadership, strategic understanding of the points most decisive to achievement of the goals and targets, and the commitment to intervene at those decisive points (von Clausewitz, 1832). A national strategy encompassing the goals of reindustrialisation, decarbonisation, value-adding and greater national sovereign capability (including CE and GC) can gain force by mobilising the very interdependencies between them.

Previous analyses (Australian Industrial Transformation Institute, 2021; Worrall et al., 2021) have detailed four critical bases for Australian reindustrialisation linked to decarbonisation, which are briefly given here:

- Potential to add value to our immense traditional and new high-growth minerals and ores through secondary processing prior to export, and selected product manufacture
- Australia's vast renewable energy sources together with metals and materials needed in the future low carbon economy. Energy-intensive steel and aluminium, for example, need to be manufactured close to the power source, favouring re-shoring of much heavy industry previously lost
- Digital technologies and associated business models that can allow competitive production over short- to medium-runs, helping overcome Australia's historical disadvantage in economies of scale dependent production
- The drive to ensure and maintain certain basic capabilities onshore in light of the pandemic experience particularly, that are fundamental sovereign capabilities relating to population health, national defence, energy, etc.

These factors mean that Australian reindustrialisation and decarbonisation are not only desirable but possible.

Australia has many resources of high global importance, and that are critical to a decarbonising world (Australian Industrial Transformation Institute, 2021; Garnaut, 2019; Stanford, 2020; Worrall et al., 2021). But these are overwhelmingly exported as unprocessed raw materials for offshore processing. Australia then imports high-value products and equipment. Australia is a world-significant exporter of ores but typically accounts for less than one percent of world production and trade in processed metals.

Australia also has world-significant resources for renewable energy production (solar and wind principally), as well as the mineral resources demanded by the net zero-carbon economy of the future: iron ore and bauxite into green steel and aluminium; together with other minerals including lithium, copper, nickel, zinc, graphene, titanium, cobalt, vanadium and others. But onshore value-adding and processing is very limited (Australian Industrial Transformation Institute, 2021).

Two features of the past quarter century of deindustrialisation are especially important for an understanding of Australia's current position:

- First, the loss of production capacity in traditional metals such as steel and aluminium (in turn impeding conversion from fossil fuel reliance to low- or carbon-free energy sources)
- Second, despite its high endowment of new and advanced materials that have emerged as critical to the coming zero-carbon economy, Australia has failed to develop the onshore production capabilities required to capture the benefits.

Consequently, Australia is failing to build the scale-based secondary processing industries and associated opportunities for downstream product manufacture that could serve as the backbone of Australia's reindustrialisation and decarbonisation (Australian Industrial Transformation Institute, 2021; Stanford, 2020).

The linking of decarbonisation to Australian reindustrialisation is favoured not only by Australia's abovementioned resource endowments and their criticality to low-carbon transition, nor only by the structural requirement for production of many green products close to the production source (because of the expense of transporting and exporting renewable power compared to coal or gas). It is also that decarbonisation substitutes critical metals for fossil fuels, and leads to higher demand for the former. Wind and wave power generation and electric motors require magnets involving advanced and specialised materials and metals. Batteries also require highly processed metals. Electronic and digitally-dependent systems for energy flow and materials efficiency in production also demand increasingly specialised materials. Further, increasingly closed loop systems of production and consumption achieved principally through recycling present increased energy requirements (Roos, 2020).

The OECD has claimed, consistent with the arguments of Mealy and Teytelboym (2020) and of this paper, that the green economy - production of goods and services with environmental benefit - is almost three-times more manufacturing-intensive than the overall economy (Backer, Desnoyers-James, Moussiegt, & Ragoussis, 2015). In all, there is a compelling case supporting the interdependency of decarbonisation with high manufacturing and industrial production capabilities.

5.1 Labor's National Reconstruction Fund (NRF) and Buy Australian Plan

Australia's lack of industrial policy and strategy comparable to those now setting strong future directions for other advanced economies, has become stark over the past decade. These nations have embraced modern industrial strategy as a key to new sources of growth, following the impacts of GFC and later COVID-19, and as providing means to help address societal challenges such as climate change, inequality and social inclusion, and establishing directions for green growth. By contrast, Australia's policy response was negligible (Aiginger & Rodrik, 2020; Australian Industrial Transformation Institute, 2021; Rodrik, 2014; Worrall, 2022a, 2022b, 2022c, 2022d; Worrall et al., 2021; Worrall, Spoehr, & Gamble, 2022)

In this environment, the new national government's pledge for a National Reconstruction Fund (NRF) stands as one of the most substantive initiatives of the past decade. The NRF is an explicit response to the necessity for reindustrialisation. It is a positive directional statement about Australia's industrial potential, prioritising key sectors (Worrall, 2022d).

The NRF's reindustrialisation agenda supports nation-building, economic diversification, regaining lost sovereign capabilities, adding value to our vast resources, and accelerating the transition to a zero-carbon economy. Recycling and greater circularity are also explicit goals.

This redeems a major component of what is lacking today – a positive directional policy, focussing on priority sectors (Worrall, 2022d). These not only have good growth prospects, but also help us deal with largescale problems like climate change and decarbonisation, food security, renewal of our urban transport systems, and ensuring capabilities in medicines, vaccines, and health technologies:

- Value-adding in resources through domestic processing (e.g., aluminium and lithium batteries) and a $1 billion Value Adding in Resources Fund
- Value-adding in agriculture, forestry and fisheries and a $500 million National Reconstruction Find for Agriculture, Forestry, Fisheries, Food and Fibre
- Transport – building car, train, and shipbuilding supply chains
- Medical science – greater sovereign capability in essential supplies, and a $1.5 billion Medical Manufacturing Fund
- Renewables and low emission technologies (wind turbines, solar panels, lithium batteries, low carbon steel and aluminium, hydrogen electrolysers, etc.), and a $3 billion Powering Australia Fund to invest in green metals, clean energy component manufacturing, and agricultural methane reduction and waste reduction
- Defence capability – building the supply chain of Australian companies
- Enabling capabilities – systems, AI, robotics, quantum computing, etc., and a $1 billion Critical Technologies Fund.

The defence, transport, resources, agriculture and food processing, medical science, renewables, and other commitments are supported through a horizontal $ 1 billion Advanced Manufacturing Fund.

The NRF sets positive directions and sectoral priorities and is of a scale to make a difference to the nation. Aligned to the NRF are commitments to focus and augment substantially the current limited benefits derived from public procurement and industrial participation provisions of major projects through a Buy Australian Plan and establishment of a Future Made in Australia Office (assisted by legislated change to strengthen existing Commonwealth Procurement Rules to assist local industry to take up government purchasing opportunities). The NRF and Buy Australian Plan also link to the Rewiring the Nation initiative to upgrade the national power grid.

6 The strategic framework

This section aims to identify where and how CE policies and practices could advance a generational project for Australia's reindustrialisation and decarbonisation. We set aside the broad CE concerns surrounding waste, landfill, the sharing economy, and biomass, to instead focus on industrial structures and processes, and critical materials, especially metals. This focus will identify ways in which CE principles and practice may most effectively and powerfully contribute to a larger defined mission to address a cluster of interdependent generational challenges and opportunities for Australia. That mission will define the nation's future. It is:

> **"To reindustrialise Australia to drive accelerated decarbonisation, and increase dramatically domestic onshore value adding, and national sovereign capabilities and self-reliance".**

This requires detailed analysis of designated individual value chains to identify the decisive points at which CE should contribute and become an embedded feature of an ambitious national industrial strategy. The concept of strategy concerns how best to deploy limited and defined resources and force (means) against an enemy or challenge or opportunity at the decisive point(s) for maximum impact (object) (von Clausewitz, 1832). The aim is to identify the decisive points at which CE interventions will be most effective in achieving decarbonisation, reindustrialisation, value-adding and sovereign capability, and which specific CE interventions are most relevant to the specific value chain in achieving such objectives (Worrall et al., 2021)

The focus areas for this analysis are derived from two critically important initiatives: the national government's National Reconstruction Fund (NRF), and the South Australian Hydrogen Jobs Plan. In the NRF there are two streams that explicitly link decarbonisation to reindustrialisation, renewables and resource value adding. These are:

- 'Value-adding in resources through domestic processing (e.g., aluminium and lithium batteries) […]
- 'Renewables and low emission technologies (wind turbines, solar panels, lithium batteries, low carbon steel and aluminium, hydrogen electrolysers, etc.)'

This determines a focus on critical materials and selected products (e.g., wind turbines, battery packs), as well as critical energy sources and the South Australian hydrogen project.
Each value chain will be considered from the viewpoint of the relevance of CE to:

- Inputs to production, especially energy source (this corresponds to CE in the mode of closing resource loops)
- Production, including business model innovation, through-life issues, servitisation, digitalisation (this corresponds to slowing the resource loop through longer-life products and improved reuse and repair opportunities)
- End of product life, recycling and reuse (this corresponds to the closing resource loops mode of CE).

This stage is then a vertical analysis of these value chains to assist in identifying the decisive points for strategy and policy. It does not involve precise specification of the decisive points but indicates where to look for the discovery and analysis of those precise points in future work.

7 Sectors, products, materials, and energy sources

The analysis now turns to the key and specific sectors, products and materials that should be targeted by the NRF and Hydrogen Jobs Plan, in support of Australia's accelerated reindustrialisation and decarbonisation, and increased value-adding and sovereign capability. This includes nomination of the nature and extent of desirable Australian ambition with respect to the sector, product or material, and specific areas of application of CE principles and policies.

