Office of Energy and Climate Change

Going circular in clean energy

Issues paper

To understand how NSW can create more value from a circular clean energy sector

January 2023

The Office of Energy and Climate Change is part of the Treasury Cluster

Acknowledgment of Country

We acknowledge that Aboriginal and Torres Strait Islander peoples are the First Peoples and Traditional Custodians of Australia, and the oldest continuing culture in human history.

We pay respect to Elders past and present and commit to respecting the lands we walk on, and the communities we walk with.

We celebrate the deep and enduring connection of Aboriginal and Torres Strait Islander peoples to Country and acknowledge their continuing custodianship of the land, seas and sky.

We acknowledge the ongoing stewardship of Aboriginal and Torres Strait Islander peoples, and the important contribution they make to our communities and economies.

We reflect on the continuing impact of government policies and practices, and recognise our responsibility to work together with and for Aboriginal and Torres Strait Islander peoples, families and communities, towards improved economic, social and cultural outcomes.

Artwork:
Regeneration by Josie Rose

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Introduction

Globally, there is broad recognition of the need to take urgent action on climate change. The NSW Government is working to address climate change by committing to reduce our emissions by 70% by 2035 and achieve net zero emissions by 2050. Backed by significant investment, we are delivering a range of initiatives that will help accelerate emissions reductions.

The path to a net zero emissions economy in the coming decades is driving exponential demand and deployment of clean energy technologies. This rapid growth is leading to concerns about environmental impacts, large increases in clean energy technology waste, resource supply constraints, national security risks, and a just transition for workers. These concerns may hinder the clean energy transition if not adequately addressed.

We need to make the entire cradle-to-grave process of designing, producing, deploying, and decommissioning clean energy technologies is sustainable.

> The NSW clean energy revolution must leverage the circular economy for a more sustainable transition.

Adopting circular economy principles for clean energy technologies presents a significant opportunity for NSW to build new economic value from industries across the clean energy supply chain while reducing waste, emissions, and environmental impacts.

There are several barriers to advancing the circular economy. NSW lacks effective and mature recovery and reuse systems for many end-of-life clean energy products. NSW also has limited capacity to deliver key parts of the supply chain, such as material processing, manufacturing, and assembly.

NSW is well-placed to overcome many of these barriers and seize key opportunities. We have internationally respected research in clean technology innovation and a unique opportunity to build local manufacturing. NSW Government initiatives such as the $250 million Renewable Manufacturing Fund and Special Activation Precincts can play a key role in this transition.

While much of the energy sector is focused on net zero goals and expanding the clean energy market, the environmental impacts of the energy transition are often overlooked. Applying a circular lens to consider some of the issues and opportunities is important to help secure a low carbon future that minimises waste, creates additional value in supply chains and mitigates pollution.

Purpose of the issues paper

This paper aims to outline some of the issues NSW faces in progressing a circular economy for clean energy technologies. This paper does not propose solutions but aims to start a conversation to help us understand key barriers and opportunities to adopting a circular economy for clean energy.

We welcome feedback from stakeholders across the clean energy value chain. This paper poses several questions to guide feedback. Your feedback may be used to inform the development of a circular economy plan for the clean energy sector in NSW.

This discussion is supported by the joint commitment from the Federal, State and Territory Environment Ministers to work with the private sector to design out waste and pollution, keep materials in use, and foster markets to achieve a circular economy by 2030.

Defining a circular economy

The circular economy involves shifting away from a linear 'take, make, use and dispose' approach towards one that maximises the value of resources. This means instead of taking resources from the earth, using them once, and disposing of them in landfill, resources are kept in use and circulating through the economy for as long as possible.

The circular economy is driven by 3 key principles:

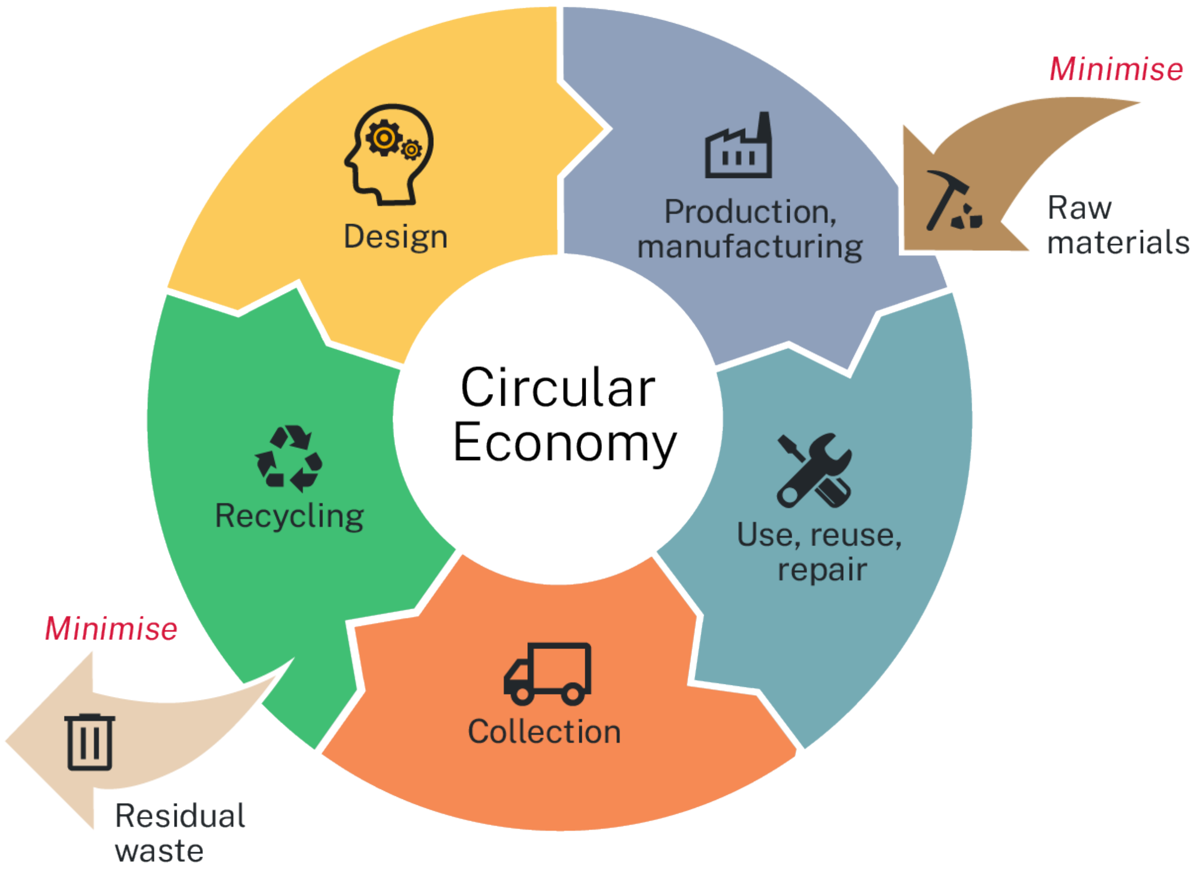
- eliminate waste and pollution
- circulate and reuse products and materials (at their highest value)
- regenerate nature.

The circular economy is a systems-based solution, centred on design, that tackles global challenges like climate change, biodiversity loss and pollution. It incorporates more than material flows – its principles are applied to other resource systems including water and energy.

