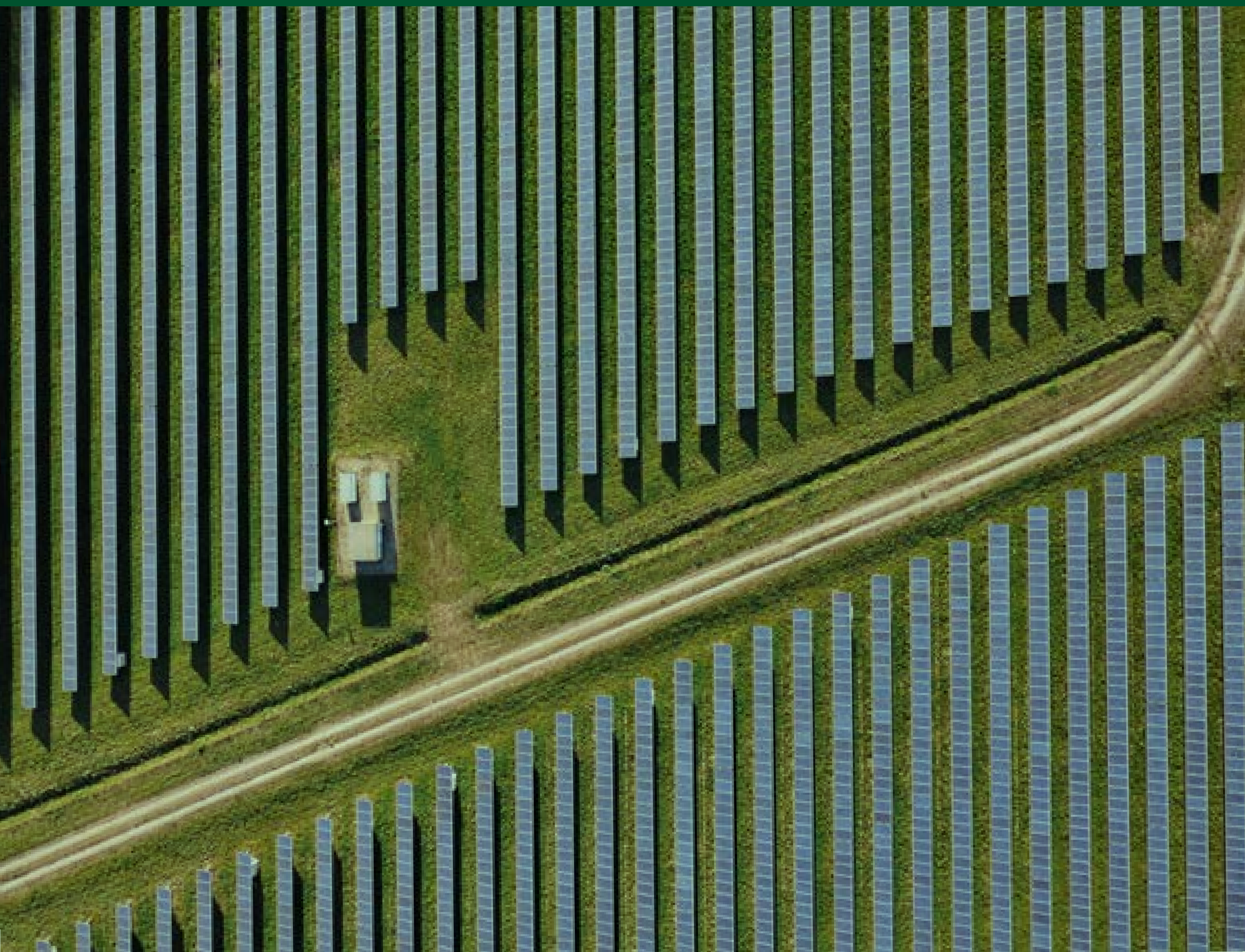
Office of the Chief Scientist & Engineer

NSW Decarbonisation Innovation 2023 Study

Refreshed opportunities with a systematic approach for the NSW clean economy

November 2023



We acknowledge and pay respect to the past, present and future Traditional Custodians and Elders of this nation and the continuation of cultural, spiritual and educational practices of Aboriginal and Torres Strait Islander peoples.

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Executive summary

Embracing the transition towards a low-carbon economy is an opportunity for NSW to innovate and potentially become a leader in decarbonisation technologies while benefiting the environment and creating economic growth and job creation. The rapid development and deployment of new climate technologies, both in Australia and overseas, provides opportunities for NSW to capitalise on its competitive advantages and experience in climate technology research, development and commercialisation.

The NSW Decarbonisation Innovation Study is a critical component of the NSW Net Zero Plan. The Study aims to identify opportunities for reducing greenhouse gas emissions while growing the economy and creating jobs. The Study is updated biennially with new technology, noting action already taken to reduce NSW greenhouse gas emissions.

The 2020 Decarbonisation Innovation Study identified 65 opportunities and served as an important guide to NSW decarbonisation policy and implementation. The 2023 Study (this report) builds on the 2020 Study, reflecting on the progress made with the 2020 Study opportunities while identifying new and emerging opportunities. Options for how best to realise the subsequent economic and environmental benefits for NSW are considered.

Drawing on results from analytical data, feedback from stakeholder consultations and expert advice, the 2023 Study presents opportunities in terms of:

- **Foundational Elements.** Eight essential components necessary for the uptake of climate technologies and services, ensuring the state gains competitive advantages to grow capability and capacity
- **Sector Interactions.** Five areas of strongest interdependencies across the different sectors, that recognise the nexus of carbon/energy/resources/materials requires a cross-sectoral approach to drive innovative solutions for decarbonisation
- **Sector Decarbonisation Innovation Readiness Level.** A new framework with four pillars and 12 indicators to assess current capability within the decarbonisation innovation environment for each sector and further identifies areas for development
- **Sector Clusters and Opportunities.** Twenty-six economic opportunities grouped under 12 sectoral clusters where they may benefit from the same core technologies, shared infrastructure, the same industrial users and customer groups, and similar incentives and policy design.

An overview of these opportunities is shown in the diagram on the following page.

For policymakers, this Study identifies areas to consider for effective policy and program design to facilitate R&D and commercialisation. For non-government stakeholders, this report serves as a guide to identify potential growth areas for investment where research and technology efforts will make a meaningful impact, and where industry development activities can add to outcomes for NSW and Australia.

SECTOR	2019 Decarbonisation innovation opportunity	2023 Decarbonisation innovation opportunity cluster	2023 Sector Decarbonisation Innovation Readiness Level	
FINANCE SERVICES	Sustainable finance system		Sustainable finance system	
ENERGY	Renewable Energy Zones	Future energy systems	Technology and service	High
	Future energy market design		Workforce and skills	Medium
	Decentralised grids and demand management	New generation renewable and storage	Public levers and policies	High
	Solar and energy storage		Industry and investment	High
TRANSPORT	Electrification and EV charging	Services and e-mobility	Technology and service	Medium
	EV charging infrastructures and hydrogen refuelling routes		Workforce and skills	Medium
	Mobility as a service	Long-haul transport and non-road machinery	Public levers and policies	Medium
	Future EV battery services		Industry and investment	Medium
BUILT ENVIRONMENT	Low emissions materials and reuse and recycling	Embodied carbon for building and infrastructure	Technology and service	Medium
	Electrification and energy efficiency and productivity		Workforce and skills	Medium
	Sustainable precincts and hydrogen hubs		Public levers and policies	Medium
	Digital technology		Industry and investment	Medium
INDUSTRY	Electrification, alternative heat and bioenergy	Biomanufacturing and synthetic biology	Technology and service	Medium
	Hydrogen	Power-to-X	Workforce and skills	Medium
	Carbon capture and utilisation		Public levers and policies	Medium
	Critical resources and material efficiency, reuse and recycling	Carbon dioxide removal	Industry and investment	Medium
LAND AND AGRICULTURE	Sustainable land management	Sustainable land management	Technology and service	Medium
	Controlled environment horticulture		Workforce and skills	Medium
	Renewable and bioenergy	Agtech and decarbonisation	Public levers and policies	Medium
	Gene technology and enteric emissons reduction		Industry and investment	Medium

Sector interaction

- Decarbonisation support services
- Renewable energy and electrification
- Clean sustainable fuels and energy carriers
- Infrastructure and planning
- Energy efficiency and productivity

Foundational element

- Circular economy
- Local manufacturing
- Standards and certification
- Government procurement
- Skills and training
- Place-based approaches and precincts
- Consumer sentiment
- Digital technology

2023 Sector Decarbonisation Innovation Readiness Level			
	High readiness level Requires targeted support	Medium readiness level Requires signicant support	Low readiness level Requires immediate intervention

1.0 Introduction and background

In September 2019, the then NSW Minister for Energy and Environment requested the NSW Chief Scientist & Engineer (CSE) to assess the challenges and opportunities associated with meeting emissions targets and adapting to climate change, with a focus on generating economic development, prosperity and jobs growth in NSW (see Appendix 1 for Terms of Reference).

The NSW Decarbonisation Innovation Study (the Study) was initiated to support the Clean Technology Program, part of the NSW Government's Net Zero Plan Stage 1: 2020-2030 (the Net Zero Plan). The Net Zero Plan aims to achieve net zero emissions by 2050 while creating jobs, cutting household costs and attracting investments.[1] The Study is a biennial report focusing on emerging technologies to reduce emissions and that are commercially competitive for NSW.

1.1 The 2020 Decarbonisation Innovation Study

The 2020 Decarbonisation Innovation Study – titled *Opportunities for prosperity in a decarbonised and resilient NSW (the 2020 Study)*[2] was released in August 2020. The 2020 Study delivered a comprehensive qualitative assessment, including 65 decarbonisation opportunities for emissions reduction and related economic benefit within NSW. The study undertook extensive stakeholder consultation and established an expert panel with expertise in areas including energy, infrastructure, innovation, sustainability and economics (see a summary of the opportunities from the 2020 Study in Appendix 2).

1.2 About the 2023 Decarbonisation Innovation Study

The 2020 Study has been an important guide for public policy and programs driving decarbonisation efforts in NSW. However, over the past two years the decarbonisation landscape has dramatically changed, highlighting the importance of the biennial assessment. There have been many new trends, strategies and initiatives to progress decarbonisation and help meet NSW emissions reduction targets since the 2020 Study. Industry and community groups have been proactively seeking decarbonisation opportunities through investment in the development and deployment of climate technologies to reduce their carbon footprint. The commercialisation of decarbonisation technologies continues to progress rapidly, with new areas of interest emerging.

The 2023 Decarbonisation Innovation Study (the 2023 Study) builds on the 2020 Study by reflecting on the progress made across sectors, providing advice on the challenges and opportunities for meeting emissions targets and adapting to climate change. The Study aims to examine the benefits of decarbonisation in generating economic development, prosperity and jobs growth in NSW.

This 2023 Study is forward-looking, with focus on industry and sector developments and advances. It does not review or assess progress made on the opportunities identified in the 2020 Study, although this was considered in developing the new list of opportunities. As such, this report complements and is intended to be read in conjunction with the 2020 Study.

As with the 2020 Study, the 2023 Study is not an exhaustive list of all decarbonisation technologies and services needed for decarbonisation and achieving net zero. It focuses on economically and technically feasible technologies and services that do not rely on long-term dependence of external incentives, as these are more likely to be rapidly and widely adopted and deliver greater emissions reductions.

1 NSW Government (2020). Net Zero Plan Stage 1: 2020-2030.
2 NSW Chief Scientist & Engineer (2020). Opportunities for prosperity in a decarbonised and resilient NSW: Decarbonisation Innovation Study.

This has been considered in the context of the NSW Government's net zero strategies and other initiatives across jurisdictions and in a global context.

To provide direction and oversight, the Office of the NSW Chief Scientist & Engineer (OCSE) re-engaged the expert panel from the 2020 Study, comprising Professor Hugh-Durrant Whyte (NSW Chief Scientist & Engineer and Panel Chair), Professor Michael Dureau AM, Professor Frank Jotzo, Ms Meg McDonald and Mr Roger Swinbourne.

OCSE consulted extensively with stakeholders across industry, research and government agencies:

- **Stage 1 consultation:** identified approaches and methodologies, mapped key stakeholder groups for Stage 2 consultation and reviewed major studies undertaken in NSW and Australia since the 2020 Study. Stage 1 Consultation occurred over several interviews, meetings and workshops with the NSW Net Zero Emissions and Clean Economy Board, the NSW Renewable Energy Sector Board and NSW Government departments and agencies that have accountability for net-zero policies and programs delivery.
- **Stage 2 consultation:** discussed and identified the main NSW decarbonisation opportunities to assist with reducing emissions and providing economic benefit to NSW, as well as identifying barriers and challenges in realising the opportunities. Consultation occurred over a series of one-on-one interviews, face-to-face and online industry roundtable sessions, and technology workshops held late 2022. A list of attending stakeholder groups is in Section 7.

Insights from targeted stakeholder consultation were further explored to refine the opportunities, considering:

- emissions reductions yet to be achieved
- new and improved technologies and services that can fast track emissions reduction with likely economic benefit
- emerging technologies that provide emissions reduction with potential economic benefit should further advances and commercialisation occur.

This report includes an update of the policy context, issues that may influence opportunities for decarbonisation and net zero, common foundational elements that support the transition to a decarbonised economy and potential cross-sector opportunities. This report introduces a new framework assessing innovation potential and includes sectoral analysis for the Financial System, Energy, Transport, Built Environment, Industry and Land & Agriculture.

The report layouts are:

- **Section 2:** Overview of public policies and programs
- **Section 3:** Common themes across sectors
- **Section 4:** Sectoral deep dive on opportunities
- **Section 5:** Summary of all opportunities and next steps
- **Section 6:** Next steps from 2023 Study.

Research was also undertaken drawing on various databases for the development of the report. The methodology, data and results are documented in the NSW Decarbonisation Innovation 2023 Study – Supplement Document (the Supplement). The Supplement includes an updated Capability Map and Technology Map from the 2020 Study.

2.0 Decarbonisation landscape

Over the last two years, there have been considerable changes in the decarbonisation landscape and an acceleration of decarbonisation throughout broader society. NSW emissions have declined from 132.4 Mt CO_2-e in 2020 to 117.1 Mt in 2022.[3]

National and global changes in the decarbonisation policy and economic landscape have influenced opportunities to drive decarbonisation. The increase in energy prices brought about by the Ukraine war,[4] the improving cost competitiveness of renewables and growing community awareness and understanding of climate change issues has seen an increasing acceptance of renewable energy, especially due to falling costs of residential rooftop solar photovoltaic (PV) systems.[5]

Another important catalyst is the move for climate-related risk disclosure in the wider market. Lenders and investors worldwide are increasingly requiring the assets they invest in to provide both a sound commercial return and positive environmental, social and governance (ESG) outcomes. Governments and regulators are bringing in new standards for reporting by all entities of climate risk and of climate risk mitigation. Climate reporting frameworks such as Task Force on Climate-related Financial Disclosure (TCFD) and the draft International Sustainability Standards Board (ISSB) include a mixture of overarching disclosure obligations and prescriptive requirements that sit underneath these overarching obligations.

Business and consumers are demonstrating greater interest in the broader issue of climate change through the uptake of ESG policies as well as looking for opportunities to reduce their energy costs.[6]

2.1 Australian decarbonisation policies and programs overview

In NSW, there is a broad suite of government policies and initiatives driving decarbonisation to achieve the State's net zero ambition, including:[7]

- Electricity Infrastructure Roadmap
- Net Zero Industry and Innovation Program
- NSW Waste and Sustainable Materials Strategy 2041
- NSW Electric Vehicle Strategy
- NSW Hydrogen Strategy
- Primary Industries Productivity and Abatement Program
- State Infrastructure Strategy
- Nature Positive Farming Program
- Zero Emissions Buses Transition Plan
- Sustainable Buildings State Environment Planning Policy (SEPP)
- Future Transport Strategy
- Net Zero Cities Action Plan.

The NSW Net Zero Emissions Dashboard tracks NSW's progress to net zero. The dashboard is an online interactive tool showing NSW's past and projected future greenhouse gas (GHG) emissions, emissions trends and progress towards targets, including the impacts of existing and planned policies and programs under the NSW Net Zero Plan Stage 1-3.

Progress under the Net Zero Plan is reported annually. In 2021, NSW was projected to reduce emissions to 47-52% below 2005 levels by 2030.[8] Projections were further revised in 2022 to a reduction in emissions of 70% below 2005 levels by 2035.[9] Informed by these projections, the NSW Government has set interim emissions reduction targets of 50% by 2030 and 70% by 2035.

3 NSW Government (2023). NSW Net Zero Emissions Dashboard.
4 World Economic Forum (2023). Energy Transition: Russia-Ukraine War Has Nearly Doubled Household Energy Costs Worldwide – New Study.
5 International Renewable Energy Agency (2002). Falling Costs Drive Strong Demand for Australia's Residential Solar PV.
6 RMIT University (2012). SDG Measurement and Disclosure 3.0: A Study of ASX 150 Companies.
7 NSW Government (2022). Net Zero Plan Implementation Update 2022.
8 NSW Government (2021). Net Zero Plan Stage 1: 2020-2030 Implementation Update.
9 NSW Government (2022) Net Zero Plan Implementation Update 2022.

At the federal level, there is a range of policies to address climate change and decrease emissions, including:

- New legislative targets committing Australia to reduce GHG emissions by 43% below 2005 levels by 2030, and net zero by 2050, reporting annually on progress[10]
- The $15 billion National Reconstruction Fund to finance projects to diversify and transform industries, including up to $3 billion for the Powering Australia plan to support renewables and low emissions technologies[11]
- An independent review of the integrity of Australian Carbon Credit Units (ACCUs) under the Emissions Reduction Fund, which found that the existing carbon crediting framework is robust, with recommendations to improve transparency and improve outcomes[12]
- The Powering Australia plan to increase renewable energy and support industry, agriculture and transport sectors to decarbonise[13]
- The Rewiring the Nation fund in the 2022-2023 Budget with $20 billion in low-cost finance over four years to unlock investment in the electricity grid[14]
- The Net Zero Authority and Net Zero Economy Agency, which is responsible for promoting orderly and positive economic transformation associated with decarbonisation and energy system change.[15]

Like NSW, other states and territories have committed to achieving net zero by 2050 or earlier and have developed several policies and initiatives to reduce emissions:[16]

- The ACT now procures 100% renewable electricity and is looking to decarbonise other sectors, including transport.[17]
- Queensland has committed to at least 25GW of renewable energy, two pumped hydro projects and development of a local hydrogen industry under the New Industry Development Strategy[18]
- South Australia is forecasted to reach 100% renewable energy by 2030[19]
- The Northern Territory aims to achieve 50% renewable energy to consumers by 2030[20]
- Tasmania has reached 100% net renewables and has legislated a new Tasmanian renewable Energy Target of 200% by 2040.[21] The Marinus Link and Battery of the Nation projects will enable the export of this renewable power to the National Electricity Market[22]
- Victoria has developed a Gas Substitution Roadmap to decrease the state's reliance in gas[23]
- Western Australia has a strong focus on hydrogen, announcing the establishment of hydrogen hubs in the Pilbara and the Mid-West and a hydrogen-to-ammonia project in the Pilbara.[24]

10 Australian Government (2022) Climate Change Bill 2022.
11 Australian Government (2022). National Reconstruction Fund: Diversifying and Transforming Australia's Industry and Economy.
12 Australian Government (2022). Independent Review of Australian Carbon Credit Units.
13 Climate Change Authority (2022). First Annual Progress Report. The Baseline, Global Context and Methodology.
14 Australian Government (2022). Improving Energy Security, Reliability and Affordability.
15 Australian Government (2023). Net Zero Economy Agency.
16 Climateworks Centre (2021). State and Territory Climate Action: Leading Policies and Programs in Australia.
17 ACT Government (2022). ACT's Emissions Vehicles Strategy: 2022-30.
18 Queensland Government (2022). Queensland Energy and Jobs Plan: Power for Generations.
19 South Australia Government Finance Authority (2020). Renewable Energy.
20 Northern Territory Government (2021). Our Renewable Energy Target.
21 Tasmanian Government (nd). 200% Tasmanian Renewable Energy Target.
22 Tasmanian Government (2020). Tasmania surges to 100% Renewable Energy.
23 Victorian Government (2022). Gas Substitution Roadmap.
24 Western Australian Government (2020). Western Australian Climate Policy: A Plan to Position Western Australia for a Prosperous and Resilient Low-Carbon Future.

2.2 International decarbonisation policies and events overview

Decarbonisation of energy is accelerating throughout the world, with the amount of renewable energy likely to double in the next five years globally. Some significant international initiatives include:

- The United States' 2022 Inflation Reduction Act to increase the pace of transition to renewable energy, zero emissions transport and industries in the next 10 years[25]
- The European Union's REPowerEU Plan to accelerate the rollout of energy efficiency measures and renewable energy generation[26]
- The European Union has also committed to implement the previously announced carbon border adjustment mechanism by October 2023[27]
- The United Kingdom Net Zero Strategy: Build Back Greener which sets out the Government's long-term plan to end the United Kingdom's (UK) contribution to human-induced climate change[28]
- China released its 14th Five-Year Plan, which sets a target of 33% of electricity generation from renewables by 2025 (up from about 29% in 2021)[29]
- India has proposed that by 2030, 500GW of energy generation will come from non-fossil fuel generation with 50% renewable generation.

International action to decarbonise economies and reach net zero has also gained momentum. Since 2020, there have been two meetings of the Conference of the Parties of the United Nations Framework Convention on Climate Change (COP) (in Glasgow in 2021 (COP 26) and at Sharm el Sheikh in Egypt in 2022 (COP 27)). Key focus has been on adaption and resilience, loss and damage, food, water and just transition:[30,31]

- Strengthening efforts to build resilience to climate change, curb GHG emissions and provide the necessary finance for both
- Phasing down unabated coal power and inefficient subsidies for fossil fuels
- Boosting low emissions energy.

In addition, many countries have entered into bilateral climate action collaboration arrangements. For example, Australia has concluded agreements with Germany, Indonesia, Japan, Republic of Korea, Singapore, UK, US and Vietnam.[32]

The 2020 Study was released while the COVID-19 pandemic was in its infancy, when major economic disruptions were occurring, and most countries were announcing large fiscal stimulus initiatives to dampen the economic impact of the pandemic. Since then, the Russian invasion of Ukraine has impacted world energy markets and led to significant increases in energy prices, highlighting the importance of energy security. In the longer term, these increased energy prices are expected to hasten the transition to clean energy as many European countries and other nations fast track their rollout of renewables.[33,34]

25 The White House (2022) Fact Sheet: The Inflation Reduction Act Supports Workers and Families.
26 European Commission (nd). Renewable Energy Targets.
27 European Commission (nd). Carbon Border Adjustment Mechanism.
28 HM Government (2021). Net Zero Strategy: Build Back Greener.
29 International Energy Agency (2022). Renewable Electricity.
30 United Nations Climate Change (nd). The Glasgow Climate Pact – Outcomes from COP26.
31 United Nations Climate Change (2022). COP27 Reaches Breakthrough Agreement on New 'Loss and Damage' Fund for Vulnerable Countries.
32 Australian Government (nd). Climate Change: International Cooperation on Climate Change.
33 The Economist (2022). The Costs and Consequences of Europe's Energy Crisis are Growing.
34 Renew Economy (2023). Germany Sets New 70GW Offshore Wind Target.

3.0 Common themes across decarbonisation ecosystems

The 2020 Study identified common foundational elements that support the transition to a decarbonised economy, which remain relevant. There are linkages across sectors, with technologies and services supporting decarbonisation in other sectors. This section outlines some of these common themes, providing an overview of the foundational elements relevant to more than one sector, as well as opportunities for cross-sector interactions.

3.1 Foundational elements enabling decarbonisation innovation

Decarbonisation and sustainability are core strategies for prosperity. Forward-looking economies are increasingly adopting focused investments in decarbonisation strategies designed for competitive advantage.

Around the world, nations that have achieved international leadership employ a range of decarbonisation strategies, with an underlying theme of seeking competitive advantage through relentless improvement in innovation and sustainability.

The challenge for NSW is to accelerate decarbonisation while its maintaining areas of existing competitive advantages and to create incentives for companies and industries to transition to sustainable low-carbon and renewable sources to create new growth and secure a new competitive position in the net-zero economy. This is critical for improving NSW's competitiveness in the changing global market, maintaining the state as an attractive investment destination and building an innovation economy to grow employment.

The NSW *20-Year R&D Roadmap (Roadmap)* is the NSW Government's vision to produce more world-leading technologies, products and services.[35] The Roadmap identifies four technology themes and 39 technology applications where NSW has competitive advantages compared with domestic and international peers. Of the four technology themes from the Roadmap, materials and chemistry, energy and biotechnology are considered core climatetech and service areas with direct emissions reduction benefits, while the digital technology theme is a key enabler for deployment.

Many technology applications groups highlighted by the Roadmap are core decarbonisation innovation technologies, including electrification, sustainable fuels and controlled environment horticulture. Some other technology groups are enablers for deploying core climatetech and services, such as simulation and training, robotics and smart materials. Figure 1 presents those technology groups in the Roadmap that have direct and enabling impacts for decarbonisation.

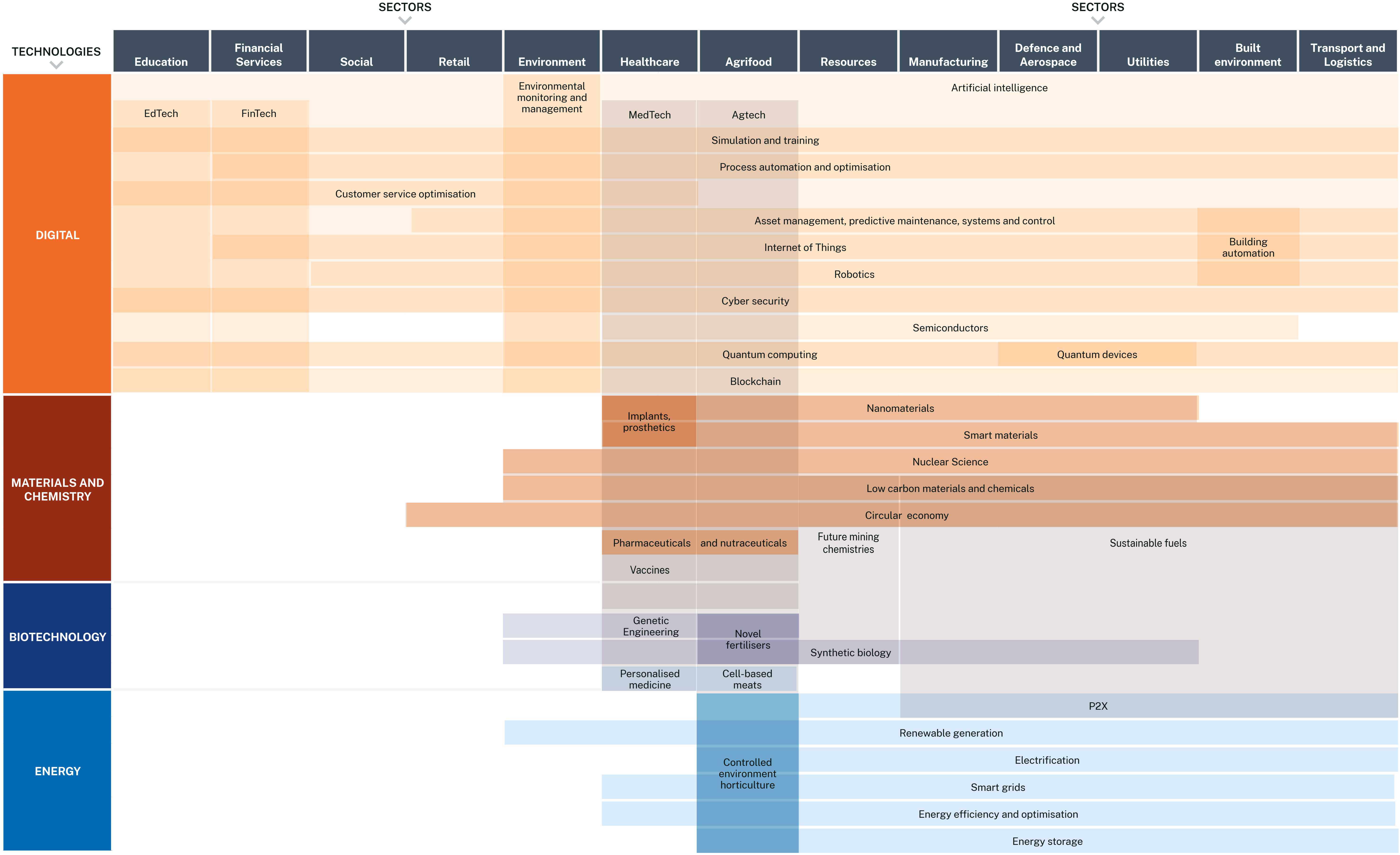
35 NSW Chief Scientist & Engineer (2022). Shaping the Future of NSW in Science and Technology: *20-Year R&D Roadmap*.

NSW's competitive advantages

As one of the largest economic centres and manufacturing and knowledge hubs in the Asia-Pacific region, NSW has competitive advantages across key factors of production:

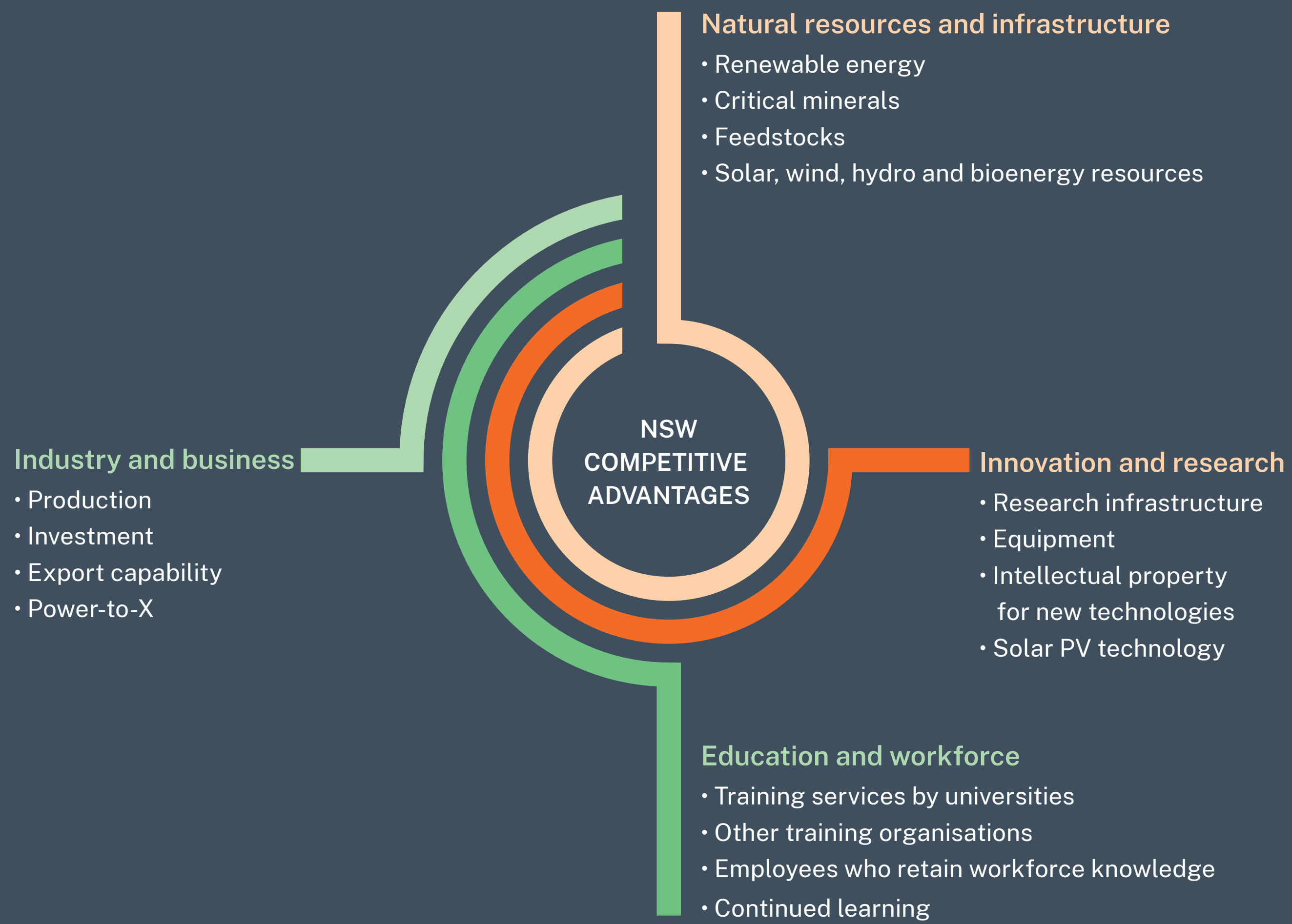
- **Policy landscape and certainty.** NSW is known for its well-managed policy landscape and regulatory framework. The government's ability to provide a stable and predictable business environment creates certainty for businesses, particularly in net zero. This stability encourages investment and enables businesses to make long-term plans, fostering growth and innovation.
- **Economy structure and reduced exposure to global risks.** The economy of NSW benefits from diverse industry sectors, which helps mitigate risks associated with global economic fluctuations. By having a broad range of industries, including finance, manufacturing, tourism and services, NSW is less reliant on a single sector or market. This economic diversity provides resilience and reduces the vulnerability to global economic downturns or specific industry-related risks.
- **Natural resources and infrastructure assets.** NSW provides access to critical natural resources such as renewable energy, critical minerals and feedstocks, existing and planned major infrastructure and physical assets. For example, rich solar, wind, hydro and bioenergy resources not only directly decarbonise the energy sector but also offer indirect electrification across the economy.
- **Innovation and research capability.** NSW excels in innovation and research capability and hosts world-class research infrastructure and advanced equipment. Experts, scientists and academics across various disciplines contribute their expertise to research projects and collaborate with businesses to drive innovation.
- **NSW fosters a strong intellectual property framework,** protecting the rights and commercialisation potential of new technologies, inventions, and discoveries. This encourages researchers and entrepreneurs to bring their ideas to market and stimulates further innovation. For example, innovation and continuous improvement for solar PV technology leads to a new generation of solar cells for higher efficiency and lower costs.
- **Education and workforce.** NSW is home to prestigious universities and reputable training organisations that provide high-quality education and training programs. The presence of internationally recognised universities attracts both domestic and international students, fostering a diverse and talented pool of graduates. The education and training services provide employees with the skills needed to adapt to evolving industries. By retaining workforce knowledge, NSW businesses can leverage the expertise of their employees, resulting in improved productivity, innovation and competitiveness.
- **Industry and business capacity.** The diverse industry base provides a robust foundation for production across multiple sectors. As noted previously, this diversity reduces reliance on a single sector and allows for a balanced and resilient economy, increasing the capacity for production and investment. NSW has a strong track record of exporting goods and services to international markets supported by established ports, transportation networks and trade infrastructure. The strong industry and business portfolio of the state encourages businesses to reinvest innovation and upskilling, driving continuous improvement and development.

Figure 1: NSW *20-Year R&D Roadmap* technology groups that have decarbonisation applications



To build and expand the sophisticated industries that will form the backbone of future clean economy, NSW would need to create competitive advantages for the most important factors of production across the decarbonisation innovation ecosystem.

Nations successfully grow industries when they are particularly good at creating production factors, being land, labour, capital and entrepreneurship. What is less obvious is that selective disadvantages in some factors can stimulate innovation to become more competitive. This section of the report lists some of the factors, which are referred to as Foundational Elements, where NSW has competitive advantages for the creation of new production factors or will experience disadvantage without focused investment and support.