This section is largely focussed on the vertical characteristics of these areas as interdependent value chains and the appropriate targets for policy intervention. The section following examines policies and instruments with a more horizontal character.

Stanford (2020) and others have emphasised Australia's potential to create and deepen a virtuous cycle in which its endowments of both renewable energy and key minerals are used "to manufacture products and equipment, that in turn can be used as inputs in the further development of that endowment" (p 53). Australia's reindustrialisation would see it making products with low- or no-carbon production processes. A considerable proportion of these products would in turn specifically enable us to produce more emissions-free energy. This would help close loops and move our economy towards greater circularity.

Aligned to this broad approach, the following analyses are organised under three heads:

1. Critical Metals, Value-Adding, Secondary Processing: Potential for onshore value chains adding value to key metals with green energy and greater circularity
2. Renewable Energy Components and Products: Based on both value-adding to critical minerals and renewable energy sources, the products we can make for the green economy and greater circularity
3. The Energy Source: With a focus on green hydrogen (wind and solar being well-understood and covered in discussion of Renewable Energy Components and Products)

7.1 Critical Metals, Value-Adding, Secondary Processing

Australia should aim to create vertically-integrated onshore value chains in green steel and green aluminium with emphasis on CE relevant downstream product manufacture, as well as recycling, reuse and remanufacturing. Other critical metals such as graphene, silicon and titanium, should be investigated to consider opportunities and strategies for building integrated onshore value chains, including on-shore production, recycling, reuse, and remanufacture.

7.1.1 Green Steel and Aluminium

Australia is the world's largest producer and exporter of iron ore and the world's largest exporter of alumina yet performs very limited onshore value adding. Developing vertically integrated value chains making green iron metal, steel, and aluminium products is one of Australia's largest opportunities for reindustrialisation, which is favoured by the requirement that production occur close to sources of renewable energy. As steel is the largest source of industrial carbon emissions (Beyond Zero Emissions, 2020; Garnaut, 2019) significant decarbonisation gains could be achieved by developing onshore green steel, and green aluminium industries, powered by renewable energy.

Steel is the dominant metal product. On the way to zero carbon green steel, emissions from gas powered furnaces can be reduced through the addition of hydrogen, and electric powered arcfurnaces can be powered by renewable energy. Hydrogen (produced via electrolysis) can also replace coke in steel production to create carbon-free steel. While the production of hydrogen from electrolysis is costly, prices are expected to fall as scale grows, and as other renewable technologies using hydrogen are developed. Garnaut favours interim use of gas in the transition to hydrogen-powered steel making in the 2030s (ibid).

Aluminium is demanded as a strong lightweight material in the low carbon economy. It is highly energy-intensive, so green energy is vital to the future of an onshore Australian aluminium industry. Green aluminium uses wind and solar, stabilised by battery technology.

Australia recycles 97% of end-of-life structural steel and 83% of all scrap steel, and between 44 and 66% of aluminum packaging. However, much of this recycling occurs offshore, with metals accounting for nearly 50 percent of Australia's total waste/recycling exports (Donovan & Pickin, 2021; Keulemans, 2021).

Expansion of onshore smelting and processing, building scale, together with factors linking location of processing to the green energy source, favour expanded onshore recycling and reuse. Garnaut (2019) claims that smelting half of Australia's current alumina exports onshore would require four to five world scale plants.

Green steel and aluminium industries are critical to the desired virtuous cycle, providing inputs for domestic production of wind towers and turbines, solar panels, emissions-free transport equipment, an upgraded national electricity grid (Rewiring the Nation) and decarbonisation of housing construction.

A strategy to build vertically integrated green steel and aluminium value chains would apply a CE focus at both ends of the value chain: to ensuring the green energy source primarily, and to onshore recycling and reuse.

Table 7: Green steel and aluminium

Inputs to production (including energy)	Production and product use	Recycling/reuse	Principal CE Facet	Decisive point(s)
Existing renewable electricity sources to power electric furnaces. Hydrogen to decarbonise gas powered furnaces and to replace coke in the production of steel. For aluminium, wind and solar stabilised by batteries.	Application of digital technologies in production and product performance monitoring, reduction of wastage using control technologies.	Steel and aluminium recycling rates in Australia are already high. However much occurs offshore. Onshore recycling capacity, close to green power source, is critical.	Green electricity. Onshore recycling and reuse.	Securing green electricity. Onshore recycling and reuse.
Specific Industrial Policy Objective: Vertically integrated green steel and aluminium value chain, with onshore recycling and reuse				

7.1.2 Other Critical Metals

The production of other critical metals such as graphene, silicon, lithium, and titanium should also be investigated to determine the extent to which their inputs can be decarbonised, production can be brought onshore, and recycling and reuse integrated into the overall value chain. These investigations would apply the principles and steps enunciated here, and go on to confirm these as industry development opportunities according to the additional steps outlined at Section 7.4.

7.2 Renewable Energy Components and Products

Australia should aim dramatically to increase levels of onshore production of renewable energy components and products. This ambition will vary, from a vertically integrated onshore lithium-ion battery industry to value-adding and substantially increased component and product manufacture in wind turbines, solar panels and hydrogen electrolysers. In most cases, the CE-related capacity to recycle, reuse and remanufacture will be important to the strategy to build the value chain overall.

7.2.1 Lithium-ion batteries

The future ability to produce lithium-ion batteries is of critical strategic importance to Australia. Their importance has been recognised by China which seeks a controlling position in the world lithium market and the manufacturing value chain, and by the US, which is now attempting to make up lost ground in its competition with the PRC. Australia should aim to create a vertically-integrated onshore lithium-ion value chain, including recycling, reuse and remanufacturing.

7.2.1.1 Critical strategic importance of large scale batteries

Batteries are critical to decarbonisation, removing the previous problem of intermittency from renewable energy sources, making solar and wind power the low cost, reliable backbone of an emissions-free energy system. They are critical to decoupling economic growth from fossil fuels and carbon pollution. A further critical benefit arises from additional national self-sufficiency and flow-on benefits to national security and defence. Battery storage increases national sovereignty. This includes the ability to recycle battery components at the end of their life, into new products, forming a virtuous cycle.

The cost of battery storage has fallen by over 80 percent in the US over the past decade, with demand growing strongly this decade. The largest applications are transport (electric vehicles), stationary storage for the whole power grid, and defence and security (The White House, 2021). Global battery consumption is expected to grow five-fold over the decade 2018-2028. The growing demand is expected to drive even lower battery unit costs (Australian Trade and Investment Commission, 2018).

For Australia, with large endowments of the resources required for batteries, and capitalising on rising demand for battery storage, an onshore manufacturing capability would be a major step to reindustrialisation, creating a new complex value chain and adding value to national resources. This would also add to Australia's sovereign capabilities, creating greater self-reliance and insulation from future external shocks.

7.2.1.2 Australia's current position

Australia should aim to create a vertically-integrated onshore lithium-ion value chain, including recycling, reuse and remanufacturing. This is favoured by our resource endowments, as it is also by physical characteristics of these batteries, such as their weight and involvement with hazardous substances, which add to the cost and risks of long-range transport. However, policy leadership has been lacking over the past decade, one consequence of which has been failures in market development and infrastructure (such as charging stations) required for domestic take-up and economies of scale.

Australia has the third-largest known resources of unprocessed lithium in the world, an essential component of lithium-ion batteries, which have revolutionised low carbon generation. Australia has nine out of the 10 essential minerals required to make most types of lithium-ion batteries. But these are exported from Australia largely in unprocessed low value form, for other countries to perform value adding and manufacture. Australia is the world's largest exporter of lithium in its least-processed form of spodumene (Australian Trade and Investment Commission, 2018).

The Biden administration's recent Executive Order 14017 on supply chain resilience and sovereign capability confirms that Australia is a world-significant supplier of almost all the critical minerals and raw materials required to produce lithium-ion batteries. But these are exported in unprocessed form, rather than being value-added on shore. Nearly 90 percent of Australian lithium is shipped to China for processing (The White House, 2021).

Australia captures less than one percent of the potential value of the lithium battery value chain for its economy (Australian Trade and Investment Commission, 2018; Beyond Zero Emissions, 2020; Garnaut, 2019; Stanford, 2020). Australia overwhelmingly exports these critical components in their unprocessed form for offshore electro-chemical processing, cell production and product assembly. One tonne of our unprocessed lithium sells for around US$750, compared to the US$150,000 price of batteries using one tonne of unprocessed lithium (Australian Trade and Investment Commission, 2018; Stanford, 2020).

This message was amplified, again, in the Biden administration's Executive Order 14017 assessment of Australia's position and capabilities. Although Australia has "significant natural resource endowments of battery-related materials", there is no "broader ecosystem for advanced batteries". The "Australian Government has not yet developed a comprehensive national strategy to develop a domestic battery industry". It has no onshore manufacturing capability, only onshore assembly of imported packs. Finally, it has no capabilities in the recycling of used battery minerals and components. In summary:

"Australia has an abundance of key commodities needed to produce advanced batteries, such as lithium, nickel, vanadium, graphite, manganese, and alumina. These commodities require processing, however, before becoming battery materials. Australia currently has no commercial production of Class 1 chemicals or battery precursors. Australia also has no cell manufacturing, but it does have an active battery pack assembly industry. Australia only recycles two percent of its lithium-ion batteries, and its recycling processes typically disassemble and homogenize materials for export to places like Korea, which have developed battery recycling capabilities.