It transforms our throwaway economy into one where we eliminate waste, circulate resources, and adopt nature-positive, low carbon, resource-efficient systems and actions.

Figure 1 below demonstrates the key elements of the circular economy. We note that all elements are interconnected and may interact at multiple points within the circular economy.

Figure 1: Key elements of the circular economy



A circular economy for clean energy technologies can provide benefits for NSW

Linear supply chains currently dominate the rapid uptake of clean energy technologies. As NSW advances our net zero goals, we must ensure the transition has a focus on protecting natural capital, minimising waste and finding new sources of value.

The circular economy offers opportunities for new and better growth that help safeguard and rebuild biodiversity, tackle climate change and improve air and water quality. [1] It is estimated that circular economy strategies could cut global greenhouse gas emissions by 39%[2] (equivalent to 22.8 billion tonnes) and reduce our long-term dependence on mining for critical metals used in clean energy technologies.[3]

A circular economy for clean energy technologies can help decouple economic growth from the use of finite virgin resources. This will promote the recovery and reuse of materials, reduce environmental impacts, enhance local manufacturing and create jobs in NSW.

It is expected that expanding further along the battery mineral value chains could support 34,700 jobs in Australia by 2030.[4] To deliver on this potential, we need to build local capabilities in downstream refining, manufacturing and integration of services, such as reusing and recycling battery materials, which are key elements of the circular economy.[5]

The circular economy can also help NSW achieve many of the United Nations' Sustainable Development Goals, with specific goals aimed at protecting the environment and encouraging responsible consumption and production. By reducing negative externalities and retaining value throughout the supply chain, we can support the delivery of these goals in the clean energy industry.

While transitioning to a circular economy is not the only solution, it can play an important role in addressing some of the challenges with our clean energy transition in NSW.

Scope

This paper examines issues around the clean energy value chain for current and emerging clean energy generation and storage technologies.

This includes solar photovoltaics (solar), wind, battery storage, electric vehicle (EV) batteries, hydroelectricity, pumped hydro energy storage (PHES) and green hydrogen. It covers all materials, equipment, and assets involved in clean energy technologies. This includes these technologies at residential, commercial and utility scale.

The clean energy value chain includes all elements across the technology lifecycle, from design and manufacturing to recycling and end-of-life waste management. It also includes the business models that support the clean energy industry.

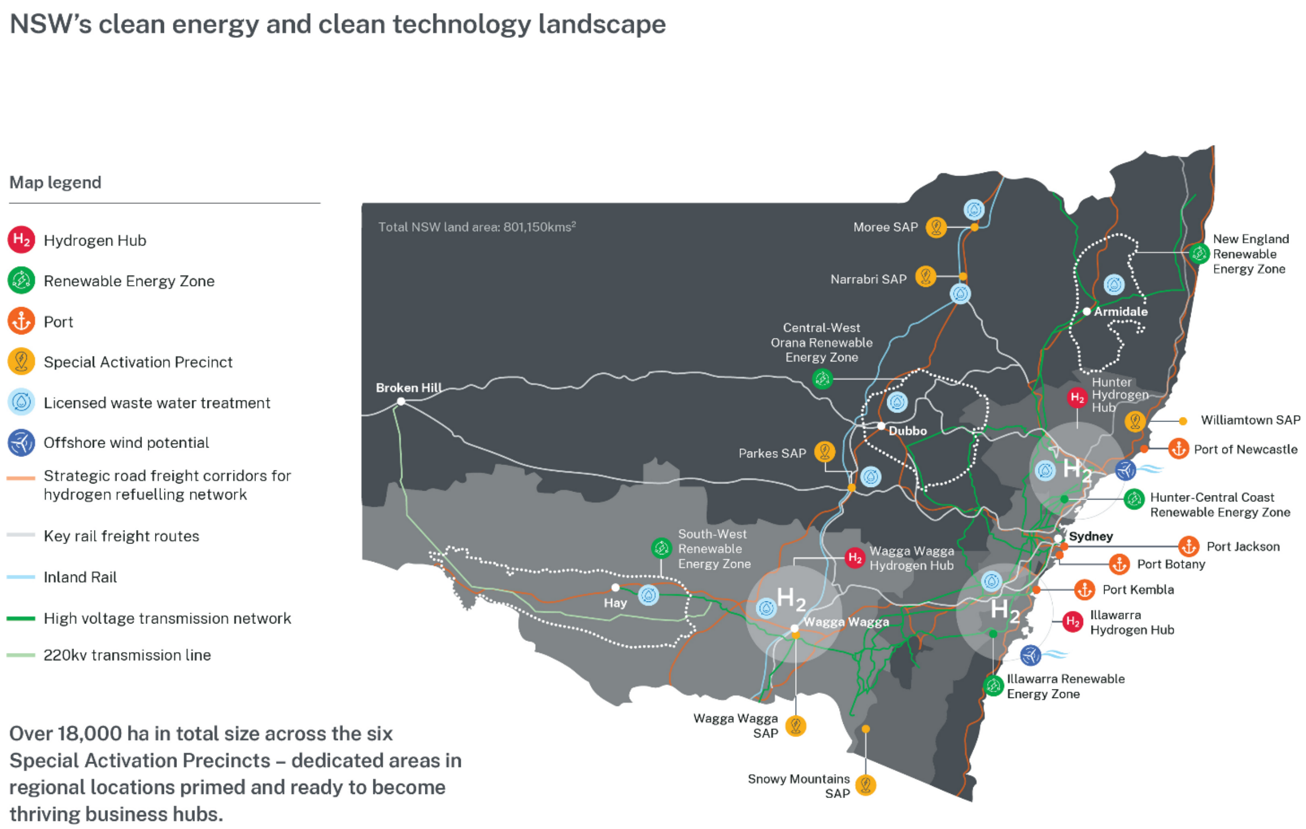
Exclusions

The scope does not include bioenergy or energy from biomass sources. It does not include offsite supporting energy infrastructure, such as transmission lines and substations.

Policy, program and funding landscape

NSW is leading the nation in taking action on climate change, accelerating our path to net zero and strengthening our state's prosperity and future growth. To support this transition, the NSW Government has launched ambitious policies, programs and initiatives. These are outlined in Appendix 1 and visually represented in **Figure 2**.

Figure 2: NSW's clean energy and clean energy technology landscape



Issues

This section explores some of the issues and opportunities associated with the management of clean energy technologies and the potential role the circular economy may play in improving outcomes.

Issues are discussed in reference to a particular stage of the circular economy, as per figure 1. However, many of these issues are not isolated to a single element in the circular economy and may span multiple elements across the circular lifecycle.

1. Raw materials

Mining or harvesting raw materials can have detrimental environmental and social impacts. Reliance on international markets can lead to supply chain disruptions that can jeopardise national energy security and delivery of our net zero targets.

A circular economy for clean energy materials can help alleviate some of these issues by bolstering secondary supply of the critical minerals essential to the clean energy transition.

The demand for critical minerals is outpacing supply

Evidence suggests clean energy technologies typically require significantly more mineral resources than existing fossil fuel-based energy production infrastructure.[6] These minerals are known as critical minerals due to their essential role in modern technologies such as clean energy. A summary of the critical minerals required for clean energy technologies is provided in Table 1 below.