Circular economy

The 2020 Study identified circular economy as being relevant to all sectors to reduce carbon emissions and bring economic benefits through resilient supply chains and job creation. Since then, there has been growing interest in and awareness of the circular economy across industry and within the public sector at all levels of government. This is demonstrated through actions such as the ban of supply of single-use plastics in NSW since November 2022,[36] the June 2023 agreement by Australian Environment Ministers on the development of the national framework for the move to a circular economy,[37] and a rising trend in the 17 Sustainable Development Goals (SDG) reporting by ASX (Australian Stock Exchange Ltd) listed 150 companies, prioritising responsible consumption and production and climate action goals.[38]

The circular economy is based on three core principles, driven by design and value-adding to eliminate waste and pollution, circulate products and materials (at their highest value) and regenerate nature.[39] Implementing the circular economy requires a combined effort by business, government, researchers and industries. To remove the barriers and to drive a zero-carbon circular economy in NSW, Circular Australia (formerly NSW Circular) partners with other stakeholders to provide transparent circular economy data, promote visibility on supply chain flow and establish taskforces to promote collaboration.[40]

NSW has a suite of policies addressing both circular economy and decarbonisation, aiming to minimise waste and improve the efficiency of use and reuse of finite resources.[41] These policies are backed by some $365 million in funding commitments and the sharing of resources planning and industry investment in precinct development such as Special Activation Precincts (SAP) and the establishment of a Critical Minerals Hub in the Central West.[42]

It is critical that Circular Economy principles and practices are an integral element of the development of the Net Zero economy industries in NSW. There is a significant opportunity to ensure that deployment of climate technologies do not lead to unintended consequences associated with materials and waste. PV and battery waste in NSW is projected to increase by 10-to 20-fold in 2035 compared to 2025.[43] It is important that circularity in material design, construction and operations in clean technologies such as wind, hydrogen and critical minerals and energy storage are considered and addressed from the outset.

NSW can take this opportunity in promoting climate technology material circularity, securing supply chains and managing the waste at the end-of-life. Existing NSW-based initiatives such as the Trailblazer for Recycling and Clean Energy (TRaCE) have a critical role to play in establishing a fully integrated ecosystem for recycling and clean energy research commercialisation in Australia. The TRaCE aims to accelerate the development and deployment of disruptive technologies and business models in these sectors.[44] Other initiatives like the NSW Circular Solar grants ($9.4 million awarded to eight grant projects[45]) seek to improve NSW's capacity to recycle, refurbish and reuse solar panels and their components, as well as batteries by over 10,000 tonnes per annum.[46] Another example is the Australian Circular Economy Hub (ACE Hub), a public-private partnership to establish a collaboration platform for advancing the circular economy.[47]

36 NSW Environment Protection Authority (2023). Compliance approach for 1 November Plastic Bans.
37 Australian Government (2022). Environment Ministers' Meeting Agreed Communique.
38 RMIT University (2021). SDG Measurement and Disclosure 3.0: A Study of ASX 150 Companies.
39 Ellen Macarthur Foundation (nd). Circular Economy Introduction.
40 Circular Australia (2022). About Us.
41 NSW Government (2021). NSW Waste and Sustainable Materials Strategy 2041. Stage 1: 2021-2027.
42 NSW Government (2021). Critical Minerals and High-Tech Metals Strategy.
43 UTS (2020). Scoping Study for Photovoltaic Panel and Battery System Reuse and Recycling Fund.
44 UNSW Sydney (nd). Trailblazer for Recycling and Clean Energy.
45 NSW Government (2022). Going Circular in Clean Energy Issues Paper.
46 NSW Government (2022). Circular Economy Boost for Solar Panels.
47 Australian Circular Economy Hub (nd). Australian Circular Economy Hub.

Local manufacturing

As highlighted in the 2020 Study, decarbonisation presents economic opportunities for NSW businesses, including leveraging new technologies and services to reduce energy and materials, and producing more products and services for larger and higher value markets more efficiently. Australia relies heavily on global markets across many supply chains. This was experienced during the COVID-19 pandemic and the Russian invasion of Ukraine. Both experiences underscore how global disturbance can impact supply of a wide range of products and services. [48,49]

In response, countries are looking to diversify supply chains and make them more resilient, including through growing their own local manufacturing capabilities. This can not only provide safeguard against global shocks but can also potentially provide export opportunities as other markets also seek to address the diversity of their own supply chains, especially in the clean energy sector. The development of local manufacturing to address supply chain issues, grow local markets and provide export opportunities was again raised by many stakeholders inputting to this 2023 Report. In some sectors this is already underway. In the battery sector, development is underway with the construction of lithium hydroxide plants with companies such as Energy Renaissance and Vecco Group developing manufacturing facilities to produce batteries. [50,51,52]

This presents opportunity for NSW to leverage our strong R&D capabilities in decarbonisation technologies[53] and develop local manufacturing, particularly in advanced manufacturing. This can provide a strong base for local commercialisation pathways.

At the federal level, the National Reconstruction Fund is being established to support projects to diversify and transform Australia's industry in priority areas, including sectors key to decarbonisation:[54]

- renewables and low emissions technologies
- transport
- value-add in the agriculture, forestry and fisheries sectors
- value-add in resources
- enabling capabilities.

In NSW, the Modern Manufacturing Taskforce provides independent advice on developing modern manufacturing capability in NSW.[55] The Taskforce has recommended NSW invest in modern manufacturing,[56] particularly in technologies supporting decarbonisation. Several activities and initiatives have been implemented in response to this recommendation.[57] Other actions include using public procurement to support the research, development and manufacture of products, and the Office of the Modern Manufacturing Commissioner working with other states, territories and the Commonwealth, to develop a nationwide, coordinated approach to supply chain resilience.[58] As part of the Net Zero Industry and Innovation Program (NZIIP), the NSW Government is supporting the development of industrial decarbonisation plans for the Hunter and Illawarra to fast track decarbonising high emitting industries and set the foundation to attract and create new, low carbon industries.[59] These are designed to bring multiple industries together, helping them to collaboratively access clean infrastructure and technology and develop a path to decarbonisation. This 'precinct' level approach has been successful overseas in reducing costs and risks associated with scaling up and providing shared enabling infrastructure for new clean technologies (like hydrogen), supporting economic growth in a low carbon economy and developing low carbon supply chains.[60] Other actions include supporting manufacturing industries to develop low carbon products and materials and components for the renewable energy and electric vehicle (EV) sectors.[61]

48 Reserve Bank of Australia (2021). Statement on Monetary Policy – May 2021.
49 OECD (2022). Policy Responses: Ukraine Tackling the Policy Challenges.
50 Australian Financial Review (2023). Will Wesfarmers $2 Billion Leap into Lithium Land it in Nirvana?
51 Australian Financial Review (2023). Entrepreneur Declares Australia's First Battery Gigafactory.
52 Renew Economy (2023). Australia's First Vanadium Flow Battery Plant Begins Construction in Townsville.
53 NSW Chief Scientist & Engineer (2022). Shaping the Future of NSW in Science and Technology: 20 Year R&D Roadmap.
54 Australian Government (2022). National Reconstruction Fund: Diversifying and Transforming Australia's Industry and Economy.
55 NSW Government (2023). Modern Manufacturing in NSW.
56 Modern Manufacturing Taskforce (2022). Making it in NSW: Time for Action.
57 NSW Government (nd). NSW: The Home of Modern Manufacturing.
58 NSW Modern Manufacturing Taskforce (2022). Making it in NSW. Time for Action.
59 NSW Government (2023). Industrial Decarbonisation Plans for the Hunter and Illawarra
60 NSW Government (2022). Investing in a Low Carbon Future for NSW Industry.
61 NSW Government (2023). Developing Renewable and Low Carbon Manufacturing Industries in NSW.

Standards and certification

As noted in the 2020 Study, robust standards and certification processes offer opportunity for businesses to adopt sustainable practices and market their credentials to consumers and other businesses seeking sustainable products and services, allowing their business to grow in a net-zero economy. It also highlighted the importance of governments encouraging standards that are internationally relevant, trusted by overseas consumers and consistent across jurisdictions. With a growing number of end-users seeking products and services with low emissions, robust standards and certification processes help create market advantage. Growing regulation also underscores the importance of standards and certification to address 'greenwashing' and prevent deceptive practices.

Standards and certification play a crucial role in providing investment certainty to businesses and investors. Standards serve as a benchmark for quality, safety and performance in various industries and sectors. When businesses adhere to established standards, they demonstrate their commitment to meeting industry best practices and delivering reliable products or services. Certification, on the other hand, validates that a business has met the required standards and has undergone rigorous assessment processes by independent third-party organisations. By investing in standards and obtaining relevant certifications, businesses establish a foundation of trust, reduce risks and enhance their reputation. This investment certainty not only attracts potential investors but also facilitates trade, collaboration and long-term partnerships, ultimately contributing to sustainable growth and success in the marketplace, leading to reinvestment in innovation.

Establishing and adopting standards and certifications requires comprehensive work and is time consuming. This can result in delays in adopting new practices and technologies. The Australian Government and standards organisations are working to minimise this. Accreditation and development of standards to assist decarbonisation has a particular focus on the development of safety regulations[62] and certification and standards for clean hydrogen.[63] This is in line with other major economies such as the US, as a key component of strategies supporting decarbonisation innovation and clean economy advantage.[64]

The Sustainable Buildings State Environment Planning Policy sets standards for residential and non-residential developments to minimise consumption of energy and reduce emission from energy use.[65] These standards are being incorporated into NSW's sustainable planning measures used for residential and non-residential buildings including the BASIX (Building Sustainability Index) and NABERS (National Australian Built Environment Rating System). As part of the National Electric Vehicle Strategy, the Australian Government is consulting on the introduction of standards for vehicle fuel efficiency and EV safety and vehicle charging infrastructure, with strong evidence from overseas that early introduction of such standards provide better market access to efficient vehicle choices, lower costs and provide consumer confidence to underpin accelerated uptake of new decarbonising technologies.[66] Care must be taken to avoid developing a novel Australian Standard where there is a 'fit for purpose' International Standard which can be used with no time delays.

Standards development work is ongoing and, as an increasing amount of decarbonisation technologies are developed, it is critical that industry, government and standards organisations continue to collaborate. It will be necessary to consider a forward-looking agenda to ensure there are capabilities and resourcing for timely development and adoption of standards to support rapid commercialisation and accelerate uptake of new technologies.

62 Standard Australia (2022). 2022 Annual Review: Investment and Delivery.
63 Standards Australia (nd). ME-093 Hydrogen Technologies: Strategic Work Plan.
64 US Government (2023). U.S. National Clean Hydrogen Strategy and Roadmap.
65 NSW Government (2023). Sustainable Buildings SEPP.
66 Australian Government (2022). National Electric Vehicle Strategy: Consultation Paper.

Government procurement

The NSW Government purchases around $30 billion of goods, services and construction each year, employs 10% of the State's workforce and manages approximately 15% of all NSW land.[67] The 2020 Study identified the role of government as a critical customer to accelerate demand for decarbonised products and services and potentially drive lower prices through economies of scale. The Net Zero Plan – Stage 1: 2020-2030 has a priority for the NSW Government to play a leading role in being an early adopter of sustainable goods, services and practices, and maximising the environmental value of the assets it oversees.[68]

Since 2020, a range of policies have been introduced or amended to support government procurement, including the NSW Government Procurement Policy Framework and the Government Resource Efficiency Policy.[69,70] Infrastructure NSW is investigating how best to decarbonise infrastructure delivery given NSW's growing infrastructure pipeline (currently $112.7 billion) and the associated embodied emissions of construction materials, which are approximately 5% to 10% of Australia's total emissions.[71]

Infrastructure NSW and the NSW Government Environment Protection Authority (EPA) are developing a Protection of Environment Policy (PEP) requiring the measurement and eventual reduction of embodied emissions in infrastructure. The PEP will also support circular economy approaches that manage waste more efficiently and reduce carbon emissions.[72]

Transport for NSW is also developing its Sustainable Procurement in Infrastructure initiative, which proposes introducing sustainability requirements and changes to support the uptake of low carbon design solutions.[73] NSW Health has established a Climate Risk and Net Zero Unit to improve the sustainability of healthcare (Australia's health system contributes an estimated 7% of Australia's total carbon footprint).[73,74]

Consultation for this study again identified the importance of government and large corporate procurement to encourage decarbonisation and grow the market for decarbonised products. By continuing to develop and implement sustainable procurement policies and targeting its purchasing power, the NSW Government has the potential to aid the deployment of low emissions products and services and drive economic development.

67 NSW Government (2022). NSW Government Procurement Policy Framework.
68 NSW Government (2020). Net Zero Plan Stage 1: 2020-2030.
69 NSW Government (2022). NSW Government Procurement Policy Framework.
70 NSW Government (2019). NSW Government Resource Efficiency Policy: For a Resource Productive Public Sector with Less Impact on the Environment.
71 NSW Government (2022). Decarbonising Infrastructure Delivery: NSW Government Discussion Paper.
72 NSW Government (2022). Decarbonising Infrastructure Delivery: NSW Government Discussion Paper.
73 NSW Government (2022). Net Zero in Local Health Districts, Specialty Networks and Health Organisations.
74 NSW Government (nd). Climate Risk and Net Zero Position Statement.

Skills and training

A combination of the ongoing effects of COVID-19 and a challenging economic landscape has exacerbated challenges linked to the surging skills gap and labour shortages over the past 12 months.[75] Further, the new technologies and services associated with decarbonisation will require a broad set of new skills to build on existing workforce capabilities.

The current challenges and opportunities facing the Australian labour market were acknowledged at the national Jobs and Skills Summit in September 2022.[76] It was agreed that immediate actions to build a better and more productive workforce are needed.
This included:

- commissioning a clean energy workforce capacity study, which is due to report mid-2023[77]
- supporting clean energy supply chain resilience, increasing Australia's clean energy manufacturing industries
- a New Energy Apprenticeships plan.

Jobs and Skills Australia notes that the continued shortage of apprentice-trained technicians and trade workers is of particular concern, with data indicating employers are having difficulty filling vacancies for positions that require an apprenticeship training pathway.[78] The Australian Apprenticeships Priority list identifies priority occupations with national shortages, including clean energy specific skills. Further, an acute and worsening shortage of professional occupations in the energy sector was reported, driven by insufficient education and training.

A cross-sector approach is required to renew focus and investment in training and mentoring, particularly in STEM (science, technology, engineering and mathematics) fields. This would ensure industry has the skills to cope with a more complex power system and emerging industry. This could be in the form of guaranteed high-quality training, strong career development programs, targeted apprentice incentives and dedicated benefits to help enhance careers.

This recognition is reflected in the Opportunity Assessment released by the Reliable, Affordable, Clean Energy (RACE) for 2030 Cooperative Research Centre (CRC) in October 2021.[79]

75 Global Energy Talent Index (2023). The Global Energy Talent Index Report 2023.
76 Australian Government (2022). Jobs + Skills Summit Outcomes.
77 Australian Government (2023). Clean Energy Capacity Study Terms of Reference.
78 Australian Government (2022). 2022 Skills Priority List: Key Findings Report.
79 RACE for 2030 (2021). E3 Opportunity Assessment: Developing the Future Energy Workforce.

The Australian Industry Energy Transitions Initiative (ETI) commissioned a report to provide a deep dive into the jobs and skills, and the decision-making required to build towards a prosperous decarbonised future.[80] The report highlighted that, despite environmental performance, Australia has historically fallen behind global leaders on co-ordinated green skill policy. This is partially as a result of the STEM crisis across Australia in innovation and technology-driven sectors. The report notes that while policy has improved considerable since 2020, future policies and programs should build on three key objectives to prevent a critical shortage of skilled workers.

These include:

1. Increasing the pipeline of future workers to address short-term skills shortage. This could be done by incentivising greater enrolment in STEM and critical trade certifications, especially in electrotechnology for electricians
2. Upskilling the existing workforce to address the renewable energy training need. This could be done through increasing incentives for existing workers to participate in renewable energy courses
3. Upskilling and reskilling carbon workers to address the medium-long term skills shortage. Supporting carbon workers to upskill their existing occupation and transition to green industries should be a priority.

Jobs and Skills Australia and other studies have emphasised that there is both collaboration and competition as nations race towards a clean energy future, and that Australia should look to best practices from other global policy leaders to prevent a critical shortage of skilled workers in the energy transition.

For example:

- in the United States, the Hydrogen Education for a Decarbonized Economy Program aims to enhance workforce readiness through training and education for the hydrogen industry[81]
- in the Philippines, the 2016 Green Jobs Act is a whole-of-government approach to identify skill needs, train and certify workers in green jobs, and includes 50% tax deductions on skills training.

Microcredentials for upskilling are becoming more broadly recognised under the new National Microcredentials Framework.[82] Microcredentials are certified short courses that teach new skills quickly at TAFE or university level. They allow for a narrower focus on industry-recognised skills and could be an important component for workers reskilling in specific avenues as the state decarbonises.[83]

Supporting this 'just transition' of the workforce in the fossil fuel and carbon-intensive industries where skills are transferable to the renewable and net zero economy sectors will be critical to support a rapid and just transition.[84]

Stakeholder feedback for the 2023 Study emphasised how critical workforce readiness is for successful decarbonisation and a just transition, highlighting the need for NSW Government support. This transition requires support for appropriate workforce development, higher education and other programs to develop the (existing and new) workforce for decarbonisation and creating pathways for developing cross-cutting skills. Students need to be able to see education and career pathways through training, accredited external training, internships and cadetships, or blended models such as the NSW Tertiary Pathways Project.[85]

80 Australian Industry Energy Transitions Initiative (2023). Skilling Australian Industry for the Energy Transition.
81 Electric Power Research Institute (2021) Hydrogen Education for a Decarbonized Economy.
82 Australian Government (2021). National Microcredentials Framework.
83 Open Universities Australia (2022). What are Microcredentials?
84 Climate Justice Alliance (nd). Just Transition: A Framework for Change.
85 NSW Government (2019). The NSW Tertiary Pathways Project.

Place-based approaches and precincts

A place-based approach and the development of precincts are recognised as powerful drivers of decarbonisation innovation. The 2020 Study identified place-based precincts as a shared opportunity across many sectors, with early work progressing on clean energy and low-carbon precincts at that time. Since then, place-based approaches for decarbonisation and industry development have been increasingly adopted. The NSW Industry Development Framework indicated that existing and emerging industries will be the focus of interventions in precincts for existing and new industries, such as clean energy, waste and digital.[86]

The place-based approach involves focusing on specific geographic areas or precincts to holistically address sustainability challenges and drive targeted solutions. By adopting a place-based approach, policymakers, businesses and communities can gain a deeper understanding of the unique characteristics and needs of a particular location, enabling them to tailor interventions and strategies accordingly. It allows for the implementation of innovative solutions tailored to the specific needs and challenges of the precinct, fostering a more effective and efficient transition to a low-carbon future. For example, industrial decarbonisation plans can accelerate the take-up of clean technology, secure supply chains, expand onshore industry and attract local low-carbon industries, jobs and skills. These precincts become the centralised innovation and industry hubs for development of zero emission technologies and future low-emissions industries, leveraging renewable energy in NSW.

The focus on precincts encourages the adoption and development of other foundational elements such as circular economy principles, standards and certification frameworks, new infrastructure, tailored training facilities training enabling innovation and growth of new industries. This integrated approach also facilitates the engagement of businesses and local communities, fostering awareness, participation and ownership of decarbonisation initiatives. A variety of studies have identified significant economic growth opportunity from the development of such precincts. A 2021 Beyond Zero Emissions (BZE) study by ACIL Allen of such a precinct in the Hunter Valley modelled significant benefits to the regional, state and national economies over 2022-2032 from such an approach.[87]

As identified in the 2020 Study, NSW continues to establish Renewable Energy Zones (REZ), Innovation Districts and Special Activation Precincts (SAP) and other placed-based initiatives including:

- **Regional Job Precincts** – an extension of the SAP program looking to drive investment and jobs in regional NSW, with precincts planned for Albury, Richmond Valley and South Jerrabomberra[88]
- **Hydrogen Hubs** – supporting the development of the future hydrogen industry and co-locating hydrogen users across industry, transport and energy markets[89]
- **Industrial Decarbonisation Plans** – in the Illawarra and Hunter regions to bring industry and clean infrastructure and technology together and support decarbonisation of industry sectors in the regions. These are designed to fast track the decarbonising of high emitting industries and establish foundations for attracting investment and creating new, low carbon industries.[90]

In addition, the Australian Government's $1.9 billion Powering the Regions Fund and the $454 million Regional Hydrogen Hubs program are focused on supporting such regional decarbonised clusters, with the Hunter being identified as one of the national hydrogen hubs to receive funding.[91]

86 NSW Government (2023). The NSW Industry Development Framework.
87 Beyond Zero Emissions (nd). Renewable Energy Industrial Precincts: Economic Analysis.
88 NSW Government (2023). Regional Jobs Precincts.
89 NSW Government (2023). Hydrogen Hubs for NSW.
90 NSW Government (2023). Industrial Decarbonisation Plans for the Hunter and Illawarra
91 Australian Government (2023). Powering Australia.

Consumer sentiment

The 2020 Study identified the potential for consumer education and research to help improve consumer confidence in energy markets, promote sustainable products and services and improve understanding of the benefits and cost of transport choices. While the 2020 Study only identified the role of consumers for some sectors, stakeholders in 2022 highlighted the need to engage with end-product users such as businesses, households and the community across all sectors to facilitate a transition to net zero and decarbonisation.

International surveys have reported that consumers do not feel they have the right information to decide how to decarbonise their life. For example, ARUP and the Imperial College in the UK reported that consumers feel they don't have 'meaningful, real and free choice' to decarbonise their heating and suggested the need to improve awareness, develop incentives for change, provide better information to enable informed choices and provide support and leadership for change to occur.[92] This is supported by other surveys that show consumers are concerned about climate change but aren't sure how to reduce their emissions.[93,94]

In the most recent Australian energy consumer survey, households ranked affordable energy prices as the most important issue, followed by transitioning to renewable energy sources, replacing old coal and gas plants and building a resilient energy system.[95] The small business survey had similar concerns, although resilience ranked higher than energy transition and replacing old coal and gas plants.[96]

When Australian household energy consumers were asked about upgrading or purchasing heating and efficiency appliances, there was greater interest in solar hot water, rooftop PV solar panel electric battery storage systems and electric vehicles compared to more traditional energy efficiency practices such as ceiling insulation and double-glazed windows.[97] Similar trends were identified in the survey of small business energy consumers.

Online resources are being promoted to assist with consumer uncertainty. Energy Consumers Australia has developed a website aimed at providing household and small business energy consumers with information to support transition to renewable energy solutions (for example, solar panel, batteries and electric vehicles).[98] The Materials and Embodied Carbon Leaders Alliance (MECLA) has also developed resources to assist the construction sector and related industries reduce embodied carbon.[99] The Australian Government has websites to assist consumers design, build or renovate energy efficient and environmentally sustainable homes and an Energy Rating system website for appliances.[100,101]

Wider community support and 'social licence' for decarbonisation has emerged as a critical set of constraints impacting the pace of decarbonisation. Stakeholders highlighted the need to consider social licence when transitioning to net zero and decarbonisation. Other social licence challenges will come from the expectation of rapid electrification of households, electrifying gas-heated homes and shifting to EVs, and will require careful management and support to ensure these changes are fair across all segments of diverse communities.

Land-based renewable energy resources are being constructed across a wider set of geographies and require large overhead transmission lines and, while there is overall support for a shift to renewables, this support may not translate to acceptance of specific projects or technology changes. A key illustration of how this impacts the pathway to net zero is the increasing pressure from landowners not supporting local projects when they impact on local land use and preservation.[102] Wind farms have been a source of community contention for several years, with concerns also for offshore wind farms.[103] No matter which sector, projects looking to support net zero and decarbonisation need to step up engagement and consultation to build social licence from planning through to demonstrating and building the acceptance through a fair sharing of benefits to communities and individuals.

92 ARUP & Imperial College London (2022). The Role of Consumer Choice in Decarbonising Heat.
93 Ofgem (2020). The Role of the Consumer in Achieving Net Zero.
94 One Tribe (2022). Consumer Expectations Towards Decarbonisation and Net Zero.
95 Energy Consumers Australia (2022). Sentiment Survey: December 2022, Household Results.
96 Energy Consumers Australia (2022). Sentiment Survey: December 2022, Small Business Results.
97 Energy Consumers Australia (2022). Behaviour Survey: October 2022.
98 Energy Consumers Australia (nd). Plug in.
99 Materials and Embodied Carbon Leaders Alliance (2022). Resources.
100 Australian Government (2022). Your Home: Australia's Guide to Environmentally Sustainable Homes.
101 Australian Government (2023). Energy Rating: Consumer Information.
102 Nous Group (2021). Unlocking the Social Licence Gate to Decarbonisation.
103 ABC News (2022). South Gippsland Residents Fear Offshore Wind Turbines Will Ruin Coastline's Beauty.

Digital technologies

Digital technologies are novel, fast growing and will significantly impact decarbonisation pathways for many industries. Technology groups such as artificial intelligence (AI), advanced communication and robotics and automation could accelerate the deployment of climatetech. The 2020 Study recognised the potential applications of digital technologies for distributed energy resources, consumer-driven energy trading, EV integration to infrastructure and advanced sensing for the built environment.

The World Economic Forum's analysis suggests that integrating digital solutions across some high-emitting and hard-to-abate sectors, including energy, mobility, building and materials, can reduce global emissions by up to 20%.[104] Digital solutions could enable efficiency improvement, circularity and Scope 3 emissions reduction across four clusters of high-impact digital technologies:[105]

- **Decision-making technologies** that augment human intelligence to energy efficiency and productivity, such as digital twin, AI and machine learning
- **Sensing and control technologies** that collect data and alter physical processes to be more sustainable, such as drones and imaging, automation and robotics, and Internet of Things (IoT)
- **Enabling technologies** that are core for any digital business today to realise benefits, such as Cloud Computing and Networks, fast speed internet network, blockchain and Augmented Reality and Virtual Reality (AR/VR)
- **Foundational technologies** that exist within current operations such as big data analytics, measurement and reporting.

The deployment of digital solutions would have substantial impacts for decarbonising land and agriculture sectors. Sensing technology would enable precision agriculture, providing farms with real-time information about crops, soil and environment to make decisions leading to improved productivity. For example, the user of remote-sensing soil-moisture sensors and weather stations could provide solutions for crop and livestock health tracking, yield management and monitoring systems.[106]

As highlighted in the NSW *20-Year R&D Roadmap* and Emerging Digital Technologies Strategy,[107] NSW has strong competitive advantages in digital technology research and development (R&D), innovation and entrepreneurship ecosystems. Emerging digital technologies have strong potential to impact the economy by transforming and creating industries, helping to reduce emissions in some of the most challenging sectors and accelerating improvements in climatetech at an unpresented scale. For example, quantum computing could allow the breakthrough of efficiency and cost reduction in chemical batteries, solar cells, hydrogen electrolysers and direct air capture technologies.[108]

The digitalisation of the economy has been accelerating in recent years, partially due to COVID-19. Changes in working and living habits have been enabled by digital technologies, with many having direct impacts on emissions. For example, work-from-home flexibility and virtual meetings can decrease emissions from office buildings and public transport but requires more decarbonised homes and private transport for net-zero economy. Advanced digital technology like AI has been attracting attention when deploying climatetech. In fact, the UK Government has announced the Artificial Intelligence for Decarbonisation Innovation Programme with two streams funding for AI application.[109]

104 World Economic Forum (2022). Digital Solutions Can Reduce Global Emissions by up to 20%. Here's How.
105 World Economic Forum (2023). 30 Digital Solutions to Power Decarbonization for Industries at Scale.
106 Climateworks Australia (2020). Decarbonisation Futures: Solutions, Actions and Benchmarks for a Net Zero Emissions Australia.
107 NSW Government (2023). Emerging Digital Technologies Strategy.
108 McKinsey & Company (2022). Quantum Computing Just Might Save the Planet.
109 UK Government (2022). Artificial Intelligence for Decarbonisation Innovation Programme.

3.2 Sector interactions

The 2020 Study acknowledged the interdependencies of the technological opportunities across the sectors, as well as the need to consider the full lifecycle of sustainability products and services across business, consumers and government.

Feedback from stakeholders for this study indicates this whole-of-business approach is still very much relevant and front of mind when considering decarbonisation solutions. Taking a comprehensive approach to decarbonisation is likely to result in greater emission reductions and economic benefit to NSW. There are several key areas where a cross-sectoral approach can unleash potential opportunities.

Decarbonisation support services

The 2020 Study emphasised the importance of environmental support services to assist business and government decarbonise and manage the risks associated with climate change and acknowledged that similar support services were needed across industry, the built environment, land and agriculture. Developments since then, especially in terms of regulatory and investor requirements for disclosure of climate risk and decarbonisation action, have further accelerated growth in market need for these specialised services. This is set to continue given greater commitment to decarbonisation and net zero across government, industry and society.

By some estimates, global sustainability consulting revenues doubled between 2020 and 2021, and then doubled again between 2021 and 2022.[110] Verdantix, a global research consultancy, finds that the overall net zero consulting services market was worth $3.5 billion in 2022 and will grow to $15 billion in 2028, at a Compound Annual Growth Rate (CAGR) of 29%.[111]

There is an opportunity for NSW to look to expand and deepen decarbonisation support services and capabilities as a sector. This provides economic benefits to the professional services sector world, and also provides impact across all sectors, helping to accelerate decarbonisation and maintain NSW's competitive advantage.

Services for different sectors are offered through existing bodies including major consulting firms, specialist sustainability and carbon markets consultancies, ESG Governance Consulting firms and research organisations such as the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and universities. There are also specialist companies to support climatetech startups and entrepreneurs connect with business and customers to commercialise and grow their products and services. The NSW Decarbonisation Innovation Hub also aims to bring industry, government and researchers together to drive the commercialisation of clean technology and provide industry solutions to decarbonisation.

Mature and robust decarbonisation support services would provide NSW with the opportunities to support the collaboration and coordination it needs to help the state decarbonise and provide economic benefit.

110 Financial Times (2023). Demand and Dilemmas Grow for Sustainability Consultants.
111 Verdantix (2023). Market Size and Forecast: Net Zero Consulting Services 2022-2028 (Global).

Renewable energy and electrification

Utility-scale solar PV and onshore wind are the cheapest options for new electricity generation worldwide.[112] Australia has the highest solar radiation per square metre of any continent and consequently some of the best solar energy resources in the world, with Western NSW having the highest level of solar radiation.[113] Australia also has some of the best wind resources in the world, with the highest wind energy potential along the higher exposed parts of the Great Dividing Range and along the coastline.[114]

It is already evident that renewable energy is reducing overall costs in the electricity market. A recent report by the Australian Energy Market Operator (AEMO) highlighted the large gap between prices in the northern regions of Queensland and NSW and those in the southern mainland due to higher-priced offers from black coal-fired generation setting prices in the north, contrasting with low middle of the day prices in the south.[115] In NSW, REZs for renewable generation are being established to address this issue and help target the construction of 12GW of renewable energy by 2030 and 2GW of duration storage. In October 2022, the NSW Government commenced its first tender for renewable and long duration storage.[116]

The 2020 Study highlighted opportunities across industries where reliable, low-cost renewable energy could grow local industries. As renewable energy penetration increases, existing industries can be revitalised and decarbonised (examples can be seen in Table 1), and new industries created.

112 International Energy Agency (2022), Renewables 2022: Analysis and Forecast to 2027.
113 Australian Government (nd). Solar Energy.
114 Australian Government (nd). Wind Energy.
115 Australian Energy Market Operator (2023). Quarterly Energy Dynamics Q4 2022.
116 NSW Government (2022). Q4 2022 Tender.

Table 1: Potential areas where reliable, low-cost renewable energy has the potential to grow industries[117]

Sector	Technology/areas
Energy	Solar, wind (onshore and offshore) and hydrogen
Industry	Clean technology manufacturing and recycling
	Direct Air Capture (DAC) and utilisation
	Power-to-X (sustainable aviation fuel, green ammonia)
	Low carbon product manufacturing (green steel, green aluminium, agricultural products)
	Biomanufacturing (biofuels, chemicals and materials)
	Cell-based meat and precision fermentation
Built environment	Energy productivity/efficiency
Land	Controlled Environment Horticulture (CEH)
	Agriculture operation
	Water efficiency and recycling
Transport	Transport fuels (green hydrogen, green ammonia, synthetic aviation fuels and electricity)

Clean sustainable fuels and energy carriers

The increased adoption of renewable energy (notably of commercial-scale solar, wind and Distributed Energy Resources (DERs)) is helping to decarbonise the energy sector and significantly decrease emissions from energy generation by the early 2030s[118] while retaining electricity reliability and affordability. Electrification of other sectors such as industrial processes, road transport and agriculture operation present opportunities to directly reduce emissions with renewable electricity but challenges exist. Clean power fuels produced from sustainable feedstock and powered by renewable energy with low or zero carbon emissions are recognised as an indirect electrification pathway to decarbonise some 'hard-to-electrify' industries.[119]

The production of sustainable fuels and energy carriers are energy-intensive processes. Low-cost electricity is critical to ensure the cost-competitiveness of sustainable fuels where energy costs generally take up one-third of the levelised cost of fuel production.[120] The economics of power fuels has been significantly improved due to the lowered costs of renewable electricity, through either grid-connected or dedicated power generation.

As 'drop-in' fuels that have the same chemical composition as their fossil-fuel counterparts, sustainable fuels would enable the use of existing infrastructure, supply chains, manufacturing capabilities and workforces.[121] This is critical for many sectors to transition from carbon-intensive towards net-zero with minimum disruption and capital costs.

Energy carriers can play an important role in transporting and relocating renewable energy sources geographically. Chemical energy carriers like hydrogen and hydrogen-derived products can export renewable energy while competing technologies in batteries and undersea cables have considerable barriers to scale and deploy.[122] Although 3% of global energy consumption is used to produce hydrogen, only 0.002% of hydrogen is used by energy carriers, with the majority used as feedstock in chemical manufacturing.[123] The global hydrogen economy is largely driven by the growing demand from traditional energy-importing countries like Japan, Germany and Korea.

NSW and Australia have a unique opportunity to leverage the solar/renewable energy 'duck curve' to facilitate the production of power fuels, particularly hydrogen.

117 KPMG (2020). NSW: A Clean Energy Superpower.
118 NSW Government (2023). NSW Net Zero Emissions Dashboard.
119 Climateworks Foundation (2018). 2050 Priorities for Climate Action: 'Electrify everything' is too simple.
120 International Energy Agency (2021). Global Hydrogen Review 2021.
121 IEA Bioenergy (2019). 'Drop-in' Biofuels: The Key Role That Co-Processing Will Play in its Production.
122 NSW Government (2021). NSW Hydrogen Strategy: Making NSW a Global Hydrogen Superpower.
123 Det Norske Veritas (nd). Hydrogen as an Energy Carrier.

The 'duck curve' represents the daily energy demand and supply pattern, where the midday solar generation surpasses the energy demand, resulting in a significant surplus of renewable energy during certain hours.[124] By capitalising on this surplus renewable energy, NSW can strategically deploy electrolysis technology to produce hydrogen and energy carriers.

Infrastructure and planning

Infrastructure is the backbone of the economy, supporting the daily activities and operations of individuals, businesses and communities, and plays a central role in decarbonisation. Infrastructure planning and delivery is critical to ensure NSW meets its emissions reduction targets.