"Australia currently lacks battery-specific initiatives at the national level." (The White House, 2021, pp. 123-124).

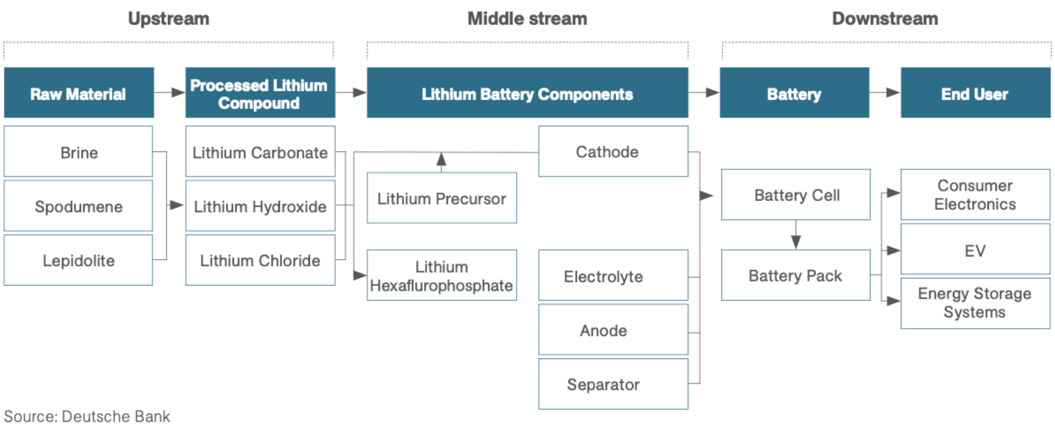
7.2.1.3 Lithium-ion battery value chain

The battery supply chain consists of:

- Raw materials production: extraction and separation of the materials
- Materials purification and refinement: refinement of the material from its base form for use in the next stage. This includes removal of impurities. Batteries require high material purity
- Processed material and cell manufacturing: integration of the processed elements into battery cells: cathode and anode powder production, electrolyte mixing, separator production, binders and conducive materials, and electrode and cell manufacture. This is the stage that technical and demand factors strongly start to favour integration and localisation of the downstream stages (The White House, 2021).
- Pack and end use product manufacturing: the manufactured cell is assembled into the final battery pack, and then integrated into the relevant end product, such as an EV
- End-of-life: recycling or disposal of batteries at end of initial life. Second use markets may exist as elements no longer suitable for their initial application may have other uses (such as in stationary storage after use in EVs), and recycling of some materials into new batteries. Batteries combine many materials. This means recycling, reuse, and remanufacture costs may be high. Costs of collection, disassembly, storage, transportation and processing will form a high proportion of the overall battery cost. The Biden Order argues that recycling is best geared to the progressive stages of the battery value chain, rather than left entirely to the product's end-of-life (The White House, 2021).

Given the complexity of the value chain, materials in current use may be subject to substitution, and supplementation and diversification in coming years (see The White House (2021)). Australia has reserves of many of the resources under consideration as alternatives or supplements.

Figure 5: Lithium-ion battery value chain



Source: Australian Trade and Investment Commission (2018)

7.2.1.4 Relevance of CE approaches to building the battery value chain

Australia currently recycles about two percent of its battery consumption. This recycling occurs mainly offshore (Australian Trade and Investment Commission, 2018).

Australia has failed to use its strong array of battery-relevant resources to develop an onshore manufacturing value-adding supply chain and industry cluster, preferring to export high-value resources in unprocessed low-value form.

The extensive analysis of the battery value chain in The White House (2021) concludes that the 'decisive point' for localisation of manufacturing and production comes at the stage of 'processed material and cell manufacturing', regardless of resource endowment. At this stage of value capture too comes the potential for ascending the value chain to manufacture battery packs and deal with end-of-life recycling, reuse and remanufacture.

It is of interest also that The White House (2021) implies that a recycling capability potentially could be of benefit not only on account of environmental and resource security and sovereign capability considerations, but also "for the United States to bolster its battery supply chain" (106). Recycling capability can stimulate upstream industrial development.

Difficulties and impediments to higher recycling include scale and facilities for collection and transportation, cost, capacity for recovery of only certain materials (often of lower value). Established recycling methods are pyrometallurgical (smelting), which cannot recover all metals, and hydrometallurgy (leaching), which has a high recovery rate. Direct recycling recovers, regenerates and reuses battery components without needing to breakdown their chemical structures. It promises high recovery and recycling, but is still in the R&D stage (The White House, 2021).

The White House (2021) argues that recycling is best geared to the progressive stages of the battery value chain, rather than left entirely to the product's end-of-life. This document recognises the positivity of a thorough-going virtuous cycle of reuse and recycling all along the battery value chain.

It should be noted that various Australian authorities (Australian Trade and Investment Commission, 2018; Beyond Zero Emissions, 2020) are both optimistic about the potential for an Australian lithium battery recycling industry, and about the positive role of expanded large scale recycling in stimulating upstream onshore production activities, as described above.

Table 8: Lithium-ion batteries

Inputs to production (including energy)	Production and product use	Recycling/reuse	Principal CE Facet	Decisive Point(s)
Lithium production from green energy sources. Intermediate inputs (copper, aluminium, nickel) can use reclaimed/recycled materials.	Improvements in battery chemistry to extend life of product. Application of digital technologies in production and product performance monitoring, reduction of wastage; use of control technologies.	Low recycling. Depends on offshore facilities. Recycling is difficult and expensive. Key critical minerals such as cobalt can be recycled at the end of the product's life. Transportation costs significantly increase recycling costs, (as well as supporting onshore recycling). Building scale for recycling is a critical challenge, and a decisive point.	Recycling, reuse. Green energy source. Recycling, reuse, as part of fully integrated value chain.	Getting to 'processed material and cell manufacturing' stage, and mass recycling and reuse.
Specific Industrial Policy Objective: Vertically integrated onshore value chain with onshore recycling and reuse				

7.2.2 Wind turbines

Australia should aim to create an onshore wind turbine manufacturing industry focussing initially on such components as towers and certain housings, as the starting point for progressive value chain capture, and on use of green steel and aluminium.

Wind turbines consist of over 8000 precision parts. The principal components of wind turbines are: the rotor, including blades, generators, towers/structures, and nacelles (housing) and controls. Further subcomponents are specified and explained in Lowe et al. (2009). Turbines are made primarily from steel, but aluminium and new composite materials are increasing in importance (Boechler et al., 2021; Lowe et al., 2009).

Wind turbines depend strongly on steel as the major input. Steel is about 90 percent of nacelle componentry. The rotor is about 45 percent steel, with the hub being 100 percent steel. Blades are low in steel content, where it is combined with fiberglass and adhesives. Aluminium and composites are increasingly under consideration. The majority of research and development in this sector concerns materials and materials science.

Currently Australia imports almost all components used in a wind turbine. There is confidence that Australia can manufacture a substantial part of a wind turbine, particularly as demand and scale increase, and as Australia supplies the green steel for these components (Beyond Zero Emissions, 2020; Garnaut, 2019; Stanford, 2020). Fortescue Future Industries (FFI) aims to establish an onshore wind turbine manufacturing facility at a future point (Phiddian, 2021).

Progressively, Australia can increase its participation in the turbine value chain. Australia should have a national strategy to replace imported components on a staged basis, starting with simpler items such as towers and various housings, progressing to rotors and nacelles and control equipment and electronics over time.

The main CE application to turbines will be use of green steel and aluminium. Electronic components, motors and magnets have shorter lives than towers and other components, and need for periodic upgrading. Hence, recycling, reuse and remanufacture of items such as these is highly relevant and important.

Electricity generated by wind turbines using green steel and aluminium in turn generate energy for their further production. Again, this represents a virtuous cycle in which we use our natural resources to create the products that enable us to further benefit from our emissions free energy, and in which adding value and secondary processing of Australia's resource endowments can promote complementary secondary product manufacture.

Table 9: Wind turbines

Inputs to production (including energy)	Production and product lifetime extension	Recycling/reuse	Principal CE Facets	Decisive point(s)
Green steel and aluminium.	Digital production controls and product performance monitoring. Waste reduction.	Long-life assets, so recycling less of an issue, although electronic component, motors and magnets have shorter lives and need recycling, reuse and remanufacturing. Can use recycled steel.	Use of green power in production. Generation of green power. Virtuous cycle.	Secure green electricity. Target towers and associated items initially to gain purchase over rest of value chain over time.
Specific Industrial Policy Objective: onshore manufacturing industry, using green steel and aluminium, initially focussed on towers and certain housings, beginning progressive value chain capture				

7.2.3 Solar Panels

Australia should aim to create an onshore solar panel manufacturing at least to solar module phase, processing high-quality Australian silicon and recycling and reusing end-of-life units.

Australia has the world's highest penetration of roof top solar panels, with around 30 percent of households having installed capacity. Over the next decade, much of this stock is coming to the end of its life, and soon will either be disposed of or recycled (Department of Climate Change Energy the Environment and Water, 2022; Garnaut, 2019; Schandl et al., 2020).

The critical mineral ingredient for panels is pure silicon made from either sand or quartz, which are combined with other compounds in a highly energy-intensive production process. Silicon of high quality is also demanded for computers (Garnaut, 2019).