The International Energy Agency (IEA) found that a concerted effort to reach the goals of the Paris Agreement would mean a quadrupling of mineral requirements for clean energy technologies by 2040. [7]

The projected increase in demand for critical minerals raises concerns about the availability and reliability of supply. This in turn risks delaying the delivery of the clean energy technology essential to reducing global emissions.[8] For example, the expected supply from existing mines and projects under construction globally is estimated to meet only half of projected lithium and cobalt requirements and 80% of copper needs by 2030.[9]

Improved recovery and recycling can help relieve the pressure on primary mineral supply. The Minerals Council of Australia has noted that a strong focus on minimising waste supports the development of the circular economy. It generates new opportunities to recycle and reuse the materials used and produced by the industry.[10]

While a circular economy for metals would not eliminate the need for new mineral extraction, it would reduce reliance on extractive processes. The IEA estimates that by 2040, recycled copper, lithium, nickel and cobalt from used batteries alone could meet around 10% of the global demand for these materials.[11]

Table 1: Minerals required for clean energy technologies

Type of mineral	Wind	Solar photovoltaic	Hydro	Energy storage
Aluminium	✓	✓		✓
Chromium	✓		✓	✓
Cobalt				✓
Copper	✓	✓	✓	✓
Graphite				✓
Indium		✓		
Iron	✓			✓
Lead	✓	✓	✓	✓
Lithium				✓
Manganese	✓		✓	✓
Molybdenum	✓	✓	✓	
Neodymium	✓			
Nickel	✓	✓	✓	✓
Silver		✓		
Titanium			✓	
Vanadium				✓
Zinc	✓	✓	✓	✓
Total	10	8	8	12

Note: this table is adapted from the *Minerals for Climate Action: The Mineral Intensity of Clean Energy Transition*, World Bank Group 2020. The red boxes that are ticked represent the minerals required. The blue unticked boxes represent where the minerals are not generally required.

Raw mineral extraction can lead to negative environmental and social outcomes

Poorly managed mineral extraction such as inadequate waste, water and biodiversity management, can lead to significant negative consequences for the environment. It can also create negative impacts on communities, such as poor worker safety, human rights abuses, and cultural loss.[12]

A circular economy approach has the potential to reduce pressure on the environment, preventing biodiversity loss and ecological degradation.

Several major mineral-producing regions such as Australia, Chile, China, and Africa are subject to increased climate risk, including water shortages, extreme heat or flooding. Copper and lithium are especially vulnerable to water shortages due to high water requirements in ore processing.

The IEA estimates that over 50% of today's lithium production is concentrated in areas with high water stress levels.

For example, in Chile, the world's largest producer of copper is experiencing their worst drought in decades. Approximately 80% of Chilean copper comes from mines currently located in high water stress and arid areas.[17]

Managing these competing pressures is likely to impact the viability of extractive activities in areas where these risks are high.

Equally, biodiversity is being lost at an unprecedented rate. A United Nations environment report estimated that more than 90% of biodiversity loss and water stress are caused by resource extraction and processing. The circular economy offers a framework to help tackle ongoing biodiversity loss.[18]

There is also increased community and investor awareness of the issues associated with mining and a strong push for more environmentally sensitive production processes. The success of Australia's minerals industry, both now and in the future, depends upon its ability to operate in line with community expectations on environmental, social and governance risk-management performance.[19]

Case study

Human rights abuses in the cobalt mines of the Democratic Republic of Congo

Cobalt is a key mineral in battery manufacturing and is critical in the world's transition away from fossil fuels. According to recent projections by the World Economic Forum's Global Battery Alliance,[13] global demand for cobalt will more than double by 2030, to 274,000 tonnes per annum.

The World Economic Forum estimates that the Democratic Republic of the Congo (DRC) currently produces approximately 50% of the world's cobalt. Of this, an estimated 20% is from artisanal and small-scale mining (ASM) sources, using basic hand tools to extract mineral-rich rocks from hand-dug tunnels deep underground.

In 2016, Amnesty International[14] released a report on the humanitarian impacts of ASM of cobalt in the DRC. The report exposed serious human rights abuses, including hazardous working conditions, deaths due to poorly secured tunnels, potentially various forms of forced labour, including child labour, and exposure to hazardous fine dusts and particulates.

Concerns such as these have driven an increase in the demand for minerals from countries with strong environmental and social governance (ESG) practices and requirements. Responsible mineral production and trade are becoming increasingly valued and Australian companies are global leaders in innovative, high-tech mining and lead the way in ESG practice.[15]

Australia has the second largest reserve of cobalt, after the DRC, but only provides approximately 10% of the total global production. This presents an opportunity to become a cobalt supplier of first choice for producers of batteries across the globe, in particular for manufacturers or producers with concerns for labour and human rights risks in the production and use of batteries.[16]

This presents an opportunity for NSW to build capacity for circularity in clean energy, reduce demand for mining and decrease pressure on natural environments. This could help NSW to become a global leader in responsible and sustainable sourcing of critical minerals.

Building local supply capacity will support improved energy security

Today's extraction and processing operations for many critical energy transition minerals are highly concentrated in a small number of countries, making the system vulnerable to climate change events, political instability, geopolitical risks, regulatory changes and export restrictions.[20]

This impacts the availability, accessibility, and price of minerals. Recent events, such as Indonesia's ban on nickel ore export and China's export ban on Rare Earth Elements (REEs), highlight these concerns.

Countries that are dominant in the critical minerals supply chains have incentives to restrict exports to provide a competitive or political advantage. This reliance on particular countries is a potential threat to our national security.[21] To counter this risk in the United States (US), in March 2022, the Biden administration invoked laws that name five key critical metals as essential to national security and set in motion activities to bolster national supply.

While no single country or region can supply all the minerals necessary to meet their energy requirements, NSW is well placed to meet a large part of that demand. A circular economy focused on recovery of minerals can help fill mineral supply gaps by bolstering local supply of critical minerals from end-of-life products like batteries and solar panels. Coupled with policies to secure mineral supplies and actions to improve local manufacturing, NSW can limit our reliance on international supply chains for future energy needs.

2. Design

Circular design can apply across the whole value chain, from how products are made, used and recovered, to how clean energy projects are constructed and decommissioned.

Design can help improve sustainability outcomes and support reuse and recycling markets. Design can also enhance strategic planning to deliver system wide benefits and reduce pressure on natural environments.

Circular design is not a strong consideration in many clean energy products

The design of clean energy products can have significant impacts across the product lifecycle, including the demand for raw materials and resource recovery outcomes. The consequences of design decisions are estimated to determine 80% of a product's environmental impact.[22]

Current design of clean energy products is generally driven by the need for increased efficiency and performance at a reduced cost. While this remains a key priority to enable the clean energy transition, the potential to support improved longevity, reuse and recovery of value is often unrealised.

> Embracing circular design principles during product development can help reduce environmental impacts and improve material efficiency.

For example, several solar home system manufacturers working in sub-Saharan Africa are moving toward selecting system components for their longevity and lower maintenance requirements, resistance to wear and tear, and greater product integrity to extend the product life, despite initially incurring higher costs.[23] While the short-term costs may be increased, long-term savings can be achieved through reduced maintenance and replacement costs as the product's life is extended.

Circular design also includes adopting digital technology to extend product life, support recovery and new market opportunities. Digital passports or 'materials passports' are an emerging data tool to enable this transition. They provide information on product design, material makeup and can also provide an end-of-life plan, such as how to efficiently disassemble then recycle them.

For instance, by understanding the material makeup of an EV battery, its age, and how the battery has been designed, other actors in the value chain can make more informed decisions about how to safely re-use, re-purpose or repair it. Information about a product's environmental and social credentials can also support improved transparency and oversight, while enabling ESG-aligned investment. However, the use of material passports may have some barriers, such as protected intellectual property rights.

Innovative product design can improve the security of clean energy supply, seen recently in developments in electrolysers for green hydrogen production. Japanese scientists have recently developed a new hydrogen electrode made from cobalt and manganese.[24] This can replace the existing electrodes that are based on very rare and expensive elements such as platinum and iridium.

If this new technology becomes commercially available, it could alleviate supply concerns, reduce prices and accelerate the rollout of green hydrogen production. With cobalt and manganese both widely used in other clean energy technologies, these minerals can circulate through our economy more efficiently.

Case study

Innovative design to make wind turbine blades recyclable

Wind turbine blades are large and notoriously difficult to recycle due to the composite nature of their materials. As a result, most wind turbine blades end up in landfill at end-of-use.[25]

Siemens Gamesa, the third largest turbine maker in the world, recently launched an innovative circular design called RecyclableBlade. Siemens Gamesa claim it is the world's first wind turbine blade that is designed to be recycled at the end of its lifecycle. The blades are made from a combination of materials cased together with resin to form a strong, flexible, and lightweight structure.

The chemical structure of this new resin type makes it possible to efficiently separate the resin from the other components at the end of the blade's working life. This process protects the properties of the materials in the blade, in contrast to existing recycling methods. The blade materials are then able to be reused in the automotive and consumer goods industries. RecyclableBlades have been deployed for the first time on offshore turbines in Germany.[26]

Circular design strategies could enhance clean energy developments

Circular design strategies can benefit clean energy developments from the outset. When projects are in the scoping phase, designers and engineers can collaborate to embrace a broad range of circular opportunities. This can include designing infrastructure that uses recycled content, low emissions materials, and construction methods that reduce material use and waste.

As with all design decisions, there may need to be trade-offs. For example, waste minimisation needs to be balanced against safety, structural strength and longevity, as well as whole-of-life embodied energy and carbon emissions.

These principles are not solely related to construction and can apply throughout the lifecycle of a clean energy development. Aligning design, construction, demolition and waste management enables circular resource and material flows between industries, sites and assets.[27]

> There are also innovative design opportunities for clean energy developments to support nature regenerative practices.

Some solar developments have embraced dual-use design, where the land around solar installations are used for low impact agriculture or environmental restoration.

Dual-use was adopted by Clif Bar's bakery in Idaho, United States (US), with its innovative pollinator-friendly solar farm. Solar panels are co-located in a bed of native flowering plants that support pollinators, conserve water and store carbon in the healthy topsoil.[28]

A US Department of Energy study found that by increasing the ability of pollinators to pollinate adjacent agricultural fields, solar-sited pollinator habitat may boost farmer's crop yields and make solar farms a more welcome neighbour to agricultural farms.[29]

Case study

Redesigning solar panels to utilise more abundant materials

Assuming a net zero by 2050 pathway, the equivalent of 30% of global silver production from 2020 will be consumed by the solar industry by 2030, a full 10% higher than today.[30] This consumption will soon present a supply risk as the industry moves to higher efficiency cells, which currently use two to three times more silver, and renewable energy deployment continues to accelerate.

SunDrive, an Australian company, is attempting to solve this issue via their high efficiency copper based solar cells. Its innovative design substitutes silver for copper, which SunDrive claim is nearly 100 times cheaper and 1000 times more abundant.[31] SunDrive aims to commercialise this technology and sell these high efficiency panels for use in the distributed and rooftop solar sector, where space is at a premium and higher efficiency cells can produce greater amounts of energy.

Circular design supports macro-scale planning considerations

Circular design principles can also apply to precinct, regional and state-wide developments. Design can ensure the right infrastructure and industries are strategically located across the clean energy value chain.

Using design considerations such as co-location, transport logistics, and resource availability, the NSW Special Activation Precincts (SAPs) demonstrate the potential benefits and supply chain efficiencies that can be achieved through effective planning and design.

SAPs are precincts that bring together industry, research institutions and government to create jobs, attract business and investors and drive economic growth in regional NSW. The Parkes SAP is the first in NSW and is strategically located on two rail lines that can move materials to 80% of Australia's population overnight.

The precinct will focus on sustainability as Australia's first United Nations Industrial Development Organisation (UNIDO) Eco-Industrial Park, where businesses will work together to achieve cost-savings and collaborate to solve problems including waste and water reuse as well as energy use and generation.[32] The precinct's infrastructure, location and existing industries will facilitate supply chain synergies that can lead to significant benefits for a circular economy.

3. Production and manufacturing

Clean energy technology manufacturing requires scaling up to meet our net zero goals. By supporting local manufacturing, we can exert greater influence over design specifications, generate demand for recycled materials and ensure materials circulate through the economy.

By enhancing our domestic manufacturing capability, we can also develop new markets, generate jobs, improve the sustainability of production and boost our energy security.

NSW lacks a strong local clean energy manufacturing sector

Australia imports most of the critical equipment used to generate clean energy. Around 80% of the solar panels used in Australia are imported from China – which also controls the vast majority of materials processing for other clean energy technologies.[33] This limits opportunities to influence and embed more circular manufacturing practices, such as using local recycled content or green manufacturing techniques (such as low emissions processes) to reduce environmental impacts and improve material circularity. A strong local clean energy manufacturing industry would also reduce transport costs and emissions associated with importing clean energy equipment.

As most clean energy products are manufactured overseas, it exposes local energy systems to geopolitical shocks and supply volatility.

NSW will become increasingly reliant on clean energy products to meet our energy needs, so reliable product supply is essential. The US Energy Secretary, Jennifer Granholm, at the Sydney Energy Forum held in July 2022 noted that:

“From an energy security point of view, it is imperative that nations that share the same values to develop our own supply chains, not just for the climate, which of course is very important, but for our own energy security.”[34]

Key drivers for overseas production of clean technologies, such as lower operating costs and greater economies of scale, may inhibit a thriving local manufacturing sector.

Case study

NSW $250 million Renewable Manufacturing Fund

In response to the closure of Eraring Power Station, the NSW Government announced a comprehensive plan to support up to 3,700 jobs in future industries. This includes a $250 million Renewable Manufacturing Fund to boost locally manufactured components for the renewable energy sector and EVs.

The Renewable Manufacturing Fund will help expand and establish local manufacturing in the renewable energy and low carbon sectors where NSW has a competitive advantage or needs to secure supply, focusing on technologies that are already commercial and ready for scaling up.

This could include wind towers for both onshore and offshore wind, electrolysers to produce hydrogen and assembly and component manufacturing for electric vehicles.

Find out more about the Renewable Manufacturing Fund.

However, by continuing to work with industry to advance local manufacturing, we can decouple our clean energy production from overseas suppliers and embed circular production principles.

> Building our manufacturing capability will also deliver significant local investment and employment opportunities.

Recent analysis into the NSW energy transition found that increasing local industry involvement across the supply chain was a primary opportunity to increase local employment.[35] It can also help attract capital in NSW, with key opportunities for investors, such as in solar farm infrastructure and wind farm manufacturing.[36] We have already taken steps to grow the local industry, such as through the $250 million Renewable Manufacturing Fund.

4. Use, reuse and repair

Ensuring products are used for as long as possible, repaired and reused helps to ensure we get the most value out of our resources. Developing a robust reuse and repair market in NSW presents the opportunity to reduce our carbon emissions and demand on finite resources.

Rapid innovation reduces incentives to repair clean energy technologies

A perverse outcome of the declining cost and rapid technological advance of clean energy technology is that repairing these products can become financially unattractive. The choice to repair a broken or damaged product depends on several factors, including the price of the repair, the price of a new product, and the cost - in time and money - to get a good repair service.[37] When an older product can be replaced by a more efficient and cheaper alternative, the economics of repair often do not stack up.[38]

These issues can be compounded by protected intellectual property and a reluctance to share information that may provide competitors with an advantage. This can limit access to skilled repair technicians who have the necessary information to repair.[39]

Product repair is, however, an important means to prolong the life of materials in products and helps to slow and close material loops in the economy and reduce our emissions and environmental impacts.

A range of barriers exist for reuse and repair markets

Fostering repair and reuse markets can play an important role in lowering manufacturing emissions and reducing demand for materials. The World Economic Forum notes that if, by 2030, 61% of batteries were recovered for repurposing, this could result in CO_2 reduction of 1 million tonnes at a cost saving of US$2 billion.[40]

However, regulatory, safety and technical barriers can inhibit the establishment of re-use markets for clean energy technologies. For example, second-hand batteries have limited information about the products previous use, such as exposure to high temperatures or shocks.[41]

Australia's reuse market for solar panels is challenging due to regulatory and market barriers, particularly for household solar. The Clean Energy Regulatory provides Small Scale Technology Certificates for new solar systems that help to offset the installation cost of the system.[50] However, the certificates are not available for second hand solar panels, meaning the cost of a new system can be comparable to a second hand one. When accounting for the likely improved efficiency of the new system, there is little incentive to establish a reuse market for solar panels in Australia.[51]

EV batteries are increasingly being considered in second-life applications. As demonstrated in the case study below, they are powering stadiums in the Netherlands and stabilising the grid in Germany. However, to fully realise the opportunity that second-life batteries offer, further consideration of safety, testing and performance measures is required.[52]

Improving reuse markets for these technologies has the benefit of extending the useful life of these products and reducing environmental pressures through extractive activities. It can also catalyse skills in the repair industry, creating new jobs and industries.

Case study

EV batteries getting second use in stationary storage systems

The continued global growth in EV sales presents an emerging opportunity for the clean energy sector, with used EV batteries having a second use as stationary storage systems once they no longer meet EV performance standards (typically 70-80% of original capacity). This presents an opportunity for NSW to shore up our grid while minimising the cost and impact on resources. Analysis by McKinsey found that stationary energy storage powered by used EV batteries could exceed 200 GWh worldwide by 2030.[42] There are an increasing number of examples across the globe where these storage solutions are being implemented.

BMW reusing and recycling EV batteries in Germany[43]

BMW takes back used EV battery packs and gives them a second use as stationary storage systems at their large-scale storage farm at the BMW plant. The storage farm powers the BMW plant, and also serves as a reserve for the public power grid. BMW estimates that it takes around 10 years to completely exhaust the energy content of an EV battery cell in its second use. After it reaches the end of its life in its second use, BMW uses a local recycler in Germany to recover a high percentage of nickel, lithium and cobalt.[44] The raw materials that are extracted are then used in the production of new battery cells for BMW vehicles.[45]

Used EV batteries powering a stadium in the Netherlands

Used Nissan EV batteries are used to power Amsterdam's Johan Cruijff Arena, which holds around 54,000 people.[46] The used batteries store energy captured by 4,200 solar panels on the stadium roof. This project has reduced the stadium's demand on the electricity grid and provides reliable and efficient energy to the stadium and surrounding homes.[47] During low-energy periods, it feeds excess power back to the grid.[48] It is estimated the system costs 20% less than a new battery.[49]

5. Collection

Collection connects end-of-life materials with the resource recovery industry, providing sustainable feedstock for further productive use. Well-coordinated collection, transport and storage of clean energy products is critical to advancing a broad range of re-use and recovery options.

Immature collection systems in NSW lead to a loss of resources

Collection services for clean energy products are limited in NSW. A responsive and coordinated collection system that anticipates supply and demand of recovered materials could offer NSW a range of benefits. It could also support the diversification of our economy by providing feedstock for new recovery markets that help build local clean energy supply chains.

For established technologies such as solar, anecdotal evidence suggests that collection systems are currently fragmented, uncoordinated, and dependent on location and scale. For newer and less established technologies, these issues are likely to be compounded.

For example, solar panels have high collection costs due to Australia's geography, market size and industry maturity. These barriers mean there are currently limited specialist collection and recovery services for solar panels operating in Australia.[53]

There are risks and hazards with the collection of clean energy technologies

There are risks associated with collecting, transporting and storing end-of-use clean energy equipment due to their diverse material composition and hazardous components.

Lithium-ion batteries (LIBs) can pose fire risks due to their high energy density and chemical composition. If a battery cell is impacted, such as by heating, crushing or penetration, it begins to release energy and generates heat and toxic and flammable gases.[54] These risks may be further increased when large numbers of batteries are aggregated and stored during collection.

Prior to recycling, mixed batteries need to be separated into single waste streams, segregated by chemistry type. This is especially important as the inclusion of LIBs in lead-acid battery waste streams can pose significant safety and fire/explosion hazards during processing.[55] Implementing appropriate safe handling and environmental measures to mitigate hazards can make collection services complex, labour intensive and expensive. Coupled with high transport costs, this reduces incentives for businesses to enter the collection market.

A lack of system coordination reduces collection opportunities

There is limited data and product tracking systems for clean energy technologies at end-of-use. This prevents coordinated collection systems which require robust data and effective standards.[61] A lack of data also poses challenges for the reuse and recycling market, due to difficulties forecasting and predicting future trends and supply of feedstock.[62]

Standardisation and verification across the supply chain are key enablers for safe and efficient collection systems. WindEurope, a key European wind energy industry body, is developing standardized decommissioning guidance for wind turbines. This includes identifying pertinent types of permits, regulations, and issues concerning handling of metals, which is critical at the collection stage.[63]

There are also limited incentives, financial mechanisms, or targets for collection of clean energy technologies which may be impacting reuse and recycling opportunities. For example, the Battery Stewardship Council reported that 5,290 tonnes of LIBs reached end-of-life in 2017-2018 in Australia, however, only 320 tonnes were collected for recycling.[64]

One strategy to mitigate these challenges is to make producers responsible for the collection and recovery of end-of-use clean energy products. Overseas initiatives such as extended producer responsibility schemes have facilitated improved collection, reuse and recycling markets for some clean energy technologies.

Case study

EV battery collection in the Netherlands

The Netherlands currently has a mandatory recycling requirement of 50% for LIBs.[56] Producers (i.e., manufacturers or importers) of EVs pay an upfront fee to cover the collection and recycling costs of EV batteries so that consumers do not pay extra costs when discarding their old vehicle.[57] EV producers fund the system and pay contributions based on battery weight. Contributions cover end-of-life battery management for the current year, including collection, sorting, processing, and administrative costs.[58]

Under this scheme, it was reported that all vehicle batteries collected, including LIBs, were given a second use or recycled in 2021. [59] Recycling companies reported a recovery of around 70% of raw materials.[60]

Case study

European Union Battery Regulation

The European Union (EU) is currently in the process of updating its main legal framework on batteries, the Battery Regulation. The proposed Battery Regulation includes a number of obligations that will apply to EV and energy storage batteries that will help drive circular outcomes, such as: [65]

- mandatory minimum levels of recycled content for raw materials such as cobalt, lead, lithium and nickel
- supply chain due diligence obligations
- increased collection rate targets
- specific material recovery targets
- requirements relating to the operations of repurposing and remanufacturing for a second life
- labelling and information requirements
- battery passport (i.e., electronic record) requirements.

6. Recycling

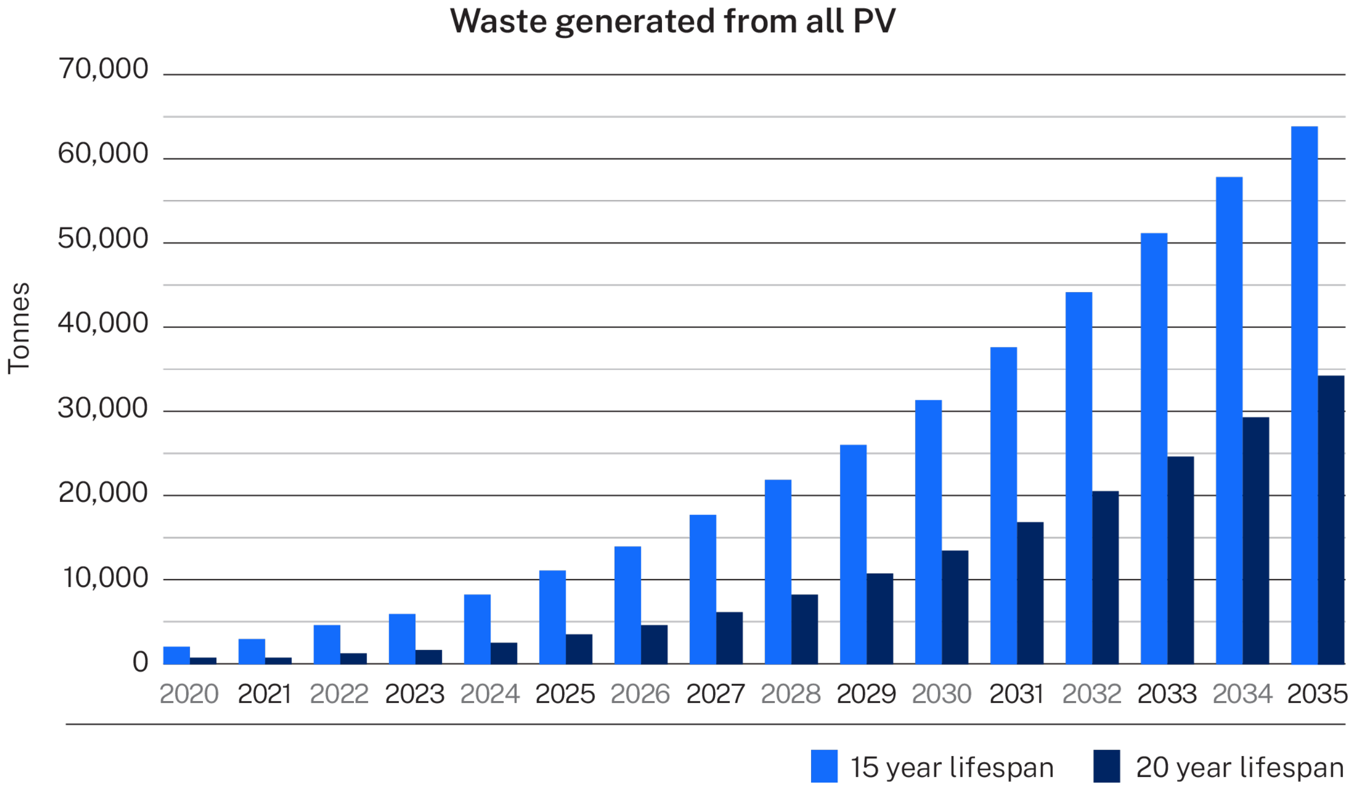
Recycling converts end-of-use products into materials that can be reused to manufacture new products. This diverts waste from landfill, reduces our demand for virgin materials and associated environmental impacts linked to resource extraction.

Building a robust clean energy recycling system in NSW can open new markets through secondary mineral supply and create significant employment opportunities.

Increased recycling capacity will be required to manage growth in clean energy waste

NSW is expected to see a sharp increase in the generation of waste from clean energy technologies over the next 10-15 years. Solar panel waste is expected to grow from 2000 tonnes per year in 2020 to between 34,000–63,000 tonnes by 2035, depending on life spans (as seen in **Figure 3** below).[66]

Figure 3: Estimated waste volumes for all end-of-life solar photovoltaic (PV) panels in NSW[67]



Australia's battery waste is currently growing by 20% per annum.[68] In NSW, battery waste is projected to grow at a faster rate than solar panel waste, with waste volumes 13 times higher in 2035 compared to 2025 (assuming a 10-year lifespan).[69]

To ensure clean energy materials remain in the productive economy, recycling (complemented by other circular opportunities such as re-use) must be widely utilised. The CSIRO report that if recycled, 95% of LIB components can be turned into new batteries or used in other industries.[70]

For effective material recovery to occur, there needs to be sufficient local recycling capacity with a strong focus on high value recovery. This also needs to be coupled with strong end-markets that create local demand for recycled materials. Without sufficient recycling capacity and viable end-markets, large amounts of valuable resources may be disposed to landfill and lost from the economy.

The energy transition also presents NSW with a unique opportunity to develop new resource recovery markets and expand local employment. For example, with NSW being only second to Queensland for the greatest monthly solar panel output by state, and a growing number of large-scale solar projects, it is well-positioned to take a leadership role in managing and future-proofing solar panel waste management.[71]

The NSW Government has already acted to help deliver improved recycling capacity for some clean energy technologies, such as via the Circular Solar grant program.

Case study

$10 million Circular Solar grant program

The $10 million Circular Solar grant program delivers on the NSW Government's 2019 election commitment to reduce the landfilling of solar panels and associated batteries. The investment helps future-proof the end-of-life management of this growing waste stream and supports NSW's transition to clean energy sources within a circular economy.

$9.4 million has been awarded to 8 grant projects. The projects will improve NSW's capacity to recycle, refurbish and reuse solar panels, their components, and associated batteries by over 10,000 tonnes per annum. Projects under the Circular Solar program are servicing greater Sydney and regional NSW, improving collection networks to support increased resource recovery.

One project example is The Solar Professionals who have designed and developed technically advanced processing equipment that can delaminate solar panels and separate materials into uncontaminated components. Whole glass sheets are recovered and remanufactured into commercial glasshouse construction. By establishing collaborative partnerships, The Solar Professionals will link their recovered resources with viable end-markets. This is a key feature across many of the Circular Solar grant projects where solutions are addressed along the supply chain to keep materials in productive use.

Recycling of clean energy technologies can reduce carbon emissions and alleviate supply concerns

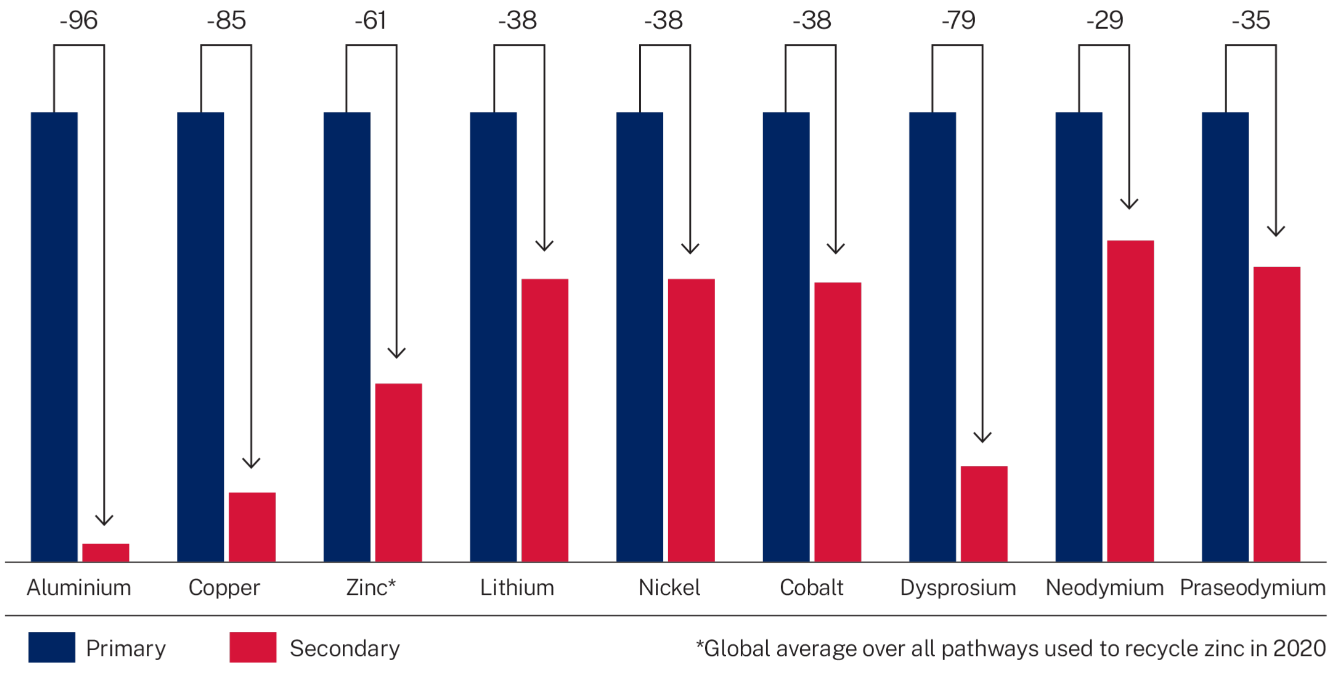
Recycling will play an increasingly important role in meeting demand for materials in clean energy production through secondary supply of minerals and other materials. Recycling also provides an opportunity to build greater resilience by localising and shortening supply chains.[72]

European research suggests that by 2050 up to 75% of Europe's mineral demand can be met through secondary supply (from recycled sources) if the right investments are made now.[73] This will reduce Europe's reliance on international material sources, improve environmental outcomes and strengthen national sovereignty.

Recycling can also significantly reduce the emissions generated from the extraction and production of many critical minerals. For example, it has been estimated that replacing primary metal with secondary metal in Europe allows for CO_2 savings of between 29-96%, depending on the waste stream and its complexity (as seen in **Figure 4** below). Recycling also prevents the need for new mining, saving resources and avoiding the environmental impacts associated with extraction.

NSW can adopt the learnings from Europe to build local resilience and be a leader in supplying secondary materials to regional and global markets.

Figure 4: CO_2 footprint of secondary supply versus primary supply (%)[74]



Rapid innovation discourages investment in recycling infrastructure

Clean energy technologies are undergoing rapid innovation, with constantly evolving design and material compositions. Significant capital investment is required to develop recycling infrastructure for these technologies. The CSIRO reported the high upfront costs of investing in LIB recycling plants coupled with the uncertainty of the market are key barriers for the recycling industry.[75]

Stakeholder feedback indicated that some businesses in NSW are wary of investing in recycling infrastructure as the waste feedstock may change significantly in a relatively short period of time. As the technologies innovate, the types of materials and composition changes, which reduces the economic lifespan of specialised recycling equipment.

Materials used in clean energy technologies can be challenging and costly to recycle

Clean energy infrastructure and equipment are often made from highly complex materials including alloyed metals and mixed materials. Recycling these products often require advanced recycling technologies, which can be expensive and energy intensive to establish and operate.[76]

Capital investment in recycling infrastructure is high, however the current scale of clean energy materials reaching end-of-use is relatively low.[77] With many minerals in individual clean energy products used in minute quantities, economies of scale are essential to ensuring commercial viability of recycling operations and the associated collection and sorting systems.[78]

Investment in recycling is largely driven by commodities prices combined with operating costs.[79] With the current high price of precious metals such as gold, palladium and platinum, these metals are achieving high recovery rates.[80] However, the recycling capacity of other minerals, such as lithium and REEs, is very limited. Recent analysis by Deloitte noted that neodymium, a REE used in very strong magnets such as those used in wind turbines, currently has a 1% recycling rate.[81]

> With the right investment, there could be a significant material recovery industry for clean energy technologies, with associated local benefits.

It is expected that by 2036, the value of recoverable metals from batteries in Australia is estimated to be up to $3.09 billion.[82]

Case study

Redwood EV battery recycling program in California[83, 84]

Redwood Materials, a US battery recycling company, currently processes 6 GWh of LIBs or the equivalent of 60,000 EVs annually. Redwood recently launched a hybrid and EV battery recycling program in California partnering with major car companies, including Ford Motor Company and Volvo Cars.

Redwood works directly with dealers and dismantlers to recover, safely package, transport, and recycle all end-of-life hybrid and EV battery packs.

The program will recover more than 95% of the metals like nickel, cobalt, lithium and copper from the hybrid and electric vehicle batteries. Instead of exporting those metals overseas, Redwood will use them to remanufacture anode and cathode components that will be supplied back to US battery cell manufacturers without these minerals ever leaving the country.

Redwood plans to increase anode copper foil and cathode production to 100 GWh annually - enough for one million EVs a year.

7. Residual waste

When clean energy equipment, materials, and infrastructure reach end-of-use, and are not re-used or recovered, they become residual waste. Residual waste is generally disposed at waste facilities, such as landfills.

Landfilling means valuable resources are lost from the economy

Landfilling of clean energy materials prevents resources from staying within the productive economy. Without improving circularity, the large increase in waste generation from clean energy technologies could lead to high rates of landfilling. This has associated costs to the community and environment.

> Reducing the landfilling of clean energy materials can also support job creation in NSW.

It is estimated that for every 10,000 tonnes of material, recycling generates 3 times as many jobs as landfill disposal.[85]

There are many options available to government and industry to reduce these impacts. For example, some jurisdictions like Victoria have banned the landfill of e-waste materials, such as solar panels, to improve recovery outcomes. However, there must be careful consideration of policy interventions, including strong consultation with industry representatives, to ensure that actions align with the needs of key stakeholders.

The disposal of clean energy residual waste can lead to harmful environmental impacts

Clean energy waste can cause environmental impacts when disposed at waste facilities, particularly those not equipped to handle that waste type or are unaware of what they are receiving. The risks are even greater if these materials are deposited in the environment, such as via illegal dumping.

Materials contained within clean energy waste, such as LIBs, can leach into soil and groundwater. This can cause environmental contamination and human health concerns if managed poorly.

When an intact end-of-life solar panel is crushed or damaged, there is the potential for hazardous materials such as lead, copper and zinc to be released. If the landfill that accepts this waste does not have appropriate environmental controls to manage hazardous waste, it could lead to harmful environmental impacts. These issues may be further exacerbated in rural and regional communities, which have specific challenges regarding access to safe disposal options for residual waste.

Keeping these materials out of landfill reduces environmental and human health issues and allows valuable resources to remain in the productive economy.

NSW lacks disposal data for end-of-life clean energy technologies

There is limited information on the disposal of clean energy technologies, such as amounts, disposal locations and waste types. This is due to factors such as a lack of reporting requirements and piecemeal approach to collection and disposal.

Much of the local waste disposal data is based on projections, rather than captured information, which prevents an accurate understanding of NSW clean energy residual waste flows. It also makes it challenging to analyse disposal activities and trends.

Enhanced data would facilitate improved decision-making by Government and industry to improve the recovery and management of clean energy residual waste.

Have your say

How do you think the circular economy can support a more sustainable clean energy transition? We want to hear the views of stakeholders across the clean energy value chain.

We welcome your feedback on what you see as the barriers and opportunities to adopting a circular economy for clean energy in NSW. We also want to understand how the NSW Government can better facilitate circular economy opportunities that arise from the clean energy transition.

This paper poses 6 questions to guide your feedback, as seen in Table 2. You may wish to answer all or some of the questions. You may also wish to include feedback not directly related to the questions. Your feedback may be used to inform the development of a circular economy plan for clean energy in NSW.

Your ideas will shape a better future as we advance our net zero goals.

To provide your feedback, complete the survey or upload a written submission on the NSW Climate and Energy Action webpage under ***Going circular in clean energy***.

All submissions will be made publicly available unless you specifically request otherwise.

Submissions are now open and will close at **2:00 pm (AEDT)** on **Thursday 2 March 2023.**

Table 1: Issues paper feedback questions

#	Issues paper question
1	What are the key barriers to adopting a circular economy for clean energy in NSW? Are there any specific barriers in your industry?
2	What are the key opportunities to advance a circular economy for clean energy in NSW? Are there any specific opportunities in your industry?
3	What role can a circular economy play in building resilient and circular supply chains for clean energy technologies? What industries or areas should be a focus?
4	How can the NSW Government facilitate a circular economy for clean energy? What policy options could the NSW Government explore?
5	What are some additional issues in creating a circular clean energy sector (if any) that haven't been discussed in the issues paper?
6	What are other ways (apart from the circular economy) that NSW could improve the sustainability of the clean energy transition?

Appendix 1: Summary of NSW government policies, programs and funding[86]

Energy, Carbon and Net Zero
The Net Zero Plan Stage 1: 2020–2030 is the foundation for NSW's action on climate change and goal to reach net zero emissions by 2050. This commitment is supported by a target of 70% emissions reduction by 2035 compared to 2005 emissions. The NSW Electricity Infrastructure Roadmap presents a coordinated approach to delivering a modern energy system that will drive low electricity prices and unlock billions of dollars in investment in renewable energy. The roadmap outlines the establishment of Renewable Energy Zones (REZs) to support the roll-out of a low carbon grid. The Net Zero Industry and Innovation Program (NZIIP) provides more than $1 billion to support and partner with industry to develop clean technologies, drive the decarbonisation of high emitting industries and position NSW to prosper in a low-carbon international economy. The Emissions Intensity Reduction Program provides $450 million to support businesses to transition their plant, equipment and processes to low emissions alternatives. This is complemented by an additional $450 million for NSW from the Commonwealth's Climate Solution Fund. The Response to the closure of the Eraring Power Station is a comprehensive plan to ensure that NSW continues to have reliable and affordable electricity following the closure of the Eraring Power Station. It includes: • $250 million over five years to boost locally manufactured content for the renewable energy sector • $300 million investment over 10 years to expand the New Low Carbon Industry Foundations element of NZIIP. The NSW Electric Vehicle Strategy outlines nation-leading policies and initiatives to incentivise the uptake of zero-emissions vehicles. The NSW Government will invest $633 million to accelerate the uptake of EVs. The NSW Hydrogen Strategy sets out the vision for developing a thriving green hydrogen industry in NSW and drive decarbonisation of the hard-to-abate transport, industrial and energy sectors and is supported by $3 billion. This includes $150 million to establish hydrogen hubs in the Hunter and Illawarra.

Energy, Carbon and Net Zero

Circular economy

The NSW Waste and Sustainable Materials Strategy 2041 outlines policies, opportunities and priorities that will reduce carbon emissions through better waste and materials management. It is supported by $356 million in funding.

The NSW Circular Economy Policy Statement sets the ambition and approach for transitioning to a circular economy in NSW. It identifies eight focus areas to guide government action to support the transition pathway, including:

- circular design
- sustainable procurement
- supporting re-use and repair.

Regional development

The 20 Year Economic Vision for Regional NSW sets out the Government's priorities and plans to achieve long-term social and economic success for regional communities across the state. This includes $1 Billion to support the delivery of Special Activation Precincts.

SAPs are dedicated areas in a regional location identified by the NSW Government to become a thriving business hub.

SAPs at Parkes and Wagga Wagga will both have a renewable energy, resource recovery and recycling, advanced manufacturing and critical minerals.

Minerals and mining

The NSW Minerals Strategy outlines commitments to drive investment in mineral exploration and mining in NSW and position the state as a major global supplier of metals for the economies of today and the future.

The NSW Critical Minerals and High Tech Metals Strategy outlines the NSW Government's vision to build on our existing potential and position NSW as a major global supplier and processor of critical minerals and high-tech metals well into the future. The strategy is supported by $130 million and will:

- establish Australia's first Critical Minerals Hub in the Central West
- promote exploration for critical minerals resources
- activate the industry through proactive development of supply chains
- attract investment for critical minerals resources, downstream processing and recycling.

Appendix 2: Glossary

Circularity: a regenerative system in which resource input and waste, emissions, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops.

Critical mineral: a metallic or non-metallic element that has two characteristics; it is essential for the functioning of modern technologies, economies or national security; and there is a risk that its supply chains could be disrupted.

End-of-use: the end of one use for a functioning product. Further uses of this product may follow.

End-of-life: the final stages of a product or material's phase of use.

Lifecycle: consecutive and interlinked stages of a product over the course of its entire life, from generation from natural resources to end-of-life.

Remanufacturing: the process of recovering, disassembling, and repairing components for resale at new product performance, quality and specifications.

Reuse: the repeated use of a product or component for its intended purpose without significant modification. Adjustments, maintenance and cleaning of the component or product may be necessary to prepare for the next use.

Value chain: the activities that businesses conduct to receive materials, add value to the materials, and deliver products or materials to customers. It involves value-adding processes across all elements of the circular economy, including raw materials, production, use, collection and recycling.

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