For example, energy infrastructure such as electricity transmission lines and distribution networks can provide clean and reliable energy sources to power homes and businesses.[125] Similarly, transport infrastructure such as public transportation systems, active transport infrastructure and planned widespread availability of EV charging infrastructure can facilitate the uptake of low carbon modes of transportation and reduce the dependence on fossil-fuelled transport.[126] In the built environment sector, green infrastructure such as parks and 'green roofs' can reducing energy consumption and enhance the carbon sequestration potential of urban areas.[127]

Planning can play a critical role in designing for a circular economy, and in the provision of infrastructure to enable successful growth of innovation precincts and place-based circular economy industries.

Research infrastructure and digital infrastructure are also key. Research infrastructure supports the development of new technologies and the improvement of existing systems. As long-term value assets, research infrastructure could attract investment, stakeholders and policy support to form innovation hubs and a supply pipeline of new technologies and services. Digital infrastructure such as high-speed internet, mobile telecom, data centres and services can enable the rapid uptake of digitalised or digital-assisted climatetech. For example, the implementation of smart grid technology would allow for real-time monitoring and control of energy consumption, distribution and generation for energy consumption and demand optimisation.

The embodied carbon of infrastructure has become an increasingly important issue, as it constitutes a significant portion of total emissions in various sectors. Embodied carbon refers to the carbon emissions generated during the production, transportation and installation of infrastructure and building materials. Embodied emissions of construction account for up to 10% of Australia's total emissions and this is expected to increase.[128]

124 AEMO (2020). Energy Explained: Minimum Operational Demand.
125 Australian Energy Market Operator (2022). 2022 Integrated System Plan.
126 NSW Government (2021). Transport Sustainability Plan 2021.
127 Greater Cities Commission (nd). Sustainability.
128 NSW Government (2022). Decarbonising Infrastructure Delivery: NSW Government Discussion Paper.

Governments must ensure infrastructure is designed, constructed and operated in a way that supports decarbonisation goals. Several policies and programs exist to support infrastructure planning for reduced embodied carbon and use of low emissions building materials (LEBMs). For example, Transport for NSW is developing a Sustainable Procurement in Infrastructure initiative.

Different types of infrastructure have different capital expenditure profiles, market and development mechanisms, and complex stakeholder ecosystems. Government's role in infrastructure planning could help influence what become the most attractive options for decarbonisation. This could have multi-sectoral impacts to help prevent technology deployment from being 'short-circuited' when no clear choice of technology exists.[129] For example, the strategic roll-out of EV charging infrastructure and hydrogen refuelling stations based on their techno-economic competitiveness for range and transport modes would incentivise both pathways and avoid locking in higher-than-optimal costs. Early planning for infrastructure build-out and actively engaging stakeholders across sectors would ensure future infrastructure provides the platform for technology deployment, while preventing unintended consequence or market failure.

Energy efficiency and productivity

Energy efficiency was identified as a crucial component for decarbonisation in 2020. The 2020 Study noted Australia's uptake of energy efficiency performance programs and equipment was slower than other comparable developed countries. Australia's energy efficiency performance has continued to lag from 2.8% to 0.8% per year in the periods 2010-2015 and 2015-2020.[130]

Australia's energy consumption bucks the international trend. Between 2002-03 to 2018-19, Australia's energy consumption per person increased by an average of 0.2% per year.

By comparison, the UK, United States, European Union, Canada and Japan all cut consumption, some by more than 20%.[131] In 2022, preliminary data indicates the global economy used energy 2% more efficiently compared with 2021.[132]

Accelerating the uptake of energy-efficient technology and practices in three key areas can help NSW and Australia meet their decarbonisation goals:

- **Building energy efficiency** – The commercial building sector is responsible for 22% of overall electricity use and 11% of total carbon emissions in Australia, and 24% of overall electricity use and 12% of total carbon emissions for residential buildings.[133] Increasing minimum standards and better information for consumers and industry, especially in the residential building sector, can improve the energy performance of this sector.
- **Industrial energy efficiency** – Mining, manufacturing and construction account for 33% of Australia's energy consumption.[134] Grants are currently provided to high emitting facilities within the manufacturing and mining sectors to help them reduce Scope 1 emissions, which will support local jobs and make Australian industry more competitive.[135]
- **Appliances and equipment** – Improvement in the energy efficiency of appliances and equipment assists with decreasing emissions.

129 McKinsey & Company (2022). The Heat is on: How Public-sector Leaders Could Drive Net-Zero Goals.
130 International Energy Agency (2022). Energy Efficiency 2022.
131 The Conversation (2022). Australia's Record on Energy Efficiency Has Been Woeful for Decades, But That Could Be About to Change
132 IEA (2022). Global Energy Efficiency is Accelerating, Signalling a Potential Turning Point After Years of Slow Improvement
133 Australian Government (2023). Government Priorities: Residential Buildings.
134 Australian Government (2022). Australian Energy Update 2022.
135 NSW Government (2023). High Emitting Industries: Reducing Industrial Emissions for NSW.

Steps being taken to improve Australia's energy efficiency performance include:

- the Australian Government's proposal to establish a National Energy Performance Strategy[136]
- the Australian Government proposal to tighten fuel efficiency standards[137]
- NABERS (National Australian Built Environment Rating System) expansion into residential aged care, retirement living, warehouses and cold stores, with plans to include schools and retail stores, and introduce a Renewable Energy Indicator (REI), disclosing the proportion of renewable energy used in buildings[138]
- the trans-Tasman energy efficiency standards and energy labelling system for household and business equipment and appliances[139]
- the NSW Sustainable Building State Environment Protection Policy (SEPP) encourages the design and delivery of sustainable buildings including minimising energy consumption by installing more energy efficient appliances and equipment
- the Global Cooksafe Coalition is a consortium of global organisations and companies promoting safe and sustainable cooking in buildings using electric appliances and equipment. In Australia, is it supported by the Green Building Council Australia, the Climate Council, Asthma Australia, GPOT and Lendlease with a number of high-profile celebrity chefs supporting the cause[140]
- increasing the energy efficiency rating for new residential building from six to seven star in the 2022 National Construction Code and the introduction of an 'whole-of-home' annual energy use budget.[141]

Shifting the focus from energy efficiency to productivity represents a natural evolution in the pursuit of sustainable and impactful resource management. While energy efficiency remains crucial, the transition towards productivity emphasises optimising overall resource utilisation and generating greater value from energy inputs.[142] Rather than solely reducing energy consumption, the goal becomes maximising output and outcomes per unit of energy used.

By prioritising energy productivity, businesses and industries can identify innovative solutions that simultaneously enhance economic performance while reducing emissions. This approach involves adopting advanced technologies, process optimisation and system integration to achieve higher levels of productivity with lower carbon intensity. For example, the implementation of intelligent automation, data analytics and digital optimisation can optimise energy usage, minimise waste and reduce emissions throughout the value chain.[143]

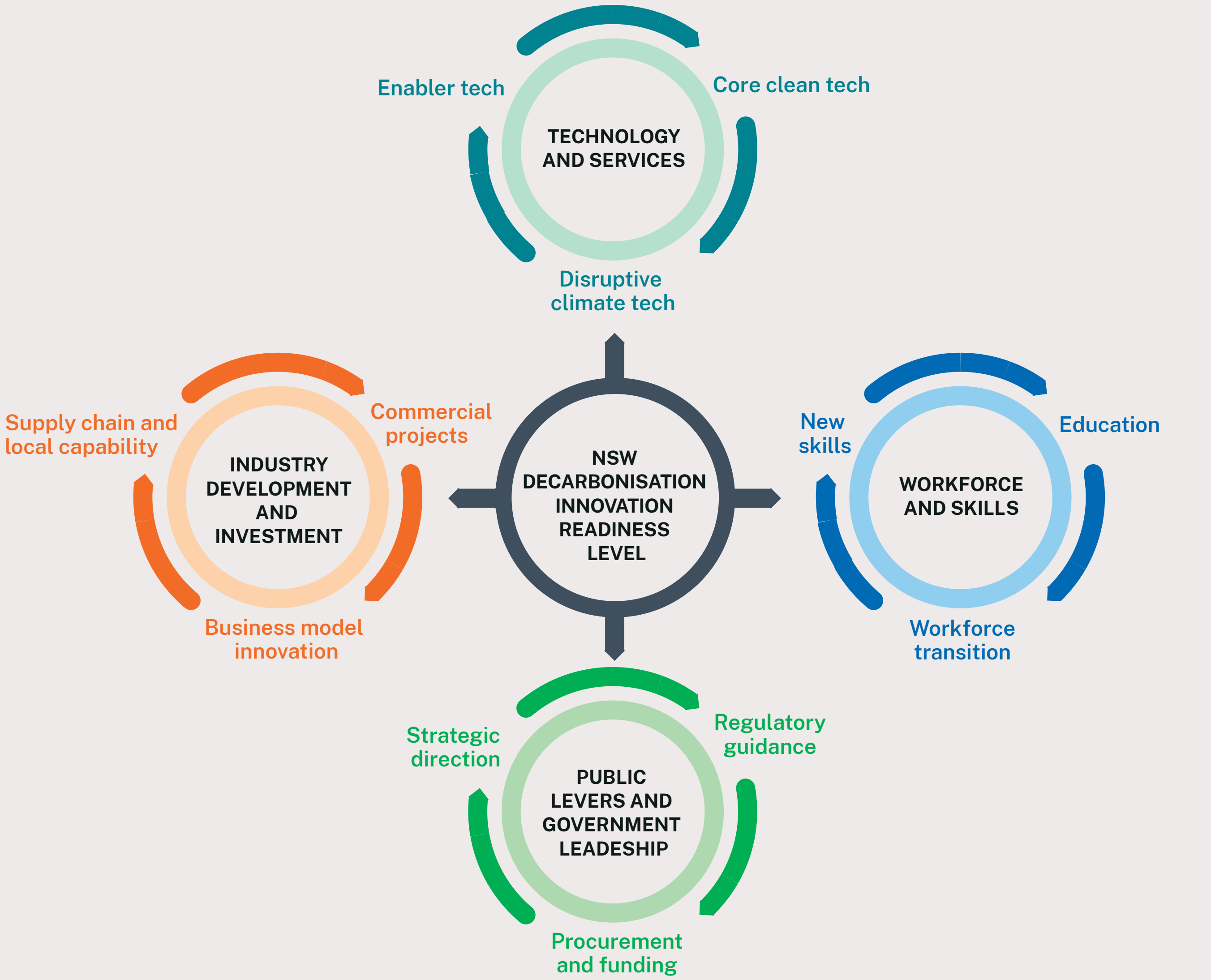
136 Australian Government (2022). National Energy Performance Strategy: Consultation Paper.
137 Australian Government (nd). Fuel Efficiency Standards: Helping Australia Save on Fuel and Reduce Greenhouse Gas Emissions.
138 NABERS (2022) NABERS Annual Report 2021/22
139 Energy Rating (2020). About the E3 Program.
140 Global Cooksafe Coalition (2022). The Global Cooksafe Coalition: Safe, Affordable, Fossil Fuel-free Cooking for Everyone.
141 Australian Government (2022). Building Ministers' Meeting: Communiqué August 2022.
142 IEA (2019). Multiple Benefits of Energy Efficiency.
143 McKinsey (2022). The Economic Transformation: What Would Change in the Net Zero Transition.

4.0 Sector decarbonisation innovation opportunities

The 2023 Study assesses innovation progress and identifies opportunities for each sector with a new process:

1. Assess sector innovation readiness level with the NSW Decarbonisation Innovation Readiness Level (DIRL).
2. Report sector residential emissions with the NSW GHG Emissions 2021-2050 Dashboard.
3. Identify individual economic opportunities and sectorial clusters where economic opportunities may benefit from same core technologies, shared infrastructure, same industrial users and customer groups and similar incentives and policy design.

Figure 2. NSW Decarbonisation Innovation Readiness framework illustration



Decarbonisation Innovation Readiness Level framework

NSW Decarbonisation Innovation Readiness Level (DIRL) was developed by OCSE as a new framework to assess the decarbonisation innovation potential and competitiveness of sectors for the 2023 Study. The development of the DIRL was based on similar practice by other organisations and case studies. The DIRL framework has four essential pillars of innovation and project lifecycle and 12 indicators that are key elements of decarbonisation innovation (Figure 2). Pillar and indicator definition with examples are described in the Supplement.

The DIRL assessment is qualitative, using a mix of scientific literature, analytic data and stakeholder consultation. Analytical data was drawn from a wide range of creditable sources, including internal analyses by OCSE and NSW Government agencies, as well as external analysis commissioned by OCSE. Additional data and analysis from recent projects, such as the NSW 20 Year R&D Roadmap, were leveraged for related areas. See the Supplement for data inputs for DIRL assessment. Based on the DIRL framework and data, each sector has been awarded a readiness level of high, medium or low.

One of the notable strengths of DIRL is its ability to capture multifaceted nuances and complexities that were previously overlooked or underestimated. It considers a wide range of factors, variables and perspectives, resulting in a more holistic assessment. This comprehensive approach enables policymakers and stakeholders to make informed decisions based on a more robust understanding.

As a new framework introduced by the study, the DIRL offers a fresh perspective on evaluating various aspects within decarbonisation innovation scope. While the initial results obtained through this framework are indicative of its potential, it is important to acknowledge that further refinements and enhancements are expected to be made in the future. The DIRL development methodology and case studies for DIRL are in the Supplement.

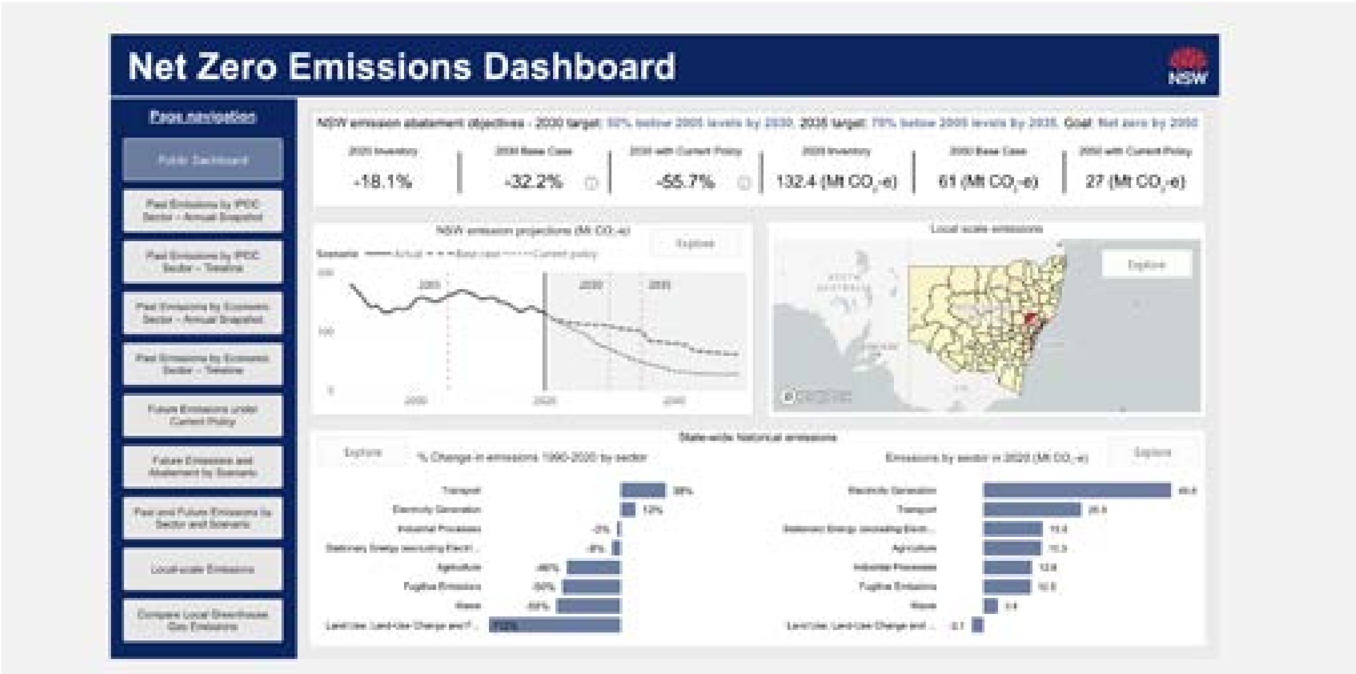
Residual emissions by NSW GHG Emissions Dashboard

In February 2023, the NSW Government launched the NSW GHG (Greenhouse Gas) Emissions 2021-2050 Dashboard to allow the community to explore progress towards the state's decarbonisation goals.

The dashboard shows NSW's emissions and trends since 1990, and the projected future NSW emissions based on several emissions scenarios. It includes a 'base case' setting and a 'current policy' scenario that considers planned emissions reductions under the Net Zero Plan and other relevant government policies and programs.[144]

In 2020, NSW carbon emissions were 132.4 Mt CO_2-e and under current policy settings are projected to reduce to 71.55 Mt CO_2-e in 2030, 48.33 Mt CO_2-e in 2035 and 27 Mt CO_2-e in 2050.[145] Without the current policy settings, NSW emission reductions are projected to be 109.63 Mt CO_2-e in 2030, 101.53 Mt CO_2-e in 2035 and 61.02 Mt CO_2-e in 2050.

By 2050, the main sectors of residual emissions are, 10.42 Mt CO_2-e in the agriculture sector, 7.33 Mt CO_2-e in the transport sector, 5.52 Mt CO_2-e in the industry sector and 3.72 Mt CO_2-e in the stationary energy sector. These sectors have been the focus for developing future opportunities, with more detail in Section 4.



144 NSW Government (2023). NSW Net Zero Emissions Dashboard.

4.1 Finance system

The 2020 Study recognises the critical role the financial service sector plays to drive the economic transformation needed to support decarbonisation.

The NSW finance sector is more carbon-exposed than other sectors, which presents both risks and opportunities. A large and ongoing pipeline of public and private investment is needed to provide the capital for climate technology commercialisation and deployment. Increasing investor interest in green financial services presents economic opportunities for NSW to build and grow a strong professional service workforce to support the decarbonisation transition.

The 2020 Study identified opportunities for NSW to:

- become a major global sustainable finance hub
- attract local and international capital, and direct it towards promising sustainable industries and infrastructure in NSW
- improve investment practices by encouraging the widespread adoption of climate change risk management initiatives
- grow jobs in carbon, resilience and sustainability services.

Sustainable finance system

Finance system: Sustainable finance system

OPPORTUNITY 1

Building an investment-ready finance system for sectoral decarbonisaton and transition pathways

The consensus among academics, industry bodies and government advisory panels is that the finance system creates the foundation of the suitable environment for sectoral decarbonisation. Widespread adoption of climate change risk management and sustainability investment initiatives across government and the private sector is necessary to attract both inbound capital flows and local finance for the energy transition and the growth of a successful net-zero economy in NSW.

Direct (Scope 1 and 2) emissions from financial institutions and funding organisations are not the central issue here. Globally, emissions associated with lending, underwriting and investment activities are 700 times higher than the direct emissions of the sector.[145] These emissions are known as financed emissions, which are Scope 3 GHGs and considered part of a financial institution's carbon footprint.[146]

145 CDP Worldwide (2023). Finance Sector's Funded Emissions Over 700 Times Greater Than its Own.
146 PwC (2023). Financial Institutions are Pledging to Lower Carbon Footprints. Here's What You Need to Know About Financed Emissions.

The finance system (defined as the ecosystem comprising providers of financial services and capitals, institutional investors, owners of and creditors for large infrastructure, the stock exchange markets and the associated regulatory framework) plays a central role in bringing about the systemic change of decarbonisation through the economy. The strong interaction between finance and other sectors means the finance system is critical to the pace and scale of mobilising capital to decarbonise the whole economy across energy, transport, built environment and industry.[147]

Financial institutions, including banks, institutional investors such as superfunds, asset managers and insurance companies as well government corporations, have obligations to identify and reduce risks that might impact the returns of their stakeholders, including climate change risks. Climate risks (which encompasses physical risks and transition risks) can manifest in large shifts in asset values and a higher cost of doing business as the world moves to a low-carbon economy.

It is forecast that substantial global economic losses will be around $23 trillion by 2050.[148] The transition is not only about risk mitigation but also presents the financial sector with tremendous growth opportunity for clean economy investment. Analysis by the International Energy Agency (IEA) estimates that investments in the clean energy transition will add 0.4% to global Gross Domestic Product (GDP) each year and global GDP will be 4% higher by 2030 as compared to other models under a net-zero pathway. Financial institutions need to fund ambitious transition pathways for business and industry to meet their net-zero goals.[149]

The rollout of the transition will vary depending on factors at play across sectors, regions and differing activities, and therefore financial system participants, require a deep understanding of the technologies and the market risks to enable the proper design of successfully tailored strategies, products and services to facilitate transition activity. Financial institutions will need to have critical information to understand each transition pathway, including the timeline for the transition, emissions reductions goals for each pathway, as well as the best business strategy and the operational changes needed to better meet the transition and, most importantly, identifying when and where the capital will be sourced that will be needed to enable this transition.[150]

Sustainable finance and taxonomy

Access to finance is paramount for government and industry to realise net zero ambitions and decarbonise economies. It is estimated that Australia will need $165 billion of investment over the eight years from 2021 for new energy infrastructure and $63 billion in investment to 2025 for an orderly transition to net zero. From 2020 to 2050, the investment opportunity in renewable and clean electricity production will be $385 billion.[151,152]

Currently, NSW's low carbon transition is being financed through overseas investors and there is an opportunity for the NSW finance sector to increase ESG investment and capitalise on the investment opportunities currently presented by NSW's shift to a decarbonised economy. This opportunity will also likely remove NSW's exposure to international price adjustment mechanisms or taxes introduced where markets have not transitioned to decarbonisation.

The strong investment opportunities are being matched with an increased interest in sustainable finance markets. In 2021, Australia sustainable investment reached a record of $1.5 trillion in assets, with sustainability-themed investment reaching $161 million.[153] This investment was primarily focused on climate change (renewables and energy efficiency), waste (waste management, zero waste and circular economy) and sustainable land management.

147 International Monetary Fund (2019) Climate Change and Financial Risk.
148 Swiss Re Institute (2021). The Economics of Climate Change.
149 IEA (2021). Pathway to Critical and Formidable Goal of Net-zero Emissions by 2050.
150 EY (2021). How Sustainable Finance Can Help decarbonise the Real Economy.
151 RenewEconomy (2021). Australia Needs to Spend $165bn To Rapidly Decarbonise Grid, But We'll Be Better For It.
152 Investor Group on Climate Change (2020). Mapping Australia's Net Zero Investment Potential.
153 Responsible Investment Association Australasia (2022). Responsible Investment Benchmark Report: Australia 2022.

While there is strong investment in established technologies and solutions for decarbonisation, as with other technology areas the climatetech sector is characterised by less interest or appetite for investing in early-stage technologies and innovations due to market depth and scale and the perceived risks associated with these investment areas. Unlike other economies such as the USA, the Australian investors are very risk-averse for climatetech, particularly in their post-R&D and pre-commercial stage.

Notable exceptions are accelerators and incubators such as Cicada Innovations (founded by four universities), Investible and EnergyLab, all of which are providing scaling up, mentoring and training services to support start-ups and innovators. The CEFC's Clean Energy Innovation Fund (managed by Virescent Ventures) remains Australia's leading specialised cleantech venture capital investor.

It provides support at the earliest stages of the cleantech ecosystem, through cornerstone and mentoring investments in three cleantech accelerator and incubator programs, Artesian, Tenacious Ventures and Startmate.[154] Community-led initiatives like Climate Salad are offering go-to-market services for accessing venture capital funds. There is an opportunity to grow the NSW green innovation ecosystem, creating a more developed venture capital environment in NSW specifically focused on clean tech, to facilitate start-ups and evolution of low carbon technology. Frameworks exists to track the scale of Cleantech development and potential:

- Deloitte's Australia Cleantech Index reported 87 (ASX-listed) climatetech companies with a combined market cap of AU$80 billion[155]
- Climate Salad's Climate Tech Survey 2022 found 171 climate tech companies across Australia and NZ, with 38% of these companies headquartered in NSW. Climatetech companies had raised $1.4 billion in capital, with half of this from overseas sources.[156]

The development and implementation of a finance taxonomy specific to decarbonisation has been recognised as a critical step in mobilising sustainable finance. The concept of finance taxonomy draws inspiration from global initiatives such as the European Union's Sustainable Finance Taxonomy.[157] These initiatives aim to establish a standard framework for classifying and labelling environmentally sustainable activities, providing a clear definition of what constitutes a green investment.

By leveraging existing global frameworks and tailoring them to NSW's decarbonisation goals and priorities, the finance taxonomy ensures alignment with international best practices while addressing the unique decarbonisation goals and priorities of the region.

The adoption of a finance taxonomy for NSW helps build trust and confidence among investors by providing a transparent and reliable system for identifying green investments. It enables investors to assess the environmental impact and sustainability credentials of potential projects, enhancing their ability to make informed investment decisions. Furthermore, a well-defined finance taxonomy supports the development of innovative financial products and instruments that cater to the specific needs of decarbonisation initiatives in NSW. This includes green bonds, sustainability-linked loans and other financing mechanisms that attract capital towards projects aligned with the taxonomy's criteria and contribute to the region's decarbonisation objectives.

Sydney as a sustainable finance and services hub

The 2020 Study identified the establishment of Sydney as a sustainable finance and services hub as one of the opportunities for the financial sector. Sydney is now the leading financial centre of the Asia Pacific region. In 2022, Sydney was ranked 13th in the top global financial sectors by Z/Yen, and 10th when it comes to green finance.[158] Analysing the dimensions used to calculate the rank, Sydney ranks 4th globally for quality of the finance products and services and 16th for prevalence of green financial services and products. This means that, while Sydney's green financial services and products are of high quality, opportunities exist to grow the range of green finance services and products on offer.

Through TCorp, the NSW Government is growing the NSW Sustainable Bond Programme, with $2 billion worth of bonds being issued in 2021/22 financial year, bringing the total amount issued under the program to $7.2 billion.[159] The green and social assets approved for use for the 2022 bonds includes clean transport, sustainable water and wastewater management.[160] The program governance is through oversight by the NSW Sustainable Bond Committee, and is guided by the NSW Sustainable Bond Framework, which has been externally verified.

154 Australian Government (nd). Supercharging Australia's Cleantech Ecosystem.
155 Deloitte Australia (2023). Deloitte's Australia CleanTech Index December 2022.
156 Climate Salad (2022). Australia & New Zealand Climate Tech Industry Report.
157 European Commission. EU Taxonomy for Sustainable Activities.
158 Z/Yen Group (2022). The Global Financial Centres Index 32.
159 NSW Treasury Corporation (2022). Tcorp: Annual Report 2022.
160 NSW Treasury Corporation (2021). NSW Sustainability Bond Programme: Annual Report 2021.

There is strong investor demand for the NSW Sustainability Bond Program with the three bonds issued in June 2020/21 being oversubscribed. This strong interest is coupled with a proposed $112.7 billion investment in infrastructure in the 2022/23 and 2025/26 financial years[161] and an objective of the NSW State Infrastructure Strategy 2022-2042 to *'achieve an orderly and efficient transition to Net Zero'.*[162] This provides the opportunity to grow the NSW Sustainability Bond Program by incorporating net zero outcomes within infrastructure business cases.

TCorp is also considering sustainability across its own investment portfolio and has developed an investment stewardship approach to achieve sustainable investment outcomes.[163] Some achievements across its portfolio include:

- moving the Developed Market Equities portfolio to a low carbon benchmark to manage climate risk, resulting in carbon intensity and exposure to fossil fuel reserves being reduced by 30-35%
- investing in a 18.5% share in Australia Pacific Airports Corporation, which has a 2025 net zero target
- 37% of domestic operating assets classified as carbon neutral as of 30 June 2022
- 29% of global property investment were classified as carbon neutral.

In 2020, the Australian Sustainable Finance Institute (ASFI)[164] launched the Australian Sustainable Finance Roadmap, which sets out a pathway to develop a financial system that supports *'a thriving, Australian society, a healthy environment, and a strong and prosperous economy'*.[165] The Roadmap was developed by 140 participants from over 80 organisations, including financial institutions, civil society, academic, regulators and government, including the NSW Government. The Roadmap has 37 recommendations for establishing a sustainable finance system by 2030 and there is evidence that participants are taking action to progress the goals of the roadmap.[166]

ASFI Taxonomy Project is now underway which aims to design a system reflecting the Australia economy and context while building on international taxonomies.[167] Phase 1, scoping of a proposed system, is expected to be completed in June 2023 followed by Phase 2, the development of the system. Phase 2 will encompass the development of taxonomy screening criteria for at least three priority sectors, and associated technical work on data requirements, methodology for incorporating transitional activities, minimum social safeguards and a 'Do No Significant Harm' framework.[168]

161 NSW Government (2022). NSW Budget 2022-23: Overview.
162 NSW Government (2022). Staying Ahead: State Infrastructure Strategy 2022-2042.
163 NSW Treasury Corporation (nd) Investment Stewardship.
164 ASFI (nd). A Bold Plan to Reshape Australia's Finance System
165 ASFI (2020). Australian Sustainable Finance Roadmap: A Plan for Aligning Australia's Financial System with a Sustainable, Resilient and Prosperous Future for all Australians.
166 ASFI (2021). ASFI Momentum Tracker: A First Report to Track Progress Implementing the ASFI Roadmap.
167 ASFI (2022). Taxonomy Project.
168 ASFI (2022). Taxonomy Project Phase 2 Development.

To further drive investment into renewable energy solutions and manage financial risks associated with climate change, the Australian Government has consulted on an Australian climate risk disclosure framework to provide more information and greater transparency around how large businesses and financial institutions are responding to climate change and supporting the transition to net zero.[169] The Australian Government is also developing a sustainable finance strategy to grow Australia's green finance strategy and seize global opportunities in sustainable finance.[170]

Mandatory climate reporting is underway at global scale and in Australia. Already, the (TCFD) framework is incorporated into guidance from governing bodies, including ASIC and the ASX and is used, in some form, by 63% of ASX-listed companies. The 2022 Australian Government Consultation Paper on Climate-related Financial Disclosure has proposed that mandatory climate reporting start from the 2024/2025 financial year.[171] The reporting process will initially target large, listed entities and financial institutions but the framework has the potential to be expanded depending on consultation results.

While investment in sustainable finance is progressing with strong interest, barriers and challenges exist, with some investors still uncertain about the sustainable finance market. The Responsible Investment Association Australasia (RIAA) reported that performance concern was the main barrier to investing in the responsible investment market in 2021.[172] This was followed by a lack of viable products or options, public awareness and understanding or capacity to apply responsible investment. This is being further complemented by the development by the ISSB decision in April 2023 to prioritise climate-related disclosures, which will catalyse the integration of sustainability with corporate financial reporting.[173]

Another significant challenge is 'greenwashing', which is the overrepresentation of the environmental credentials of practices or products.[174] Greenwashing poses a significant threat to genuine aspirations and effective communication of interests, ultimately leading to negative impacts on decarbonisation efforts. When organisations engage in greenwashing, they create a false perception of their commitment to decarbonisation, thereby obscuring the true environmental impact of their actions.

Greenwashing can undermine trust and credibility. When companies or industries falsely portray themselves as environmentally conscious, it erodes public confidence in sustainability initiatives. Greenwashing can divert attention and resources away from legitimate decarbonisation measures.[175] By focusing on superficial and misleading claims of sustainability, attention is diverted from addressing the core challenges and implementing effective solutions. This diversion hampers progress towards achieving meaningful emissions reductions and sustainability goals.[176]

Greenwashing and its associated negative impact is a global issue, with the International Organizations of Securities Commissions establishing a Sustainable Finance Task Force to protect investors from greenwashing. In response to concerns over the practice, in 2022 the Australian Securities & Investment Commission issued information to assist financial service avoid greenwashing products.[177] A 2023 Australian Competition & Consumer Commission (ACCC) report found that 57% of 247 businesses investigated have made sustainability claims that either have misleading information or inadequate evidence.[178]

169 Australian Government (2022) Climate-related Financial Disclosure: Discussion Paper.
170 Ministers Treasury Portfolio (2022). More Transparency and More Investment in Cleaner and Cheaper Energy.
171 Australian Government (2022). Consultation Paper on Climate-related Financial Disclosure.
172 Responsible Investment Association Australasia (2022). Responsible Investment Benchmark Report: Australia 2022.
173 IFRS Foundation (2023). ISSB Decides to Prioritise Climate-related Disclosures to Support Initial Application.
174 Australian Securities & Investment Commission (2021). What is 'Greenwashing' and What are its Potential Threats?
175 Institute for Public Policy Research (2022). The End of Greenwashing?: Driving Decarbonisation in the Real Economy.
176 Australia Institute (2022). How the Government Supports Greenwashing.
177 Australian Securities & Investment Commission (2022). How to Avoid Greenwashing When Offering or Promoting Sustainability-related Products.
178 ACCC (2023). Greenwashing by businesses in Australia - Findings of the ACCC's Internet Sweep of Environmental Claims.

4.2 Energy

SECTOR	2019 Decarbonisation innovation opportunity	2023 Decarbonisation innovation opportunities	Sector readiness level	
ENERGY	Renewable Energy Zones	Future energy systems (including smart grids)	Technology and service	●
	Future energy market design		Workforce and skills	●
	Decentralised grids and demand management	New generation renewable and storage (solar PV, battery, wind and offshore wind)	Public levers and policies	●
	Solar and energy storage		Industry and investment	●

In 2020, the National Electricity Market (NEM) was in transition, moving towards a more decentralised grid powered by renewables.

The 2020 Study predicted that the future distributed and low emission energy system would likely exhibit:

- renewable-dominated generation supported by firming technologies
- rapid uptake of distributed energy resource and a two-way energy market
- decentralised, digitalised and smarter grids.

Since then, the NEM has changed significantly. There is an increasing amount of large intermittent renewables and the deterioration of the reliability of coal fired power stations. Additionally, there has been continued expansion of 'behind the meter' rooftop solar PV, with a third of detached homes having installed solar.[179] These homes are exporting surplus power to the grid, impacting on the NEM, particularly during the middle of the day.

In 2022, the Australian Government announced a goal to have 82% of energy in the NEM from renewable sources by 2030. In addition, NEM jurisdictions agreed to include an emissions objective in the National Energy Objectives and develop a fully integrated national energy and emissions agreement.[180]

To achieve this, the electricity system needs to be built around:

- low-cost renewable energy
- firming technology to address issues of peak demand
- new transmission and distribution networks to link the new generation.[157]

The AEMO Integrated System Plan (ISP) highlights the enormity of the challenge to electrify an economy with continually increasing electricity demand, which is projected to double in size by 2050 to 320 terrawatt hours per year.[181]

179 AEMO (2022). AEMO CEO Speech at Melbourne Energy Institute Annual Symposium: Paving the Way to Australia's Net-Zero Future.
180 Australian Government (2022). Consultation on Proposed Legislative Changes to Incorporate an Emissions Reduction Objective into the National Energy Objectives.
181 AEMO (2022). 2022-Integrated-System-Plan.