PV panels are made by reduction of sand to produce raw silicon which is then purified for wafer production. The wafer is a crystalline semiconductor that provides the base for integrated circuits. This is vital to production and must be high in purity, undergoing cleaning, doping and coating. These are combined to create cells for integration into solar modules (Garnaut, 2019).
China produces around 60 percent of the world's silicon, but production is energy- and environmentally-constrained and has remained at fairly static levels for some years. Its capacity to export is similarly constrained by growing domestic demand.

Australia is a small producer of silicon but is of international significance on account of the resource's high quality. The capacity to expand production, potentially into vertically-integrated solar panel production, is reliant principally on the presence of high-quality deposits close to supplies of competitive green power. Australia has several locations with these characteristics (Garnaut, 2019). Beyond sands, Australia has most of the 16 minerals required to produce solar panels (Beyond Zero Emissions, 2020).

More than a decade ago Australia gave up its solar panel manufacturing capability, with capacity exported offshore largely to China. One producer, heavily reliant on imported content, maintains onshore production. Fortescue Future Industries (FFI) aims to establish an onshore solar cell manufacturing facility at a future point (Phiddian, 2021). Garnaut (2019) and Stanford (2020) express confidence that Australia progressively can increase its involvement in panel manufacture with green energy sourced close to the high quality silicon deposits (Beyond Zero Emissions, 2020; Stanford, 2020). This would be further aided by a focus on development of an onshore recycling and reuse capacity, which would likely be of economic scale given the accumulation of end-of-life units later this decade.

The main CE applications to panels will be use of green power for production and building capacity for recycling, reuse and remanufacture. Once again, this envisions a virtuous cycle in which green energy is used to produce solar panels, adding value to key minerals extending into product manufacture, enabling greater production of emissions-free energy in turn.

Table 10: Solar panels

Inputs to production (including energy)	Production and product lifetime extension	Recycling/reuse	Principal CE Facet	Decisive point(s)
Green steel and aluminium. Glass and silicon produced from green energy.	Digital production controls and product performance monitoring, waste reduction.	Opportunities for recycling and reuse, but current low rates. Large accumulation of panels' end-of-life over next decade. Build scale for onshore solar panel production through support for onshore recycling.	Use of green power in production. Generation of green power. Virtuous cycle. Onshore recycling and reuse.	Green electricity close to silicon (sand and quartz). Leverage Australia's significant deposits. Target local production to at least solar module phase. Onshore recycling and reuse of large stock of end-of-life panels this decade.
Specific Industrial Policy Objective: onshore manufacturing at least to solar module phase, processing Australian silicon and recycling and reusing end-of-life units onshore				

7.2.4 Hydrogen Electrolysers

Australia should aim to develop an onshore electrolyser manufacturing industry. Hydrogen electrolysers create hydrogen and oxygen gas from water. Hydrogen is a relevant input across all sectors analysed here – both as a source of carbon-free energy, but also for the development of fuel cells, and as a reducing agent in the production of emissions free steel. Hydrogen produced from an electrolyser can be a completely emission free process, compared to hydrogen derived from fossil fuels. Hydrogen electrolysers are fuel cells containing an anode, cathode, and electrolyte. It is the electrolyte material which separates hydrogen electrolysers from other fuel cells. Current generation electrolysers use proton exchange membranes, but research into alkaline and solid oxide-based electrolytes is continuing. Research and development into new electrolyte materials, and battery technology will be necessary to reach the clean energy hydrogen cost target of 1 USD/kg by 2030, producing emissions free hydrogen at a cost lower than that of fossil-fuel derived hydrogen. Garnaut (2019) sees the cost of electrolysers falling significantly over the decade.

Having an onshore vertically integrated green hydrogen sector will require the development of capabilities in hydrogen electrolysers. Electrolysers are the largest single cost component in green hydrogen although, as stated above, their cost is falling relative to competitor technologies. Electrolyser technologies can be applied to small-scale fuel cells to large-scale stationary plants. An Australian Renewable Energy Agency (ARENA)-supported demonstration project exists, but its electrolyser was manufactured offshore. Fortescue Future Industries (FFI) aims to establish an onshore electrolyser manufacturing facility from 2023 (Phiddian, 2021).

Table 11: Hydrogen electrolysers

Inputs to production (including energy)	Production and product lifetime extension	Recycling/reuse	Principal CE Element	Decisive point(s)
Green steel and aluminium.	Digital production controls and product performance monitoring, waste reduction.	Not immediately relevant.	Use of green power in production. Generation of green power. Virtuous cycle.	Downward sloping cost curve, combined with favourable cost effects of rising demand/scale. Decisive point is policy decision to support an onshore manufacturing capability (NRF, SA Hydrogen Jobs Plan, other state initiatives).
Specific Industrial Policy Objective: onshore manufacturing electrolyser industry.				

7.3 The Energy Source

Decarbonisation of the energy source helps close resource loops and significantly increases the circularity of Australia's economy. This forms part of the virtuous cycle, allowing the production of critical materials and renewable energy components to be decoupled from carbon emissions. Australia should aim to build significant production capabilities for green energy, through solar, wind, and hydrogen, balanced by large scale batteries, in turn using this energy to further decarbonise critical material and renewable energy component production. This would serve the objectives of reindustrialisation, decarbonisation, greater energy self-sufficiency, and sovereign capability.

7.3.1 Green Hydrogen

Green hydrogen is an important energy source for Australian reindustrialisation, particularly for energy-intensive production of products such as green steel and aluminium, and ammonia for food production and security. The South Australian government has developed a hydrogen jobs plan, while the NRF explicitly references green hydrogen and the development of capital items like electrolysers.

In addition to powering heavy industry, hydrogen is a green energy source complementary to solar and wind, with potential for applications in electric vehicles, ammonia-powered ships, and a substitute for natural gas in home cooking and heating. Additionally, hydrogen can be stored, producing electricity at peak time to maintain stability in the energy grid, and can be transported over long distances, opening up opportunities for export of renewable energy to developing industrial nations, to assist in global decarbonisation, and contributing to Australia's economic development. This latter aspect could also provide a qualitative and structural benefit of integration of Australia with Asian industry superior to the present model as supplier of unprocessed raw materials.

The rising costs of fossil fuels and the falling cost of green hydrogen as technologies are proven and scale grows, are moving in favour of green hydrogen. Green hydrogen contributes to the mass stationary electricity system mostly on account of its storage function. Direct electricity production via hydrogen is less efficient than by wind or solar. Green hydrogen storage compensates for their intermittency and variability. It has several modes of storage and transport to users. It helps stabilise and firm green energy supplies.

7.3.2 Australia's current position

Australia should aim to create a vertically-integrated onshore green hydrogen value chain. This would include onshore production as an input to other energy and industrial production, as well as export, and the development of an ammonia industry both as a carrier for exported hydrogen, and as a critical input to food production and security. The expansion of green hydrogen will likely eventuate from a combination of conversion of existing facilities to green processes, and the development of capacity in new facilities. Looking upstream of eventual hydrogen production itself, highly sophisticated plant and equipment is needed, together with advanced systems and systems integration. These are for the most part supplied by MNCs such as General Electric and Siemens. Plant and equipment is mainly available in modular form, often cancelling opportunities for local industry participation. This harms the goal of an Australian vertically integrated hydrogen value chain. Australia should assess potential for Australian engineers and manufacturers to gain a foothold in the upstream manufacturing of plant and equipment, engineering, process and services areas of the green hydrogen value chain, as well as opportunities in through-life support.

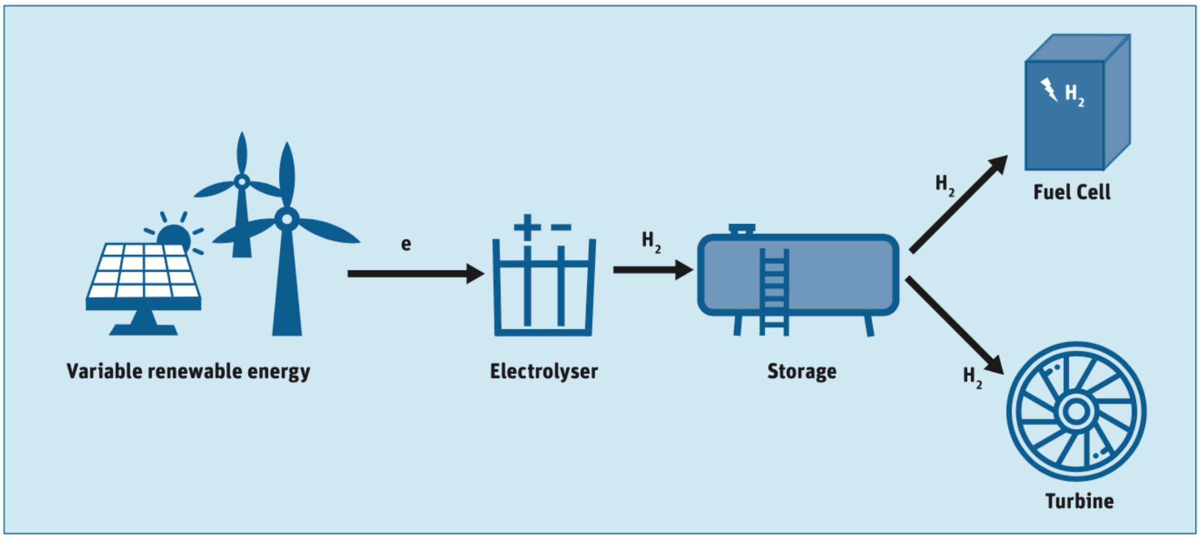
7.3.3 The Hydrogen Value Chain

Green hydrogen is made from renewable, non-fossil fuel, energy. Brown, grey and blue forms of hydrogen use various amounts of fossil fuels in various production processes. Green hydrogen uses electrolysis, which passes an electrical current through a tank of water, to separate the hydrogen from the water. When this is powered by renewable electricity, green hydrogen is produced. The critical process for hydrogen production is electrolysis carried out in hydrogen electrolysers (Bruce et al., 2018; Purtill, 2021).