The ISP highlighted:

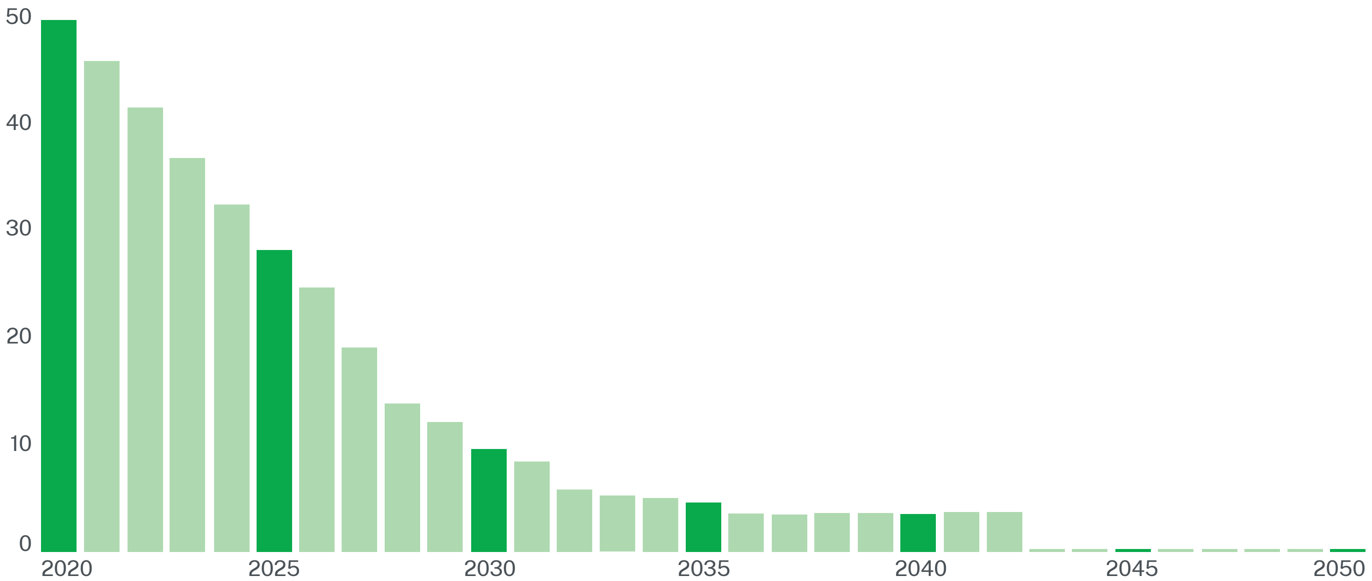
- the operational challenges faced in the transition to renewables, including around retaining levels and reliability
- the need for investment in transmission
- the need for dispatchable capacity to firm the renewable supply (batteries, hydro storage and gas fired generation, as well as virtual power plants, behind-the-meter batteries and potentially vehicle to grid)
- the continuing need for market and technical reforms for system services and two-way electricity flow.[182]

In NSW, the transition is underway, and the share of renewables is projected to increase from 47% in 2025 to 87% in 2030 and 97% in 2035.[183] Emissions are forecast to fall from 36.59 Mt CO_2-e in 2023 to 9.5 Mt CO_2-e in 2030 and 4.55 Mt CO_2-e in 2035 (Figure 3).[184]

Several initiatives are driving these emissions reductions:

- the Electricity Infrastructure Roadmap, which targets large scale renewables and coordinates investment in transmission, generation, storage and firming infrastructure as coal-fired generation is retired[185]
- the creation of five REZs, which group new wind and solar power generation into locations where it can be efficiently stored and transmitted across NSW[186]
- planning and constructing transmission links to connect the REZs, with the connection of NSW's REZs and Snowy 2.0 into the grid announced by the Australian Government in December 2022[187]
- Expansion of storage through recoverable grants to assist with feasibility studies for pumped hydro projects[188] and developing firming capacity through the establishment of grid scale batteries such as the Waratah Super Battery. This battery will provide a continuous active power capacity of at least 700MW and a guaranteed useable energy storage capacity of at least 1,400MWh. [189]

Figure 3: Actual and projected emissions for energy – 2020-2050. Source: NSW SEED



182 AEMO (2022). 2022-Integrated-System-Plan.
183 Australian Government (2022). Australia's Emissions Projections.
184 NSW Government (2023). NSW Net Zero Emissions Dashboard.
185 NSW Government (2023). Electricity Infrastructure Roadmap.
186 NSW Government (2023). What is a Renewable Energy Zone?
187 Australian Government (2022). Rewiring the Nation Deal to Fast-Track Clean Energy Jobs and Security in NSW.
188 NSW Government (2023). Pumped Hydro Grants.
189 NSW Government (2023). Waratah Super Battery.

Future energy systems

Decentralised grids were highlighted in the 2020 Study as offering cost-effective deployment of renewable energy. Since then, there is increasing interest in future distributed energy resources by communities and companies. Many electricity retailers now have an increasing focus on decentralised assets such as EV home charging and battery solar.[190]

Distributed energy resource

Energy sector: Future energy systems cluster

OPPORTUNITY 2

Deploying Distributed Energy Resources (DER) technologies and smart systems to maximise consumer benefits and improve electricity grid efficiency and security

Highlighted in the 2020 Report as having much potential, DER aims to transition the electricity grid from a one-way directional system to a decentralised, two-way-directional energy system.[191] DER commonly refers to small generation units that are located on the consumer side of the system, mostly 'behind the meter'.

DER uptake is consumer driven, and provides greater choice in flexible, personalised energy services and products whilst reducing electricity bills.[192] The demand for DER in Australia is expected to grow. The Electricity Network Transformation Roadmap estimates that by 2050 DER could contribute up to 45% of total electricity generation capacity.[192] The most common form of DER is rooftop solar PV and has expanded substantially in the last two years, with capacity now exceeding 20GW.[193] AEMO anticipates this will continue, with rooftop solar PV capacity doubling or even tripling by 2040.[194]

This high penetration of consumer solar is laying the foundation for the uptake of other forms of DER, such as batteries, EV and demand side management devices.

Increased DER capacity can offer a range of benefits to energy industry and consumers. For energy industry and the market operator, DER will bring additional generation and storage capacity to the grid. This creates cost savings from large scale renewable projects and transmission infrastructure as well as long-term costs for asset replacement and maintenance services. Generation and use at consumer locations means higher energy efficiency by avoiding transmission and distribution energy losses. For consumers, it means improved energy reliability and flexibility where DER can supply individual customers and local networks with a low risk of being impacted by system faults.[195]

The advent of DER presents technical challenges to the NEM, just like most other national and international grids built for large, centralised generators connected transmission grids that flow to consumers in a one-way direction. DER like rooftop solar PVs add complexity, for example lack of visibility and control over individual DER, increased variable power generation based on renewable sources and weather and consumption shifts in response to electricity prices. However, many of the challenges presented by DER can be addressed with digitalisation of DER and other smart digital solutions. Those technologies and services can enable DER owners to manage their resources in real-time and help grid operators more closely monitor and influence DER operations, boosting the value of DER to the grid.

DER remain an ongoing opportunity and the digitalisation of the DER for better system integration and management is emerging as a new opportunity for NSW. Digitalised DER are especially powerful and can be scaled to any aggregated level, from individual devices to buildings, communities, or even a larger region. Virtual Power Plant is a good example where advanced optimisation algorithms and AI deliver value to DER owners while maintaining grid reliability.[196]

Traditional DER will continue to grow and new forms of DER are expected to be deployed, increasing in the number of smart and consumer-controlled technologies like advanced inverters, two-way EV charging and smart heat pump water heaters.

190 Renew Economy (2023). AGL Looks to EVs, Batteries and Rooftop Solar as it Goes Local and Digests Massive Loss.
191 AEMO (2022). About the DER Program.
192 Energy Networks Australia (2017). Electricity Network Transformation Roadmap.
193 Financial Review (2023). Rooftop Solar Hits Record 20GW.
194 Australian Energy Regulator (2022). DER Integration Expenditure Guidance Note.
195 Australian Government (2022). DER Integration Expenditure Guidance Note. 4.1.1 - Attachment A - AER - Draft Customer Export Curtailment Value Methodology - April 2022
196 IEA (2021). Distributed Energy Resources for Net Zero.

Advanced inverters can adjust rooftop PV system generation rate to reduce grid congestion with 'riding through' capability to remain online from minor grid disturbances. This function will not only improve electricity reliability for consumers but also prevent a substantial number of rooftop PV systems being disconnected from the grid too early, causing grid instability for other users.[197]

Vehicle to grid

Energy sector: Future energy system

OPPORTUNITY 3

Integrating vehicle to grid and other new technologies into the electricity system

Electrification is one of the most cost-effective decarbonisation pathways for the transport sector. The market share of EVs is growing, particularly for passenger vehicles. In 2022 the Australian Electric Vehicle Council estimated that 3.8% of all new cars purchased in 2022 were electric, with 83,000 EVs on the roads.[198] The integration of EV charging into the energy sector is critical to maintaining a reliable power system whilst providing a secure supply of electricity for transport decarbonisation. The accelerated rollout of EVs and charging infrastructure will impose challenges to the energy systems to supply and manage substantial loads. Taking advantage of EV flexibility, Vehicle to Grid (VtG) technologies and services could unlock new opportunities for the energy sector through the seamless integration of electrified transport.

VtG is a new form of DER that provides additional solutions for peak demand management and flexible load. EVs fitted with VtG technology allow bi-directional charging and can act as a distributed energy storage to the grid. This storage capacity can provide more grid flexibility by addressing periods of surplus power and peak demand periods, especially if combined with demand-controlled devices. The VtG market is at an early stage of development and faces similar challenges to EVs, including a lack of infrastructure, the cost of VtG capable vehicles and limited model options for chargers and vehicles. However, the VtG market is expected to surge with the increase in EV technology and infrastructure. Market estimates suggests that the global VtG technology market was US$2.7 billion in 2021 and will reach US$20.06 billion by the end of 2030.[199]

VtG passenger vehicles are available and the technology to support bi-directional charging is being trialled with a range of projects underway in Denmark[200] and Germany.[201] In Australia, the Australian Renewable Energy Agency (ARENA) funded a 'Realising Electric Vehicle-to-Grid Services' project, piloting 51 bi-directional charges and a fleet of 51 VtG capable vehicles in the ACT. The project aims to demonstrate VtG technology, provide grid services to the NEM and deliver a roadmap for the mass deployment of VtG services.[202] Research undertaken as part of the pilot suggests several factors will influence the value proposition for VtG, such as the length of time vehicles are plugged in, demand and energy prices and grid value vs transport availability.[203]

The rollout of VtG requires careful management to ensure benefits can be realised, just like other EV infrastructure and assets. However the impacts of VtG on the electricity grid is not substantial, with a recent Australian study finding most EV users charged their vehicles without placing stress on the grid. The study noted that, as EV numbers grew, encouraging vehicle charging outside peak electricity usage periods would be beneficial.[204]

In addition to VtG, VtX (referred as vehicle-to-everything) is another abbreviation often mentioned in relation to bi-directional charging and smart charging. In some cases, VtX implies the different use cases and services, such as vehicle-to-home (VtH), vehicle-to-building (VtB) and vehicle-to-load (VtL) services.

197 AEMO (2021). Application of Advanced Grid-scale Inverters in the NEM.
198 Australian Eclectic Vehicle (2022). Australian Electric Vehicle Industry Recap 2022.
199 Transparent Market Research (2022). Vehicle-to-Grid Technology market Outlook 2031.
200 Nissan Motor Corporation (2016). Nissan, Enel and Nuvve Operate World's First Fully Commercial Vehicle-to-Grid Hub in Denmark.
201 BMW Group (2021). Bidirectional Charging Management (BCM) Pilot Project Enters Key Phase: Customer Test Vehicles with the Ability to Give Back Green Energy.
202 ARENA (2020). Realising electric Vehicle to Grid Services.
203 Australian National University (2022). Modelling V2G: A Study on the Economic and Technical Value for V2G.
204 The Conversation (2023). Australia's Electric Vehicle Numbers Doubled Last Year. What's the Impact of Charging Them on a Power Grid Under Strain?

In other cases, VtX refers to communication that would allow cars to share information with each other, their drivers and their surrounding environment. These include vehicle-to-vehicle (VtV), vehicle-to-infrastructure (VtI) and vehicle-to-network (VtN). VtX connectivity consists of sensors, cameras and wireless connectivity (e.g. Wi-Fi, radio frequencies and LTE and 5G cellular technology). These VtX technologies are in their infancy but will offer a range of opportunities including advanced charging devices, software for dynamic pricing, load shifting monitoring and sophisticated information technologies that will improve the connectivity and efficiency for energy and transport sectors but also enhanced sectorial interactions.

Demand-side management

Energy sector: Future energy systems cluster

OPPORTUNITY 4

Deploying additional demand side management measures to maximise the utility of rooftop solar and improve electricity grid efficiency

Demand side management seeks to reprofile energy usage by supporting electricity customers to shift their energy consumption away from peak consumption periods. It can maximise the benefits of energy assets and infrastructure. Demand side management is considered the most cost-effective solution for the transition to a renewable-based electricity system. The benefits of demand side management include better alignment of demand to supply from renewable generation, reduction in peak demand and grid congestion and greater use of DER. These benefits will reduce overall investment required for grid infrastructure, including peaking generation.

Initiatives to boost demand side management are being adopted for the NEM for large consumers and industry users. In October 2021, Wholesale Demand Response (WDR) was implemented following the rule change on WDR mechanism, enabling large and commercial businesses to bid and receive a payment for reduced demand.[205] In addition to public infrastructure, shopping centres, sports clubs and swimming pools are well placed to participate in demand side management initiatives. For example, the NSW Bankstown Sports Club entered an agreement with a demand side aggregator and using on-site generation, can dispatch electricity during periods of high market prices.[206]

Enabled by digital technologies, DER and connected energy devices have the potential to contribute significantly to demand-side management. Coupling smart meters and digital management systems allows for the aggregation and remote control of smaller and multiple energy devices. The most demand side management opportunities are in the built environment and transport sectors. IEA modelling under the Net Zero Emissions by 2050 Scenario suggests there are 250GW and 50GW of demand response capacity from buildings and EVs, respectively.[207] This capacity is made available to the market at rapid rate with the deployment of enabling digital technologies.

Consumers need to be incentivised for demand side management. Like WDR, there are programs being developed by energy providers and infrastructure owners, particularly distribution services providers seeing the clear benefits of DER by avoiding costs in new distribution assets. For example, Endeavour Energy, a NSW electricity distributor, offers a range of programs to consumers for lowering electricity bills.[208]

Strong business cases for demand side management are catalysing innovative solutions and approaches that could further unlock demand management potential. For example, smart energy appliances are being tested for interoperable demand response through a government program in the UK.[209] VtG experiments are being carried out by EU countries and in the US for EVs to supply aggregated generation during supply shortage.[210]

New public and private Virtual Power Plant (VPP) projects are another form of demand-side management solutions with 31MW enrolled in the AEMO VPP Program in 2021 and also the rollout of state-based programs.[211]

205 AEMC (2020). National Electricity Amendment (Wholesale Demand Response Mechanism) Rule 2020
206 Australian Government. Demand Side Opportunities – Case Study Bankstown Sports Club.
207 IEA. Demand Response.
208 Endeavour Energy. Demand Management Programs.
209 UK Government (2022). Interoperable Demand Side Response Program.
210 IEA. Demand Response.
211 Institute for Energy Economics and Financial Analysis (2022). What is the State of Virtual Power Plants in Australia.

New generation renewables and storage

A rapid transition away from coal generation is underway in NSW with the retirement of coal-fired generators planned, beginning with the Liddell (2023) and Eraring (early 2025) power stations.[212,213]

Bayswater power station is scheduled for the early 2030s. This transition from coal requires significant investment in renewable power and support with firming solutions provides several opportunities for NSW.

Advances in solar technology

Energy sector:
New generation renewable and storage

OPPORTUNITY 5

Developing local manufacturing and recycling capability for new solar technologies

The 2020 Study identified opportunities for new and improved solar cell technologies developed in NSW, building on strength in digitalisation, technology, data analytics and modelling. International and Australian advances have continued since, both in performance of solar cells, improved modularity and installation practices. Some examples of those technological advancement include perovskites replacing silicon,[214] improving efficiencies of Passivated Emitter and Rear Cells/Perc cells,[215] copper solar cells,[216] tandem solar cells[217] and printed solar cells.[218]

These new solar technologies are expected to reduce the manufacturing and maintenance costs of solar PVs by replacing high-cost materials with alternatives, improving efficiency and lifetime, and enhancing flexibility and integrity of cells.

NSW has a competitive advantage in solar technology R&D, with many NSW universities and research institutions undertaking major R&D projects. Examples include utilising silver-lean screen printing to reduce silver consumption,[219] integrating molecular singlet fission layer to improve efficiency,[220] high efficiency chalcogenide/silicon (Si) tandem solar cells,[221] investigating the cost and sustainability of PV Systems at the terawatt scale,[222] improving efficiencies of PERC cells and Tunnel Oxide Passivated Contact (TOPCon) cells.[223] The commercialisation and mass production of these next generation solar PV would not only benefit decarbonisation but also transfer R&D capability into local manufacturing capacity.

Solar manufacturing opportunities in NSW are also being explored, with companies such as SunDrive seeking to develop solar manufacturing capability in NSW. SunDrive, a UNSW spinout, has developed copper-based solar cells that significantly reduce the cost of solar production and increase efficiency compared with silver-based cells.[224] SunDrive is supported by investment and partnerships from top venture firms, federal government agencies and universities. Following $21 million investment from Series A, SunDrive is planning for market entry and scaling up production aiming for 5GW annual manufacturing capacity.[225] In addition to manufacturing with alternative materials, there are innovation opportunities to reduce the balance of system and overall installation and operations and maintenance costs,[226] with increased modularity being explored as one solution. One such company is Sydney-based 5Bt, which has developed a modular, prefabricated plug-and-play solar farm.[227] NSW can capture more of the solar value chain through further development of solar panel and componentry manufacturing, and the provision of services.

212 AGL (2022). Energy Annual Report 2022.
213 Origin (2022). 2022 Annual Report: Where all Good Change Starts.
214 University of Washington (2020). Perovskite Solar Cell
215 BBC (2023). Queen Elizabeth Prize: Solar Team Wins Prestigious Engineering Award
216 Sundrive (2023). Unlocking Solar's Full Potential.
217 Renew Economy (2023). Australian Researchers Hit Solar Stretch Goal with Tandem Cell Breakthrough.
218 CSIRO (nd). Printed Solar Film.
219 Australian Government (2022). Silver-Lean Screen Printing for Sustainable Low-Cost Industrial PV Manufacturing.
220 Australian Government (2022). Low-Cost >30% Efficient Silicon Photovoltaic Solar Cells Achieved Through Singlet Fission.
221 Australian Government. 2022. Efficient & Stable Chalcogenide-Si Tandem Cells: Integrating PV Technologies.
222 Australian Government (2022). Low Cost and Sustainable PV Systems for the Terawatt Scale.
223 Australian Government (2022). Rear-Junction P-Type PERC/TOPCon Hybrid Solar Cells (RJ-PERP) Project.
224 Financial Review (2022). Dropping Out of Uni was the Best Thing This Solar Pioneer Ever Did.
225 RenewEconomy (2023). Solar Innovator Sundrive Maps Out Plan for 5GW of Australian PV Manufacturing.
226 Australian Government (2022). Ultra Low Cost Solar PV Research and Development Round.
227 5B Holdings Pty Ltd (2023). 5B Maverick Brochure.

With an increasing number of solar panels at the end of their lifespan, the issue of solar PV panel recycling is an emerging issue and is an important element of a circular economy, as discussed in Section 3 1. Internationally, the global value of solar PV recycling is expected to be US$2.7 billion in 2030, rising to US$80 billion in 2050.[228] It is estimated that more than 100,000 tonnes of solar panels will enter Australia's waste stream by 2035.[229] NSW estimates 3,000 tonnes of waste solar PV panels will be generated in 2025 and increase to 30,000 tonnes in 2035.[230] Solar panel recycling, in addition to reductions in landfill, can minimise waste, and increase resource efficiency through the recovery of materials such as aluminium, silicon, copper, silver and glass.

Australia currently has limited recycling of solar panels. Now that the South Australian, Victorian and ACT governments have banned them from landfill, there is an opportunity to develop a solar PV recycling industry.[231] In NSW this is already being considered as part of the circular solar grants program supporting whole of supply chain projects for solar panels and battery systems.[232]

Offshore wind

Energy sector:
New generation renewable and storage

OPPORTUNITY 6

Developing a local offshore wind industry prioritising Renewable Energy Zones

Offshore wind can diversify renewable energy generation, potentially being available when renewable energy generation from solar or onshore wind is low.

Internationally, offshore wind has expanded rapidly over the last decade making it increasingly cost competitive for large scale energy generation.

Offshore wind systems include fixed-bottom turbines, which operate in waters to the depth of 60 metres, and newer floating wind power technology which can operate in deeper waters and offer simplified installation and decommissioning.[233]

The Australian Government passed the Offshore Electricity Infrastructure Act 2021, which with its associated regulations came into force June 2022. This provides the framework for the construction, operation and decommissioning of offshore electricity infrastructures including offshore wind and solar farms, wave energy plants and undersea interconnectors.[234] The first area for offshore renewable energy infrastructure has been declared in Victoria, and two priority areas have been identified in NSW in the Pacific Ocean off the Hunter and Illawarra regions. Consultation has already commenced on a proposal to declare the area off the Hunter region.[235]

The importance of offshore wind was recognised by the NSW Government by the creation of the Hunter –Central Coast REZ and the Illawarra REZ.[236] Given the proximity of offshore wind to the industrial areas of Newcastle and Wollongong there is a range of potential economic benefits for both regions. These regions have good port and transport infrastructure, a skilled workforce and the capacity to repurpose existing assets. Region-specific opportunities include new services, manufacturing, construction and business opportunities, as well as skills development and employment.

Because of its narrow continental shelf, NSW is well suited for the deployment of floating wind power technology. Floating offshore wind power technology is in the early stages of development, with only a few wind farms operating internationally, but it provides potential opportunities in much the same way as fixed bottom offshore wind provided opportunities for countries surrounding the North Sea.

The announcement of offshore renewable energy infrastructure areas in NSW and the inclusion of offshore wind farms in the two REZs has generated considerable industry interest, despite planning still being in the early stage. In February 2023, two companies announced proposals for floating offshore windfarms in the Hunter-Central Coast REZ.

228 Rystad Energy (2022). Reduce, Reuse: Solar PV Recycling Market to be Worth $2.7 Billion by 2030.
229 Sustainability Victoria (2022). National Approach to Manage Solar Panel, Inverter and Battery Lifecycles.
230 NSW Government (2020). Scoping Study for Photovoltaic Panel and Battery System Reuse and Recycling Fund.
231 ABC (2022). Solar Panels are Leading the Clean Energy Revolution, but Recycling Them Isn't Easy.
232 NSW Government (2022). Circular Solar Grants Program.
233 The Economist .2021. Floating Wind Turbines Could Rise to Great Heights
234 Australian Government (2022). Establishing Offshore Renewable Energy Infrastructure.
235 Australian Government (2023). Offshore Renewable Energy Infrastructure Area Proposal: Pacific Ocean off Hunter.
236 NSW Government (2023). Renewable Energy Zones.

EDF Renewables, a subsidiary of the French company EDF, announced the acquisition of the Newcastle Offshore Wind (NOW) farm, a floating offshore project.[237] BlueFloat Energy announced plans for a 1.7GW offshore floating windfarm, which it aims to construct over a seven-year timeframe.[238]

The offshore wind supply chain and industry ecosystem is complex and highly specialised in nature. Globally, the offshore wind market is characterised by a handful of original equipment manufacturers (OEMs) (e.g. Goldwind, Siemens, Vestas, Gamesa, GE and ABB). Attracting these manufacturers will be important for leveraging opportunities for NSW industry to participate in the supply chain, locally and internationally, for this growing global clean energy industry.

Battery storage

Energy sector:
New generation renewable and storage

OPPORTUNITY 7

Developing long duration and fast responding energy storage solutions and growing the battery supply chain

Energy storage is a key firming technology for the energy grid transition. To successfully enable the transition from coal-fired power stations, a combination of long, medium and short duration energy storage is needed.

Within NSW, this will largely be in the form of pumped hydro energy storage (PHES) and battery storage. Snowy 2.0 PHES is being constructed to provide an additional 35,000MWh of large-scale storage across the NEM,[239] with an additional 2GW of long-duration storage capacity. Despite a revised budget and delays in operation time, the delay of Snowy 2.0 is not expected to impact NEM stability in the short-term following the closure of Eraring coal-fired power plant.[240] In NSW, energy storage systems will be developed through other PHES projects (using existing water management systems or innovative solutions such as using abandoned mining sites) and grid scale batteries.[241] The rollout of grid scale batteries has commenced with the first battery at Wallgrove operational,[242] and other battery projects have been announced, such as the Waratah Super Battery[243] and projects at Broken Hill,[244] the Liddell Power Station site[245] and at Wallerawang.[246]

The 2020 Study identified opportunities for establishing a local battery manufacturing industry. In a report by the Future Battery Industries CRC, it is estimated that a diversified battery industry in Australia could contribute A$16.9 billion gross value added and 61,400 jobs to the economy by 2030.[247] The report also notes that global battery demand has increased more than forecast, with the prediction that the supply of key battery materials won't match demand. The report outlines opportunities for Australia and the need to act quickly and decisively to capture the economic and strategic opportunity of diversified battery industries.

Research and develop in battery technology is continuing, with research driving continuous improvement in battery performance and capability. Illinois Institute of Technology and the US Department of Energy's Argonne National Laboratory recently announced a higher density lithium-air battery that extends the driving range of motor vehicles to 1,500 kilometres and has the potential to power long haul trucks and aircraft.[248]

NSW has world-leading expertise in novel energy storage materials, energy conversion efficiency improvement, demand control technologies and storage integration to energy systems. It also has strong R&D capabilities in active materials, cell manufacturing and pack assembly and electrical and chemical engineering.

237 EDF Renewables (2023). Media Release: EDF Renewables in Australian Complete Acquisition of the Newcastle Offshore Wind Project.
238 Bluefloat Energy (2023). BlueFloat Energy Announces Latest Offshore Floating Wind Development in the Hunter Region - 'Eastern Rise'.
239 Snowy Hydro (2020). Snowy 2.0 About.
240 Financial Review (2023). Power Worries Grow as Snowy 2.0 Finish Date Blows Out.
241 NSW Government (2023). Electricity Infrastructure Roadmap.
242 Transgrid (2022). Major Milestone with NSW First Grid-Scale Battery Fully Operational
243 NSW Government (2023). Waratah Super Battery.
244 AGL (2022). Breaking Ground at Broken Hill for AGL's New Grid-Scale Battery.
245 NSW Government (2022). New Battery to Power Up at Liddell.
246 NSW Government (2022). Wallerawang Battery Energy Storage System.
247 Future Batteries Industries CRC. 2023 Charging Ahead – Australia's battery powered future.
248 Argonne National Laboratory (2023). New Design for Lithium-air Battery Could Offer Much Longer Driving Range Compared with the Lithium-ion Battery.

Examples of the NSW R&D capability include vanadium flow batteries at UNSW,[249] sodium sulphur battery research at USYD[250] and thermal storage materials at UoN.[251] NSW also has expertise in the commercialisation and supply chain for a variety of clean energy technologies, including long duration energy storage, hydrogen, flow and non-flow batteries. This has resulted in approximately 40% of Australian businesses developing battery, energy storage and fuel cell technologies being based in NSW.[252]

Australia is in the process of establishing its energy storage ecosystem, with Australia's first lithium-ion battery manufacturing plant being constructed in the Hunter region by Energy Renaissance.[253] In the same region, MGA thermal is building a plant to demonstrate and manufacture its thermal energy storage technology, which has longer storage duration than most lithium batteries.[254] In Sydney, Gelion Technologies has developed products for stationary storage and additives to improve the performance of electric vehicles batteries, and recently purchased an Intellectual Property (IP) portfolio of lithium-sulphur and silicon anode patents.[255]

The new energy storage manufacturing sector is still in its infancy in Australia and opportunities exist for it to be a significant economic and employment driver in NSW. Creating the right incentives to commercialise battery research and develop a battery manufacturing and energy storage ecosystem will support the expansion of this sector.

Opportunities also exist in NSW to deploy regional, neighbourhood and community batteries. Most battery projects have focussed on the larger grid or individual household scale. Mid-scale projects can increase integration of solar PV energy generation into the distribution network and help to manage peak demand and increase resilience of the grid.[256] Queensland are pursuing the rollout of mid-scale batteries, announcing 35 neighbourhood batteries in the Ipswich area, to store excess energy from domestic solar systems.[257] Small trials are underway in NSW, led by AusGrid in Cameron Park, Beacon Hill and Bankstown.[258]

The financial viability of regional, neighbourhood and community batteries depend on the ownership model, which can be third party-owned community batteries, third party-owned for-profit, network-owned community batteries and network-owned for-profit batteries. An ARENA cost benefit analysis found that third party-owned community battery models are likely to be financially viable in the current energy market, with network-owned community batteries unlikely to be financially viable without adding a significant proportion of the battery cost to its revenue asset base.[259]

249 UNSW Sydney (nd). Flow Battery Storage for Integrated Energy Systems.
250 University of Sydney (2022). Low-Cost Battery Built with Four Times the Capacity of Lithium.
251 University of Newcastle (2023). The Missing Block to Build an All-renewable Electric Grid.
252 NSW Government (2022) Shaping the Future of NSW in Science and Technology. 20-Year -NSW-R&D Roadmap.
253 Energy Renaissance (2022). The Renaissance.
254 Australian Government (2022). MGA Thermal Energy Storage Project.
255 Gelion (2023). The World's Leading Lithium Sulfur IP Portfolio is Now in the Hands of the Right Team to Deliver Global Energy Freedom.
256 Australian National University (2020). Community-Batteries: A cost/benefit Analysis.
257 Queensland Government (2023). Energy Update: Cleaner Energy for Queenslanders.
258 Ausgrid (2022). Community Battery Trial
259 Australian National University (2020). Community Batteries: A Cost/Benefit Analysis. 2020.

Renewable energy export

Energy sector:
New generation renewable and storage

OPPORTUNITY 8

Developing a renewable energy export ecosystem

Australia has been an energy-exporting superpower for decades, shipping massive quantities of coal and gas around the world. As decarbonisation accelerates in many energy-importing economies, there is a strong demand in renewable energy communities for various forms of energy carriers. As noted in the 2020 Study, the development of a renewable export industry requires significant government and industry investment for local production capacity and infrastructure.

The NSW Hydrogen Strategy seeks to establish NSW hydrogen hubs, providing export opportunities to major trading partners that rely on energy imports and/or have announced hydrogen targets.[260] Other states have also started supporting the establishment of hydrogen export industries,[261,262] and several private hydrogen export facilities have been proposed.[263]

In addition to the establishment of energy carrier exports, Sun Cable has proposed an alternate approach by exporting renewable electrons (i.e. electricity) via a subsea link to Singapore.[264] Sun Cable entered voluntary administration in early 2023, related to questions about its future direction.[265] Recently, a consortium of investors has agreed to buy the company and reprofile the project.[266] The opportunities of direct export of electrons from NSW is very limited by the geographic conditions and would be less competitive compared with regions such as Northern Territory.

NSW's greatest opportunity likely rests with the export of molecules via green hydrogen and derivatives (such as ammonia, methanol and other Methylcyclohexane), rather than electrons. The substantial wind resources off the Hunter and Illawarra coast could provide the necessary feedstock for the development of a molecule export industry. Both regions already have a skilled workforce and existing infrastructure that could be repurposed to support industry development. Hydrogen energy exports also offer these regions diversification away from their existing coal export industries.

260 NSW Government (2021). NSW Hydrogen Strategy.
261 Renew Economy (2023). South Australia Swamped with Nearly 30 Proposal for World Leading Green Hydrogen Plan.
262 Queensland Government (2022). Enabling Queensland's Hydrogen Production and Export Opportunities Report.
263 BP Australia (2023). Renewable Energy Hub in Australia.
264 Sun Cable. (2023). Sun Cable is Developing the World's Largest Solar Energy Infrastructure Network, Making it Possible to Power Whole Cities with Renewable Energy.
265 Renew Economy (2023). Sun Cable Sale Process Kicks Off, Plays up Singapore Link and Green Hydrogen.
266 Recharge (2023). Billionaire's partners in talks with wind developers over Sun Cable mega-project.

4.3 Transport

SECTOR	2019 Decarbonisation innovation opportunity	2023 Decarbonisation innovation opportunities	Sector readiness level	
TRANSPORT	Electrification and EV charging	e-mobility and services	Technology and service	●
	EV charging infrastructures and hydrogen refuelling routes		Workforce and skills	●
	Mobility as a service	Aviation, shipping and long-haul road transport	Public levers and policies	●
	Future EV battery services	Non-road vehicle and machinery	Industry and investment	●

Transport accounts for the second largest source of GHG emissions in NSW, accounting for 38% of total GHG emissions in 2018-2019 and is projected to become the largest source of NSW's GHG emission (33-36%) by 2030.

Emission reductions from the projected uptake of light duty electric vehicles and from electrification of buses will be offset by increased emissions from aviation and trucks.[267]

The transformation to net zero of NSW's transport system is a significant challenge, but one that offers a powerful opportunity to achieve positive change in mobility. The first NSW Future Transport Technology Roadmap was launched in 2016 with a vision to use innovative technologies to provide customers with transport and mobility solutions that are more convenient, personalised and sustainable.[268] In partnership with organisations including start-ups, vehicle and systems technologies have been delivered.

There have been several strategies and initiatives to reach net zero ambitions for transport, including:

- The Future Transport Strategy to set the direction for future mobility[269]
- The NSW Electric Vehicle Strategy to incentivise the uptake of zero emission vehicles and accelerate the rollout of charging stations across NSW[270]
- The Zero Emissions Buses Strategy to transition NSW's bus fleet to zero tailpipe emissions[271]
- NSW Hydrogen Strategy to progress heavy vehicles as an early industrial user for the transport sector and hydrogen industry.[272]

Transport use has shifted since the 2020 Study. Of note, transport emissions were lower in 2020 compared to previous years due to the impact of the COVID-19 pandemic. In NSW, emissions are forecast to fall from 25.8 Mt CO_2-e in 2023 to 23.6 Mt in 2030 and 17.5 Mt CO_2-e in 2035 (Figure 4).[273]

267 NSW Government (2021), Greenhouse Gas Emissions.
268 NSW Government (2021). Future Transport Technology Roadmap 2021-2024.
269 NSW Government (2022), Future Transport Strategy: Our vision for transport in NSW.
270 NSW Government (2021). NSW Electric Vehicle Strategy.
271 NSW Government (2023), Zero Emission Buses.
272 NSW Government (2021), NSW Hydrogen Strategy, Making NSW a Global Hydrogen Superpower.
273 NSW Government (2023). NSW Net Zero Emissions Dashboard.

The 2020 Study identified the development of EV charging infrastructure, electrification of different transport modes, transport corridors that provide access to hydrogen and low emission fuels and recycling and reuse of EV batteries as key decarbonisation and economic growth opportunities for transport. Interest in these opportunities remains strong and has been progressing.

Opportunities for decarbonised passenger vehicles have already been realised and progressed, focused on EVs, supported by the NSW Electric Vehicle Strategy. According to the report released by the Electric Vehicle Council, the overall EV market share of new car sales in Australia has increased from 2.05% in 2021 to 3.39% in 2022, representing 3.7% of new car sales.

Fuel type consideration

Regarding decarbonisation potential, there is no single optimal fuel type for each mode of transport. The choice of fuel depends on end-use, for example, EVs are likely to be most effective as urban passenger vehicles and buses due to charging infrastructure. The experiences in the rollout and uptake of EVs provides some insights which may be valuable for the rollout and uptake for other types for low emissions transportation as these different technologies move to commercialisation.