The cost of green hydrogen is moving downward relative to competitor sources reliant on fossil fuels (Bruce et al., 2018). Garnaut (2019) sees the respective price points crossing toward the end of this decade, as scale is built, lowering electrolyser costs, in line with a "perhaps thousandfold increase in global hydrogen production required for realisation of zero global emissions in industry, power generation and transport (p 122)". While the cost of green hydrogen remains higher than blue hydrogen, development of blue hydrogen capabilities, combined with carbon capture and abatement technologies will assist in both building general hydrogen capabilities, and provide a short-term reduction in emissions (Garnaut, 2019).

Figure 6 below shows a process of electrolysis powered by renewables, leading to mass storage, that can then go to power turbines or to be stored in cells.

Figure 6: Hydrogen value chain



Source: Bruce et al. (2018)

7.3.4 The South Australian Hydrogen Jobs Plan

Of the several green hydrogen projects current in Australia, the SA Hydrogen Jobs Plan is the most significant, not only as the largest, but also the first example of a government resuming public ownership of an item of power infrastructure within a largely privatised market and industry.

It will lead to construction of 200 MW of power generation capacity using 250MWe of electrolysers, and storage capacity of 3600 tonnes of hydrogen. The facility to be built in Whyalla will provide firming and additional stability to the grid to help further the reliability of renewables and allow further expansion of and investment in the renewable power industry.

It is expected to reduce electricity prices by 8 percent, cost $593 million and be operational by the end of 2025.

From the viewpoint of integrated value chain development, however, this positive development contains the risk of pronounced import dependence for upstream plant, equipment and technology. The timeframe implies reliance on MNCs such as GE and Siemens and imported integrated modular systems which, as stated above, could cancel local industry participation, and with it, at least some aspects of circularity.

7.3.3.1 CE Relevance of Green Hydrogen

Green hydrogen is an emissions-free energy source that can be used in other areas of production, including energy-intensive recycling, reuse, and remanufacturing. Green hydrogen specifically also has CE relevance due to its role as a reducer in the production of green steel, and transport, construction, and household consumption applications. Renewable energy sources can contribute to a virtuous cycle in which emissions-free energy powers the making of manufactured products that in turn increase supply of renewable energy.

Table 12: Green hydrogen

Inputs to production (especially energy)	Production and product lifetime extension	Recycling/reuse	Principal CE Facet	Decisive point(s)
Electrolysers produced using green energy.	Digital controls in production, and production performance monitoring, waste reduction.	Long life plant and equipment, but potential for recycling and reuse at end of first life of certain items. Power source for recycling, reuse and remanufacture.	Green energy to production, recycling and reuse.	Follow the downward cost curve for electrolysers. Develop capabilities for hydrogen storage and integration with natural gas network for transmission.
Specific Industrial Policy Objective: Secure green hydrogen energy supply for industrial production and recycling and reuse.				

7.4 Decisive Points for Policy Focus

This 'vertical' stage of the analysis has sought to define points along the relevant value chains at which program and policy effort would yield the highest returns to Australia by their contributions to reindustrialisation, decarbonisation, value-adding and enhanced sovereign capability. Clearly this represents only a preliminary stage of the analysis and assessment that would be required to confirm these as decisive points and their viability as industry development opportunities. That much more extensive task requires a methodical approach for each value chain of:

- Assessing current and future strengths and weaknesses
- Understanding competitors and suppliers
- Looking at anticipated international market conditions and industry demand
- Understanding the industry's economics and structure (minimum efficient scale, barriers to entry)
- Assessing the size and significance of the opportunity
- And confirming precisely the decisive points along the value chain where Australia could participate (Worrall, 2022c)

Later comes defining the desired pathways for development, designing the required strategies, interventions, and policies and programs, and then putting these into practice in a sector strategy and roadmap, with defined targets and timelines (NSW Government, 2020; The White House, 2021; Worrall, 2022c; Worrall et al., 2021).

The present analysis concerns where to look to commence the process.

Recommendation 1: Adopt Sectoral Targets and Focal Points

That the following sectoral targets, aims and policy ambitions be given priority consideration for later official adoption:

Table 13: Circular economy sectoral targets

Sector	Product(s)	IP Objective(s)	CE Relevance	Decisive point(s) for securing IP Objective(s)
Critical Metals, Value-Adding, Secondary Processing.	Green Steel and Aluminium.	Vertically integrated onshore value chain.	Green electricity. Onshore recycling and reuse.	Securing green electricity. Onshore recycling and reuse.
	Other Critical Minerals (titanium, graphene, silicon, other).	Investigate.	Investigate.	Investigate.
Renewable Energy Products and Components.	Lithium-ion batteries.	Vertically integrated onshore value chain.	Recycling, reuse. Green energy source.	Attaining 'processed material and cell manufacturing' stage, and mass recycling and reuse.
	Wind turbines.	Onshore manufacturing of key selected components; capture more value chain elements over time as scale allows.	Use of green power in production. Generation of green power. Virtuous cycle.	Secure green electricity. Target towers and associated items initially to gain purchase over rest of value chain over time.
	Solar panels.	Onshore manufacturing of key selected components, with selective capture of other components over time as scale allows.	Virtuous cycle. Use of green power in production and generation of green power. Onshore recycling and reuse.	Green electricity close to silicon deposits. Target local production to at least solar module phase. Recycling and reuse of large hump of end-of-life panels this decade.
	Hydrogen electrolysers.	Onshore electrolyser manufacturing industry.	Use of green energy. Generation of green power. Virtuous cycle.	Downward sloping cost curve, rising demand/scale. Decisive point is policy decision to support an onshore manufacturing capability (NRF, SA Hydrogen Jobs Plan, other state initiatives).
The Energy Source	Green Hydrogen.	Integrated onshore value chain, with progressive capture of upstream plant, equipment and technology areas, as scale grows.	Green energy to production, recycling and reuse.	Follow the downward cost curve for electrolysers. Develop capabilities for hydrogen storage and integration with natural gas network for transmission.
Value adding, Decarbonisation, Sovereign Capability, Reindustrialisation				

8 CE Policy Framework

The previous section isolated within the key industry verticals designated in the NRF and SA Hydrogen Jobs Plan, the main areas in which CE practices should play a role. These were sectors with high returns to the nation in the terms of the four defining planks of the mission:

- 'Value-adding in resources through domestic processing (e.g., aluminium and lithium batteries)
- 'Renewables and low emission technologies (wind turbines, solar panels, lithium batteries, low carbon steel and aluminium, hydrogen electrolysers, etc.) '

Now the focus turns more to the horizontal elements of policy that could be applied, in various ways, to each vertical. This section surveys Industry 4.0 and digital technologies, business model innovation, Green Public Procurement, legislative intervention and mechanisms to build scale to identify specifically where these can best contribute to the CE fundamental requirements of 'narrowing, slowing and closing' resource loops. A final element is consideration of the South Australian Hydrogen Jobs Plan.

8.1 Industry 4.0 and Digitalisation

Digital technologies are transforming enterprises, industries, sectors and the global economy. The application of digital technologies to manufacturing (Industry 4.0, the Fourth Industrial Revolution or the Industrial Internet) seeks the creation of high-performance production systems through end-to-end digitalisation of physical assets and integrated vertical and horizontal value chains. This end-to-end digitalisation of enterprises and of whole value chains is more and more setting terms for production and consumption generally. It is increasingly a vector for CE practices at firm, industry and government levels.

The headline definition of Industry 4.0 here adopted is: the application of digital technologies to manufacturing to create high-performance production systems through end-to-end digitalisation of physical assets and integrated vertical and horizontal value chains. An extensive survey of Industry 4.0 definitions from the literatures is given in Worrall and Spoehr (2021).

The merging of the virtual and the physical, the ubiquitous use of sensors to gather data in real time, the real-time networking of products, processes and infrastructure, the use of robotics, big data and analytics, horizontal and vertical systems integration, simulation, augmented reality, additive manufacturing and cyber security: all these characteristics make Industry 4.0 and digitalisation critical to the CE. Digital applications can serve CE objectives in the following ways:

Table 14: Applications of digital technologies to Circular Economy objectives

Smart Factory	Smart products	Smart operations	Data driven services
• Productivity improvement • Improved asset utilisation and reduced downtime • Reduced waste • Reduced inventory	• Remote diagnostics • Digitalisation of product and service offerings • Data analytics for condition monitoring • Predictive maintenance	• Reduced wastage and faults • Improved optimisation of production and operations • Ability to manage data across supply chain • Ability to network all partners with real time information	• Remote problem resolution • Ability to add services to product portfolio • Through life support services • Predictive maintenance • Environmental monitoring

• Real time supply chain optimisation • Better planning, vertical integration across supply chains • Reduced carbon footprint		• Data analytics for collaboration within the firm and across the supply chain • Pooled data for supply chain collaboration • Reconfigurability of production • Reduced energy consumption • Potential for better jobs • Better production lifecycle management	• New business models/service enhancement.

Note: Edited from Worrall and Spoehr (2021). For analysis of the links of CE to digital production systems see also: Tonelli and Cristoni (2019) and OECD (2018).

These attributes of Industry 4.0 can serve greater circularity and its aims of increased resource efficiency in production, and use of secondary materials to replace virgin material exploitation. Digital technologies also support bundling of services with products, extended product life, through-life performance monitoring and objective data on material and product history. Industry 4.0 assists the application and achievement of the key CE principles of 'closing, slowing and narrowing':

- Digital technologies help close resource loops to reduce materials extraction and waste through increased recycling and use of secondary materials by:
  - Sensors assisting in resource recovery, and materials separation for recycling, reuse and remanufacture
  - Superior production controls and use of inputs through access to real time data, reducing waste and increasing resource efficiency in production or in recycling or remanufacturing
- Digital technologies help slow the resource loop through longer-life products and improved reuse and repair opportunities by:
  - Data analytics for production optimisation and condition monitoring in real time
  - Predictive maintenance helping to keep equipment in use for longer through real time monitoring, and expanding options for repair prior to more serious damage or compromise of the product or material
  - Digital histories of products and materials to assure their continued use, or alternatively their potential for reuse, repair, remanufacture or recycling
  - Improved lifecycle management and more intensive use of productive assets with reduced downtime
- Digital technologies can narrow the resource flow by enabling expanded sharing practices and service models resulting in more intensive asset use:
  - Coordination of transport systems and equipment to enable scheduling and sharing of transport equipment
  - Digital coordination for more intensive use of buildings
  - Sharing and more intensive use of industrial equipment along the supply chain, often remotely.

Recommendation 2: Promote Industry 4.0 Applications to the CE in NRF-Supported Projects

That, noting Industry 4.0 is integral to both the CE and the reindustrialisation, decarbonisation and value-adding objectives of the NRF, consideration be given to resourcing to ensure NRF-supported projects and businesses are comprehensively assessed for digital readiness and competence, together with use of digital technologies to build Australian industry participation and the onshore value chain, and the ability to apply CE principles as appropriate.

This should include enlistment and networking of the various intermediate organisations and living labs around the country to become more systematically articulated to the needs of the national strategy.

8.2 Business Model Innovation and CE

Both the CE and digital technologies simultaneously enable and require changes in business models. Sometimes these dramatically change how the firm or the entire value chain is organised internally and externally in relation to its markets. Both 'digital' and the CE imply changes in economic structure and new business models, in which value is created through such things as greater use of secondary materials, greater waste recovery for use in production of secondary raw materials, product life extension through reuse, repair or remanufacture, and greater bundling of services with product offerings (servitisation) (OECD, 2019a, 2021; Tonelli & Cristoni, 2019).

What was formerly a business cost can become new value, a new product or market, and a revenue source. The business model is reconfigured from a single transaction (sale) of the product repeated as often as possible, with a longer-term relationship between producer and purchaser underpinned by the bundling of services with the product(s). This may require a business's revenue model to go from profit on sale to revenue extended potentially to the end of the life of the product, or its reuse, remanufacture or recycling. Between production of the product and its end of life, the vendor may have provided condition and real-time performance monitoring, preventative maintenance (using sensors and other digital technologies), and through-life modular equipment upgrades. For both vendor and purchaser, a relatively larger part of the revenue or cost of providing the product comes from the associated services compared to production costs. This involves high levels of collaboration between vendors and customers.

The bundling of products with services extends the life of materials and products in line with 'reuse, repair and remanufacture'. Extended Producer Responsibility (EPR) initiatives align with this ethos, paying particular attention to environmentally responsible recycling, reuse or disposal at the product's end-of-life.

The OECD (2019a) has classified and examined business models for their relevance to and impact upon the CE. Business model innovation contributes to the three fundamental requirements of 'closing, slowing and narrowing':

- Closing:
    - Circular supply models replace virgin materials with secondary ones
    - Resource recovery to recycle waste into secondary raw materials
    - Industrial symbiosis
- Slowing:

    - Product life extension or Extended Product Responsibility (EPR)/Product Stewardship to keep existing products in use for as long as possible
    - Product service system models, or servitisation, or manufacturing as a service, service- enhanced manufacturing, that combine production and sale of a product and technology with ongoing services and guarantees of outcomes and performance. These business models favour keeping products and equipment in more intensive use for longer, and include use of digital technologies
    - Remanufacture to rebuild a product or component using reused, repaired and new parts
- Narrowing:
    - Sharing models to increase the intensity of underutilised assets to reduce demand for new ones

Product service system models are definitive of business model innovation in general, and most connected to Industry 4.0 and digital technologies. Regardless of this, it is also notable that all definitions cited refer to business model innovation as industrial processes, systems, and symbiosis (in which the by-product of one industry becomes the raw material of another).

The OECD (ibid) finds that whilst current levels of CE business model innovation are rather low ("no more than 5 to 10% in economic terms" – p 13), the majority of these models are scalable with expected increased demand. It finds current rates of secondary production of metals such as steel, aluminium, and copper to be low at between 15 and 30 percent, with newer metals such as lithium at negligible levels. Remanufacturing remains small as a share of total manufacturing consumption and output, with its labour intensity seen as an impediment to broad application.

Not only individual firms but also governments and public authorities concern themselves with promotion of business model innovation through policies and programs. This is because the understanding of the economic opportunities is not automatically provided through an unrealistic and idealised version of the market automatically dispensing free knowledge, but impeded by endemic forces, including asymmetric information. Systems defined by public good principles are critical to efficient market economies (Stiglitz, 2010).

Product Stewardship or Extended Producer Responsibility (EPR) helps extend producer responsibility over the whole product lifecycle, internalising costs of end-of-life disposal or recycling. It can be supported by application of digital technologies. In Australia the relevant legislation on EPR, (here called product stewardship, (Product Stewardship Act 2011), is over a decade old, has limited breadth of application and has no mandatory powers. There is support from the waste and recycling industry to reconsider the ambit of this legislation.

Recommendation 3: Link Promotion of Service-Enhanced Business Models to Promotion of CE Practices in NRG-Supported Projects

That in connection with the NRF's recommended promotion of Industry 4.0, a focus also be placed on advice and assistance on adoption of new business models consequential to digital adoption and CE objectives. This should include consideration of updated legislation and requirements relating to Extended Product Responsibility (EPR) or Product Stewardship.

8.3 Strategic and Green Public Procurement (GPP)

Previously AITI surveyed the rationale, applications and key underlying factors for the success of 'advanced', 'innovation' or 'strategic' procurement, as practiced in Europe, the US and the UK (Worrall et al., 2022). Government procurement is increasingly used as an instrument of industrial policy, just as industrial policy itself is being deployed to accelerate the development of new green products, and to help address largescale societal challenges such as global warming.

Across advanced economies strong demand-pull policies of public procurement are in use to deliberately stimulate and accelerate the development of new products, services and technologies. The principle at work is to use the immense demand-pull and purchasing power of the public sector in a directional manner to bring into existence new products, services and technologies – where the unassisted private market would not.

Public purchasing power is deployed to create and capture national economies of scale, as well as to use that purchasing power as a demanding lead customer with detailed knowledge of the nature of the problem to be solved, able to drive technical improvement along the value chain. The focus is on capturing technological advantage and spill overs, and industries vital to effective national sovereignty, and the avoidance of excessive external reliance: communications technology, electronics and software, aerospace, medical technologies, and especially defence. A key element is mapping of, and an interventionist orientation to, key value chains.

Australia has vastly underplayed the strategic potential of public procurement in influencing the future development of its industrial structure. There are many ways in which the NRF and associated entities (such as the Buy Australian Plan and Future Made in Australia Office, strengthening of existing Commonwealth Procurement Rules) could help direct largescale public and private procurement towards value chain development as recommended in the 'Sectors, Products and Materials' section above.

Green Public Procurement (GPP) principles could be operationalised within the larger more ambitious strategic procurement framework advocated. GPP sets expectations and standards for supply of selected products to the public sector. This helps promote innovation and gives desired direction to production and consumption norms for the CE. Where the public sector is a significant customer in environmentally- and resource-intensive sectors such as construction, health services, public transport, communications technology and IT, GPP can be a powerful setter of new directions. This can include ERP provisions.

GPP contributes to the three fundamental requirements of 'closing, slowing and narrowing' by use of largescale purchasing power to shape future markets by setting standards and other measures that favour economically efficient production of goods with closed, slowed, or narrowed resource loops.

Recommendation 4: Commit to Sector-Focused and Targeted Use of GPP

That the Commonwealth announce its future intention to apply GPP principles following investigation of the appropriate design, scope, and nature of a GPP program. This time-limited investigation and design phase would involve consultation with the states to help build scale, alignment and support. Focus sectors would likely include: construction and urban development, electricity grid renewal, and public transport. The roll-out of a GPP framework should be staged to reflect highest priority and beneficial impact, and to allow the gaining of knowledge and experience.

Recommendation 5: Commit to Targets for Application of GPP That Build Over Time

That the endorsed national GPP principles, programs and framework include time-based and progressive GPP targets in collaboration with the states for GPP expenditure as a proportion of total procurement.