For EVs, policy and standards, public misconceptions and infrastructure hurdles including design, construction and maintenance, and operation of charging stations have all proved challenges to uptake. Ultimately the goal for infrastructure is to provide the EV with unlimited driving range while still optimising battery size and vehicle costs. Battery charging must be safe, affordable, fast and convenient and the travel distance of EVs is heavily dependent upon the battery cycle and the location of the charging stations. Therefore, charging infrastructure will need to be supported as the EV market penetration increases in passenger vehicles, which in turn should look to support heavy vehicle and freight EV uptake into the future. Although charging stations have increased in recent years, the success of EVs, especially in non-passenger vehicles will be dependent on further specialised infrastructure installation. Table 2 summarises the relative emissions and deployment cost for each mode of low emissions transportation.

Figure 4. Actual and projected emissions for transport – 2020-2050. Source: NSW SEED

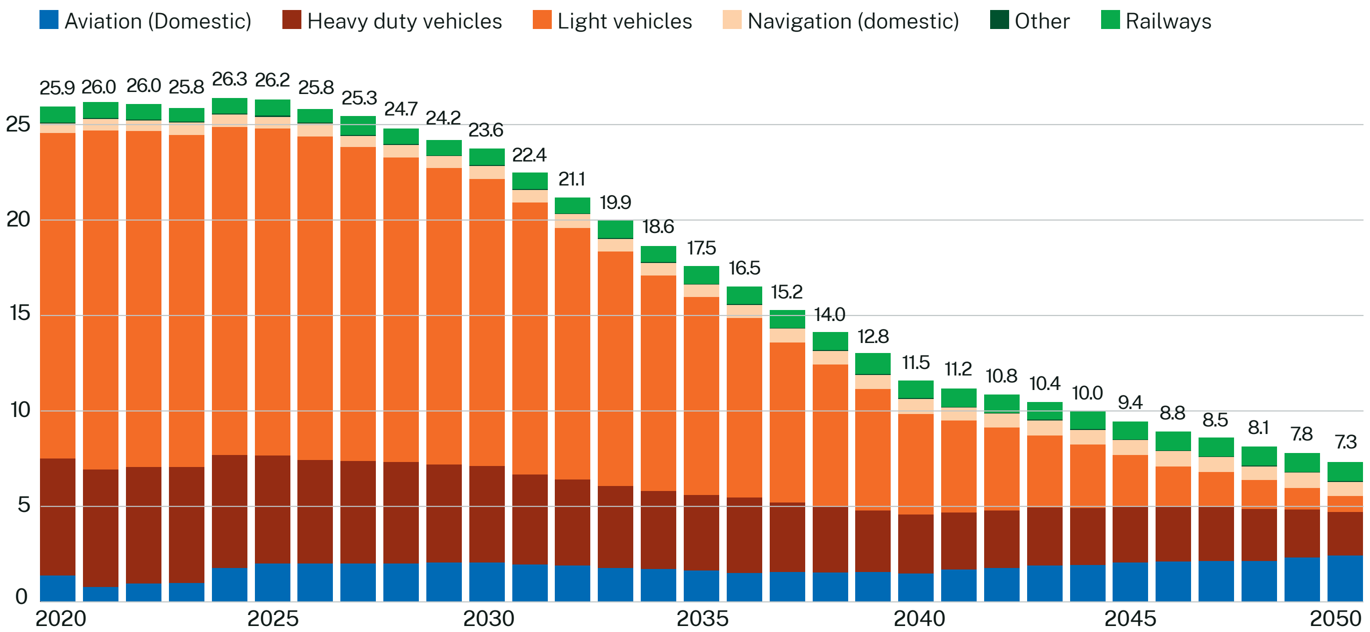


Table 2. Summarises the relative emissions and deployment cost for each mode of low emissions transportation.

Mode	Operational Emissions	Deployment cost
Active transport	Zero to low	Low
e-scooter and e-bike	Zero to low	Low
Electric bus	Low to medium, depending on energy generation and grid portfolio	Medium to high, vehicle costs are lower than hydrogen fuel cell vehicles but infrastructure costs could be substantial and have potential impacts on energy systems
Electric rail and light rail	Low to medium, depending on energy generation and grid portfolio	Medium to high, technology is already deploying and costs are competitive against hydrogen rail
Operational Emissions	Low to medium, depending on hydrogen production methods and feedstocks (fossil fuel or electrolysis)	Medium to high, costs of hydrogen fuel cell EV or rail are higher than battery EV or rail, running costs are competitive given the higher fuel efficiency
Sustainable Aviation Fuel (biofuel pathway)	Low, up to 80% emissions reduction potential	Low to medium, technology pathway is mature, large-scale production in planning. Limited modifications required for aircrafts and airports
Sustainable Aviation Fuel (e-fuel pathway)	Low, up to 80% emissions reduction potential	Medium to high, technology pathway at early-stage development, price premium depends on blending ratio. Limited modifications required for aircrafts and airports
Battery-electric aircraft	Medium to high, based on energy source or power grids	High, significant modifications to aircraft and airport infrastructure e.g. charging infrastructure and energy systems
Hydrogen-powered aircraft	Medium to high, based on hydrogen production methods (fossil fuel feedstock or electrolysis)	High, significant modifications to aircraft and airport infrastructure e.g., fuel supply and storage
Electric ferry	Low to medium, depending on energy generation and grid portfolio	Medium to high, ferry costs are lower than hydrogen powered ferries, but infrastructure costs could be substantial and potential impacts on energy systems
Hydrogen ferry	Low to medium, depending on hydrogen production methods and feedstocks (fossil fuel or electrolysis)	Medium to high, costs of hydrogen fuel cell EV or rail are higher than battery EV or rail, running costs are competitive given the higher fuel efficiency

Services and e-mobility

Multi-model transport

Transport sector:
Services and e-mobility cluster

OPPORTUNITY 9

Developing and deploying technologies and services to support a multi-model approach to transport

With population growth generally centralised within large cities, changing the way people move around will be critical for decarbonisation. The car sharing industry has experienced rapid growth globally and is projected to continue to grow over the next 10 years. With the average privately owned car remaining unused for 95% of the time, the car sharing industry in Australia is valued at approximately $54 million.[274] The development of digital technology and innovations such as keyless entry technology, mobile integrated vehicles and driverless cars have been key to car sharing's growth. Further technological advances will be important to entice consumer uptake and allow for a smoother transition to car sharing.

The latest NSW Future Transport Technology Roadmap commits to deliver six priority programs to transform the customer journey experience, with the first being Mobility as a Service (MaaS).[275] MaaS was also identified in the 2020 Study as a key opportunity to improve efficiency, flexibility and affordability in low emission transport. MaaS integrates various low-emission transport options into a single platform, such as a user-friendly app, personalised journeys across multiple modes, real-time information, and affordable pricing and incentives to encourage more people to use low-emission modes of transport and reduce emissions.

Efficient mobility is identified as more of an enabler than a technology opportunity, with shared, clean and efficient transport offering a significant opportunity for the transport sector to decarbonise. Supporting and deploying e-mobility technology and services is critical due to the strong policy connection.

Micro-mobility

Transport sector:
Services and e-mobility cluster

OPPORTUNITY 10

Supporting the deployment of micro-mobility to lower costs and accelerate uptake

There has been a significant uptake of e-bikes since the 2020 Study, with the number of e-bikes imported to Australia tripling over the past three years and sales growing faster than any other segment of the Australian bike market.[276] E-bikes can help consumers get more exercise, ease traffic congestion and reduce vehicle emissions. However, uptake in the Australian market, especially NSW, lags behind other countries due to an inadequate bicycle infrastructure, a lack of safe cycleways and outdated e-bike regulations.[277] Addressing these issues is critical to support e-bike uptake.

It has been found that 'bicycle-friendly' societies such as the Netherlands, the UK and France became safer for cyclists (compared to Australia) when a critical mass of bike use was reached to instil behavioural change in drivers. This culture shift occurred decades before adequate bicycle infrastructure caught up but accelerated the demand for better infrastructure.[277]

Risks associated with increased bicycle uptake without adequate infrastructure or policy are illustrated in China's 2017 bike share roll out.

274 Uber Carshare (2020), Care Sharing Industry Trends: A New Era of Mobility.
275 NSW Government (2021). Future Transport Technology Roadmap 2021 – 2024.
276 Bicycle NSW (2022), The Rise of E-bikes.
277 Nikitas, A., et al (2021), Cycling in the Era of COVID-19: Lessons Learnt and Best Practice Policy. Recommendations for a More Bike-centric Future. Sustainability, 13(9), p.4620.

Dozens of bike share companies quickly flooded city streets with millions of rental bicycles. This rapid growth vastly outpaced immediate demand and overwhelmed Chinese cities where infrastructure and regulations were not prepared to handle the growth. Riders would park bikes anywhere or abandon them, resulting in bicycles piling up and blocking streets and pathways. As cities impounded derelict bikes by the thousands, they moved quickly to cap growth and regulate the industry.[278] NSW should learn from this scenario and ensure better supporting infrastructure and policies are implemented as uptake increases. Similarly, a wave of concerns over mass bike dumping was experienced in Sydney in 2017 when bike share schemes were introduced. Dockless bike share schemes allow access to share bikes with an app with no requirement to return the bike to a docking station. This led to the dumping of bikes across the city. Consequently, six Sydney councils created the inner Sydney bike-sharing rules in December 2017, specifying the requirements for dockless bike-share operators.[279]

Long-haul transport and non-road machinery

Transport sector:
Long haul transport and non-road machinery

OPPORTUNITY 11

Developing and deploying alternative fuels technologies with supporting infrastructure for hard-to-electrify transport

OPPORTUNITY 12

Deploying EV for heavy vehicle sector with focused industry applications (mining, agriculture and non-road)

Road freight is the fastest-growing CO_2 emitter, with road freight accounting for 80% of the global net increase in diesel use since 2000. Achieving NSW's net zero goal will require the adoption of zero emissions fuels across the freight sector.

Of the 143,000 heavy trucks registered in NSW, only 100 are electric or hybrid vehicles.[280] Replacing the energy source used by freight vehicles is a huge challenge, but also an economic opportunity. A decarbonised freight industry is likely to be a foundational customer for emerging clean energy industries. Electrifying freight will increase demand for and drive investment in wind and solar farms, pumped hydro storage, grid-scale batteries, transmission and distribution, and hydrogen production. It will also accelerate demand for advanced skills and bring new opportunities for local engineering, manufacturing and refining.[281]

Internationally the transport sector is under pressure to decarbonise, but the heavy truck sector is difficult to electrify due to the weight of batteries and recharging times for long-haul vehicles.

The 2020 Study highlighted heavy road transport as a potential early user of a domestic hydrogen industry. However, the specific type of technology (electric battery or hydrogen fuel cell) to achieve zero-emission freight in Australia remains yet to be determined, as neither technology has been fully proven. What is clear however, is that considerable investment is required in infrastructure and the supply chain for both the technologies and the energy source for zero emissions road freight.[282]

Light commercial vehicles

Zero-emission trucks and buses for the intra-urban freight and passenger task are currently dominated by battery technology. NSW's urbanised population means much of the light freight and distribution tasks occur in urban centres, where battery-powered electric commercial vehicles and medium-duty trucks are well suited. They reduce noise and air pollution, and improve the liveability of urban environments. Battery technologies already provide sufficient range for many light and medium-sized freight vehicles in urban areas, and their overnight charging demands are more readily accommodated without power supply upgrades.

278 The Atlantic (2018), The Bike-share Oversupply in China: Huge Piles of Abandoned and Broken Bicycles.
279 NSW Government (2018). New Penalties to Address Bike Dumping.
280 NSW Government (2021). Decarbonising Freight.
281 NSW Government (2020). Future Energy Action Plan.
282 McKinsey (2022). Unlocking Hydrogen's Power for Long-Haul Freight Transport.

Electric buses are the most successful zero-emission heavy duty electric vehicles and are often cost-effective. The rollout of electric buses to replace the state's 8,000 diesel and natural gas buses under the Zero Emission Buses Program is not expected to be delivered until 2047 across metropolitan and regional NSW.[283,284]

In February 2022, the NSW Government awarded a contract for the design, manufacture and assembly of 79 electric buses to a St Mary-based company (taking their contract to a total of 101 buses).[285] A number of Australian truck and freight companies have announced a transition to electric medium duty trucks, including Linfox and Volvo FL Electric, with refrigerated electric trucks entering the Woolworths fleet in Melbourne.[286] Australia Post is undertaking the rollout of an electric fleet ranging from electric bikes to electric delivery vehicles and trucks.[287]

Heavy freight

For long-haul and heavy trucks, it is still unclear whether the technology to achieve zero-emission freight will be dominated by electric battery or hydrogen fuel cells. Their intense duty cycles and high average speeds are not yet economic for battery technology on long-haul routes. The improvement in battery technology is attractive for truck operation. However, innovative charging solutions are needed to ensure smooth operation. EVs are increasingly being used in the mining sector, although at this stage it is predominately for lighter vehicles. In 2021, BHP, Rio Tinto and Vale launched the Charge On Innovation Challenge, a global competition to develop effective solutions for large-scale haul truck charging.[288]

Among eight finalists, Ampcontrol and Tritium proposed a mining haul truck battery swap solution with an end-to-end ultra-fast modular recharging station that is fully automated, relocatable, scalable and cell agnostic.[289] Further, a range of large electric trucks with a range of 400km are now being produced by established manufacturers such as Daimler, Volvo and Scania.

Another drawback for battery technology is the increase in vehicle weight from batteries, which may impact the economics of long-haul operations and limit the roads on which they can operate. Therefore, hydrogen fuel cell vehicles may play roles where battery vehicles are not applicable. To investigate the potential of hydrogen fuel for heavy vehicles market share and to explore viable pathways to transition to zero-emission freight, Transport for NSW is partnering with Australian Road Research Board and Movement to conduct the Hydrogen Powered Heavy Vehicle Demand and Infrastructure Assessment.[290] In the meantime, some companies are heavily investing in different technologies. For example, Scania and Daimler have unveiled battery electric trucks for long haul operations and Hyzon Motors have started producing hydrogen fuel cell trucks for industrial operation.[291]

The high upfront costs of electrification will be a short-term challenge for the freight sector, but costs will fall as core technologies improve and markets grow. In the longer term, dramatically lower fuel costs of electric vans and trucks will increase productivity. The successful introduction of zero-emission road freight will require investment in refuelling and/or electric charging infrastructure.

283 NSW Government (2023). Zero Emission Buses.
284 The Sydney Morning Herald (2022). Electrifying state's entire bus fleet will now take until 2047.
285 NSW Government (2022). NSW Built Electric Buses Power Local Manufacturing Jobs.
286 Power Torque (2021). Electric Truck is Going into the Woolworths Fleet.
287 Australia Post (2022). Here's How Australia's Largest Electric Delivery Fleet is Charging the Way You Receive Parcels.
288 BHP (2021). Charge On Innovation Challenge Global Competition Launched to Electrify Mine Truck Fleets.
289 Charge On (2022). Winning Technology Innovators Announced.
290 NSW Government (2023). Hydrogen Powered Heavy Vehicle Demand and Infrastructure Assessment.
291 Hyzon (2021). Hyzon Motors to Deliver Australia's First Hydrogen-powered Trucks to Coregas, A Wesfarmers company.

Rail, aviation and maritime

Rail is already the cleanest option for containerised and bulk freight, with emissions up to 16 times lower than road haulage. Investment to improve access, capacity, reliability and timing of operations can help shift freight to rail. Transport for NSW has developed a target with a commitment to net zero transport operations by 2035.[292] They aim to fully decarbonise rail freight through investing in alternatives to diesel trains. A new fleet of hybrid electric passenger trains for NSW's regional lines using bi-mode technology is currently being rolled out.[293] Of note, the UNSW Engine Research Laboratory has developed a new Hydrogen-Diesel Direct Injection Dual-Fuel System that significantly cuts carbon emissions, with retrofitting of any diesel engine used in trucks and power equipment in the transportation, agriculture and mining industries to the new hybrid system in a few months.[294]

Aviation is another hard-to-abate transport industry. The long lifespan of aircraft and refuelling and the current infrastructure, high-cost and low-maturity of electrification applications, and limited technological improvement in fuel efficiency are some of the factors responsible for the sector's decarbonisation stagnation.[295] According to the International Energy Agency, aviation emissions are not on track towards net-zero in 2050 and the aviation industry requires technically and commercially viable solutions to cut more than 500 Mt CO_2 by 2040 in line with IEA's Net Zero Emissions pathway.[296] The challenge is even greater for Australia, where the aviation sector alone contributes approximately AUD$20 billion to the economy, supports many industries and provides key linkages for tourism, education, international trade and business.[297]

Sustainable Aviation Fuels (SAF) is widely accepted as the only near to medium term decarbonisation solution to reduce global aviation emissions while maintaining economic benefits.[298]

Compared to alternative technologies such as all-electric and hydrogen-powered aircrafts, SAF has advantages for economic, emissions and infrastructure legacy benefits:

- high technology readiness level at market adoption phase for technology industrial translation and a growing pipeline of commercial projects across value chains
- significant emissions reduction potential with high applicability to both passenger and cargo flights, long haul and regional flights due to advantages in high power density
- compatibility with current airport refuelling infrastructure, aircraft design and manufacturing, refuelling model and duration as well as training and upskilling requirements for existing workforce
- established global supply chains with the support of financial incentives mechanisms by major economies and airlines globally.

SAF presents an opportunity for significant economic and environmental benefits for NSW and Australia. The rate of growth and scale of the global SAF market is projected to accelerate, with the market size expected to reach between US$12 billion and US$18 billion in 2030, with a compound annual growth rate of more than 50%.[299] For every per cent increase of SAF blending, the Australian aviation industry could reduce 80,000 tonnes of emissions (2019 emissions data).[300] The development of SAF local capability and supply chain would have significant spill over values to economies. SAF could generate additional revenue streams from excessive renewable energy and waste materials for valuable commodities. New eco-industrial precincts built on SAF research and production capability could co-locate R&D institutions, training facilities and commercial projects for continuous innovation and productivity enhancement across sectors.

292 Transport for NSW (2023). Building on Australia's first net zero train fleet.
293 The Driven (2019). NSW to Switch Regional Train Fleet to Hybrid Electric, Starting 2023.
294 UNSW Newsroom (2022). New system retrofits diesel engines to run on 90 per cent hydrogen.
295 World Economic Forum (2022). The Aviation Sector Wants to Reach Net Zero by 2050. How will it do it?
296 International Energy Agency (2021). Net Zero by 2050. A Roadmap for the Global Energy Sector.
297 Commonwealth of Australia (2022). COVID-19 Support to the Aviation Sector, Auditor-General Report No. 40 2021-22.
298 International Energy Agency (2021). Aviation Emissions.
299 Forecast modelling results from various sources of ResearchAndMarkets, AlliedMarketResearch and MarketsandMarkets
300 Australian Government (2021). Australia's Emissions Projects 2021.

For the maritime sector, investments in renewable synthetic fuel and biofuels can assist the transition while the development in electric battery and hydrogen technology continues. Australia has a competitive advantage in terms of feedstock availability for renewable biofuel production. However, as all industries will compete for the same sources of biomass, there is a need for coordinated effort and resources towards similar feedstock sourcing and biofuel production pathways.[301]

For long-term solutions, synthetic fuels such as methanol and green ammonia are emerging as alternative fuels for shipping industries. The use of ammonia as vessel fuel will need to address the technology and regulatory gaps that prevent its adoption. Further, the implementation of wind-assisted propulsion technologies has been suggested to significantly reduce the use of fossil fuels in the global shipping industry.

For example, a UK-based consultancy BARTech Windwings are using ship-based wind sails designed to offer up to a 30% reduction in fuel consumption for bulk carriers, tankers and other large shipping vessels.

While progress is being made for alternative fuel types for long-haul transport and non-road machinery, their uptake will be dependent on the infrastructure. Electric road systems are not available for commercial use and an increased push for alternative fuel types requires adequate refuelling deployment across the state. Further, infrastructure in this context also relates to issues such as the readiness of the supply chain to deliver the required technologies both in term of vehicles and their support structure.

301 EMSA (2022). Update on Potential of Biofuels for Shipping.

4.4 Built Environment

SECTOR	2019 Decarbonisation innovation opportunity	2023 Decarbonisation innovation opportunities	Sector readiness level
BUILT ENVIRONMENT	Low emissions materials and reuse and recycling	Embodied carbon for building	Technology and service
	Electrification and energy efficiency and productivity		Workforce and skills
	Sustainable precincts and hydrogen hubs		Public levers and policies
	Digital technology		Industry and investment

As noted in the 2020 Study, the built environment is a major driver of economic growth. In 2022, it employed over 1.2 million people nationally, or 9.4% of Australia's total workforce.[302]

Both the commercial and residential building sectors are significant contributors of carbon emissions and electricity use in Australia:

- the commercial building sector is responsible for around 22% of overall electricity use and 11% of total carbon emissions.[303] Nationally, emissions from this sector are expected to remain consistent between 2020 and 2035 at 6 Mt CO_2-e per annum.[304]
- the residential building sector is responsible for around 24% of overall electricity use and 12% of total carbon emissions in Australia.[305] Residential building emissions are expected to remain steady between 2020 and 2030 at 11 Mt CO_2-e, declining to 8 Mt CO_2-e by 2035 as new buildings transition to electric-only connections and existing residential buildings switch from gas to electricity.[306]

Given its significance to both emissions reduction and economic activity, the 2020 Study identified several embedded emissions reduction opportunities in this sector, including:

- efficient, modular designs – increasing efficiency and modularity in building design
- low emission construction materials – substituting high emission construction materials with cost-effective low emission materials and developing novel decarbonised materials.

Since the 2020 Study, the NSW Government has introduced a range of measures:

- expanded NABERS by developing a framework to measure, benchmark and certify embodied emissions of building materials[307]
- established the Materials and Embodied Carbon Leaders Alliance (MECLA), working with the building industry to encourage the voluntary use of low emission building materials (LEBMs)[308]
- launched the NABERS Sustainable Finance Criteria to support green investment and sustainable buildings[309]

302 Australian Government (2022). Construction Labour Market Insights.
303 Australian Government (nd). Commercial Buildings.
304 Australian Government (2022). Australia's Emissions Projections 2022.
305 Australian Government (nd). Residential Buildings.
306 Australian Government (2022). Australia's Emissions Projections 2022.
307 NSW Government (2022). Net Zero Plan Implementation Update 2022.
308 NSW Government (2023). Low Emission Building Materials.
309 NSW Government (2022). Launched: NABERS Sustainable Finance Criteria.

- introduced the Building Sustainability SEPP 2022, which sets sustainability standards for residential and non-residential development and starts the process of measuring and reporting on the embodied emissions of construction material at the development application phase.[310]

Embodied carbon for building and infrastructure

Built environment sector: Embodied carbon for building and infrastructure cluster

OPPORTUNITY 13

Developing and deploying low emission construction materials and construction technologies

The embodied emissions of construction materials make up approximately 5% to 10% of Australia's total emissions.[311]

Their proportion of overall built environment emissions is increasing as improvement are made with energy efficiency and the uptake of renewable energy generation in buildings. The Green Building Council of Australia (GBCA) estimates that by 2050, embodied emissions in the built environment could account for up to 85% of emissions, up from just 16% in 2019.[312]

Given its increasing proportional contribution, there is greater focus on reducing embodied emissions of construction material. Strategies to reduce the embodied emissions include reducing the quantity of materials used in building construction and increasing the use of low emission building materials (LEBMs) to replace the conventional steel, concrete, aluminium and other products.

Opportunities to develop and deploy low emission construction materials were included in the 2020 Study, particularly:

- traditional materials that store carbon (e.g. timber and engineered wood products)
- low emission conventional materials (e.g. 'green' steel)
- new low emission or carbon storage materials (e.g. new geopolymer cements).
- The report also noted the potential for developing and deploying decarbonised building materials that sequester carbon emissions.

LEBMs are being developed, although opportunities still exist for further innovation to reduce embodied emissions using low emission products and new technologies, such as the 3D printing of homes as occurring in Arizona, Texas and California.[313] Low emission building products now being produced or which are available in Australia include:

- low emission concrete products using alternative binders and cementitious materials such as slag, fly ash, blast furnace slag and calcined clay, with claims some contain up to 70% less embodied carbon.[314] Products and producers include Boral for ENVISIA and Envirocrete, Wagners for Earth Friendly Concrete and Holcim Australia for ECOPact.[315,316,317] There are other products such as plasterboard/wall and ceiling panels that use compressed agricultural fibres or use less energy-intensive manufacturing processes, such as those produced by Durra Panel[318]
- low emission engineered wood products, such as Wesbeam for laminated veneer lumber and Hyne Timber for glue laminated timber[319,320]
- carbon neutral and/or low emissions bricks, such as Brickworks for carbon neutral bricks[321] and Hemp Block Australia for HempBlock[322]

310 NSW Government (2023). Sustainable Buildings SEPP.
311 Australian Government (2021). Australian Buildings and Infrastructure: Opportunities for Cutting Embodied Carbon.
312 NABERS (2022) Nabers Annual Report 2021/22.
313 Dezeen (2022). Mighty Buildings Completes 3D-Printed Net-Zero Home in Southern California.
314 Construction (2021). Wagners marks global launch of Earth Friendly Concrete.
315 Boral (2023). Concrete. Lower Carbon Concrete.
316 Wagners (2023). Earth Friendly Concrete: Reduce Your Carbon Footprint by 70%.
317 Holcim (2023). ECOPact: Low Carbon Concrete Made Easy.
318 Durra Panel. (nd). The Product: Durra Panel Finishes.
319 Wesbeam (nd). Building Better Wood.
320 Hyne Timber (nd). Glue Laminated Timber (GLT) for Residential, Commercial & Mass Timber Construction.
321 Brickworks (nd). 5 Ways to Shrink Your Carbon Footprint on Your Home Build.
322 Hempblock Australia (2022). Efficient Building Technology.

Low emission steel is very much in the development phase in Australia. The current technology is to use hydrogen instead of coke as the reagent or a closed-loop carbon recycling system.[323] There are currently no low emissions steel facilities in Australia, although several plants are planned for Europe.[324] In NSW, BlueScope is working with a range of partners including the CO2 CRC, ARENA and UoW, to cut iron and steelmaking emissions.[325]

Aluminium production has two carbon-intensive stages, with natural gas used in the steam and calcination process to make alumina, and electricity in the aluminium smelting process.[326] There is currently no decarbonised (green) aluminium production in Australia, although companies like Rio Tinto are seeking to reduce aluminium's carbon intensity by using renewable power coupled with firming solutions.[327] Pilot projects are also underway, with Alcoa seeking to electrify the production of steam and calcination in alumina refining in Western Australia.[328,329]

LEBMs continue to be developed and NSW is well placed to maximise the economic as well as decarbonisation benefits, through the manufacture of these. The state has an existing ecosystem for building material manufacturing and significant research is being undertaken by NSW universities. To encourage the manufacturing of low emissions products in NSW, the Net Zero Industry and Innovation Program seeks to assist high emitting industries accelerate their decarbonisation.[330] Additionally, the Low Carbon Product Manufacturing Fund and the Renewable Manufacturing Fund has been established to focus on technologies that are commercially available to expand local manufacturing in the renewable and low emissions sectors.[331]

One local company developing low carbon building products is MCI Carbon, which has established a pilot facility in Newcastle. Their process permanently stores carbon through mineralisation, which is embedded within cement or plasterboard.[332]

Steps are being undertaken to increase the knowledge and overall demand for LEBMs. The NSW Government is working with commercial builders and asset owners encourage the voluntary use of LEBMs.[333]

MECLA is also working to address opportunities and barriers in LEBMs by developing a range of resources to inform people about them.[334]

A range of policies and frameworks are also being developed to measure, benchmark and certify embodied emissions of building materials. This includes NABERS which is developing a national standard to measure, compare and then certify the embodied carbon footprint of buildings.[335]

Built environment sector: Embodied carbon for building and infrastructure cluster

OPPORTUNITY 14

Utilising government procurement to increase the uptake of low emissions construction materials and modular designs

Increasing the use of modular building and prefabrication brings a range of decarbonisation benefits including material efficiency, less building waste and energy efficiency through better draught sealing and improved insulation. They also provide advantages of design efficiencies and economies of scale. A recent UK study has found that factory-produced homes can produce up to 45% less emissions than traditional methods of residential construction.[336]

323 The Economist (2023). A New Way to Clean Up the Steel Industry.
324 BBC (2023). The Race Across Europe to Build Green Steel Plants.
325 MECLA (nd). Low Embodied Carbon Steel: Reinforcing a Low Carbon Future or Pipe Dream?
326 Australian Government (2022). World-first Pilot to Electrify Calcination in Alumina Refining.
327 Sydney Morning Herald (2023). World's Emissions Targets at Risk if Pace of Change Doesn't Pick up: Rio Tinto.
328 Australian Government (2021). Alcoa to Investigate Low Emissions Alumina.
329 Australian Government (2022). World-first Pilot to Electrify Calcination in Alumina Refining.
330 NSW Government (2022). Investing in a Low Carbon Future for NSW Industry.
331 NSW Government (2023). Developing Renewable and Low Carbon Manufacturing Industries in NSW.
332 MCI Carbon (2022). Low Carbon Materials.
333 NSW Government (2023). Low Emission Building Materials.
334 MECLA (2022). Resources.
335 NABERS (2022) NABERS Annual Report 2021/22.
336 Archinect News (2022). New Study Finds that Modular Construction Produces 45% Less Carbon than Traditional Methods.

Modular buildings require less carbon-intensive products, such as concrete and steel, and less transport for on-site workers and materials. A study based on a modular building designed for disassembly at Curtin University found that the building cut emissions to almost a tenth of a conventional building process.[337]

On the supply side, government can take the lead through specifying LEBMs in its own procurement and tendering criteria and by funding and conducting studies to evaluate the techno-economic viability for producing LEBMs. These studies can help identify any barriers or challenges that need to be addressed, provide evidence-based recommendations and facilitate informed decision-making. The NSW Government is providing funding towards transformative emission reduction projects for existing industrial operations, such as Orica, Tomago Aluminium, Boral and Manildra Group.[338] These studies can provide improved investment certainty for high-emitting industries to transition towards low-emissions production.

On the demand side, government procurement plays a crucial role in shaping the market by influencing the adoption of sustainable practices and technologies. As a major procurer and planner of building and infrastructure, the government can enable low and zero carbon procurement practices, particularly for tendering major construction, infrastructure and public works projects. There are international best practice examples where governments have mandatory embodied emissions reduction targets or plans for infrastructure tenders. The UK Government has introduced procurement rules that require any relevant bids to include a carbon reduction plan detailing carbon footprint and commitment to reach net zero in UK operations by 2050.[339] In addition to direct procurement, government leadership is critical to drive demand and stimulate the industry for low emission construction materials. The NABERS Embodied initiative provides an excellent example of government funding the development of a framework for measuring, benchmarking and certifying emissions from construction and building materials.[340] The framework is being incorporated into the existing NABERS suite of measuring and rating building sustainability and could be adopted nationally.

By taking a leadership role and leveraging procurement power, the NSW Government can shape the market for LEBMs and modular design to reduce embodied carbon emissions and overall costs.[341]

Built environment sector: Embodied carbon for building and infrastructure cluster

OPPORTUNITY 15

Increasing recycling and the reuse of construction materials in new buildings

OPPORTUNITY 16

Maximising the use of existing assets and reducing the use of materials in new buildings and infrastructure

Minimising waste and improving recycling rates, including in building and demolition materials, is being addressed by government within circular economy and decarbonisation strategies and initiatives, as discussed in Section 3.

The construction sector is one of the largest contributors to waste. In 2020/21, Australia-wide construction and demolition amounted to 29.0 million tonnes of waste, representing 38% of all waste. Recycling rates are improving, with an 80% resource recovery rate in 2020/21,[342] however the high demand of housing and a large pipeline of approved or planned construction projects will lead to large volume of waste. This poses challenges for the built environment sector and industry is seeking solutions from circular economy principles.

337 The Conversation (2020). A Third of our Waste Comes from Buildings. This One's Designed for Reuse and Cuts Emissions by 88%.
338 NSW Government (2023). Successful Transformative Industry Projects.
339 MECLA (2022). Best Practice Policy Development: International Review of Policies and Programs for Low Emissions Building Materials.
340 NABERS (2021). NABERS Embodied Emissions Initiative.
341 The Economist (2023). From High-Speed Rail to the Olympics, Why Do Big Projects Go Wrong?
342 Blue Environment Pty Ltd (2022). National Waste Report 2022.

Circular economy opportunities include designing buildings for future disassembly and reuse of components, enhancing material recovery during demolition, maximising the reuse of materials in future construction projects and recycling materials into new products.[343] It has been estimated that a circular built environment could deliver $29 billion in direct economic benefits to NSW per year by 2040. Strategies and approaches for the NSW Government to assist improving reuse and recycling rates includes providing information on recycled material and suppliers, promoting government's own use of recycled material, using new approaches such as modular design and novel uses of 'products as a service'.

The supply of LEBMs for new construction projects is essential for growing the new market of sustainable material as discussed in other opportunities for the build environment sector. There is also a strong need to reuse and recycle existing materials (which are not necessarily low embodied carbon). Reusing, recycling, repurposing and recovering materials should always be the priority to minimise waste and demand for new material.[344] Localised material reuse and recycling should be prioritised over imported material to reduce freight emissions.

The traceability and certification of local reused materials require the support of a consolidated database, transparent data and digital solutions, some of which are not yet available to NSW industry.

Adaptive reuse of existing assets for other purposes presents decarbonisation and cost saving opportunities for the built environment sector. Rather than demolishing structures, adaptive reuse involves repurposing existing buildings or infrastructure to meet new needs which offers financial efficiency and productivity incentives. Adaptive reuse aims to maximise the benefits of material reuse through smart design, planning and retrofitting. Retrofitting and repurposing existing structures often requires less investment compared to constructing new buildings. This not only saves on material costs but also minimises construction time, disruption and associated expenses for improved overall productivity and efficiency. Repurposed assets might enhance the values for underused properties, transforming them into productive and economically viable spaces. For example, the global push of converting empty offices into apartments has attracted support as office occupancy levels remain low and hybrid working arrangements are being more commonly accepted.[345]

343 NSW Government (2021). NSW Waste and Sustainable Materials Strategy 2041.
344 World Economic Forum (2022). Create a Circular System for the Built Environment.
345 UNSW (2023). Adaptive Reuse: Should We Convert Empty Offices to Address Housing Shortages?

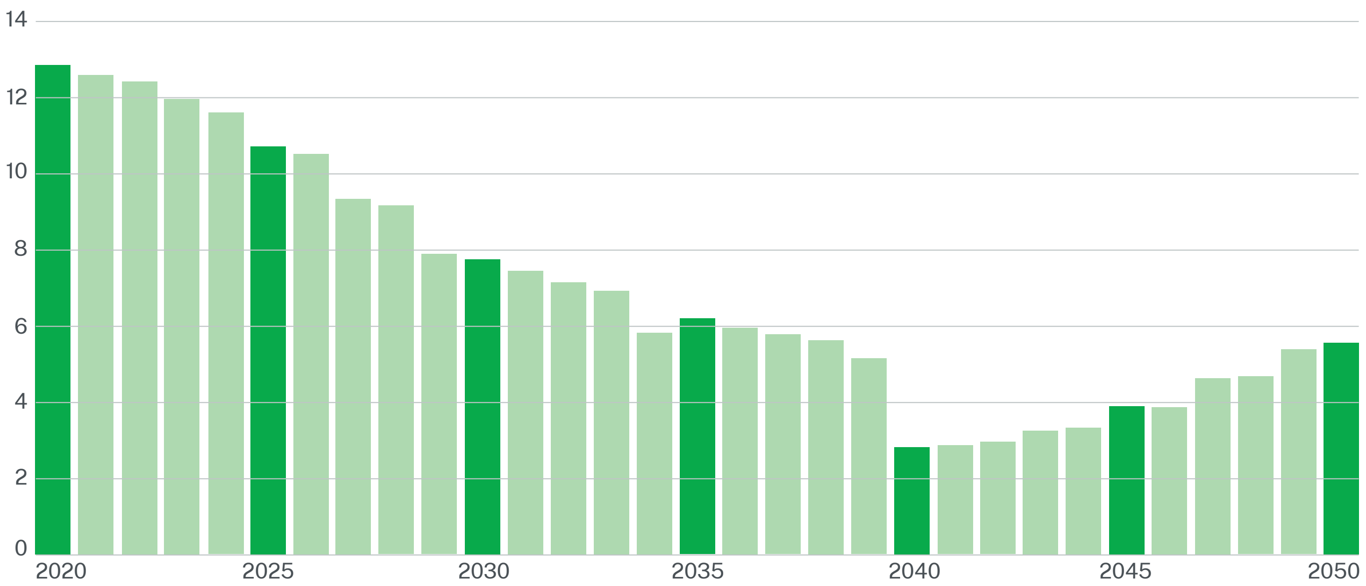
4.5 Industry

SECTOR	2019 Decarbonisation innovation opportunity	2023 Decarbonisation innovation opportunities	Sector readiness level
INDUSTRY	Electrification, alternative heat and bioenergy	Synthetic biology and bio manufacturing	Technology and service
	Hydrogen	Power-to-X	Workforce and skills
	Carbon capture and utilisation		Public levers and policies
	Critical resources and material efficiency, reuse and recycling	Carbon dioxide removal (including direct air capture)	Industry and investment

NSW is currently pursuing decarbonisation of industry processes and product use, which are a significant proportion of total emissions, representing 9.66% of total emissions in 2020.

Emissions reductions from these sectors are expected to continue based on current policy settings, with overall emissions forecast to fall from 11.93 Mt CO_2-e in 2023 to 7.70 Mt CO_2-e in 2030 and 6.18 Mt CO_2-e in 2035 (Figure 5).[346]

Figure 5. Actual and projected emissions for industry – 2020-2050. Source: NSW SEED



346 NSW Government (2023). NSW Net Zero Emissions Dashboard.

Emission targets are being developed by the NSW and Australian governments to lower emissions from high emitting industries. These include:

- the Safeguard Mechanism to reduce emissions at Australia's largest industrial facilities. Baselines or limits will be established and facilities will be required to meet those baselines by either reducing GHG emissions or purchasing carbon credits. The baselines will be tightened annually in line with Australia's climate goal to reduce national emissions to 43% below 2005 levels by 2030 and to achieve net zero emissions by 2050.[347] The 2023 reform of Safeguard Mechanism introduced a net carbon emission cap to 2030 and a pollution trigger as strengthened emissions reduction measurements by Australia
- the introduction of GHG emission reduction targets and related pathways for key industry sectors licensed by NSW Environment Protection Authority (EPA) (Action 16).[348]

These measures are supplemented by incentives, including grants programs for technology to transition existing industries and develop new low emission industries, and support for industrial transformation towards low carbon-intensive operation.[349]

The 2020 Study identified several opportunities for the industry sector:

- developing and deploying new technologies and services to increase energy productivity, electrification and material efficiency in industrial processes
- leveraging low-cost renewable energy and energy productivity technologies to grow new and expanded energy-intensive industries in precincts and regions
- reusing, recycling and repurposing materials in industrial supply chains
- growing industries in hydrogen, alternative heat and bioenergy, and deploying these energy platforms across other industrial processes and economic sectors.

Biomanufacturing and synthetic biology

New opportunities are emerging for future industries to grow the bioeconomy and clean manufacturing sectors, and develop and commercialise biotechnologies, electrochemical synthesis technologies and carbon removal technologies.

Biomanufacturing is the use of biological systems that have been engineered or that are used outside their natural context, to produce commercial products, such as screening through strain selection and hybridisation.[350]

Biomanufacturing can provide a greener alternative to traditional manufacturing, which typically relies on petrochemicals for its energy source or feedstock. For example, microalgae-based biomanufacturing converts CO_2 into organic matters to produce a variety of biofuels and biochemicals.

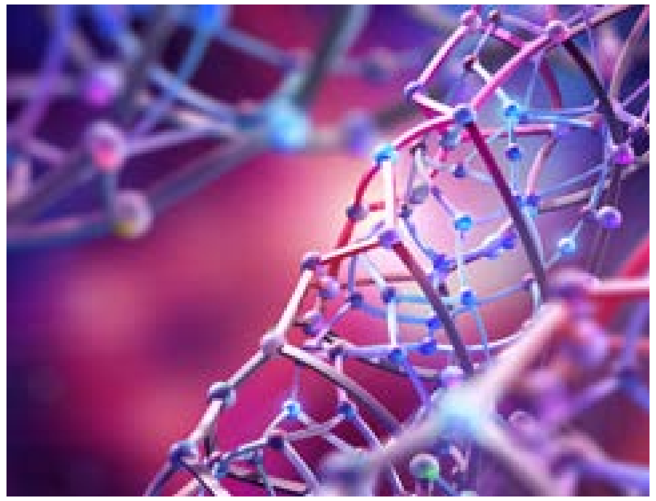
Synthetic biology refers to the creation and engineering of new genomes, biological pathways, or organisms not found in nature, or the redesign of existing genes, cells or organisms.[351] An example of synthetic biology is human food production with animal cell cultures (i.e. synthetic meats), which uses less land and water and releases less GHGs into the atmosphere compared with traditional farming methods.

Bioeconomy for low-carbon products

Industry cluster:
Biomanufacturing and synthetic biology cluster

OPPORTUNITY 17

Developing and deploying the creation and engineering of new genomes, biological pathways or organisms to create a synthetic biology ecosystem



As relatively new market segments, commercial estimates of market size vary widely for biomanufacturing and synthetic biology, but the consensus is that they are substantial.

In 2018, the global market for synthetic biology was valued at almost US$5 billion, with North America accounting for the largest share at US$2.2 billion.[352]

The Asia-Pacific region accounted for a quarter of the market in 2018 and is expected to have the highest growth over the next five years.

347 Australian Government (2023). Safeguard Mechanism.
348 NSW Government (2023). Climate Change Action Plan 2023-26.
349 NSW Government (2020). Net Zero Industry and Innovation Program.
350 Centres for Disease Control and Prevention (2019). Biomanufacturing and Synthetic Biology.
351 C. DeLisi et al. (2020). The Role of Synthetic Biology in Atmospheric Greenhouse Gas Reduction: Prospects and Challenges.
352 BCC Research (2022). Synthetic Biology Global Markets.

Private investment in the field is also growing. In 2017, top synthetic biology companies raised US$1.7 billion in capital in the USA for technology development and in 2018 it was US$3.8 billion.[353]

A 2021 CSIRO report forecasts synthetic biology has the potential to bring AUD$27 billion per year and 44,000 jobs in Australia under a high growth, high market share scenario.[354] Food and agriculture would have the highest market share, with up to 70% for alternatives to animal proteins, agricultural chemicals, engineered crops and biological treatments. Many of these products will not only deliver decarbonisation benefits but also have increased resilience against extreme weather and improved nutritional content. All of these were opportunities identified in the 2020 Study.

Biomanufacturing of industrial chemicals, materials and fuels using synthetic biology is estimated to make up 3% of the market share. However, policy and market developments such as the Inflation Reduction Act in the US and the urgent need to transition to lower carbon energy solutions such as sustainable biofuels could accelerate this market.[355]

Integrating carbon capture technology using microalgae to produce biomass and other bioproducts either through selected natural strains or engineered microorganisms will play a critical role to reduce emissions without competing with food production or being dependent on the agricultural waste supply.

There is growing interest in biomanufacturing and synthetic biology as a decarbonisation solution for many industries, with applications ranging from enzyme manufacturing, sustainable production of biofuels, drug design, sustainable farming practices and specialty foods. Some of the industries of most interest are discussed below and include algae, cell-based meats and yeast.

NSW has strong innovation capabilities in biomanufacturing and synthetic biology that can be catalysed to grow a technology-led future industry. The growth in the number of companies, and research and investment in synthetic biology and biomanufacturing, has increased the demand for talent pipelines for synthetic biologists and fermentation engineers.

Existing capability clusters are centred around:

- the UTS's Climate Change Cluster (C3 UTS), which focuses on algae-based biotechnology and biomanufacturing. For example, Algal Phenomics Facility (APF) for rapid automated algae strain selection, Green Genie Technology as distributed biological carbon capture unit and the Deep Green Biotech Hub (DGBH) providing acceleration and incubation services.[356]
- Macquarie University's expertise in synthetic biology, including the ARC Centre of Excellence in Synthetic Biology for engineered microbes and BioPlatforms Australia and Yeast 2.0 Consortium.

Strategic investment in infrastructure and skills development by government in partnership with industry will allow Australia to capitalise on its research expertise, industry strengths and record of investment to develop new products and industries.

The public investment in synthetic biology in Australia has been increasing since 2016.[357] Most start-ups focus on the development of cultivated meat and precision fermentation products (such as animal-free dairy or protein), with seven Australian private companies (four of which are based in NSW) working in these areas, supported by over $44 million worth of funding in 2021.[358] Other companies tackle decarbonisation directly using microorganisms to fixate carbon dioxide to produce high-value compounds, green hydrogen and biofuels.

The government's $6 million investment in the Emerging Industry Infrastructure Fund (EIIF) round for Synthetic Biology and Biomanufacturing, is supporting the technology to scale up from laboratory scale (1-10 L) to pilot scale (1,000 L) and commercial

353 C. Schmidt (2018). These 98 Synthetic Biology Companies Raised $3.8 Billion in 2018.
354 CSIRO (2021). A National Synthetic Biology Roadmap.
355 IEA (2021). Net Zero by 2050.
356 UTS (nd). Climate Change Cluster: Innovative Solutions to Progress Australia's Bio-economy.
357 CSIRO (2021). A National Synthetic Biology Roadmap.
358 Cellular Agriculture Australia (2021). Annual Report.

scale (>10,000 L).[359] One of the two grant recipients is a project that will provide support to both synthetic biology and biomanufacturing by increasing the capacity of start-up companies to prototype, test and scale-up their products and processes within the Australian Genome Foundry and MQ Impact labs.

Like all new industries, biomanufacturing and synthetic biology have challenges and barriers. There are concerns around the use of genetically modified or non-native microorganisms and associated risks to health and safety for people and the environment. This raises discussions over ethical use, regulatory scope and social acceptance of synthetic biology and biomanufacturing. Communication, consultation and collaboration between researchers, social scientists, regulatory officials, company representatives, biosecurity experts and general public should be done throughout the technology development and commercialisation process.

Biomanufacturing and synthetic biology industries are still in their infancy in Australia. States and territories are establishing biomanufacturing capability based on local knowledge centres and industries. For example, Provectus Algae and University of Queensland's BioFoundry are active in microalgae biotechnology development and large-scale production. NSW has all the successful ingredients to build a NSW biomanufacturing and synthetic biology innovation and industry cluster to lead future bioeconomy development in Australia and internationally.

Bioengineering technologies and services

Industry cluster:
Biomanufacturing and synthetic biology

OPPORTUNITY 18

Advancing bioengineering technologies, processes and services in simple organisms (such as algae and yeast) for low-carbon materials and products.

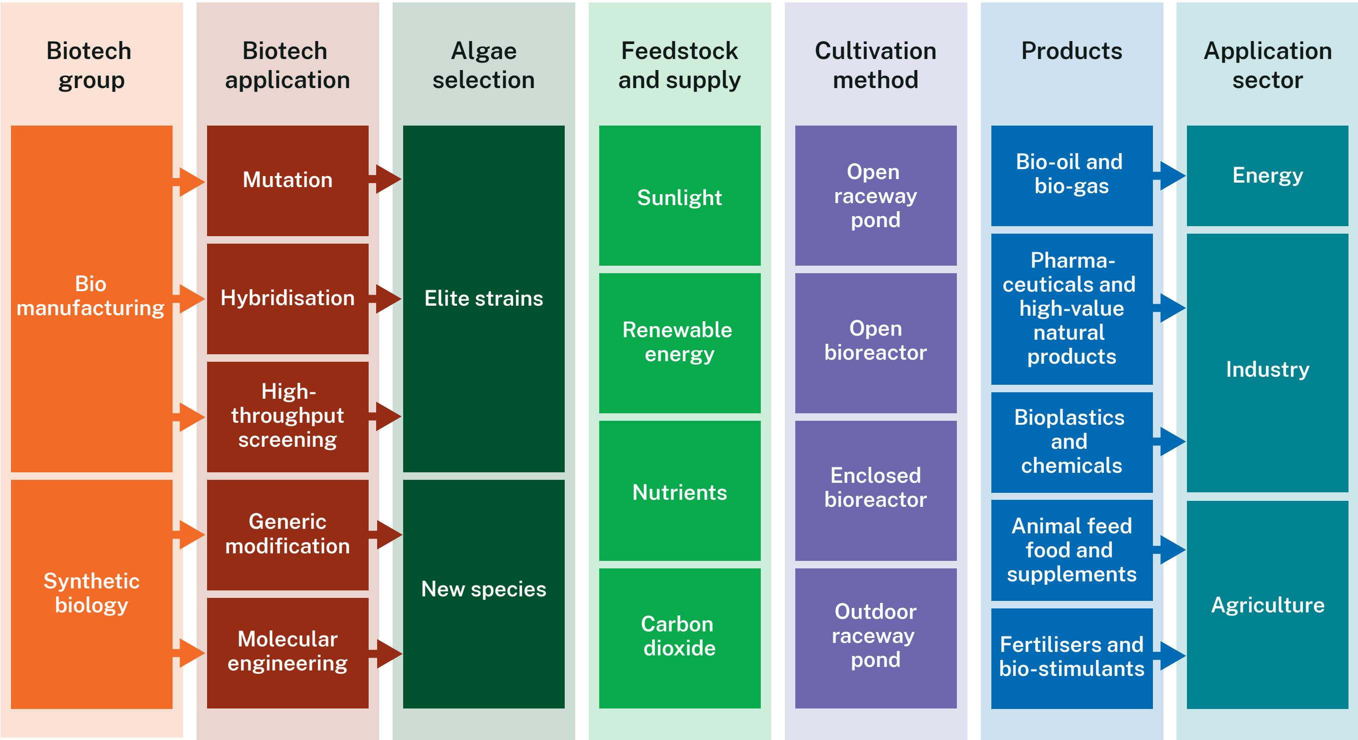
Algae-based biomanufacturing and synthetic biology are biological carbon removal technologies that consume carbon dioxide through photosynthesis, similar to other land and aquatic crops. In this way, the algae bioeconomy has significant potential to provide decarbonisation benefits while generating economic values and growing new industries.

Algae is one of the most versatile, low-cost and low-maintenance bio-feedstocks and biomanufacturing capability will enable the mass production of algae as a sustainable alternative for emissions-extensive products across many industries[360] (Figure 6).

The global algae industry is a fast-growing sector, forecast to reach a value of US$36 billion by 2028, driven largely by algae-based biomanufacturing.[361] The Australian algae industry has a relatively small share of the global value chain, with our seaweed production accounting for 0.01% of the global market with a gross value of AUD$3 million in 2020.[362,363] However, there is strong interest from industry in microalgae-based biomanufacturing in Australia, evidenced by the steady growth in businesses engaged with the microalgae supply and value chain since 1991 with a 30% increase between 2018-2020.[364]

359 NSW Government (nd). Synthetic Biology and Biomanufacturing.
360 Fabris, M. et al. (2020). Emerging Technologies in Algal Biotechnology: Toward the Establishment of a Sustainable, Algae-based Bioeconomy. Frontiers in Plant Science, 11, p.279
361 Vantage Market Research (2022), Outlook on the $36 Bn Algae market is expected to grow at a CAGR of over 10.5% during 2022-2028
362 Food and Agriculture Organisation of the United Nations (2021). Seaweeds and Microalgae: An Overview for Unlocking Global Aquaculture Development.
363 AgriFutures (2020). Australian Seaweed Industry Blueprint – A Blueprint for Growth
364 Climate Change Cluster UTS (2018). Industry Survey Results.

Figure 6: Algae-based bioengineering technology pathways



Yeast provides another simple organism form for biomanufacturing and synthetic biology, with selectively bred yeast strains from ethanol plants for use in the biofuels industry having decarbonisation potential. They can also be used as sustainable animal feed, with the *Saccharomyces cerevisiae* yeast strain able to produce single cell protein from low value substrates and waste streams, at 500 times the efficiency of current food crops.[365] Use of this yeast as a food source would ensure a more stable feedstock supply under climate change and extreme weather events.

Synthetic biology has allowed for the genetic modification of yeast to produce a host of useful chemicals such as pharmaceuticals, industrial enzymes and fragrances. By generating alternatives to fossil fuel-based chemicals, engineered yeast can contribute to decarbonisation. For example, yeast can be engineered to produce jet fuels by increasing its ability to transform sugars into highly volatile chemicals.

The production of new chemicals using genetically engineered yeast offers several advantages over traditional chemical synthesis methods.

Yeast:

- has the ability to produce highly specific enzymes, which results in less energy consumed and fewer toxic byproducts compared to traditional petrochemical manufacturing
- can be grown on a variety of feed stocks, from sugar cane to sewage, enabling flexibility in supply chain and a true circular economy
- can be grown in simple conditions, allowing biomanufacturers to easily switch the type of yeast being grown (and thus the product produced) in response to changes in demand or to adopt new methods without incurring significant costs.

MicrobioGen is undertaking promising work in NSW, by incorporating multiple desired traits into a single yeast strain. The use of the enzymes extends to bread and baking, biochemicals, pharmaceuticals, nutraceuticals, animal feed, wine and beer. The selective breeding, non-GM approach of MicrobioGen uses technologies that accelerate evolution and gene shuffling to produce superior yeast phenotypes, including temperature and ethanol tolerance, organic acid resistance, faster fermentation, lower glycerol production, growth on non-sugars, nitrogen efficiency, protein levels and enzyme expression.

In addition to simple organisms like algae and yeast, works are underway for more complex production.

365 Bell, P.J. (2022). An Electro Microbial Process to Uncouple Food Production from Photosynthesis for Application in Space Exploration.

Alternative proteins represent a major economic opportunity and a potential lower-carbon food source for the world. While currently these proteins are mainly plant-based meat or dairy products, there is rapid development underway of identical milk and meat products grown in 'cultivated meat'. To meet growing global demand for protein, incubators and venture capitals are aiming to create new Australian protein products (including animal-based, plant-based and novel proteins) estimated to earn an additional $10 billion in revenue by 2027.[366] Rising demand for proteins, particularly internationally, is likely to see both industries grow. Some traditional protein producers are already investing in these new technologies.

The cell-based meat industry is set to grow as technology progresses, price decreases and consumer awareness grows. Australia is seeing an increase in startups with strong venture capital investment and there are currently nine cell-based agriculture startups growing meat, milk, cell media and scaffolds that turn mince-like products into three-dimensional pieces of meat. Of these, two are producing cell-based meat, including the Sydney-based Vow, which has attracted nearly $20 million in venture capital. Eden Brew, a NSW-based company, is commercialising animal-free diary supported by Norco, Main Sequence and the CSIRO.[368]

While cultivated meat is technically feasible, there are still questions around its economic feasibility and environmental impacts, including the carbon emissions generated in the process lifecycle. Most techno-economic and lifecycle assessments for these processes have a high degree of uncertainty because they are at the early technology development stage. Recent lifecycle assessments for cultivated meat generally agree that it is more environmentally friendly than conventional beef but may have higher emissions than pork.[367]

Opportunity exists to create regulatory conditions for opening and growing a domestic market. This will expand consumer choice and could help Australian companies develop the capacity needed to capture the substantial alternative-protein opportunity that is emerging in international markets.[368]

Power-to-X and Hydrogen

Power-to-X (P2X) technology refers to the production of green power fuels and clean chemicals using renewable energy and sustainable materials. P2X products include green hydrogen and ammonia, and synthetic hydrocarbons such as methane, methanol and aviation fuels.

Increased and sustained demand for P2X products will displace fossil fuels and reduce NSW's reliance on imported petroleum and crude oil.

P2X technologies convert renewable energy into a range of versatile chemical energy carriers that can be used as feedstocks for many industries and fuels for power supply. These types of indirect electrification can decarbonise hard-to-abate sectors such as chemical manufacturing, heavy industry and aviation. By using water and waste materials as feedstock and renewable energy for production, P2X is a good example of the nexus between energy, water and waste for sustainable development with competing resource demands.

The 2020 Study identified hydrogen as one of the most critical climate technologies across many sectors. There were several opportunities associated with hydrogen across energy, industry, transport and built environment. Since the report's release, the NSW Government has released the *NSW Hydrogen Strategy* to support the development of a strong, commercial green hydrogen industry in NSW. The *NSW Hydrogen Strategy* is intended to help industry reduce the cost of hydrogen by up to $5.80 per kilogram and provide up to $3 billion worth of incentives to deliver the goal of 110,000 tonnes of annual production, 700MW electrolyser capacity and a hydrogen cost that's less than $2.80/kg by 2030.[369]

Industry sector:
Power-to-X and hydrogen cluster

OPPORTUNITY 19

Building a NSW P2X economy for decarbonising domestic hard-to-abate industries and green commodities exporting.

366 CSIRO (2021). Animal-free Dairy.
367 C.S. Mattick et al. (2015). Anticipatory Life Cycle Analysis of In Vitro Biomass Cultivation for Cultured Meat Production in the United States.
368 Grattan Institute (2021). Towards Net Zero: Practical Policies to Reduce Agricultural Emissions.
369 NSW Government (2021). NSW Hydrogen Strategy.

The global hydrogen economy has gained substantial momentum, with many countries and regions announcing national production and importing targets.

The hydrogen market is expected to reach US$168 billion in 2026, a compound annual growth rate of 6.25%.[370] It's estimated that establishing a robust hydrogen industry in Australia could generate approximately AUD$200 million in additional GDP annually by 2030.[371] Although yet to reach the price target for industry-wide adoption, the economics of hydrogen application are improving as technology is refined.

The use of hydrogen derivatives to decarbonise the chemical manufacturing industry is expected to be more attractive for industry and investment in the short to medium term. The market size of clean chemical products manufacturing from P2X is substantial given NSW's AUD$11.3 billion chemical manufacturing industry, which employs over one-third of Australia's chemical industry workforce (based on 2017/18 figures). Every percentage point increase in global market share of ammonia production would be equivalent to an extra AUD$102 million in ammonia exports for NSW.[372] Markets for synthetic ethanol and methanol are expected to be worth tens of billions of dollars as they displace fossil-based fuels and chemicals.[373]

NSW has strong R&D capabilities in P2X and hydrogen, underpinned by world-class research institutions and universities. Almost all NSW-based universities have research projects and teams in P2X and hydrogen. UNSW, USYD and UTS have strong supply and value chain capabilities with multidisciplinary hydrogen research centres, access to expertise and state-of-the-art facilities, a track record of delivering disruptive technologies and well-established partnerships with government, industry and academia internationally. UoN and UoW have a close relationship with local industrial partners for applied research, technology pilot testing and demonstration projects at industrial precincts and ports in the vicinity of each university.

NSW and Australia are recognised by many economies as major P2X and hydrogen producers and exporters. There is work underway investigating the technical and commercial feasibility of multilateral supply and value chain projects. These feasibility studies could reduce investment risks and build relationships for cooperation on policies, research, investment and industry development.

The NSW and Australian governments are actively engaging in international partnerships for value chain feasibility studies and joint-funding programs, examples being HySupply and HyGate for the Australia-Germany hydrogen value chain.[374]

The NSW Power-to-X Industry Pre-Feasibility Study outlined a roadmap to deploy emerging technologies and build a foundation for local production capability.[375] Recent NSW Government policies have also identified NSW P2X and hydrogen hubs for large scale production. These locations have access to renewable energy and low-cost electricity, abundant feedstock, aggregated and co-located demand, major technology users and export infrastructure. Techno-economic assessments and modelling have identified clear business cases for priority applications (such as synthetic methanol and green hydrogen) that could accelerate the adoption and deployment of P2X.[377]

Social license to operate, especially with regional communities, will be a critical factor in any scaling up of these industries. Active communications and trust building engagement demonstrating the sustainability of feedstocks for P2X industries, including renewable energy sources, materials, carbon dioxide and water, as well as a whole-of-system approach to mitigate safety perception risks will be important. Water impacts within the context of the local community must be further considered, while the acceptability of different carbon sources and the 'life-cycle assessment' require clarity to provide greater investment and project certainty.[376]

370 Global Market Insights (2019). Hydrogen Generation Market Size.
371 Australian Government (2019). National Hydrogen Strategy.
372 NSW Government (2021). NSW Hydrogen Strategy.
373 KPMG (2020). NSW: A Clean Energy Superpower (2020).
374 Australia Government (2022). Growing Australia's Hydrogen Supply Chain with Germany.
375 UNSW Sydney (2021). NSW Power to X (P2X) Pre-Feasibility Study.
376 Future Fuels CRC (2023). Research: RP2.1-02 A Social License and Acceptance of Future Fuels

Hydrogen for energy, transport and P2X feedstocks

Industry sector:
Power-to-X and hydrogen cluster

OPPORTUNITY 20

Deploying commercial hydrogen projects for energy, transport and P2X feedstock productions

Hydrogen for power generation and mobility is the most promising direct application that is technically feasible and economically viable for decarbonisation. Rapid technology adoption to drive down production and transport costs would require a significant pipeline of commercial projects at both large-scale (MW and above in electrolyser capacity) and micro-level (kW to MW).

Major hydrogen power projects in NSW have already received public and private investment. For example, Energy Australia's Tallawara B Power Station can operate as a dual-fuel peaking gas plant using a blend of natural gas and green hydrogen.[377] The project will consume at least 200 tonnes of hydrogen per year from 2025.[378] Other gas power projects including Tallawarra B, the Snowy Hydro Hunter Power Project, and the Squadron Energy Port Kembla Power Station will also be capable of hydrogen or natural gas blending and co-firing.[379] Hydrogen blending work in gas pipelines is underway in NSW, including Jemena's Western Sydney Green Hydrogen Hub Trial.[380]

The conversion process from hydrogen to derivatives and back to hydrogen is energy-intensive and industry is exploring the case for direct use of hydrogen-derivates. For example Japanese companies are working on retrofitting existing coal power plants for ammonia and natural gas co-firing. However, ammonia-coal co-firing is unlikely to become an economically viable path for Japan to reduce power sector emissions, according to a new report published by research firm BloombergNEF (BNEF).[381]

The *NSW Hydrogen Strategy* sets targets of 10,000 hydrogen light vehicles, 100 refuelling stations and hydrogen heavy vehicles making up 20% of government fleets by 2030.[379]

Initiatives underway for public-funded refuelling networks and stations include:

- a Memorandum of Understanding between the NSW, Victorian and Queensland governments for an east coast hydrogen refuelling network
- $20 million for Hume Hydrogen Highway initiatives by the NSW and Victorian governments for four refuelling stations and 25 hydrogen-powered linehaul trucks[382]
- a hydrogen refuelling station in Port Kembla to enable the introduction of hydrogen fuel cell trucks to the Illawarra-Shoalhaven region.[383]

In addition to direct use of hydrogen for energy and transport sectors, there is a strong interest emerging for hydrogen production as feedstock for other P2X industries. The IEA estimates that, by 2050, approximately one-third of hydrogen demand will be used to produce hydrogen-based fuels such as ammonia, methanol, synthetic natural gas (SNG) and SAF.[384] The Global Alliance Powerfuels organisation supports this estimate, finding P2X fuels will progressively increase between 2030 and 2050 to displace fossil-based manufacturing.[385]

377 NSW Government (2021). NSW Hydrogen Strategy.
378 HyResource (2021). Tallawarra B Dual Fuel Capable Gas/Hydrogen Power Plant.
379 UNSW Sydney (2021). NSW Power to X (P2X) Pre-Feasibility Study.
380 Jemena (2021). Western Sydney Green Hydrogen Hub.
381 BloombergNEF (2022). Japan's Ammonia-Coal Co-Firing Strategy a Costly Approach to Decarbonization, Renewables Present More Economic Alternative.
382 NSW Government (2022). Delivering the Renewable Hume Hydrogen Highway.
383 CSIRO (2022). Port Kembla Hydrogen Refuelling Facility.
384 IEA (2021). Global Hydrogen Review 2021.
385 Global Alliance Powerfuels (2020). Powerfuels in a Renewable Energy World: Global Volumes, Costs and Trading 2030 to 2050.

Decentralised hydrogen-microgrids and P2X facilities

Industry sector:
Power-to-X and hydrogen cluster

OPPORTUNITY 21

Deploying decentralised hydrogen-based microgrids and P2X facilities for multi-users, particularly in regional and remote areas

The 2020 Study identified microgrids and Stand Alone Power Systems (SAPS) as opportunities to deploy DER in metropolitan and regional areas, using renewable electricity with improved reliability and lower costs. Their smaller scale, simpler engineering complexity and low investment risk make microgrids and SAPS ideal systems to test newly commercialised technologies or innovative solutions that are not yet being deployed at centralised and large scale. There are emerging opportunities to advance decentralised energy systems with the rapid development of hydrogen technology. Hydrogen-based microgrids would not only further decarbonise residual emissions from natural gas or diesel backup generation but also supply power fuels and clean chemicals for regional industry operations such as mining, agriculture and manufacturing.

Hydrogen-based microhubs are emerging globally, with some projects already in operation in Europe. For example, the Orkney Islands are transforming into 'green hydrogen islands' where a fully integrated hydrogen supply chain is being established through collaborative efforts across all levels of government, industry and research. Orkney is on track to become 'fossil free' and the world's first island community to be fully powered by green hydrogen.[386]

NSW also has the opportunity to develop P2X microhubs for multi-industrial users and applications, with projects being planned elsewhere in Australia, including the Denham Project in WA and the Daintree Project in Queensland.[387,388]

Carbon dioxide removal and utilisation

Industry sector:
Carbon dioxide removal and utilisation cluster

OPPORTUNITY 22

Developing and deploying carbon dioxide removal technology

The 2020 Study identified carbon capture and use as being a feasible and potentially cost-effective way to eliminate residual emissions in hard-to-abate sectors, such as steel manufacturing. However, this opportunity relies on a financial incentive for emissions reduction. The report also canvassed the potential for significant economic opportunities if NSW was to develop products manufactured with carbon capture, for example:

- ammonia production, where high purity carbon dioxide emissions are partially captured for use in food and beverage production
- waste management, where biomethane emissions can be captured to produce hydrogen and solid carbon (graphite)
- industrial processes such as steel and cement manufacture or power generation, where carbon dioxide emissions can be captured to produce magnesium carbonate, for building and construction materials
- synthetic fuel production, where carbon dioxide can be captured directly from the atmosphere and combined with green hydrogen to produce carbon-neutral e-fuels for aviation (kerosene) and other industries.

386 Orkney Renewable Energy Forum (2023). Hydrogen: H2 in Orkney – The Hydrogen Islands.
387 CSIRO (2022). Denham Hydrogen Demonstration Plant.
388 CSIRO (2022). Daintree Microgrid Project.

Since 2020, there has been an increased focus on carbon dioxide removal (CDR), with significant technological progress in all areas.

Preliminary research conducted by Common Capital for the Office of Energy and Climate Change highlighted a range of CO_2 technologies that could be advanced in NSW. Their research focused predominantly on two technologies, enhanced weathering and direct air capture (DAC). While most rely on some form of financial incentive, there are economic opportunities emerging for some of these technologies such as mineral carbonation that use captured carbon to develop a range of manufactured products.

DAC is gaining significant international attention but, at this stage, remains more costly than many other mitigation measures, with estimates presently ranging from US$250 to US$600 per tonne.[389] However, momentum for this technology is increasing and costs are expected to fall significantly over the next five years to between US$150 to US$200 per tonne as the technology is scaled up.[415] There are currently 18 DAC plants operating worldwide, capturing almost 0.01 Mt CO_2 per year and several other plants are planned. If all these plants are developed, almost 5.5 Mt CO_2 per year by 2030 will be captured.[390]

Momentum for DAC has been further driven by the US Inflation Reduction Act, which includes an amendment to a provision of the US tax code that provides a tax credit designed to increase corporate investment in storing or converting carbon to fuels. Reinforcing the importance of DAC, the US Department of Energy has launched the Carbon Negative Shot, which aims for the capture of carbon for less than $100 per tonne of CO_2-equivalent.[391]

Overall DAC is still at the formative and developmental stage and there are opportunities to drive down its net costs by:

- reducing costs through improved technology and maturing of production methods and supply chains
- using the captured carbon as a resource and revenue stream.

With limited financial incentives in Australia for carbon capture, early adoption of CDR technologies, including DAC, is likely to depend on a reduction of cost and generation of alternative revenue streams.

NSW's existing research landscape, industry capabilities and physical resource alignment means it can be a leader in the development of DAC. Much of the existing work in NSW is either research or in the pilot phase. Research projects include:

- the use of metal organic frameworks based on zirconium to draw atmospheric carbon into its capture module[392]
- the conversion of halloysite nanotubes into advanced nanomaterials that can be used as novel adsorbent systems and catalysts for carbon capture and conversion processes[393]
- the use of algae to capture carbon for use as source materials for products such as food, pharmaceuticals, bioplastics and textiles.[394]

Examples of NSW pilots where carbon dioxide is being converted to carbonated minerals and synthetic fuels include:

- a collaboration between AspiraDAC and Southern Green Gas to capture CO_2, using an active process and a metal-organic-framework and then utilising it to produce synthetic fuels[395]
- the MCi Carbon project to react concentrated carbon dioxide (from point-source capture or DAC) with silicate minerals from industrial waste (steel slag and fly ash) and mine tailings to form carbonates that are embedded within cement or plasterboard. At a pilot plant in Newcastle, MCi aim to store a cumulative 1Gt of carbon dioxide by 2040, which is equivalent to about two-and-a-half years of Australia-wide carbon dioxide emissions.[396]

Scaling these technologies and developing the necessary supply chains provides significant economic opportunities for NSW, given the markets for synthetic ethanol and methanol are expected to be worth tens of billions of dollars as they displace fossil-based fuels and chemicals.[397]

Another atmospheric carbon dioxide removal technology is enhanced weathering, which accelerates the natural processes of the slow carbon cycle and involves the weathering of minerals with CO_2 from the atmosphere.[398] The rate at which it captures CO_2 depends on factors such as pH, temperature and water availability. It has significant potential although it is very much at the formative stage and requires considerable research.

389 World Resources Institute (2022). 6 Things to Know about Direct Air Capture.
390 International Energy Agency (2022) Direct Air Capture.
391 Office of Fossil Energy and Carbon Management (nd). Carbon Negative Shot.
392 Financial Review (2022). How Elon Musk's Cash Helped These Aussies Suck Carbon Out of the Air.
393 University of Newcastle (2021) University Announces $4 Million Partnership in Carbon Capture and Conversion.
394 UTS (nd). Climate Change Cluster: Innovative Solutions to Progress Australia's Bio-economy.
395 Southern Green Gas (2023).Solar-Powered Carbon Capture Technology Leading the Way
396 MCi Carbon (2023). MCi Carbon.
397 KPMG (2020). NSW: A Clean Energy Superpower.
398 CSIRO (2022). Australia's Carbon Sequestration Potential.

Optimising the weathering reaction is key to cost effectiveness with higher rates of weathering resulting in higher rates of captured CO_2. At this stage, the most common form of enhanced weathering is grinding and crushing silicate rocks (e.g. to sizes below 1mm) with the increased surface area increasing the reaction rate to remove atmospheric CO_2.

NSW has significant ultramafic[399] deposits and has a high potential for enhanced weathering based on its resource profile. These include the Great Serpentinite Belt, the Coolac Serpentinite Belt and the Gordonbrook Serpentinite Belt[400] as well as magnetite deposits at Tallawang and Broula.[401] Previous mining in NSW also suggests that former mines may have existing reserves of mafic and ultramafic tailings.

At present, mine site implementation is the cheapest form of enhanced weathering. Key factors influencing the cost and potential of mine site implementation include:

- integration with other mining operations
- rock type and reactivity
- energy requirements
- weathering methods and rates.

Social licence needs to be considered for enhanced weathering projects to succeed. As this CDR method is very much location and site specific, it will be important to work closely with local communities on any proposals, especially First Nations peoples.

Fugitive emissions abatement

Fugitive emissions (emissions not confined to a stack, duct or vent for example, from gas fields or coal mines), are forecast to be 13.6 Mt CO_2-e in 2023, 13.7 Mt CO_2-e in 2030 and then fall to 8.77 Mt CO_2-e in 2035. By 2050, this is forecast to be 3.18 Mt CO_2-e and will represent 11.7% of NSW emissions.[402]

Fugitive emissions were included in the 2020 Study, which recognised that there were technologies available to use methane emissions for electricity generation. Since then, the Australian Government has signed the Global Methane Pledge, which aims to reduce global methane emissions by at least 30% below 2020 levels by 2030. Organisations like the CSIRO have continued to develop technologies to mitigate methane by either destroying or enriching the gas, or by capturing Ventilation Air Methane (VAM) emissions. These technologies have now been proven and provide an opportunity for the coal mining industry to reduce its fugitive emissions.[403]

Coal Innovation NSW and South32 are funding a large-scale research facility to demonstrate various VAM technologies for coal mining.[404]

Eco-industrial transition

Industry sector:
Eco-industrial transition cluster

OPPORTUNITY 23

Developing and deploying decarbonised manufacturing clusters to maximise productivity benefits

Industrial clusters account for 20% of global CO_2 emissions[405] and offer decarbonisation opportunities through their economies of scale, infrastructure and skilled workforces. The co-location of companies in industrial clusters has the advantage of resource and logistic sharing, as well as infrastructure access. This physical co-location can be leveraged to significantly reduce the emissions in industrial clusters, even enabling a transformation towards net-zero emissions. They also provide opportunities to aggregate energy demand, use waste heat and industrial waste. They can comprise one or more industries and include large and small enterprises in a net-zero industrial ecosystem. Such clusters offer the opportunity for significant synergies in energy innovation and circular economy. Collaboration between industry, innovators and multidisciplinary research institutions is critical to accelerating decarbonisation of high-emitting and hard-to-abate sectors of NSW industry.

399 Mafic and ultramafic rocks are igneous rocks that are rich in magnesium and iron.
400 NSW Government (nd). Serpentine.
401 NSW Government (nd). Magnetite.
402 NSW Government (2023). NSW Net Zero Emissions Dashboard.
403 CSIRO (nd). Mine Ventilation Air Methane Abatement.
404 NSW Government (nd). Fugitive Emissions Projects.
405 World Economic Forum (2023). Decarbonization of Industrial Clusters Initiative Gains Global Momentum.

Internationally, this approach to accelerate industrial decarbonisation and build a net-zero industrial future is gaining momentum. The World Economic Forum's Transitioning Industrial Clusters Towards Net Zero initiative was launched in 2021.[406] It now has 11 industrial clusters seeking to achieve carbon neutrality and includes the Humber in the UK, H2Houston Hub in the US and the Kwinana Industrial Area in WA.[408] The Initiative focuses on four key areas for clusters to achieve this transition: partnerships, policy, financing and technology. Each cluster has adopted a balanced set of targets and strategies to engage with communities, companies and government entities, all with the goal of creating a sustainable and economically viable business model for decarbonisation. It aims to have more than 100 industrial clusters engaged by 2024. The Kwinana Industries Council is targeting net zero by 2050, with an 80% average recovery rate from all waste streams by 2030.[408]

The Port of Rotterdam aims to achieve a 55% reduction by 2030 and reach carbon neutrality by 2050 via a transition strategy built around four pillars:

- increasing the efficiency of existing industry and building extra infrastructure for heat, CO_2, electricity and hydrogen
- renewing the energy system by switching from fossil fuels to green electricity and hydrogen.
- moving to a new materials and fuel system
- making transport more sustainable.[407]

Both the Illawarra and Hunter regions have industrial bases, a range of small and large industry, existing infrastructure, and skilled workforces at the scale comparable to a number of those which are part of the initiative. Following a like model to accelerate and deepen decarbonisation efforts at regional scale in the Hunter and the Illawarra would provide the opportunity to develop these as decarbonised industrial clusters more rapidly, sustainably and equitably.

406 World Economic Forum (2023). Transitioning Industrial Clusters towards Net Zero.
407 Port of Rotterdam (nd). Strategy and Research.

4.6 Land and agriculture

SECTOR	2019 Decarbonisation innovation opportunity	2023 Decarbonisation innovation opportunities	Sector readiness level
LAND AND AGRICULTURE	Sustainable land management	Sustainable land management (including enteric emissions and blue carbon)	Technology and service
	Controlled environment horticulture		Workforce and skills
	Renewable and bioenergy	Agtech and decarbonisation	Public levers and policies
	Gene technology and enteric emissions reduction		Industry and investment

The 2020 Study identified several decarbonisation opportunities in the land and agriculture sector, as well as opportunities for growing and developing agriculture and land-based businesses using low cost renewable energy.

Some of these – which are discussed in Section 3 – are common across the different sectors or are realised through opportunities in other sectors. This section will focus on opportunities directly associated with land output and activity.

With current NSW Government policies in NSW, emissions in the agriculture sectors are expected to decrease from 17.23 Mt CO_2-e in 2023 to 13.98 Mt in 2030 and to 11.81 Mt CO_2-e in 2035 (Figure 7).[408]

For Land use and land use changes the negative emissions are expected to change from -10.28 Mt CO_2-e in 2023 to -8.86 Mt in 2030 and 7.46 Mt CO_2-e in 2035 (Figure 8).[409]

The 2020 Study identified sustainable land management, access to sustainability markets (e.g. carbon and biodiversity markets) and enteric emission reduction technologies as key decarbonisation opportunities for the sector. In addition, they also provide economic benefits for landowners and users through increased productivity, adaptive climate resilience, more diverse income streams and international competitiveness in a carbon-constrained world. Interest in these opportunities remains strong and has been progressing. The following sections review these opportunities and potential emerging opportunities since 2020.

408 NSW Government (2023). NSW Net Zero Emissions Dashboard.
409 NSW Government (2023). NSW Net Zero Emissions Dashboard.

Figure 7: Agricultural actual and projected emissions 2020 2050. Source: NSW SEED

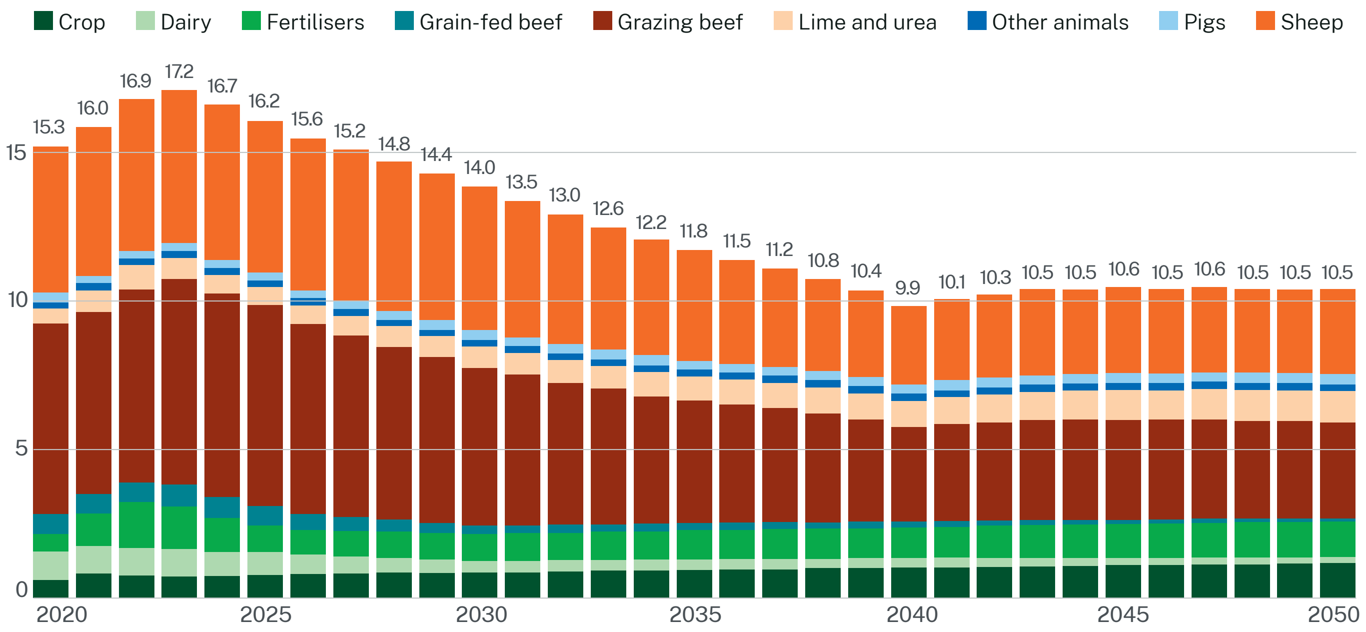
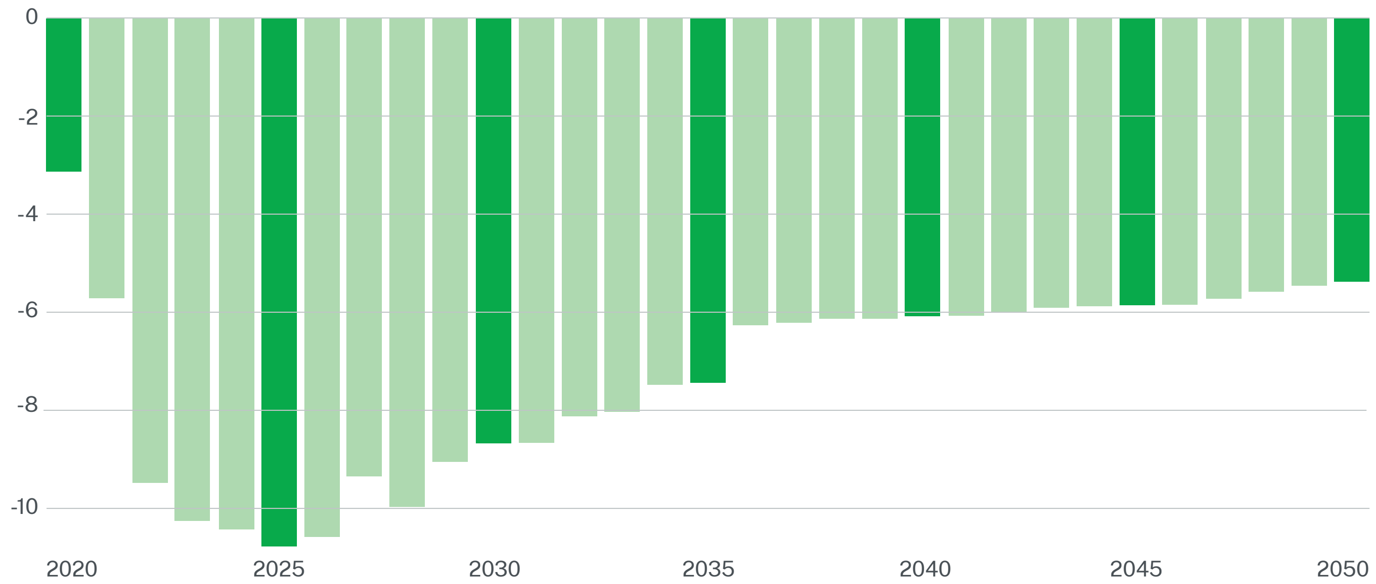


Figure 8. Land use and land use change actual and projected emissions for land and agriculture – 2020-2050. Source: NSW SEED



Sustainable land management

Land and agriculture sector: Sustainable land management cluster

OPPORTUNITY 24

Developing a robust and creditable local decarbonisation services sector across the land and agriculture sectors through sustainable land management (including enteric emissions reductions and blue carbon)

OPPORTUNITY 25

Enhancing benchmarking and certification to improve investor certainty

Several agricultural industry groups have committed to net zero or carbon neutral by 2050 or sooner. However, Australian Government 2020 projections suggest emissions from the agriculture and land sectors will rise this decade. Addressing these sources of emissions will mean less emissions-intensive activity (e.g., raising fewer cattle) or making agriculture less emissions-intensive (e.g. feeding supplements for cattle that reduce methane emissions).

Since 2020, the NSW Government has implemented the Primary Industries Productivity and Abatement Program (PIPAP), which helps land manager and producers access environmental markets, including carbon and biodiversity markets.[410]

It also helps landowners develop and implement carbon abatement opportunities and facilitates access to markets and consumers interested in sustainably certified products, business and projects.

The focus of the PIPAP includes:

- developing market and industry foundations
- building critical mass and capacity
- accelerating finance for natural capital and low carbon farming.

In addition to the PIPAP, several programs are supporting the primary industries sector to implement sustainable land management practices, including the Nature Positive Farming Program, Private Land Conservation Program and the Biodiversity Supply Program.[411]

There are also several other initiatives that support sustainable land management practices while providing economic benefit. NSW has released a natural capital statement of intent, a framework to partner with land managers and farmers to attract capital investment and increase opportunities to participate in carbon, biodiversity and natural capital markets.[412] Through the Agriculture Biodiversity Stewardship Program, the Australian Government, with the Australian National University (ANU), is investigating how environmental markets can increase private sector participation and deliver biodiversity outcomes.[413]

This includes both the Carbon + Biodiversity (C+B) and Enhanced Remnant Vegetation Pilot Programs, which are trialling how a market-place approach could reward private landowners for increasing biodiversity by either undertaking carbon plantings or retaining and improving existing native vegetation. To support landowners gain access to private sector biodiversity markets, the National Stewardship Trading Platform has also been developed to connect buyers and sellers.

While progress is being made, there is even more scope for primary producers to reduce emissions and increase carbon sequestration. The NSW Department of Primary Industries has undertaken research to identify several carbon sequestration and emissions reduction activities that will result in significant carbon abatement.[414]

As outlined in Section 3, the NSW Government has a role to help businesses implement decarbonisation solutions and achieve net zero. This is especially the case for the land and agricultural sector, where a wide variety of landowners will need to consider implementing initiatives designed to address sustainable land management practices and/or solutions to decrease enteric emissions (see below).

410 NSW Government (2022). Growing NSW' Primary Industries and Land Sector in a Low Carbon Work: Primary Industries Productivity and Abatement Program.
411 NSW Government (2022). NSW Natural Capital Programs.
412 NSW Government (2022). Natural Capital Statement of Intent.
413 Australian Government (2022). Agriculture Biodiversity Stewardship.
414 NSW Government (2020). Abatement Opportunities from the Agricultural Sector in New South Wales.

Given the diversity of landowners, generic planning and programs may not be possible and there will be a strong need for local and regional support. NSW should strategically plan for localised decarbonisation services in the land and agriculture sector. While current activity across sustainable land management and enteric emissions provides a framework for decarbonisation, further work is needed to map out potential implementation across NSW.

Enteric emissions reductions

There is increasingly strong interest in addressing enteric emissions from farm animals which accounts for more than 10% of Australia's total emission. The voluntary Global Methane Pledge was launched at COP 26 and commits 150 countries to reducing anthropogenic methane emissions across all sectors by at least 20% below 2020 levels by 2030.[415]

The pledge includes reducing agricultural emissions through technology, incentives and partnerships with farmers.[416] The Australian Government joined the pledge in 2022 and committed to investing in low emissions technologies, component manufacturing and agricultural methane reduction.[417]

Under current policy, the NSW Net Zero Emissions Dashboard predicts emissions from farm animals (dairy and beef cattle, pigs and sheep) will decrease from 13.35 Mt CO_2-e to 2.66 Mt CO_2-e from 2020 to 2040 and then remain relatively stable to 2050 (2.83 Mt CO_2-e).[418]

As identified in the 2020 Study, algae-based feed supplements and 3-nitrooxypropanil (3-NOP) are major areas for commercialisation to address enteric emissions. Vaccines remain of interest, although an effective vaccine is unlikely before 2030 with barriers such as interregional differences in rumen microbiome and animal variability needing to be overcome.[419,420]

There is strong interest both nationally and internationally in the use of algae-based feed supplements to reduce menthane emissions from cattle. Most activity is based around the macroalgae Asparagopsis, with at least four entities across Australia undertaking research and/or commercialisation activities.[421,422,423,424] With strong interest in Asparagopsis as a feed supplement both nationally and internationally, attempts have been made to calculate potential economic opportunities of an Australian Asparagopsis industry. One study estimates the potential gross value of production of between $90-$200 million in 2025 and $1 billion in 2040 with direct jobs (FTE) expected of between 450-1,000 in 2025 and 5,500 in 2040, assuming commercialisation occurs with aquaculture farms established in South Australia, Tasmania and WA.[425] There is also interest in microalgae, with at least one group undertaking research and commercialisation activities.[426]

Although 3-NOP is not yet approved for use in Australia,[427] work is progressing to understand its potential, with some studies finding it could reduce methane production by up to 90% when fed to cattle under Australian feedlot operations.[428] While both algae-based feed supplement and 3-NOP are being trialled through feedlots and appear commercially feasible, their use in grazing systems or extensive production systems is not possible without feed supplementation.[429] 3-NOP may offer a reliable and effective strategy for methane abatement in beef, sheep and dairy cattle, yet as a relatively novel feed additive, there may be resistance to adoption, particularly as the magnitude of the mitigation appears to differ between ruminant species.

415 European Commission & United States of America (2021). Global Methane Pledge.
416 Climate & Clean Air Coalition (nd). Global Methane Pledge.
417 Australian Government (2022). Australia Joins Global Methane Pledge.
418 NSW Government (2023). NSW Net Zero Emissions Dashboard.
419 NSW Government (nd). Opportunities for Sequestration and Emissions Reduction from the NSW Agricultural Sector.
420 Beauchemin, K.A et al. (2022). Invited Review: Current Enteric Methane Mitigation Options. Journal of Dairy Science. Vol. 105, Issue 12, p 9297-9326.
421 CH4 Global (2022). The Surest, Fastest Route to Bend the Climate Curve is to Radically Reduce Methane Emissions in the Next 10 years.
422 Future Feed (2021). Building an Entire Industry to Lower Methane Emissions from Livestock using Asparagopsis.
423 Sea Forest (nd). Cultivating Solutions to Climate Change.
424 CRCNA (2021). Developing Asparagopsis Seaweed Cultivation at Scale in Northern Australia
425 Agrifutures Emerging Industries (2020). Australian Seaweed Industry Blueprint: A Blueprint for Growth.
426 Young Henrys (nd). Young Henrys & UTS: The Algae Project.
427 NSW Government (2020). Abatement Opportunities from the Agricultural Sector in NSW South Wales.
428 Meat & Livestock Australia (2021) The Feed Additive Reducing Methane Emissions by up to 90%.
429 Beauchemin, K.A et al. (2022). Invited Review: Current Enteric Methane Mitigation Options. Journal of Dairy Science. Vol. 105, Issue 12, p 9297-9326.

Optimal doses of 3-NOP to be used are yet to be defined to allow registration as a permitted feed additive, to enable the use of 3-NOP in the meat, wool and dairy industries in Australia.[430]

Nitrate supplements, which can be delivered via a lick-block in grazing systems, have been shown to decrease methane production in cattle, although lack of awareness, risks of nitrate poisoning and issues with monitoring, reporting and validation are potential barriers.[431] Animal and feed management strategies are also effective in reducing methane from cattle and there is some evidence that greater methane reduction may be achieved when implementing more than one strategy.[433]

Irrespective of the strategies NSW chooses to focus on, the NSW Government will need to provide support for producers during implementation, including understanding and disseminating information about what will work locally, likely reduction potentials and potential economic benefits from market participation.[431] Further to realising the opportunities associated with reducing enteric emissions, there is a need to develop the systems so that once algae-based feed supplements and 3-NOP are commercially available, they are acceptable to producers and can be implemented at scale. Decarbonisation support services for enteric emissions could be considered as part of the overall framework of decarbonisation services for agribusinesses.

Blue carbon

Blue carbon is the capture of carbon and storage in marine and coastal ecosystem and is an area of emerging interest.[432] It has been estimated that Australia holds approximately 5 to 11% of the blue carbon global stock,[433] providing the nation with potential significant emissions reductions and economic benefits, as well as benefits to biodiversity and resilience to climate change.

To realise the benefits from blue carbon, the NSW Government has released the blue carbon strategy, which provides a pathway to develop a blue carbon market, including:

- conserving existing blue carbon ecosystems
- addressing barriers associated with blue carbon projects and supporting land managers, including First Nations communities, to deliver blue carbon projects
- embedding blue carbon in coastal and marine policy planning and management
- progressing blue carbon research
- promoting pathways for blue carbon investment.

In January 2022, the blue carbon method within the the Emissions Reduction Fund (ERF) was finalised, allowing tidal restoration of blue carbon ecosystems to earn Australian carbon credit units.[434] The NSW Blue Carbon Strategy 2022-27 has identified 20 coastal tributaries that have the potential to benefit from blue carbon ecosystem restoration.[434]

While there are definite emission reduction benefits associated with blue carbon ecosystem restoration, more work with stakeholders is needed to identify investment opportunities, which is progressing under the strategy.[434]

As the strategy progresses, similar to other sustainable land management approaches, decarbonisation services will be essential to support interested parties implement blue carbon projects.

430 NSW Government (2021). Managing Livestock to Reduce Methane Emissions: Assessment of Strategies for Abatement of Enteric Methane.
431 Arndt, C. (2022). Full Adoption of the Most Effective Strategies to Mitigate Methane Emissions by Ruminants Can Help Meet the 1.5˚C target by 2030 but not 2050. Proceedings of the National Academy of Sciences. Vol. 119, No. 20.
432 NSW Government (2022). NSW Blue Carbon Strategy 2022-2027.
433 Kelleway, J.J et al. (2020). A National Approach to Greenhouse Gas Abatement Through Blue Carbon Management. Global Environmental Change. Vil. 63, July 2020.
434 Australian Government (2022). Tidal Restoration of Blue Carbon Ecosystems Method.

AgTech and decarbonisation

Land and agriculture sector: Sustainable land management cluster

OPPORTUNITY 26

Developing and deploying technology to support agriculture and land decarbonisation

AgTech is innovation used across the value chain to improve the efficiency, profitability and sustainability of the land and agriculture sectors. AgTech can contribute to decarbonisation through the:

- use of technology to gather data to make more effective and fast management decisions to minimise wastage and improve crop and livestock yields[435]
- use of GPS, sensors and high-tech equipment to target site-specific applications to reduce the use of carbon intensive fertilisers and pesticides, and optimise crop yields [436]
- development of autonomous farm vehicles and equipment that optimise routes, harvest crops and minimise energy consumption[437]
- development of measure-model-verification technologies to measure levels of soil carbon.[438]

Currently, the global AgTech market is estimated to be worth US$500 billion and growing at a rate of 8% per year.[439,440] In Australia, it has been predicted that by 2030, AgTech will create 3,500 new jobs and lead to a AUD$20 billion increase in agricultural productivity and AUD$10 billion increase in revenue from AgTech products and services.

Australia's AgTech sector is relatively small and at an early investment stage compared with global counterparts. However, NSW is ideally placed to grow its AgTech service sector, given its highly skilled workforce and number of research institutions with an AgTech focus. NSW is also home to 50% of the Australian startups, including a large proportion of Australian AgTech startups to scaleups. These are predominately located in the Greater Sydney area, complemented by regional agricultural precincts and hubs.[441]

The NSW Government has recognised this opportunity and implemented several actions in the past year, including:

- establishing the NSW Regional Investment Attraction Fund
- extending the Farms of the Future Program
- helping SMEs access technical equipment, with regional incubator initiatives in agribusinesses and AgTech through the Boosting Business Innovation Program
- establishing The Gate, a NSW Department of Primary Industries research and technology facility designed to develop and accelerate the adoption of AgTech research
- identifying AgTech as a priority in the NSW *20-Year R&D Roadmap.*

Through increased research and business-to-business collaborations, as well as the establishment of a strong NSW AgTech service sector, NSW can decarbonise the land and agriculture sector and improve on-farm productivity and economic outcomes for the state.

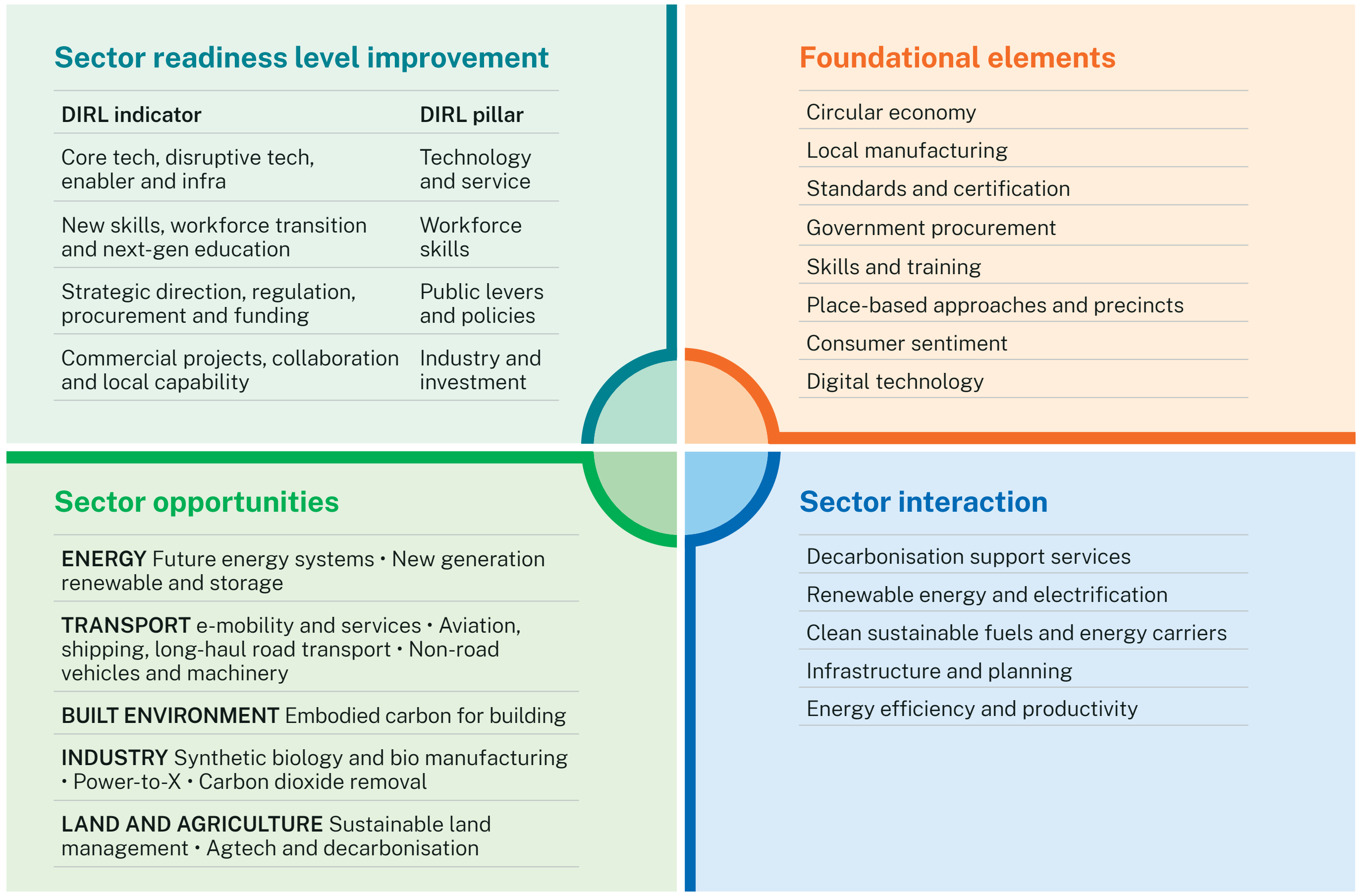
435 PWC (2022). Farming for the Future: Improving Natural Capital.
436 Center for Climate and Energy Solutions (2022). Unlocking Precision Agriculture's Climate Potential.
437 Clickworker (2023). Autonomous Farming: The Future of the Agriculture Industry.
438 QUT. (2022). New Soil Carbon Measurement Tools to Cut Costs and Raise Farmer's Profits.
439 Australian Financial Review (2020). Australia Risks Missing out on $700b Agrifood Tech Industry.
440 Cision PR Newswire (2010). Global $725+ Billion Food & Agriculture Technology and Products Market Analysis 2018-2019 & Forecast to 2023.
441 OECD (2018). Enabling SMEs to Scale Up: Discussion Paper.

5.0 Opportunities and next steps

This section details the opportunities based on observations and findings of previous sections in the report (Figure 9):

- **Foundational Elements Opportunities** (Section 3). The foundational elements identified to support the transition to a decarbonised economy and essential to support sector opportunities. How best to progress these opportunities has been considered, focusing on key areas such as technology development, market incentives, regulatory frameworks and public-private partnerships.
- **Sector Interaction Opportunities** (Section 3). The transition to a low-carbon economy requires the understanding that reducing GHG emissions and adopting new technologies and services cannot be achieved in isolation. Instead, it requires collaboration and integration amongst the different sectors. By acknowledging these sector interactions, NSW can leverage cross-sector opportunities and create synergies that enhance the effectiveness of decarbonisation initiatives.
- **Sector Cluster Opportunities** (Section 4). The 13 sector clusters and 29 sector-specific opportunities are important for driving decarbonisation in NSW. They provide a focus for stakeholders to act. Progressing these opportunities has the potential to enhance collaboration, target resource allocation, grow the market and align policy for all sectors.
- **Decarbonisation Innovation Readiness Level** (DIRL) Improvement Opportunities (Section 3 and 4). The DIRL focuses on assessing the current capabilities of technologies and services, skills and training, public levers and leadership, and industry and investment needed to drive decarbonisation in each sector. Opportunities to improve DIRL can enhance the readiness for decarbonisation innovation and the transition to a low-carbon economy. DIRL opportunities support and bring together all other opportunities from foundational elements, sector interactions and sector clusters within the decarbonisation innovation landscape and provide a holistic view of the readiness and potential for achieving decarbonisation while offering a structured approach.

Figure 9: Groups of opportunities based on observations and findings



All opportunities identified in the 2023 Study were assessed to provide guidance on how to best drive decarbonisation in NSW. This assessment involved analysing various factors and data used in the report. This led to the development of next steps, a series of actions, strategies and initiatives that can be undertaken to advance the opportunities. They are designed to address key challenges, leverage existing strengths and capitalise on emerging trends and technologies. They offer a systematic approach to guide decision-making and resource allocation, ensuring that efforts are focused on areas with the highest potential for impact and success. They include suggestions for the NSW Government to create an enabling environment for innovation and investment. Additionally, they include collaboration and partnerships with key stakeholders, such as industry leaders, research institutions and community organisations to foster knowledge sharing, cooperation and collective action. Importantly, the proposed next steps consider the unique context and priorities of NSW. By embracing and implementing these next steps, NSW can accelerate its progress towards a decarbonised economy. They serve as a practical and actionable guide to translate the opportunities into concrete measures and outcomes. Through continuous evaluation and adaptation of these opportunities and next steps, NSW can continue the decarbonisation of the economy, fostering sustainable growth, mitigating climate change impacts and contributing to the global transition to a low-carbon economy.

Foundational elements, opportunities and next steps

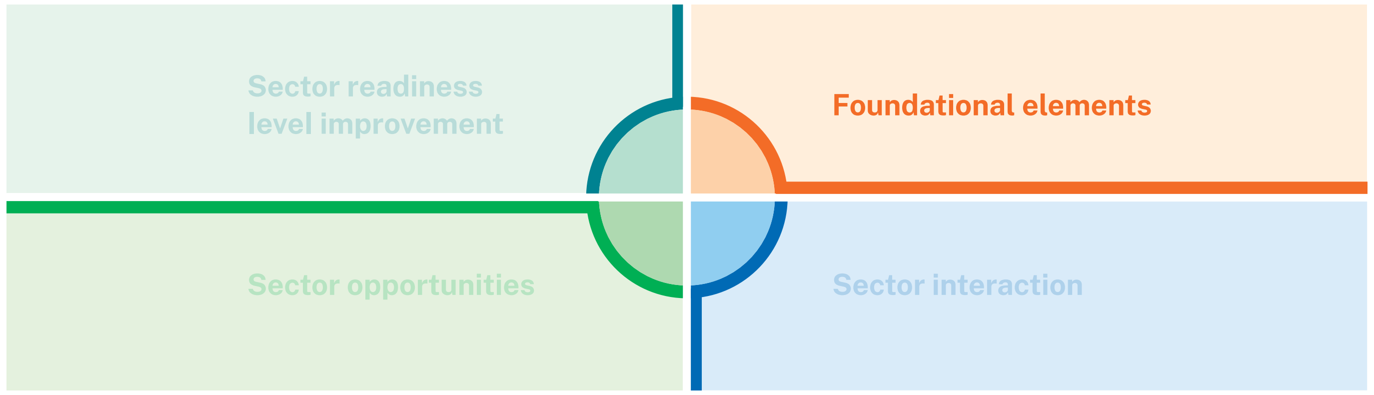


Table 3: Foundational elements, opportunities and next steps

Foundational elements	Opportunity	Next steps
Circular economy	Accelerating decarbonisation progress through local supply of recycled/reused/repurposed clean economy technologies, materials and goods	NSW Government to consider strong support to develop a NSW market for circular economy technologies, materials and goods. NSW Decarbonisation Innovation Hub and Networks to work with industry peak bodies and networks (e.g. Circular Australia, MECLA) to support government strategy and program development.
Local manufacturing	Growing NSW manufacturing capability in low-carbon products, climatetech and services, attracting global investment and talents and developing an export industry	NSW Government to consider strategic approach for the development of local manufacturing capability and supply chains for low-carbon products and clean energy technologies. NSW Decarbonisation Innovation Hub and Networks to consider the role they can play with industry and government partners to progress local manufacturing of climatetech and services.
Standards and certification	Continue to develop standards and certification systems to support decarbonisation technologies and services across the sectors and NSW economy	NSW Government to consider initiating discussions for the development of standards and certifications systems and infrastructure to support NSW entities with technology development and commercialisation.
Government procurement	Leveraging NSW Government procurement power to drive uptake of climatetech and services across government procurement activities and projects, especially infrastructure projects	NSW Government to consider an overarching climatetech procurement strategy for government activities and projects that can support businesses and researchers to progress their climatetech and services.
Skills and training	Developing clear educational pathways programs to enable the transition of high emitting industry jobs and the uptake of new jobs from future low-carbon industries	NSW Government, with industry, educational institutions (secondary, tertiary and vocational), unions and other stakeholders to consider developing a climatetech skills and training strategy that provides a clear education pathways for workforces transitioning to low-carbon industries and supports future workforces with climatetech career pathways.
Place-based approaches and precincts	Continue establishing place-based precincts to maximise the benefits of industry agglomeration and accelerate the deployment of climatetech and services	NSW Government to consider supporting R&D programs and research infrastructure within industrial precincts and hubs to drive climatetech collaboration across precincts. NSW Decarbonisation Innovation Hub and Networks to consider engagement with NSW place-based precincts, facilitating regional industry development.
Consumer sentiment	Building consumer trust and confidence in preparing for the uptake of new wave of climatetech, services and jobs	NSW Government to consider in all climatetech programs the need to establish strong consumer engagement to increase trust and acceptance of climatetech and services and in turn increase consumer uptake of climatetech. NSW Decarbonisation Innovation Hub and Networks to consider looking for ways to support consumer engagement in climatetech.
Digital technologies	Rapid and wide adoption of digital technologies and services to enable the uptake of climatetech and service	NSW Government to consider: • deploying commercialised digital technologies to enable the rapid uptake of climatetech and services • NSW Decarbonisation Innovation Hub and Networks to consider working with NSW Connectivity Innovation Network, Sydney Quantum Academy, NSW Smart Sensing Network and other networks, investigating the applications of emerging digital technologies for decarbonisation (e.g. AI, Quantum, Drones).

Sector interactions, opportunities and next steps

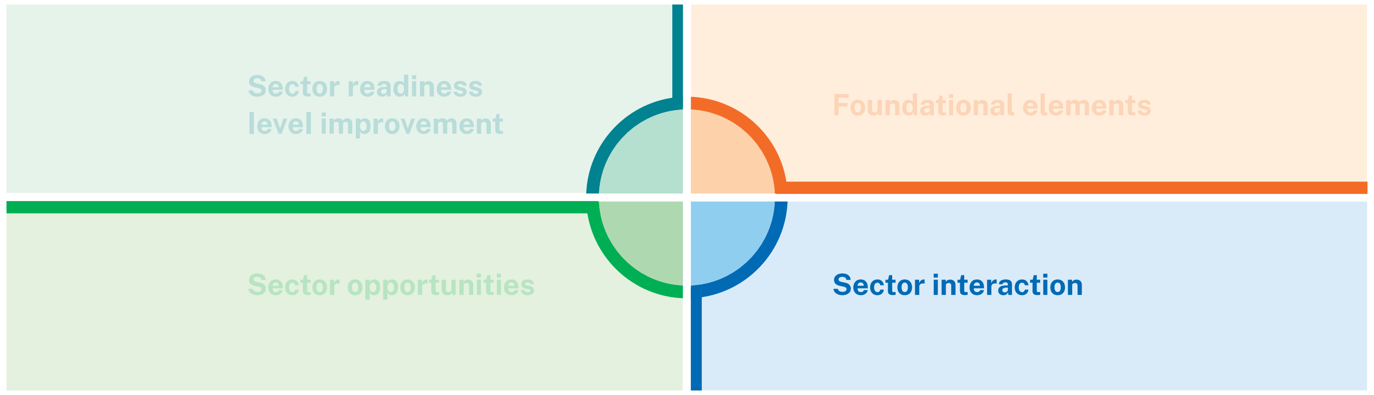


Table 4: Sector interactions, opportunities, next steps and relevant foundational elements

Sector interactions	Opportunities	Next steps	Relevant foundational elements
Decarbonisation support services	Decarbonisation Support Services support a successful sector decarbonisation strategy. They include bodies such as ESG Governance Consultancy groups, carbon market groups, financial markets and researchers. It includes support for climate startups and supports businesses to commercialise their products and services. They foster collaboration, knowledge sharing and the exchange of best practices, thereby accelerating the transition to a low-carbon economy	Building a strong decarbonisation services sector to assist government, business and community to achieve decarbonisation innovation outcomes.	• Circular economy • Local manufacturing • Standards and certification • Government procurement • Skills and training • Place-based approaches and precincts • Consumer sentiment • Digital technologies
Renewable energy and electrification	The widespread adoption of renewable energy sources and electrification is pivotal for decarbonisation. It supports the transition of various sectors, such as transportation and heating, to electric power, further reducing reliance on fossil fuels and paving the way for a sustainable energy future	Powering clean economy development with low-cost, low-carbon energy for secure, affordable and reliable decarbonisation	• Circular economy • Local manufacturing • Skills and training • Place-based approaches and precincts • Consumer sentiment • Digital technologies
Clean sustainable fuels and energy carriers (fuel options)	Clean sustainable fuels and energy carriers encompass innovative solutions that provide alternatives to conventional fossil-based fuels. They support decarbonisation of sectors that are challenging to electrify, such as aviation, shipping and heavy industry	Maximising sector-coupling opportunities enabled by Power-to-X technologies for accelerated rollout of renewable energy projects to decarbonise hard-to-abate industries.	• Local manufacturing • Standards and certification • Skills and training • Place-based approaches and precincts • Consumer sentiment
Infrastructure and planning	Effective infrastructure and planning can support the transition to a decarbonised economy, creating the necessary framework for low-carbon technology and services to grow	Incorporating decarbonisation outcomes within government planning and procurement of infrastructure and building projects.	• Circular economy • Standards and certification • Government procurement • Skills and training • Place-based approaches and precincts • Consumer sentiment
Energy efficiency and productivity	Implementing energy-efficient technologies, optimising industrial processes and adopting energy-saving practices can reduce energy waste, lower GHG emissions and enhance economic competitiveness	Reducing overall energy costs for business and households through improved energy efficiency and productivity.	• Local manufacturing • Standards and certification • Government procurement • Skills and training • Consumer sentiment • Digital technologies

Sector opportunities and next steps

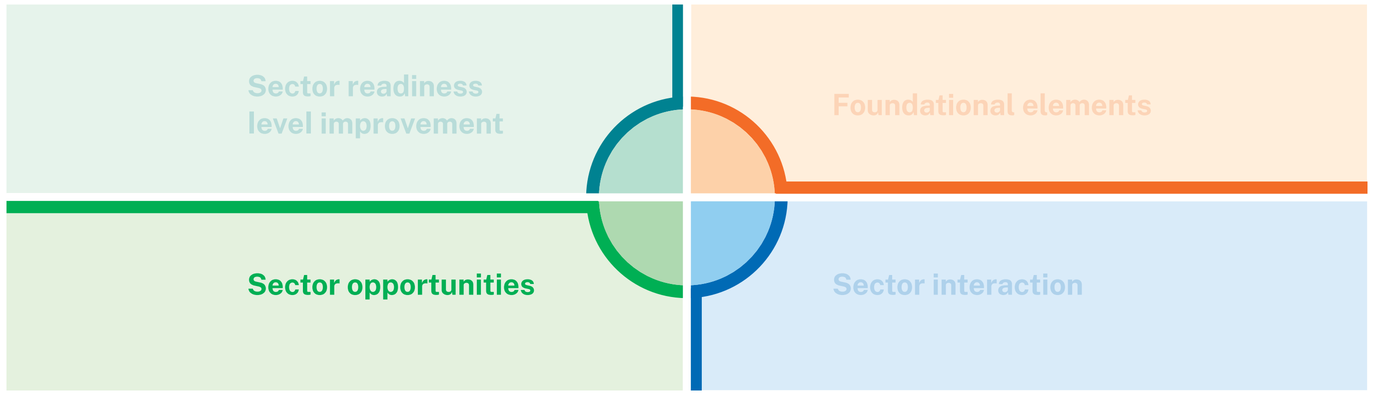


Table 5: Sector clusters, opportunities and next steps

Sector and sub-sector	Opportunity	Next steps
Finance system	1. Building investment-ready finance system for sectoral decarbonisaton and transition pathways	
Energy sector Future energy systems	2. Deploying DER technologies and smart systems to maximise consumer benefits and improve electricity grid efficiency and security 3. Integrating Vehicle to Grid and other new technologies into the electricity system 4. Deploying additional demand-side management measures to maximise the utility of rooftop solar and improve electricity grid efficiency	The NSW Government to continue to work with NEM bodies to develop the future energy systems. NSW Government support for the establishment of infrastructure to support the testing of technologies for the future energy system to address: • Improved electricity grid efficiency and security • VtG integration • Demand side management.
Energy sector New generation renewable and storage	5. Developing local manufacturing and recycling capability for new solar technologies 6. Developing a local offshore wind industry prioritising Renewable Energy Zones 7. Developing long duration and fast responding energy storage solutions and grow the battery supply chain	The NSW Government to engage with organisations such as the Decarbonisation Innovation Hub, ATRaCE, and RACE 2030 to identify and progress research and commercialisation opportunities for solar, wind, battery storage and DER technologies which offer significant opportunity for the NSW Net Zero economy. The NSW Government to consider new solar and battery technology when developing initiatives under the Net Zero Industry and Innovation Program. The NSW Government to work with the Australian Government on the development and enablers of offshore wind industry in NSW.
	8. Developing a renewable energy export ecosystem	The NSW Government to consider energy export opportunities within the NSW Hydrogen Strategy and other initiatives.
Transport sector e-mobility and services	9. Developing and deploying technologies and services to support a multi-model approach to transport 10. Supporting the deployment of micro-mobility to lower costs and accelerate uptake	Through the Future Transport Strategy, the NSW Government to continue to advance multi-model approaches to transport and steps to support the development of micro-mobility.
Transport sector Long-haul transport and non-road machinery	11. Developing and deploying alternative fuels technologies with supporting infrastructure for hard-to-electrify transport	Through the Decarbonisation Innovation Hub, support the development and commercial deployment of alternative fuels for hard-to-electrify transport. The NSW Hydrogen Strategy to consider how to support EV for the heavy vehicle sector, especially in respect to charging infrastructure.
	12. Deploying EV for the heavy vehicle sector with focused industry applications (mining, agriculture and non-road)	The NSW EV Strategy to consider how to support EV for the heavy vehicle sector, especially with respect to charging infrastructure.
Built environment sector Embodied carbon for building and infrastructure	13. Developing and deploying low-emission construction materials and construction technologies 14. Utilising government procurement to increase the uptake of low-emission construction materials and modular designs	The NSW Government to strengthen and expand incorporation of low-emission construction material and technology and modular design in all infrastructure projects, planning strategies and procurement.
	15. Increasing recycling and the reuse of construction materials in new buildings 16. Maximising the use of existing assets and reduce the use of materials in new buildings and infrastructure	NSW Government and MECLA to look for ways to ensure circular economy principles are applied to building designs and material that include maximising use of existing buildings, recycling of material in building and infrastructure.
Industry sector Biomanufacturing and synthetic biology	17. Developing and deploying the creation and engineering of new genomes, biological pathways or organisms to create a synthetic biology ecosystem 18. Advancing bioengineering technologies, processes and services in simple organisms (such as algae and yeast) for low-carbon materials and products	NSW to consider establishing a Biomanufacturing and Synthetic Biology Innovation and Industry Cluster to lead future bioeconomy development in Australia and internationally.

Sector and sub-sector	Opportunity	Next steps
Industry sector Power-to-X and hydrogen	19. Building a NSW P2X economy for decarbonising domestic hard-to-abate industries and green commodities exporting 20. Deploying commercial hydrogen projects for energy, transport and P2X feedstock productions 21. Deploying decentralised hydrogen-based microgrids and P2X facilities for multi-users, particularly in regional and remote areas	The NSW Government to work with the Decarbonisation Innovation Hub Power Fuel Including Hydrogen Network and ATRaCE to progress P2X opportunities.
Industry sector Carbon dioxide removal	22. Developing and deploying carbon dioxide removal technology	The NSW Government to include carbon dioxide removal technology in initiatives under the Net Zero Industry and Innovation Program.
Industry sector Eco-industry transition	23. Developing and deploying decarbonised manufacturing clusters to maximise productivity benefits	NSW to intensify and prioritise programs taking a precinct-based approach to the development and deployment of decarbonised manufacturing industries.
Land and agriculture sector Sustainable land management	24. Developing a robust and creditable local decarbonisation services sector across the land and agriculture sectors (including enteric emissions reductions, soil carbon and blue carbon)	The NSW Government works with the Decarbonisation Innovation Hub to support the development of regional decarbonisation services for agriculture and land.
	25. Enhancing benchmarking and certification to improve investor certainty	The NSW Government to work with the Decarbonisation Innovation Hub to investigate a benchmarking and certification mechanism for NSW.
Land and agriculture sector Agtech and decarbonisation	26. Developing and deploying Agtech and enabling technologies to support agriculture and land decarbonisation	In developing regional decarbonisation services, the use of Agtech and enabling technologies are to be considered.

DIRL improvement opportunities and next steps

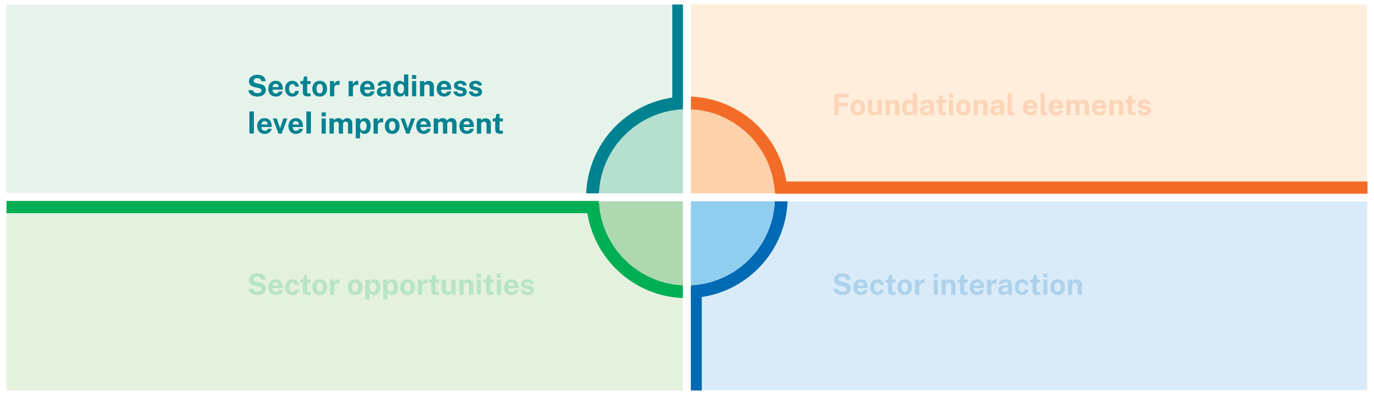


Table 6: DIRL pillar, cross-sectoral opportunities and next steps, relevant foundational elements, sector cluster opportunities

Cross-sectoral opportunities and next steps	Relevant foundational elements	Sector cluster opportunities
DIRL pillar – Technology and services		
• NSW Government to continue investment in research, development and demonstration (RD&D) of climate technologies and services where the state has clear competitive advantages • NSW Government to consider increased investment and support of shared research infrastructure and testing facilities • NSW to de-risk citizens against carbon risk through asset optimisation and including carbon impacts in strategic planning policies, business cases and environmental impact statements	• Competitive advantages • Government procurement • Digital technologies	1. Finance system 2. DER technologies and smart systems (Future Energy System Cluster, Energy Sector) 3. VtG technologies (Future Energy System Cluster, Energy Sector) 4. Demand-side management (Future Energy System Cluster, Energy Sector) 5. Solar manufacturing and recycling (New-gen Renewable Energy and Storage Cluster, Energy Sector) 6. Offshore wind industry (New-gen Renewable Energy and Storage Cluster, Energy Sector) 7. Energy storage solutions (New-gen Renewable Energy and Storage Cluster, Energy Sector) 8. Renewable energy export (New-gen Renewable Energy and Storage Cluster, Energy Sector) 9. Multi-model transport technologies (e-Mobility and Services Cluster, Transport Sector) 10. Micro-mobility (e-Mobility and Services Cluster, Transport Sector) 11. Alternative fuels technologies and infrastructure (Long-haul and Non-road Cluster, Transport Sector) 12. EV for industry user (Long-haul and Non-road Cluster, Transport Sector) 13. Low-emission construction materials and technologies (Embodied Carbon for Building and Infrastructure Cluster, Built Environment Sector) 14. Government procurement of low-emission construction materials and modular designs (Embodied Carbon for Building and Infrastructure Cluster, Built Environment Sector)

Cross-sectoral opportunities and next steps	Relevant foundational elements	Sector cluster opportunities
		15. Construction materials recycling and reuse (Embodied Carbon for Building and Infrastructure Cluster, Built Environment Sector) 16. Maximising the use of existing assets and reducing the use of materials in new buildings and infrastructure (Embodied Carbon for Building and Infrastructure Cluster, Built Environment Sector) 17. Synthetic biology ecosystem (Biomanufacturing and Synthetic Biology Cluster, Industry Sector) 18. Bioengineering technologies (Biomanufacturing and Synthetic Biology Cluster, Industry Sector) 19. NSW P2X economy (P2X and Hydrogen Cluster, Industry Sector) 20. Hydrogen for energy, transport and chemical feedstock (P2X and Hydrogen Cluster, Industry Sector) 21. Decentralised hydrogen microgrids and P2X facilities (P2X and Hydrogen Cluster, Industry Sector) 22. Carbon dioxide removal and utilisation (Carbon Removal Cluster, Industry Sector) 23. Decarbonised manufacturing clusters (Eco-Industry Cluster, Industry Sector) 24. Decarbonisation services sector (Sustainable Land Management Cluster, Land and Agriculture Sector) 25. Benchmarking and certification (Sustainable Land Management Cluster, Land and Agriculture Sector) 26. Agtech and enabling technologies (Agtech and Decarbonisation Cluster, Land and Agriculture Sector)

Cross-sectoral opportunities and next steps	Relevant foundational elements	Sector cluster opportunities
DIRL pillar – Workforce and skills		
• NSW Government to ensure that education, training and reskilling programs are in place to support the transition of existing workforce and the development of future workforces	• Competitive advantages • Standards and certification • Skills and training • Place-based approaches and precincts • Consumer sentiment	1. Finance system 5. Solar manufacturing and recycling (New-gen Renewable Energy and Storage Cluster, Energy Sector) 6. Offshore wind industry (New-gen Renewable Energy and Storage Cluster, Energy Sector) 8. Renewable energy export (New-gen Renewable Energy and Storage Cluster, Energy Sector) 10. Micro-mobility (e-Mobility and Services Cluster, Transport Sector) 11. Alternative fuels technologies and infrastructure (Long-haul and Non-road Cluster, Transport Sector) 12. EV for industry user (Long-haul and Non-road Cluster, Transport Sector) 13. Low-emission construction materials and technologies (Embodied Carbon for Building and Infrastructure Cluster, Built Environment Sector) 15. Construction materials recycling and reuse (Embodied Carbon for Building and Infrastructure Cluster, Built Environment Sector) 16. Maximising the use of existing assets and reducing the use of materials in new buildings and infrastructure (Embodied Carbon for Building and Infrastructure Cluster, Built Environment Sector) 17. Synthetic biology ecosystem (Biomanufacturing and Synthetic Biology Cluster, Industry Sector) 18. Bioengineering technologies (Biomanufacturing and Synthetic Biology Cluster, Industry Sector) 19. NSW P2X economy (P2X and Hydrogen Cluster, Industry Sector) 20. Hydrogen for energy, transport and chemical feedstock (P2X and Hydrogen Cluster, Industry Sector) 21. Decentralised hydrogen microgrids and P2X facilities (P2X and Hydrogen Cluster, Industry Sector) 23. Decarbonised manufacturing clusters (Eco-industry Cluster, Industry Sector) 24. Decarbonisation services sector (Sustainable Land Management Cluster, Land and Agriculture Sector) 25. Benchmarking and certification (Sustainable Land Management Cluster, Land and Agriculture Sector) 26. Agtech and enabling technologies (Agtech and Decarbonisation Cluster, Land and Agriculture Sector)

Cross-sectoral opportunities and next steps	Relevant foundational elements	Sector cluster opportunities
DIRL Pillar – Public levers and government leadership		
• NSW Government to continue playing a leadership role in developing and implementing decarbonisation and innovation policies and programs • NSW Government to increase understanding of NSW's carbon exposure through continual measurement and benchmarking • NSW Government to consider factoring decarbonisation innovation in strategic planning and business case building	• Competitive advantages • Standards and certification • Government procurement • Place-based approaches and precincts	1. Finance system 4. Demand-side management (Future Energy System Cluster, Energy Sector) 7. Energy storage solutions (New-gen Renewable Energy and Storage Cluster, Energy Sector) 8. Renewable energy export (New-gen Renewable Energy and Storage Cluster, Energy Sector) 9. Multi-model transport technologies (e-Mobility and Services Cluster, Transport Sector) 11. Alternative fuels technologies and infrastructure (Long-haul and Non-road Cluster, Transport Sector) 12. EV for industry user (Long-haul and Non-road Cluster, Transport Sector) 13. Low-emission construction materials and technologies (Embodied Carbon for Building and Infrastructure Cluster, Built Environment Sector) 14. Government procurement of low-emission construction materials and modular designs (Embodied Carbon for Building and Infrastructure Cluster, Built Environment Sector) 15. Construction materials recycling and reuse (Embodied Carbon for Building and Infrastructure Cluster, Built Environment Sector) 16. Maximising the use of existing assets and reducing the use of materials in new buildings and infrastructure (Embodied Carbon for Building and Infrastructure Cluster, Built Environment Sector) 20. Hydrogen for energy, transport and chemical feedstock (P2X and Hydrogen Cluster, Industry Sector) 21. Decentralised hydrogen microgrids and P2X facilities (P2X and Hydrogen Cluster, Industry Sector) 25. Benchmarking and certification (Sustainable Land Management Cluster, Land and Agriculture Sector)

Cross-sectoral opportunities and next steps	Relevant foundational elements	Sector cluster opportunities
DIRL pillar – Industry development and investment		
• NSW Government to support decarbonisation innovation projects that align to the 2023 Study opportunities	• Competitive advantages • Circular economy • Local manufacturing • Standards and certification • Place-based approaches and precincts	1. Finance system 4. Demand side management (Future Energy System Cluster, Energy Sector) 5. Solar manufacturing and recycling (New-gen Renewable Energy and Storage Cluster, Energy Sector) 6. Offshore wind industry (New-gen Renewable Energy and Storage Cluster, Energy Sector) 8. Renewable energy export (New-gen Renewable Energy and Storage Cluster, Energy Sector) 11. Alternative fuels technologies and infrastructure (Long-haul and Non-road Cluster, Transport Sector) 12. EV for industry user (Long-haul and Non-road Cluster, Transport Sector) 13. Low-emission construction materials and technologies (Embodied Carbon for Building and Infrastructure Cluster, Built Environment Sector) 15. Construction materials recycling and reuse (Embodied Carbon for Building and Infrastructure Cluster, Built Environment Sector) 16. Maximising the use of existing assets and reducing the use of materials in new buildings and infrastructure (Embodied Carbon for Building and Infrastructure Cluster, Built Environment Sector) 17. Synthetic biology ecosystem (Biomanufacturing and Synthetic Biology Cluster, Industry Sector) 18. Bioengineering technologies (Biomanufacturing and Synthetic Biology Cluster, Industry Sector) 19. Nsw P2X economy (P2X and Hydrogen Cluster, Industry Sector) 20. Hydrogen for energy, transport and chemical feedstock (P2X and Hydrogen Cluster, Industry Sector) 21. Decentralised hydrogen microgrids and P2X facilities (P2X and Hydrogen Cluster, Industry Sector) 22. Carbon dioxide removal and utilisation (Carbon Removal Cluster, Industry Sector) 23. Decarbonised manufacturing clusters (Eco-industry Cluster, Industry Sector) 24. Decarbonisation services sector (Sustainable Land Management Cluster, Land and Agriculture Sector) 25. Benchmarking and certification (Sustainable Land Management Cluster, Land and Agriculture Sector)

6.0 Next steps from the 2023 Study

The success in decarbonising the NSW economy to date can be attributed to the NSW's strong focus on policies and programs for reaching net zero and collaboration between businesses, industries and communities to drive the state's decarbonisation agenda.

Policies, regulatory frameworks and supportive measures that drive decarbonisation provide the enabling environment that encourages and incentivises the adoption of low-carbon technologies and practices. Equally important is the collaborative effort by businesses, industries and communities across NSW. Recognising the urgency and importance of addressing climate change, stakeholders have come together to actively participate in decarbonisation initiatives. By sharing knowledge, resources and best practices, an ecosystem of innovation and collective action has been fostered.

As NSW continues to advance its decarbonisation progress, the importance of strong leadership and collaborative efforts cannot be overstated. The ongoing commitment by government, researchers, industries and communities will be essential in driving further innovation, scaling up decarbonisation efforts and achieving ambitious climate targets. These two factors will be the most critical to realise the opportunities identified by the 2023 Study.

The 2023 Study provides a wide range of opportunities for emissions reduction and sustainable economic growth. However, it is crucial to recognise that the 2023 Study presents a framework, and there will be the need for government, researchers, industry and communities to work collaboratively to determine the specific actions required to capitalise on these opportunities. This could be achieved by establishing a working group between government and communities. The working group could commence with the NSW Office of Energy and Climate Change and NSW Decarbonisation Innovation Hub and Networks (as industry, research and NGO representatives) working with OCSE to provide governance and oversight for progressing the opportunities and next steps.

While NSW has embraced innovation as part of its decarbonisation strategies, competitiveness against other regions should not be underestimated with many racing towards net-zero and a clean future. The 2023 Study offers some examples of policies and programs from other economies which may prove effective in driving the transition to a clean economy (see the Supplement). These examples serve as references for the proposed working group, although it is important to consider their relevance for NSW. NSW has its unique set of challenges, opportunities and stakeholder dynamics that require a tailored approach. By aligning these examples with the state's specific goals and priorities, the working group can maximise the positive impacts and optimise resource allocation.

7.0 Acknowledgements

OCSE would like to express its gratitude and deep appreciation to the stakeholders who participated in the consultation process for their invaluable input and contributions

The active engagement and thoughtful insights from stakeholders have greatly enriched the outcomes of the 2023 Study and have played a pivotal role in shaping the strategic direction for the NSW decarbonisation innovation future.

OCSE extends its thanks to the government agencies, industry representatives, community organisations, research institutions and individuals who generously shared their expertise, perspectives and experiences. Their unwavering commitment and willingness to actively participate in the consultation demonstrated a remarkable dedication to addressing the challenges of climate change and fostering sustainable growth in our community.

Airlines for Australia and New Zealand (A4ANZ)
Algion
Arup
AusEng
Ausgrid
Austrade
Australian Hydrogen Council
Australian National University
Australian Renewable Energy Agency (ARENA)
Australian Sustainable Built Environment Council
Bioenergy Australia
Boeing
Business Finland
Carbon Farmers of Australia
Cellular Agriculture
Change Foods
Charles Sturt University
Clarke Energy
Clean Energy Finance Corporation (CEFC)
Climate Salad
Climate-KIC Australia
Coal Innovation NSW
CSIRO
Deloitte
Department of Regional NSW
Eden Brew
EnergyAustralia
EnergyLab
EnergyLink Services
Essential Energy
Ethanol Technologies Pty Ltd
Fichtner Australia
Fulcrum BioEnergy
Future Food Systems CRC
Greater Cities Commission
HFM Assets
HIF Asia Pacific
HIF Global
Hitachi Zosen Inova Australia
Hunter Circular Economic Zone
Infrastructure NSW
Investible
Investment NSW
LCI Consultants
Licella
Macquarie University (ARC Centre of Excellence in Synthetic Biology)
Masdar Tribe Australia
Meat and Livestock Australia
Melbourne Airport
MicroBioGen
NABERS
National Energy Resources Australia (NERA)
Neste
NSW Decarbonisation Innovation Hub
NSW Department of Customer Service
NSW Department of Planning and Environment
NSW Department of Primary Industries
NSW Ministry of Health
NSW Smart Sensing Network
NSW Treasury
NSW Treasury, Office of Energy and Climate Change
Orica
Port of Newcastle Clean Energy Precinct
Qantas
Queensland Futures Institute
Race for 2030 CRC
Regional Growth NSW Development Corporation (RGDC)
Resilience NSW
Rolls Royce - Defence
Scimita Ventures
Southern Green Gas Ltd
Sumitomo Mitsui Banking Corporation
Sunshine Coast Airport
Sydney Airport
The University of Newcastle
The University of Sydney
thyssenkrupp Uhde
Toshiba International Corporation
Transport for NSW
University of New England
University of Newcastle
University of Sydney - Net Zero Initiative
University of Technology Sydney Climate Change Cluster
University of Wollongong
UNSW Sydney (ARC Training Centre for the Global Hydrogen Economy)
US Grains Council
UTS Institute for Sustainable Futures
Virgin Australia
Vow
Wagner
Western Parkland City Authority
Western Sydney University
Worley
World Wide Fund for Nature
Young Henrys

8.0 Acronyms

3-NOP	3-Nitrooxypropanil
AI	Artificial Intelligence
AR	Augmented Reality
ACCU	Australian Carbon Credit Units
AEMO	Australian Energy Market Operator
ANU	Australian National University
ARENA	Australian Renewable Energy Agency
ASX	Australian Stock Exchange Ltd
ASIC	Australian Securities & Investments Commission
ASFI	Australian Sustainable Finance Institute
ATRACE	Australian Trailblazer for Recycling and Clean Energy
CDR	Carbon Dioxide Removal
CSE	Chief Scientist & Engineer
COP	Conference of the Parties of the United Nations Framework Convention on Climate Change
CEH	Controlled Environmental Horticulture
CRC	Cooperative Research Centre
DIRL	Decarbonisation Innovation Readiness Level
DAC	Direct Air Capture
DER	Distributed Energy Resources
EV	Electric Vehicle
ERF	Emissions Reduction Fund
ESG	Environment, Social and Governance
GBCA	Green Building Council of Australia
GHG	Greenhouse Gases
IP	Intellectual Property
ISP	Intergrated System Plan
IEA	Internation Energy Agency
IoT	Internet of Things
LEBM	Low Emissions Building Materials
MQU	Macquarie University
MECLA	Materials and Embodied Carbon Leaders Alliance
Mt CO2-e	Million metric tonnes of carbon dioxide equivalent
MaaS	Mobility as a Service
NABERS	National Australian Built Environment Rating System
NEM	National Energy Market
NZIIP	Net Zero Industry and Innovation Program
OCSE	Office of the Chief Scientist & Engineer
PV	Photovoltaics
P2X	Power-to-X
PIPAP	Primary Industries Productivity and Abatement Program
PHES	Pumped Hydro Energy Storage
REI	Renewable Energy Indicator
REZ	Renewable Energy Zones
STEM	Science, technology, engineering and mathematics
SAP	Special Activation Precincts
SAPS	Stand Alone Power Systems
SEPP	State Environment Protection Policy
SAF	Sustainable Aviation Fuel
SDG	Sustainable Development Goals
UoN	University of Newcastle
UNSW	UNSW Sydney
USYD	University of Sydney
UTS	University of Technology Sydney
UoW	University of Wollongong
VtG	Vehicle to grid
VR	Virtual Reality
WSU	Western Sydney University

9.0 Appendix

Appendix 1 – Terms of Reference

Terms of Reference for a study into the challenges and opportunities for NSW innovation to support decarbonisation of the economy

Background and context

The NSW Government has a target of achieving net zero emissions by 2050 and to make NSW more resilient to a changing climate. One of the five policy directions in the NSW Climate Change Policy Framework is 'Take advantage of opportunities to grow new industries in NSW'. The shift to a net-zero emissions economy can create new opportunities in sectors where NSW has a competitive advantage, such as professional services, agriculture, advanced energy technology, property management and financial services.

However, such a shift will affect established sectors of the NSW economy such as resources and commodities.

There may be an opportunity for NSW to become a global leader in innovative technologies and services that enable decarbonisation and adaptation to climate change. A decarbonisation innovation strategy could deliver economic and job growth, improve energy affordability and support a managed transition of the energy market from high to low emission energy sources. It could also catalyse change in the emissions profile of all major industry sectors. Innovation in decarbonisation and adaptation technologies and services could serve the dual purpose of addressing the NSW emissions and adaptation challenge and growing the NSW economy through economic diversification and export opportunities.

Scope of review

The NSW Chief Scientist & Engineer is to assess and provide advice on the challenges and opportunities for meeting emissions targets and adapting to climate change. This work will examine the benefits of decarbonisation and climate adaptation in generating economic development, prosperity and jobs growth in NSW, including a discussion of best practice approaches to transitioning industry, including skills development and market access.

The NSW Chief Scientist and Engineer will report on:

1. Technologies and services to reduce carbon emissions, adapt to or mitigate the impact of climate change in which NSW could have a competitive advantage.
2. The net-value of these technologies and services for NSW in terms of both emissions reduction and economic growth.
3. Any barriers to the development of the technologies and services in NSW.
4. The role of the NSW Government in:
   a. Addressing any of the identified barriers
   b. Supporting the acceleration of the development/commercialisation of these opportunities, and
   c. Ensuring that NSW takes advantage of carbon emission reduction technologies to maximise economic opportunities.

The Chief Scientist and Engineer will convene a panel with expertise in science and technology, business, economic and social insights. The Department of Planning, Industry and Environment will provide support to the study as required.

As needed, the NSW Chief Scientist and Engineer will:

- draw on additional sources of advice and expertise
- commission or recommend papers or studies.

The NSW Chief Scientist and Engineer will:

- undertake targeted consultations with stakeholders.

Appendix 2 - Summary of 2020 Decarbonisation Innovation Study

Sector	Summary of key opportunities for NSW
Services Global services powerhouse	• Becoming a major global sustainable finance hub. • Attracting local and international capital, and directing it towards promising sustainable industries and infrastructure in NSW. • Improving investment practice by encouraging the widespread adoption of climate change risk management initiatives. • Growing jobs in carbon, resilience and sustainability services.
Electricity A distributed and low emission electricity system	• Deploying low cost renewables and storage to lower electricity costs for businesses and households. • Developing and deploying innovative electricity generation, storage, grid and management technologies and services for a future low cost, low emissions, distributed, reliable, secure, digital and flexible electricity system. • Improving consumer confidence, participation in new electricity markets and adoption of low cost energy technologies.
Industry Low carbon industrial transformation	• Developing and deploying new technologies and services to increase energy productivity, electrification and material efficiency in industrial processes. • Leveraging low cost renewable energy and energy productivity technologies to grow new and expanded energy-intensive industries in precincts and regions. • Reusing, recycling and repurposing materials in industrial supply chains. • Growing industries in hydrogen, alternative heat and bioenergy, and deploying these energy platforms across other industrial processes and economic sectors.
Built environment A sustainable built environment	• Developing and deploying new technologies and services to increase energy productivity, electrification and material efficiency in the built environment. • Growing the market for efficient and modular designs that incorporate sustainable materials, energy generation and storage, and efficiency improvements. • Growing local supply chains in sustainable, reused and recycled construction materials. • Building net zero industrial, commercial and residential precincts and public infrastructure that showcase best practice design, construction and operation.
Land Sustainable agriculture and land use	• Promoting best practice sustainable land management, and growing sustainability markets and ecosystem services to provide complementary decarbonised income sources for landholders, including indigenous landholders. • Improving agricultural productivity and resilience through technologies including controlled environmental horticulture, renewables, bioenergy, water efficiency and recycling, gene technologies and synthetic biology. • Growing local demand and supply chains in agricultural goods and tourism services.
Transport Electrified and efficient mobility	• Increasing productivity in transport through digital connectivity, automation and new decarbonised modes of transport. • Growing availability and uptake of decarbonised energy sources in transport, including renewable electricity, green hydrogen and synthetic fuels. • Increasing awareness and uptake of Mobility as a Service solutions.

Office of the Chief Scientist & Engineer