8.4 Building Scale: Focus on Batteries and Solar Panels

The Biden Order examines the US's lagging uptake of lithium-ion battery technologies and production capabilities. Scale is critical. It criticises the failure to promote actively the end markets for battery power that would grow scale, together with failure to address structural and technical barriers to greater recycling and reuse. In the latter, the main factors are the complicated intermingling of different metals in a battery, their weight and involvement with hazardous materials (making transport difficult) and by-products, and especially the dispersion and failure to invest in collection and recycling infrastructure.

In countering weak domestic production and overdependence on foreign supplies, the Biden Order argues domestic scale must be stimulated through deliberate demand-side measures involving large scale electrification of transport systems, building demand for batteries in utilities and public procurement, building EV charging infrastructure, and so on.

Issues of scale and inadequacy of infrastructure apply with greater force to Australia. Australia also has very low rates of recycling, and almost none onshore. The White House (2021) and Beyond Zero Emissions (2020) are positive about concentrated effort on recycling and reuse to stimulate scale and upstream production. Australia must catchup by building infrastructure such as charging stations, and collection and recycling centres, as well as accelerating market penetration of EVs on the private market, and electric public and freight transport equipment, where opportunities exist for Australian production.

Australia has a national product stewardship scheme for small scale battery recycling, whilst a business offers mixed battery recycling which promises recycling and reuse of 95 percent of recovered materials, including reduction of used lithium, cobalt, graphite and nickel for reuse.

Given low EV penetration rates, however, there would seem to be little capacity for onshore recycling of valuable large, heavy batteries. As EV use is to increase, development of onshore recycling and reuse will need to be planned for the end of the decade.

Australia has the highest uptake of solar globally, with around 30 percent of homes with rooftop solar PV (Department of Climate Change Energy the Environment and Water, 2022). These are coming to the end of their lives and under the current policy settings will simply go to landfill. The significant scale of Australia's household solar represents an industrial opportunity to develop a strong domestic recycling and reuse capability, together with regaining upstream manufacturing capabilities.

Building scale facilitates closing, slowing, and narrowing resource loops by lowering cost curves for both production and recycling, reuse, and remanufacture of these essential products. When this occurs, barriers to entry to the industry fall and potential private revenues increase. But the deliberate organisation of the demand side factors enabling this is critically one for public policy.

Building scale requires infrastructure investment, use of GPP, and promotion of business models that internalise the social cost of a product over its full life. Such business models bundle services with products to create an ongoing relationship between vendor and user beyond point of sale. In Europe particularly, these are promoted legislatively by EPR (here known as Product Stewardship, a Federal Act over a decade old, without mandatory provisions and arguably of narrow scope).

Greater scale delivers potential for:

- 'slowing' through application of Industry 4.0 for real time performance monitoring of battery and solar cells, greater research and development into different battery chemistries with longer use life, and lowering cost curves by bringing end of life costs and recycling into purchase price
- 'closing': through recycling of batteries and solar panels with deposit and other price schemes and application of EPR/Product Stewardship principles, and remanufacturing of used battery and solar panel components, including to alternative uses (e.g. battery reuse from EVs into stationary power facilities).

It is rational and important to focus efforts to build scale on areas of high return to the key four goals. Because of their strategic importance, concentrated effort on recycling and reuse of batteries and solar panels, with an immediate start to planning and design, should be prioritised.

Recommendation 6: Build Scale for Recycling and Reuse Focussed on Batteries and Solar Panels

That consideration be given to a suite of measures targeted to build scale for a battery and solar panel recycling and reuse industry, to include consideration of an ambitious EPR/Product Stewardship initiative, use of deposit charges for disposal, and GPP involving deliberate use of secondary battery and solar panel materials, focussed R&D, and targeted investment attraction.

Recommendation 7: Set Targets and Aim for Scale by the End of the Decade

That the effort to build scale for recycling and reuse of batteries and solar panels be on measures that reach maximum effect by the end of this decade, and that the combination of measures eventually agreed be supported by time-bound targets.

8.5 A Vision for Resource Efficiency and the CE

The measures recommended above can be supported through an overarching statement of purpose, direction and intent, of the kind recently advocated by the OECD. This made resource efficiency and the planks of narrowing, slowing and closing material loops the backbone of the CE. It emphasised integration that promotes the more efficient use of natural resources, the use of more durable products, and recycling, reuse, repair and remanufacturing, together with improved end-of-life sorting and treatment (OECD, 2021).

It further stressed integration by stating: "Resource efficiency policies should target all stages of materials lifecycle, namely material extraction, transport, manufacturing, consumption, recycling and disposal" (Ibid, 38), with key policy planks being EPR, GPP and development of partnerships and coordination across stakeholders.

Recommendation 8: Adopt CE and Resource Efficiency Vision Statement With Time-Based Targets

That adoption of the above recommended directions be supported by an explicit statement of purpose, direction and intent in favour of the CE and resource efficiency. That statement should link the CE and resource efficiency to Australia's reindustrialisation, decarbonisation, value-adding to national resources and enhanced sovereign capability, and include time-based targets.

8.6 South Australian Hydrogen Jobs Plan

As outlined previously, the SA Hydrogen Jobs Plan is of great importance as a major public intervention in a privatised electricity market which, over two decades, has failed tests of supply, affordability and investment and most particularly those coordination tasks associated with reducing fossil fuel dependency. This is in addition to the project's importance in providing firming and additional stability to the grid to help further the reliability of renewables and allow further expansion of and investment in the renewable power industry.

Australia should aim to create a vertically-integrated onshore green hydrogen value chain. One group of challenges to this comes upstream of the actual production of green hydrogen, and these challenges are underlined by the SA Plan. It is the onshore (versus offshore) manufacture of major plant, equipment and technology, and their integration into systems. MNCs such as Siemens and GE dominate supply, providing turnkey modular units and integration of systems operating the plant and equipment.

This form of supply is familiar to those with experience of largescale procurement for the resource industry (particularly offshore oil and gas) and parts of the defence industry in Australia over recent decades. The model favours maximum capture by the overseas vendor over opportunities to use the procurement's scale to expand opportunities for local industry development and onshore value chains. This undermines the goal of a vertically integrated value chain supporting the larger goals of reindustrialisation, value adding and sovereign capability, as well as greater circularity.

The NRF specifically targets electrolysers as a development opportunity. The SA Plan projects 200 MW of power generation capacity using 250MWe of electrolysers. The SA plant is to be operational by end 2025. This timeframe implies reliance on imported integrated modular systems which could cancel local industry participation, and with it, at least some aspects of circularity. As described above, there exists some Australian and South Australian capability in water-based electrolysis, which requires proper assessment and analysis. Fortescue Future Industries (FFI) aims to establish an onshore electrolyser manufacturing facility from 2023 at Gladstone.

Discussion and negotiation should be undertaken between the South Australian government, the NRF and foreign vendors as well as potential local manufacturers, to develop an agreed local industry participation framework and strategy, that builds local capability and extends the scale and scope of Australian capture of the upstream components of the hydrogen value chain over time. The quantity and quality of Australian industry participation should be a weighted element in assessment of bidders' proposals.

Recommendation 9: Identify Strongest Potential for Australian Industry to Supply Plant, Equipment and Technology to the South Australian Project and an Onshore Hydrogen Industry

That the South Australian government, in cooperation with the NRF and Future Made in Australia Office, assess potential for Australian engineers and manufacturers to gain a foothold in the upstream manufacturing of plant and equipment, engineering, process and services areas of the green hydrogen value chain, including electrolysers, as well as opportunities in through-life support.

Recommendation 10: Develop a Plan and Strategy for Australian Industry Participation

That the South Australian government develop an Australian industry participation plan and strategy for its hydrogen project and for the longer-term growth of a vertically-integrated onshore hydrogen industry with a focus on technology and plant and equipment requirements. This would influence the later design of a national framework and dovetail with it. The strategy's scope would encompass local industry participation rules, processes and objectives, together with capability development including a focus on SMEs, targeted R&D and technology development, and linkages to adjacent industries to build scale, such as ammonia.

9 Bibliography

Advisory Board for Circular Economy. (2017). *Recommendations for the Danish Government*.

Aiginger, K., & Rodrik, D. (2020). Rebirth of Industrial Policy and an Agenda for the Twenty-First Century. *Journal of Industry, Competition and Trade, 20*(2), 189-207. doi:10.1007/s10842-019-00322-3

Australian Industrial Transformation Institute. (2021). *Manufacturing Transformation: high value manufacturing for the 21st Century*. Retrieved from Adelaide:

Australian Trade and Investment Commission. (2018). *The Lithium-Ion Battery Value Chain: New Economy Opportunities for Australia*.

Backer, K. D., Desnoyers-James, I., Moussiegt, L., & Ragoussis, A. (2015). *Australian Manufacturing in the Global Economy*. Retrieved from

Bastein, A., Roelofs, E., Rietveld, E., & Hoogendoorn, A. (2013). *Opportunities for a Circular Economy in the Netherlands*: Delft: TNO.

Beyond Zero Emissions. (2020). *The Million Jobs Plan: A unique opportunity to demonstrate the growth and employment potential of investing in a low-carbon economy*. Retrieved from https://bze.org.au/research_release/million-jobs-plan/:

Bibas, R., Chateau, J., & Lanzi, E. (2021). *Policy scenarios for a transition to a more resource efficient and circular economy*. Retrieved from

Blomsma, F., & Brennan, G. (2017). The emergence of circular economy: a new framing around prolonging resource productivity. *Journal of Industrial Ecology, 21*(3), 603-614.

Bocken, N. M. P., Olivetti, E. A., Cullen, J. M., Potting, J., & Lifset, R. (2017). Taking the Circularity to the Next Level: A Special Issue on the Circular Economy. *Journal of Industrial Ecology, 21*(3). doi:10.1111/jiec.12606

Boechler, E., Hanania, J., Heffernan, B., Sheardown, A., Stenhouse, K., & Donev, J. (2021). Energy Education - Wind turbine. Retrieved from https://energyeducation.ca/encyclopedia/Wind_turbine

Brears, R. C. (2018). *Natural Resource Management and the Circular Economy*. London: Palgrave Macmillan.

Bruce, S., Temminghoff, M., Hayward, J., Schmidt, E., Munnings, C., Palfreyman, D., & Hartley, P. (2018). *National Hydrogen Roadmap*. Australia

Circular Economy Promotion Law of the People's Republic of China, (2008).

Department of Climate Change Energy the Environment and Water. (2022). Solar PV and batteries. Retrieved from https://www.energy.gov.au/households/solar-pv-and-batteries

Donovan, S., & Pickin, J. (2021). *Exports of Australian waste and recovered materials in 2020-21*. Retrieved from

Eisenriegler, S. (2020). *The Circular Economy in the European Union: An Interim Review*.

Ekins, P., Domenech, T., Drummons, P., Bleischwitz, R., Hughes, N., & Lotti, L. (2019). *The Circular Economy: What, Why, How and Where*. Retrieved from Paris:

Ellen Macarthur Foundation. (2015). *Growth Within: A Circular Economy Vision for a Competitive Europe*. Retrieved from

EPA. (2015). *U.S. EPA Sustainable Materials Management Program Strategic Plan*.

European Commission. (2015). *Closing the loop - An EU action plan for the Circular Economy*. Brussels

European Commission. (2020). *A new Circular Economy Action Plan For a cleaner and more competitive Europe*.

FPS Economy, & FPS Public Health. (2014). *Towards a pioneering circular economy Belgium*.

Garnaut, R. (2019). *Superpower: Australia's low-carbon opportunity*: La Trobe University Press.

Ghosh, S. K. (2020). Introduction to Circular Economy and Summary Analysis of Chapters. In S. K. Ghosh (Ed.), *Circular Economy: Global Perspective*: Springer.

Government of Canada. (2018). Dialogue on Plastic Waste: Online consultation for moving Canada toward zero plastic waste. Retrieved from https://www.canada.ca/en/environment-climate-change/news/2018/04/dialogue-on-plastic-waste-online-consultation-for-moving-canada-toward-zero-plastic-waste.html

Hausmann, R., Hidalgo, C. A., Bustos, S., Coscia, M., Simoes, A., & Yildirim, M. A. (2013). *The Atlas of Economic Complexity: Mapping Paths to Prosperity*: MIT Press.

Hidalgo, C. A., & Hausmann, R. (2009). The building blocks of economic complexity. *Proceedings of the National Academy of Sciences, 106*(26), 10570-10575. doi:10.1073/pnas.0900943106

Hidalgo, C. A., Klinger, B., Barabási, A.-L., & Hausmann, R. (2007). The Product Space Conditions the Development of Nations. *Science, 317*(5837), 482-487. doi:10.1126/science.1144581
HM Government. (2018). *Industrial Strategy: building a Britain fit for the future*.
Keulemans, G. (2021). We've smelted a billion tonnes of recyclable aluminium. Do we need to make more? *The Conversation*.
Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, conservation and recycling, 127*, 221-232.
KPMG. (2020). *Potential Economic Pay-off of a Circular Economy*. Retrieved from
Lacy, P., Long, J., & Spindler, W. (2019). *The Circular Economy Handbook: Realizing the Circular Advantage*: Palgrave Macmillan UK.
Lambert, C. (2018). The EU Circular Economy vision: a powerful force for climate action. In E. Commission (Ed.).
Levitzke, P. S. M. V. (2020). The Development of a Circular Economy in Australia. In S. K. Ghosh (Ed.), *Circular Economy: Global Perspective*.
Lowe, M., Gereffi, G., Ayee, G., Goyal, M., Robinson, J., & Tsai, A. (2009). Manufacturing Climate Solutions. In: Centre on Globalization Governance & Competitiveness.
Mao, J., Li, C., Pei, Y., & Xu, L. (2016). *Circular Economy and Sustainable Development Enterprises*: Springer.
Matthews, J. A., & Tan, H. (2016). Lessons from China. *Nature, 531*(The Circular Economy), 440-442.
Mazur-Wierzbicka, E. (2021). Circular economy:advancement of European Union countries. *Environmental Sciences Europe, 33*(111). doi:https://doi.org/10.1186/s12302-021-00549-0
Mealy, P., & Teytelboym, A. (2020). Economic complexity and the green economy. *Research Policy*.
Melles, G. (2021). Figuring the Transition from Circular Economy to Circular Society in Australia. *Sustainability, 13*(19), 10601.
Never waste a crisis: the waste and recycling industry in Australia, The Senate, (2018).
NSW Government. (2020). *Australian Semiconductor Sector study*.
OECD. (2018). *RE-CIRCLE Resource Efficiency & Circular Economy Project*. Retrieved from
OECD. (2019a). *Business Models for the Circular Economy: Opportunities and Challenges for Policy*. Retrieved from Paris:
OECD. (2019b). *Waste Management and the Circular Economy in Selected OECD Countries*.
OECD. (2020). *Environment at a Glance 2020*. Retrieved from Paris:
OECD. (2021). *Towards a more resource-efficient and circular economy. The role of the G20*. Retrieved from
Otter, C. (2018). *The Circular Economy: An explainer*. Parliament of Victoria
Phiddian, E. (2021). How to make electrolysers and other hydrogen equipment in Australia. *Cosmos*. Retrieved from https://cosmosmagazine.com/technology/energy/electrolysers-hydrogen-fuel-manufacture-australia/
Purtill, J. (2021). What is green hydrogen, how is it made and will it be the fuel of the future? *ABC Science.* Retrieved from https://www.abc.net.au/news/science/2021-01-23/green-hydrogen-renewable-energy-climate-emissions-explainer/13081872
PwC. (2018). *Closing the loop - the circular economy, what it means and what it can do for you*. Retrieved from
Rodrik, D. (2014). Green industrial policy. *Oxford Review of Economic Policy, 30*(3), 469-491.
Roos, G. (2020). Some issues around moving towards a more sustainable economy.
Schandl, H., King, S., Walton, A., Kaksonen, A., Tapsuwan, S., & Baynes, T. (2020). *National circular economy roadmap for plastics, glass, paper and tyres*. Australia
Sillanpaa, M., & Necibi, C. (2019). *The Circular Economy: Case Studies about the Transition from the Linear Economy*: Elsevier Science & Technology.
Stanford, J. (2020). *A Fair Share for Australian Manufacturing: Manufacturing Renewal for the Post-COVID Economy*. Retrieved from https://www.futurework.org.au/a_fair_share_for_australian_manfacturing:
Stiglitz, J. (2010). *Freefall: Free Markets and the Sinking of the Global Economy*: Penguin Books Limited.
The Warren Centre. The Circular Economy: Global trends and future challenges [Press release]
The White House. (2021). *Building resilient supply chains, revitalizing american manufacturing, and fostering broad-based growth*.
Tonelli, M., & Cristoni, N. (2019). Strategic Management and the Circular Economy. *Routledge Research in Strategic Management*.
United Nations. (2020). *Global Resources Outlook 2019: Natural Resources for the Future We Want*: United Nations Environment Programme.

von Clausewitz, C. (1832). *On War* (A. Rapoport Ed. 1968 ed.): Penguin Books.
Wijkman, A., & Skånberg, K. (2015). The circular economy and benefits for society. *Club of Rome*.
Wood, T., & Dundas, G. (2020). *Start with steel: A practical plan to support carbon workers and cut emissions*. Retrieved from https://grattan.edu.au/report/start-with-steel/:
Worrall, L. (2022a, 7 February). Can-do Capitalism and a do-nothing government. *@AuManufacturing*. Retrieved from https://www.aumanufacturing.com.au/can-do-capitalism-and-a-do-nothing-government
Worrall, L. (2022b, 28 April). Election 22 The Real Issues - Political Leadership. *@AuManufacturing*. Retrieved from https://www.aumanufacturing.com.au/election-22-the-real-issues-political-leadership-by-lance-worrall
Worrall, L. (2022c, 14 March). How to Reindustrialise Australia. *@AuManufacturing*. Retrieved from https://www.aumanufacturing.com.au/how-to-reindustrialise-australia-by-lance-worrall
Worrall, L. (2022d, 17 February). Labours National Reconstruction Fund: A Path to Reindustrialisation. *@AuManufacturing*. Retrieved from https://www.aumanufacturing.com.au/labors-national-reconstruction-fund-a-path-to-reindustrialisation
Worrall, L., Gamble, H., Spoehr, J., & Hordacre, A.-L. (2021). *Australian Sovereign Capability and Supply Chain Resilience - Perspectives and Options*. Retrieved from Adelaide:
Worrall, L., & Spoehr, J. (2021). *Naval Shipbuilding and Industry 4.0. Building the Value Chain and Industry Capability*. Retrieved from Adelaide:
Worrall, L., Spoehr, J., & Gamble, H. (2022). *Innovation Procurement - Lessons for Australia*. Retrieved from Adelaide: