NSW Decarbonisation Innovation 2023 Study – Supplement Document

July 2023

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Introduction

The NSW Decarbonisation Innovation 2023 Study – Supplement Document (the Supplement) provides further detail on the methodology and selected underlying data used in the development of the NSW Decarbonisation Innovation 2023 Study (the 2023 Study).

Sections of the Supplement and for reference to the 2023 Study

1. NSW Decarbonisation Innovation Readiness Level Framework

Background and Context

The terms Technology Readiness Level (TRL) and Commercial Readiness Index (CRI) are well defined and widely used by research, government and industry as methods to estimate the maturity of technology. TRL and CRI are useful tools for tracking progress and supporting the development of a specific technology. Stakeholders expressed a strong need for a systematic view of the innovation ecosystem and for a new framework to assess the progress of sectors/industries identified.

The NSW Decarbonisation Innovation Readiness Level (DIRL) was subsequently developed for the 2023 Study and is based on similar approaches of other organisations. This paper illustrated the methodology, data and some case studies of well-developed readiness/index framework used for the NSW DIRL development. The development of this assessment framework incorporates research, data analytics and a holistic approach as well as case studies. The framework embraces a more comprehensive understanding of the decarbonisation innovation systems.

NSW Decarbonisation Innovation Readiness Level Development

The DIRL framework has four essential pillars of innovation and project lifecycle and 12 indicators (Figure 1), with each indicator being an element for the success of the pillar. Table 1 provides a description for each indicator with examples.

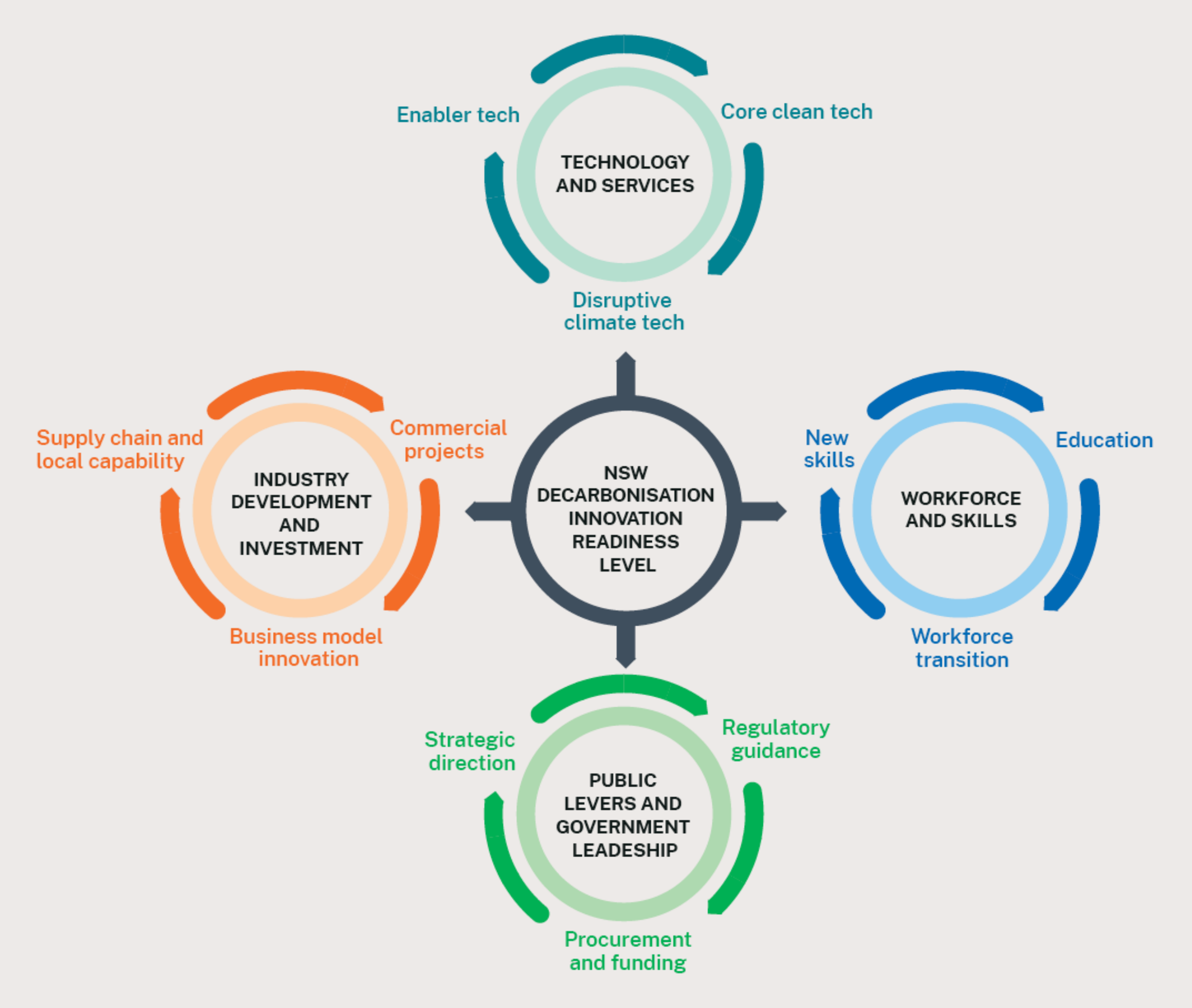

Figure 1: DIRL Framework Illustration

Table 1: DIRL Indicators and Examples

DIRL pillar	DIRL indicator	Indicator description and example
Technology & Services	Core decarbonisation technology and deployment	The continued innovation, commercialisation and deployment at industrial scale of existing critical technology that could significantly improve the economic and decarbonisation performance for the sector. Early local market adoption and rapid deployment of core technology could have substantial benefits for medium to long-term decarbonisation. For example, silicon-based tandem solar photovoltaics (PV) cells are widely regarded as leading next-generation solar technology with high efficiency, better energy productivity and longer lifespan.
	Disruptive technology and Intellectual Property (IP)	Disruptive technology can significantly alter the way that consumers, businesses or industries operate and potentially supersede the existing process or product for decarbonisation. The ownership of IP is essential for disruptive technology's research, development and industrial translation, transforming the next wave of decarbonisation technology. For example, direct air carbon capture is a disruptive carbon removal technology that can extract carbon dioxide from atmosphere for use in controlled environment horticulture, synthetic fuel production and many other carbon-based materials, replacing traditional carbon feedstocks from fossil fuels.
	Enabling technology, services and infrastructure	Enabling technology, services and infrastructure that are not expected to have direct economic or decarbonisation benefits but are crucial for the core or disruptive technologies to succeed. Advanced enabling technology, affordable services and access to physical and digital infrastructure as well as capability could further accelerate the R&D of decarbonisation technology and business model innovation. For example, fast charging technologies, charging services and innovative business models with access to charging stations and networks could enable the uptake of electric vehicles.
Workforce & Skills	New skills development	While conventional engineering, manufacturing, project management and operation skills will still be in demand, new technology-driven skills will be required for the future workforce. Both specialists and generalists are in demand for low carbon technology rollout. Industry-wide upskilling would benefit services providers, tradespeople and sustainability professionals taking advantages of global decarbonisation strategies. For example, new skillsets, knowledge and on-the-job training related to data analytics, digital design, automation and AI will be needed for future net zero industries.
	Workforce transition	Emissions-intensive industries and workforces will be highly exposed to structural changes during the net zero transformation. The demand of those occupations will not decline but will transition from fossil fuel- based industries towards clean energy and low-emissions industries. Some workforces can be easily transformed but some areas will require training and upskilling to ensure a smooth transition. For example, coal mining workforces can be easily deployed for mineral and rare earth metal mining industries. In contrast, car mechanics are likely to need support to transition to electric vehicle servicing and maintenance.
	Future generation education	The career pathways in the Australian clean energy industry include tertiary education, vocational education and training, workforce transition or skilled migration. Each of these pathways faces obstructions that limit the pool of skills and talent entering the industry.

DIRL pillar	DIRL indicator	Indicator description and example
Public Levers & Government Leadership	Strategic direction and leadership	Incorporating decarbonisation in business and government strategies will assist to prioritise and manage the transition from high emission energy sources to low emission. This will demonstrate the organisation's commitment to sustainability, potentially providing a competitive advantage.
	Policy and regulatory guidance	State and federal government policy and regulatory guidance needs to be clear and aligned, with consistent decarbonisation/net zero targets to all stakeholders. Policies can incentivise transition, manage risks – particularly during early transition – and set the pace and interactions for stakeholders.
	Public procurement and funding	Government procurement and funding can drive innovation and mobilise action.
Industry Development & Investment	Commercial-ready and commercial projects	Commercially competitive technologies require significant private investment for pilot, demonstration and deployment stages. The quantity of commercial-ready/commercial projects and investments in them is a direct indication of new technology uptake rate and readiness level.
	International collaboration	The supply and value chains are more integrated with trade, R&D collaboration and decarbonisation policies worldwide. Engagement between technology vendors, services providers, renewable energy importers and suppliers has become extremely important in forming partnerships and relationships for mutual benefits. International partnerships for advancing technology development and deployment of commercial projects are essential for a future global green economy.
	Local manufacturing capability and/or access to global supply chain	Disruptions to supply chains are a threat to progress in decarbonisation projects. These can be addressed by having and expanding local manufacturing capability, supported by a skilled workforce. Where the local manufacturing capability is limited or not available, access to global supply chains needs to be secured through diversification.

Data and Assessment

NSW DIRL conducts qualitative assessment for sectors, including energy, transport, built environment, industry, land and agriculture. Based on the DIRL framework and data, each sector has been awarded a readiness level of high, medium or low (Figure 2).

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

Figure 2 DIRL Illustration

The readiness level assessment is based on a range of data including scientific literature, analytic data and stakeholder consultation. Analytic data was drawn from a wide range of creditable sources. See Table 2 data inputs for DIRL assessment.

Table 2: DIRL Assessment data and analysis examples

DIRL pillar	Data and analysis examples	Data Date
Technology & services	NSW Decarbonisation Innovation Technology Map (external analysis by NSW Decarbonisation Innovation Hub)	February 2023
	NSW Decarbonisation Capability Map (external analysis by NSW Decarbonisation Innovation Hub)	February 2023
	NSW 20-Year R&D Roadmap including data sources on Excellence in Research Australia Outcomes (2018-19), Australian Research Council National Competitive Grants Program Projects datasets (2012-2021) and CWTS Leiden Ranking (2021) (OCSE internal analysis)	December 2021
Workforce & skills	NSW Decarbonisation Capability Map (external analysis by NSW Decarbonisation Innovation Hub)	February 2023
	NSW 20-Year R&D Roadmap including data sources on: QS University Rankings by Subject (2021), Shanghai Ranking's Global Ranking of Academic Subjects (2021), Australian Higher Education Completions Data (2015-2019) (OCSE internal analysis)	December 2021
Public levers & government leadership	NSW Government Climate Program Map and Australia Juridical Map (NSW Government internal analysis)	September 2022
	NSW Government Net-Zero Policies and Program Update for NSW Decarbonisation Innovation Study 2023 (OCSE and NSW Government internal analysis)	October 2022
Industry development & Investment	NSW Decarbonisation Capability Map (external analysis by NSW Decarbonisation Innovation Hub)	February 2023
	NSW 20-Year R&D Roadmap including data sources on DFAT Trade Statistical Pivot Tables, ABS International Trade in Goods and Services and ABS Australian State Accounts (OCSE internal analysis)	December 2021

While the initial results generated by the framework are promising, it is essential to note that DIRL serve as indicators rather than definitive conclusions. The assessment framework will evolve through the incorporation of feedback, new data and integrating emerging research.

Case Studies

Case Study 1: KPMG Net Zero Readiness Index

KPMG's Net Zero Readiness Index (NZRI)[1] is a tool that compares the progress of 32 countries to reduce their greenhouse gas emissions and assesses their preparedness and ability to achieve Net Zero emissions by 2050.

The KPMG's NZRI considers 103 indicators for each of the 32 countries. These have been split between two key elements – national preparedness and sector readiness.

- National preparedness considers a country's national commitment to decarbonise, its past decarbonisation performance and the national enabling environment for decarbonisation
- Sector readiness, which covers electricity and heat, transport, buildings, industry, and agriculture, land use and forestry. An example of sector readiness is the example of Australia which is ranked 17th among the 32 countries.

Case Study 2: EY Middle East and North Africa Climate Change Readiness Index

EY launched its Middle East and North Africa (MENA) Climate Change Readiness Index (CCRI) in 2023[2]. The MENA CCRI is designed to help countries in the region assess and improve their resilience to the impacts of climate change. The Index measures the readiness of the six members of the Gulf Cooperation Council as well as Egypt and Jordan. Areas measured include the effectiveness of their adaptation and mitigation strategies and their ability to finance and implement these strategies. The Index provides scorecards that can assist governments, investors and citizens in tracking performance compared to global benchmarks on 37 quantitative and qualitative indicators of climate change readiness. It also offers a comprehensive overview of the regional and global context in which these countries operate, including the economic, political and social factors.

[1] KPMG (2020). Net Zero Readiness Index.
[2] EY (2023). Middle East and North Africa (MENA) Climate Change Readiness Index.

2. Decarbonisation Technology Mapping

The following set of tables updates the technology mapping tables in the NSW Decarbonisation Innovation 2020 Study. Price points, time to market and interdependencies as well as Technology Readiness Level and Commercial Readiness Index[3] have been updated by NSW Decarbonisation Innovation Hub (the Hub). As they are a point in time, the Hub proposes to monitor NSW progress and update this information through their website.

Electricity Mapping

Technology	Brief description	TRL/ CRI	Price points	Time to market	Interdependencies (technologies)	Comments
Building integrated photovoltaics	Building integrated photovoltaics (BiPV) are solar panels integrated into building materials, such as roofs, façades or windows.	9/4	0.09 EUR/kWh (2021) LCOE for BIPV system as a building envelope material for the entire outer skin of the building. 0.14 USD/kWh (2021)	Un-mastered technology, available to overseas market.		
Community batteries	Community batteries are large-scale energy storage systems connected to multiple homes, creating decentralised energy storage hubs.	9/2	~400,000 AUD/battery (150kW/267kWh). Client subscription: 1.20 AUD/day for 4kWh or 1.40 AUD/day for 8kWh of storage. Expected savings of 100-300 AUD/year to clients.	Available to market.	Battery technology VPPs Microgrids.	
Compressed air energy storage	Compressed air energy storage (CAES) involves pumping air into a pressurised vessel, which can be later used to generate electricity.	9/4	0.061 USD/kWh (2012) 400-800 USD/kW (2009–2014) 2-50 USD/kWh (2009–2014) Capital cost based on energy and power.	Un-mastered, available to market.		
Concentrated solar thermal	Concentrated solar thermal (CST) energy involves using mirrors or lenses to focus	8/4	0.114 USD/kWh (2021)	Technology highly developed and	Development of PCMs, MGAs and	

[3] The Technology Readiness Level and Commercial Readiness Index (TRL/CRI column) reflect the progression of a technology through the phases of research, development, demonstration and commercial deployment. There is some overlap between the TRL and CRI. The TRL is a globally accepted technology benchmarking tool and is a scale that encompasses all phases from blue sky research (TRL 1) to actual system demonstration over the full range of expected conditions (TRL 9). The CRI has been developed by ARENA as a tool for assessing the 'commercial readiness' of renewable energy solutions and it encompasses all stages from hypothetical commercial proposition (CRI 1) to a technology becoming a bankable asset class (CRI 6).

Technology	Brief description	TRL/ CRI	Price points	Time to market	Interdependencies (technologies)	Comments
	sunlight, producing high-temperature heat that drives turbines to generate electricity.			commercialised in other countries. Multiple small projects operating in Australia.	salts. High efficiency heat exchangers.	
Diffuser-augmented wind turbine	A diffuser-augmented wind turbine increases power output using a diffuser to increase airflow.	9/6	0.66 AUD/kWh (2021), based on 700 kWh per system per year and a bulk cost of 1000 systems at ~3000 AUD (2020) over 20-year lifetime.	Limited market availability.		
Electrochemical battery (Li-ion)	A rechargeable lithium-ion battery uses lithium ions to store and release electrical energy.	9/6	0.360 USD/kWh (2023), 1200-4000 USD/kW (2009-2019), 100-2500 USD/kWh (2009-2019)	Available to market.	Development of charge-holding lithium composites.	
Energy harvesting	Energy harvesting technologies involve harvesting energy from ambient power sources including sound, humidity, heat, vibration/motion and electric fields from power lines. They can provide power for sensors and other low-demand applications where other power sources are not viable.	4/1	NA	Available to market.		
Flow battery	A rechargeable flow battery stores energy in liquid electrolyte solutions, providing longer battery life and greater flexibility for energy storage applications.	9/4	LCOS: 0.23 USD/kWh (10 MW/40 MWh), 0.306 USD/kWh (2023), 0.266-0.312 USD/kWh (2012).	Un-mastered, available to market.	Membrane/catalyst development.	
Flywheel	A flywheel is a mechanical battery that stores kinetic energy by spinning a rotor and is capable of releasing energy rapidly and efficiently in a short amount of time.	5/1	Capital cost: 300-1000 USD/kW (2019), 3000-6000 USD/kWh (2019). LCOS: 0.186 USD/kWh (2023).	Available to market.	Room temperature superconducting materials High specific strength and low-density materials.	
Onshore wind turbines	Onshore wind farms generate electricity using wind turbines placed on land.	9/6	0.075 USD/kWh (2021)	Available to market.		
Offshore wind turbines	Offshore wind farms generate electricity using wind turbines placed in the ocean, taking advantage of stronger and more consistent wind speeds.	9/6	0.033 USD/kWh (2021)	Development required for widespread Australian utilisation.		Supply chain constraints.

Technology	Brief description	TRL/ CRI	Price points	Time to market	Interdependencies (technologies)	Comments
Latent heat thermal energy storage (MGAs)	Miscibility gap alloys (MGAs) store thermal energy at high temperatures owing to their high latent heat capacity.	8/2	37 USD/kWh (2020)	Technology proven, large scale use case and production developing.	Concentrated solar thermal.	
Latent heat thermal energy storage (PCMs)	Phase change materials (PCMs) store thermal energy in materials over a narrow temperature difference owing to the latent heat of phase transition.	9/4	20-40 USD/kWh (2019)	Available to market, growing industry and improving materials.	Concentrated solar thermal.	
Liquid air energy storage	Liquid air energy storage involves using excess energy to cool and liquefy air, which can be expanded to generate electricity as required.	9/5	Key link to number of cycles per year. Coupling with organic Rankine cycle decreases LCOS by 10% 0.17 USD/kWh (2020) (price of electricity at 0.03 USD/kWh and 365 cycles per year).	Un-mastered, available to market.	Cryogenics.	
Microgrids	DER and off-grid power system management technologies enable users to generate, store and manage their own power independently of the main power grid.	9/4	Directly related to the size of the system and the technology used.	Available to market.	Battery technology Solar PV Renewable grid resource response and management.	
Organic printable photovoltaics	Organic printable photovoltaics are a type of solar cell made from organic materials that can be printed onto surfaces like plastic or paper, allowing for flexible and lightweight solar panels.	7/1	0.49–0.85 USD/kWh (2009), based on 50–140 USD/m^2, 5-year lifetime and 5% efficiency. 0.12 USD/kWh (2014) with decreased manufacturing cost to 7.4 USD/m^2 (2014), 5-year lifetime and 5% efficiency.	Un-mastered, available to market.		Strong link to improvements in efficiency, degradation, and lifetime.
Pumped hydro-electric storage	Pumped hydro-electric storage uses surplus energy to pump water to a high elevation, which can be recovered via turbine at a lower reservoir.	9/6	1.8 AUD/W (2020) for 1 GW/14 GWh system	Available to market.	Turbine technology improvements.	
Renewable grid resource response and management	Energy management systems maintain grid stability through coordinating the response of renewable energy and other distributed energy resources.	8/4	NA	Un-mastered, available to market.		
Sensible heat storage (thermocline)	A thermocline energy storage tank stores heat energy by separating hot and cold	6/1	19 USD/kWh (2022)	Un-mastered, available to market.	Use of CST.	Terrafore developed PCM encapsulated balls for use in a single tank.

Technology	Brief description	TRL/ CRI	Price points	Time to market	Interdependencies (technologies)	Comments
	fluids through changes in density, allowing for on-demand heating or cooling.					
Sensible heat storage (tube in concrete)	Sensible heat storage using a tube in concrete involves circulating a heat transfer fluid through a tube embedded in concrete to store thermal energy.	7/1	0.8-1 USD/kWh (2013)		Concrete composition enhancement.	
Smart appliances	Devices with sensors and communication enable two-way communication with grids to optimise energy use, reduce costs and provide remote control.	9/6	For smart water heaters, interface adds about 10 AUD (2013) to cost of appliance and activation 75–180 AUD (2013). Lower operating costs provide a positive return on investment well within unit lifetimes.		VPPs Digital analytics and monitoring Communications infrastructure.	
Solar paint	Solar paint involves applying photosensitive materials to complex surfaces to generate solar power.	7/1	NA			
Solar photovoltaics	Conventional solar photovoltaics uses crystalline silicon structures to convert solar energy directly to electricity in residential, commercial and utility-scale settings.	9/6	48 USD/MWh (2021) (utility scale)	Available to market.		Lowest LCOE (without firming technologies).
Solid mass gravitational energy storage	Solid mass gravitational energy storage involves using surplus energy to move solid masses such as rocks or concrete blocks to a higher elevation and releasing this energy by lowering the solid masses.	7/1	0.05-0.11 USD/kWh (2018), depending on capacity	Un-mastered, available to market.	NA	
Solid particle thermal energy storage	Solid particle thermal energy storage involves heating and storing solid materials, such as ceramics, rocks or salts, that have high melting points and heat capacities, which can then be used to generate electricity or provide heat for various applications.	5/1	2 USD/kWh (2020)	In development.		
Solid state transformers	Solid state transformers (SSTs) use power electronics and high-frequency magnetic materials to convert and distribute power more efficiently than traditional	4/1	The cost of a standard low frequency transformer for AC/DC applications is ~30 USD/kVA (2014). The	Not yet widely adopted, but becoming commercially viable in some applications, such as data centres, EV	Power electronics Advanced materials Control systems.	

Technology	Brief description	TRL/ CRI	Price points	Time to market	Interdependencies (technologies)	Comments
	transformers, which rely on low-frequency magnetic cores.		solid state counterpart is about 1.14 times more expensive at 34.1 USD/kVA (2014).	charging stations, and RE systems.	Integrated network communication.	
Supercapacitors	Supercapacitors are high capacity capacitors useful for small-scale energy storage.	9/4	200-400 USD/kW (2009) 500-1000 USD/kWh (2009)	Available to market.	Graphene/graphite technologies Complement to other energy storage technologies, such as Li-ion batteries.	
Superconducting magnetic energy storage	Surplus energy can be stored in the magnetic field of a superconducting wire coil with a near-zero energy loss.	5/1	200-300 USD/kW (2009) 1000-10,000 USD/kWh (2009)	Technology proven, but use case and cost need to be developed for market uptake. High temperature superconductors are developing rapidly with aid of modern supercomputing power.	High temperature superconductor development	
Thermochemical energy storage	Thermochemical energy storage involves storage of heat through a reversible chemical reaction.	5/1	0.106 USD/kWh (2022) Estimate for a reversible calcium reaction	In development.		
Thermomechanical energy storage - pumped heat	Pumped heat energy storage involves pumping heat from a cold storage tank to a hot discharge tank, which can then be discharged to drive a generator.	9/2	0.03–0.06 USD/kWh (2017)	Un-mastered, available to market. Pilot plants demonstrated outside of Australia.		
Tidal power	Tidal power is the use of turbines to generate power from the currents flowing due to tidal movements.	9/1	Levelised cost of 81.25 GBP/MWh (2011)			
Vertical axis wind turbine	A vertical axis wind turbine has its main rotor shaft set vertically, and the blades attached to the rotor in a vertical orientation, providing the ability to capture wind from any direction and a smaller ground footprint than horizontal axis turbines.	9/6	0.27 USD/kWh (2018) near term cost basis. Projected 0.11 USD/kWh (2018) (floating offshore).	Un-mastered, available to market.		
Virtual power plants (VPPs)	Virtual power plants involve coordinated control of consumer distributed energy resources (DER).	9/5	NA	Un-mastered, available to market.	Smart appliances	

Technology	Brief description	TRL/ CRI	Price points	Time to market	Interdependencies (technologies)	Comments
Wave power	Wave power generation is a technology that converts the kinetic energy of ocean waves into electricity.	9/2	Levelised cost of 189.66 GBP/MWh (2011)			

Agriculture and Land Use Mapping

Technology	Brief description	TRL/ CRI	Price points	Time to market	Interdependencies (technologies)	Comments
Bagasse bioenergy	Bagasse bioenergy is a process that involves burning of sugarcane waste to generate power.	9/4	Competitive in NEM	Available to market where sugar milling occurs.		Queensland Government's 10-year Energy Plan of $4 million to fund feasibility and technical studies to identify options and pathways to expand bioenergy generation and support technology innovation in the bioenergy sector. A key finding of the ASMC's preliminary work was that the sugar milling sector had the potential, under the right policy and commercial conditions, to significantly increase its co-generation capacity and generate more renewable power for Queensland consumers.
Biodiesel and bio-aviation fuel	Biodiesel and bio-aviation fuel are alternative fuels made from renewable resources, such as vegetable oils, animal fats, and recycled cooking oils.	9/2		Available to market in small quantities.		
Bioethanol	Bioethanol is a renewable fuel made from plant matter by fermenting sugars into ethanol, used as a sustainable alternative to fossil fuels.	9/4	IPART determined wholesale price of ethanol is 1.672 AUD/L from 1 January 2023, comparable with regular unleaded petrol.	Available to market.	Biomass hydrolysis	There is a mandate in NSW for 4% of ethanol in unleaded petrol.
Biogas	Biogas can be produced from Anaerobic Digestion (AD) or pyrolysis and gasification of organic matter. It comprises 50–70% methane, 30–50% carbon dioxide and traces of other gases.	9/4		Available to market.	Biomass pyrolysis and gasification	
Biomass for bioenergy	Woody biomass crops can be burned to generate heat or electricity. Biomass can	8/4		Available to market.		

Technology	Brief description	TRL/ CRI	Price points	Time to market	Interdependencies (technologies)	Comments
	be grown directly or diverted from waste streams such as forestry wastes.					
Biomass hydrolysis	Lignocellulosic biomass can undergo hydrolysis to convert it into sugars, which can be subjected to fermentation to produce ethanol.	7/2			Bioethanol	
Biomass pyrolysis and gasification	Pyrolysis and gasification offer ways of converting solid biomass into an easily stored and transported liquid and gas fuels. A wide range of biomass feedstocks can be used in pyrolysis and gasification processes.	9/2				
Blue carbon	Blue carbon refers to carbon captured and stored by coastal ecosystems, including mangroves, seagrasses, kelp and salt marshes.	6/1		In development.		
Bushfire prevention	Greenhouse gas emissions from burning of Australia's temperate forests can be avoided through bushfire prevention.	8/6	NA			
Fugitive emissions abatement	Fugitive emissions abatement involves estimating fugitive methane emissions from open cut coal mining operations and mitigating these methane emissions using underground mine ventilation air.	8/3	NA			
Commercial kangaroo harvesting	Kangaroo harvesting involves sustainably taking kangaroos from the wild and processing them for food and other products.	9/4	1 AUD/kg wholesale for unprocessed carcass. 20-24 AUD/kg retail for premium cuts.	Available to market.		
Edible insects	Insect derivatives such as meal worm and cricket flour can be used as nutrient- and protein-rich ingredients in manufactured food products.	9/4	150 AUD/kg retail for cricket protein powder	Available to market.		
Enteric emissions reduction	Use of Asparagopsis (Red seaweed) as a feed ingredient for livestock can reduce enteric methane emissions.	8/3		Currently on the market, supplies expected to rapidly expand by 2025.		
Improved fertiliser application	Improved fertiliser application can decrease GHG intensity per tonne of grain up to 20%, while increasing production.	6/1				

Technology	Brief description	TRL/ CRI	Price points	Time to market	Interdependencies (technologies)	Comments
Microalgal carbon capture	Microalgal carbon capture involves growing microalgae in a controlled environment for direct capture of CO2 for sequestration or feedstock for biofuels, bioplastics etc.	4/2		In development.		
Microbial carbon sequestration	Microbial carbon sequestration involves creating formulations of microbial fungi and bacteria that support plant growth and rapidly build stable forms of soil organic carbon.	7/2		In development.	Soil carbon sequestration	
Mineral carbonation	Mineral sequestration aims to trap carbon in the form of solid carbonate salts.	4/1	NA			
Protected cropping	Protected cropping involves using polytunnels and glasshouses to grow crops	9/6	NA	Available to market		
Regenerative farming	Regenerative farming provides products to enhance the biological pump in the soil system.	9/4	NA	Available to market		
Soil carbon sequestration	Soil carbon sequestration involves storing carbon in soils through improved land management.	9/4	N/A	Available to market.		
Vegetation carbon sequestration	Vegetation carbon sequestration involves storing carbon in plant matter through improved land management.	9/5	NA	Available to market.		
Vertical farming	Vertical farming is an indoor farming method that uses stacked layers to grow crops, maximising space efficiency and reducing water usage.	8/4	Breakeven cost of production of about 3.07 USD/lb (2022), compared to 0.65 USD/lb (2022) for conventional outdoor farm.	Available to market for leafy greens and herbs with short growing periods. Requires reductions in capital and energy costs for widespread adoption.	Protected cropping Solar PV LED lighting	

Industry, Building and Infrastructure Mapping

Technology	Brief description	TRL/ CRI	Price points	Time to market	Interdependencies (technologies)	Comments
Air-source heat pump	An air-source heat pump extracts heat from air and transfers it for either space heating/cooling or water heating.	9/5	Retail price of 250 L heat pump domestic water heater before installation and government rebates is about 2800 AUD (2500 AUD with installation and rebates), compared to 1170 AUD (1500 AUD) for a conventional storage electric unit. Lifetime operating cost of heat pump unit is about 3400 AUD, compared to 5500 AUD for conventional unit.	Available to market.		
Engineered timber	Engineered timbers includes cross-laminated timber (CLT), glued laminated timber and plywood. CLT is made from machine-graded, kiln-dried radiata pine, which is finger jointed, dressed and arranged to form a solid timber panel.	9/6	NA	Available to market.	Wood milling technologies	
Inert electrodes for aluminium smelting	Replacing the carbon anodes conventionally used for aluminium smelting with inert materials can reduce Scope 1 emissions.	7/2	NA			
Geothermal/ ground source heat pump	Ground source heat pumps use the earth as a heat source for either space heating or water heating.	9/4	0.068 USD/kWh (2021) 0.56–0.93 USD/kWh (2021)	Limited feasible options, Available to Market		
Green concrete	Green concrete is a type of concrete that uses recycled materials and has lower carbon emissions than traditional concrete.	8/6				
Industrial process heat using biomass	Industrial process heat using biomass involves using organic wastes or other sources of biomass to generate fuels or heat for industrial processes.	9/3	0.067 USD/kWh (2021), though varies based on biomass composition and conversion process used.	Available to market		
Low carbon aluminium	Low carbon aluminium can be produced using renewable energy for electrolysis.	9/6	The BaU levelised cost of primary aluminium is 1679 USD/ton, with clean energy			

Technology	Brief description	TRL/ CRI	Price points	Time to market	Interdependencies (technologies)	Comments
			and inert anodes reducing the cost to 1589 USD/ton. The BaU levelised production cost of secondary aluminium is 1461 USD/ton. Using low carbon methods such as carbon capture or biofuels can increase the cost to 1511 USD/ton.			
Modular architecture	Modular architecture is a design approach that uses standardised components to create flexible, scalable structures, allowing for efficient production, customisation, and easy assembly of buildings, products and systems.	9/6	NA	Available to market.	Numerous technologies involved	
Recycled timber	Recycled hardwoods can be used for a variety of purposes, reducing the demand for new timber.	9/6	NA	Available to market.	Wood milling technologies	
Solar process heat	Solar process heat involves using sunlight to heat a fluid, which is then used in industrial processes.	8/2	Commercially viable for some applications. More cost effective than solar thermal electricity generation.	Available to market.		
Warehouse automation	Warehouse automation involves use of digital and physical process automation to supply streamlined and robotics-assisted workflows.	9/5	Varies based on complexity, depending on size, scope and processes.	Available to market.		
Wireless EV charging	Wireless EV charging uses coils underneath road surfaces to charge compatible electric vehicles while they are in use.	5/1	6.3-6.6 million USD/mile (2022)	Available to market for niche applications. Widespread adoption requires increased EV uptake and suitable business case.		

Transport Mapping

Technology	Brief description	TRL/ CRI	Price points	Time to market	Interdependencies (technologies)	Comments
Autonomous drones	Autonomous drones can deliver goods to clients, replacing courier vans.	7/1	Trials and estimations point towards reductions of 70-80% of traditional delivery expense	Available to market, but dependent on development of policy, private industry uptake and social licence to operate.		
Autonomous vehicles	Autonomous vehicle technology allows for driverless shuttle buses and cars for public and private transportation.	9/4	Current difference in cost between Tesla with and without autopilot is 7000 USD, with most of the hardware already existing on the car. A driverless shared-vehicle future may decrease costs per mile from ~1 USD/mile to ~0.3 USD/mile.	Timeline in Australia is closely tied to pace of technology development, infrastructure upgrades, and regulatory approvals.	Artificial intelligence, machine learning, Computer vision and sensor technology, Global Navigation Satellite Systems (GNSS) and mapping.	
BEV passenger vehicle	A BEV passenger vehicle uses a chemical battery to store electricity, which then drives an electric motor.	9/6	0.43 AUD/km (2023). Five-year cost of ownership for 2019 Nissan Leaf is 39,200 AUD versus 35,600 AUD for Nissan Pulsar (2016). Running cost per month is 110 AUD (EV) versus 350 AUD (FF).	Available to market.	Li-ion batteries	
BEV trucks	A BEV small or large haulage truck uses a chemical battery to store electricity, which then drives an electric motor, as a fossil fuel replacement.	9/6	TCoO on an EV truck is stated to be 1.26 USD/mile versus 1.51 USD/mile for diesel.	Limited market availability.	Li-ion batteries	
E-bikes and scooters	E-bikes and scooters can provide cost-effective and distributed public personal transportation.	9/6	Beam = 1 AUD + 0.65 AUD/min Lime = 1 USD + 0.15-0.25 USD/min Bird = 1 USD + 0.15 USD/min Lyft = 1 USD + 0.20-0.39 USD/min	Available to market.		

Technology	Brief description	TRL/ CRI	Price points	Time to market	Interdependencies (technologies)	Comments
Electric aircraft	Aircraft with batteries and electric motors can be used as a replacement for jet fuel turbine engines on short-haul flights.	9/5		Limited availability in market. Widespread commercial viability likely in 2030s, depending on development of battery technology.	Li-ion batteries	
Hydrogen FCEV - ferry	Ocean-going ferries can use hydrogen as a source of fuel through fuel cells and electric powered propulsion.	9/3	Total cost of Australian Sealink project estimated at 20.6 million AUD.	First hydrogen-ready ferries delivered in Norway 2021. Will set sail 'once supply becomes available'.	Hydrogen production Electrolysers Hydrogen storage Fuel cells	
Hydrogen FCEV - heavy road transport	Heavy fuel cell electric vehicles (FCEVs) are zero emission vehicles that use an electric motor powered by a hydrogen fuel cell.	9/4	300,000-900,000 AUD per vehicle. Hydrogen costs of 7-10 AUD/kg are needed to be comparable with diesel trucks.	Available to market	Hydrogen production Electrolysers	While hydrogen fuel cell vehicles have higher related costs compared to BEVs, they maintain several advantages including faster charge times, and a longer range, which are important considerations for effective road transport.
Hydrogen FCEV - passenger and light vehicles	Light fuel cell electric vehicles (FCEVs) are zero emission vehicles that use an electric motor powered by hydrogen fuel cell.	9/5	100,000-120,000 AUD per vehicle.	Available to market	Hydrogen production Electrolysers Fuel cells	While hydrogen fuel cell vehicles have higher related costs compared to BEVs, they maintain several advantages including faster charge times, and a longer range, which are important considerations for effective road transport.
Hydrogen FCEV - regional train	Hydrogen fuel cell electric rail is an emission-free alternative to diesel powered trains using green hydrogen as fuel through fuel cell technology.	9/2	Recent German fleet of 14 hydrogen trains cost ~10 million AUD per train.	Available to market	Hydrogen production Electrolysers Fuel cells	A fleet of hydrogen powered trains have been implemented in Germany at a cost of 92 million EUR. However, the German state of Baden-Wurttemberg will no longer consider hydrogen trains as a possible replacement after a commissioned study found that installation of overhead electricity lines and battery

Technology	Brief description	TRL/ CRI	Price points	Time to market	Interdependencies (technologies)	Comments
						powered hybrid trains to be more economical solutions.
Solar vehicles	Electric vehicles with integrated photovoltaic panels offer extended range and can charge themselves while parked.	9/4	29,900 EUR (2023) for Sion model from Sonos Motors.	Limited availability to market.	Solar PV Li-ion batteries EV charging infrastructure	
Taxi/rideshare	Electric taxi and rideshare services can provide a more cost-effective and lower emission transport option for passengers compared to private vehicles.	9/6	~3 AUD + 0.4 AUD/min + 1.45 AUD/km	Available to market.		

Energy Conversion Technology Cluster Mapping

Technology	Brief description	TRL/ CRI	Price points	Time to market	Interdependencies (technologies)	Comments
Blue hydrogen production through SMR with carbon capture	Blue hydrogen is produced from natural gas or coal and is supported by carbon capture technologies to lower emissions.	9/6	Price-competitive with green hydrogen production	Available to market.	CCS technologies	Cheapest production method with existing industry infrastructure and assets. Guarantees of origin for clean hydrogen production and possible certification scheme in Australia. Discussions over the sustainability of fossil-derived feedstocks and their certification as clean fuels.
Green hydrogen	Green hydrogen is produced via the electrolysis of water using renewable energy.	9/4	National target of 2 AUD/kg production cost by 2030	Electrolytic hydrogen projects totalled a capacity of 0.7 GW in 2021 with many more planned in the next few years. Include recent 150 MW Chinese project, which began operations in Feb 2022, and 300 MW renewable hydrogen plant in China, which is planned to open in June 2023.	Renewable energy Power convertors Buffering technologies (e.g. battery)	The national economic target of 'H2 under 2' is the production cost when hydrogen becomes competitive with alternatives for large scale deployment. The price point for each sector depends on end-user applications e.g. FCEV vs ICE.
Green steel	Green steel is produced by a direct reduction iron and electric arc furnace with hydrogen replacing natural gas.	7/2	1000-1700 AUD/t steel	First large-scale green steel plant to open in 2030, producing 5 million t/year in Boden Sweden.	Hydrogen production cost, electrolyser costs	Australian company BlueScope Steel is currently investigating carbon capture and fuel blending options and recently stated that green steel production using hydrogen only will require time.
Power to ammonia	Power-to-ammonia produces green ammonia by using renewable green hydrogen to replace fossil-derived hydrogen in a conventional Haber-Bosch ammonia production plant.	9/6	750 USD/t in 2022. Projected 500 USD/t in 2030	Demonstration projects operational around the world. 2025-2030 for hundreds of MW plant size.		The conversion technologies for the production of green ammonia is identical to current industrial Haber Bosch ammonia production

Technology	Brief description	TRL/ CRI	Price points	Time to market	Interdependencies (technologies)	Comments
						and thus can also be considered mature.
Synthetic liquid organics	Synthetic liquid organics such as methanol and synthetic fuels are produced from carbon dioxide captured from waste resources or direct air capture by reaction with renewably produced green hydrogen.	7/2	Projected 1.26 EUR/L in 2030 and 1.00 EUR/L in 2050	Demonstration projects operational around the world. 2025-2030 for hundreds of MW plant size.	Carbon capture, integration with intermittent renewables	The conversion technologies for the production of synthetic liquid organics such as methanol and other synthetic fuels are very similar to current industrial technologies for methanol synthesis and SASOL FT synthetic fuels and thus can also be considered mature.
Synthetic methane	Synthetic or green methane is produced from carbon dioxide captured from waste resources or direct air capture through reaction with renewable green hydrogen.	8/3	Projected 0.14 EUR/kWh in 2030 and 0.11 EUR/kWh in 2050	Demonstration projects currently in operation. Scaleup expected in 2025-2030.	Carbon capture	

Platform Technologies Mapping

Technology	Brief description	TRL/ CRI	Price points	Time to market	Interdependencies (technologies)	Comments
Digital analytics and monitoring	Digital analytics and monitoring systems allow tracking, analysing and optimising the performance of renewable energy sources for businesses and homes such as solar panels and energy storage systems.	9/4	Subscription-based or one-off fee. Cost depends on complexity of analysis and monitoring. e.g. Solar Analytics costs 5.99-99.99 AUD/year or up to 800 AUD for 10 years for systems larger than 15 kW.			
Energy trading (blockchain)	Blockchain-based energy trading platforms may enable peer-to-peer trading, virtual power plants, and renewable energy certificates.	8/2	NA	Pilots in progress. Adoption likely several years away.	VPPs Smart grids	
Gene technology	Gene technology involves changing the genome of an organism to express positive attributes.	9/5	NA	Available to market since 2001.		
Synthetic biology	Synthetic biology is the rapid development of functional DNA-encoded biological components and systems through the application of engineering principles and genetic technologies.	3/1	NA	2025-2030		

3. NSW Decarbonisation Innovation Ecosystem Mapping

This is an updated table of the NSW's research and development capabilities included in the 2020 Decarbonisation Innovation Study. It has been prepared by the NSW Decarbonisation Innovation Hub and is a point in time. The Decarbonisation Innovation Hub will be progressively updating this information.

Sector	Organisation	Primary role
Built environment	Australian Climate Change Adaptation Research Network for Settlements and Infrastructure (UNSW Sydney)	Policy development & strategy
Built environment	Australian Urban Research Infrastructure Network (AURIN)	R&D (early stage)
Built environment	Centre for Advanced Structural Engineering (CASE) (University of Sydney)	R&D (early stage)
Built environment	Centre for Built Infrastructure Research (University of Technology, Sydney)	R&D (early stage)
Built environment	Centre for Infrastructure Engineering (Western Sydney University)	R&D (early stage)
Built environment	Centre for Infrastructure Engineering and Safety (CIES) (UNSW Sydney)	R&D (early stage)
Built environment	Centre for Smart Modern Construction (Western Sydney University)	R&D (early stage)
Built environment	Centre for Sustainable Material Research & Technology (SMaRT) (UNSW Sydney)	R&D (early stage)
Built environment	City Analytics Labs (Fac of Built Env) (UNSW Sydney)	R&D (early stage)
Built environment	City Futures Research Centre (CFRC) (UNSW Sydney)	R&D (early stage)
Built environment	Geospatial Research Innovation Development (UNSW Sydney)	R&D (early stage)
Built environment	Planning Research Centre (PRC) (University of Sydney)	R&D (early stage)
Built environment	Smart Green Cities (Macquarie University)	R&D (early stage)
Built environment	Sustainable Buildings Research Centre (SBRC) (University of Wollongong)	R&D (early stage)
Electricity	Amotus	Market development - systems integration
Electricity	ARC Research Hub for Microrecycling of Battery and Consumer Wastes	R&D (early stage)
Electricity	ARC Training Centre for The Global Hydrogen Economy	R&D (early stage)
Electricity	ARC Training Centre in Energy Technologies for Future Grids	R&D (early stage)
Electricity	Australian Centre For Advanced Photovoltaics (UNSW Sydney)	R&D (early stage)
Electricity	Centre for Smart Power and Energy Research	R&D (early stage)
Electricity	Collaboration on Energy and Environmental Markets (CEEM) (UNSW Sydney)	R&D (early stage)
Electricity	Deakin Energy Networks	R&D (early stage)
Electricity	Future Battery Industries CRC (FBI CRC)	R&D (early stage)
Electricity	Intyalheme Centre for Future Energy, Desert Knowledge Research Institute	R&D (early stage)
Electricity	NREL	R&D (early stage)
Electricity	Priority Research Centre for Organic Electronics (COE) (University of Newcastle)	R&D (early stage)
Electricity	UNSW Engineering (UNSW Sydney)	R&D (early stage)
Industry	Advanced Manufacturing Technologies (AMT) (University of Wollongong)	R&D (early stage)
Industry	ARC Centre of Excellence in Synthetic Biology	R&D (early stage)
Industry	ARC Research Hub for Transforming Waste Directly in Cost-Effective Green Manufacturing	R&D (early stage)
Industry	ARC Steel Research Hub	R&D (early stage)
Industry	ARC Training Centre for Food and Beverage Supply Chain Optimisation	R&D (early stage)
Industry	Australian Institute for Innovative Materials (AIIM) (University of Wollongong)	R&D (early stage)

Sector	Organisation	Primary role
Industry	Centre for Technology in Water and Wastewater (University of Technology Sydney)	R&D (early stage)
Industry	Centre for Workforce Futures (Macquarie University)	R&D (early stage)
Industry	CRSPI (the Climate Research Strategy for Primary Industries)	R&D (early stage)
Industry	Digital Grid Futures Institute (UNSW Sydney)	R&D (early stage)
Industry	Hydrogen Industry Mission	R&D (early stage)
Industry	Institute for Superconducting and Electronic Materials (ISEM) (University of Wollongong)	R&D (early stage)
Industry	NSW Energy & Resources Knowledge Hub	R&D (early stage)
Industry	Renergi	R&D (early stage)
Industry	SmartCrete CRC	Market development - manufacturing
Industry	ARC Centre of Excellence for Australian Biodiversity and Heritage	Commercialising
Industry	ARC Research Hub for Legumes for Sustainable Agriculture	Commercialising
Industry	ARC Training Centre for Advanced Technologies in Food Manufacture	Commercialising
Industry	ARC Training Centre for Functional Grains	Commercialising
Industry	ARC Training Centre in Food Safety in the Fresh Produce Industry	Funding - internal
Land	Australian Centre for Agriculture and Law (University of New England)	Market development - buyers/deal makers
Land	Centre for Advanced Food Enginomics (University of Sydney)	R&D (late stage)
Land	Centre for Agribusiness (University of New England)	R&D (early stage)
Land	Centre for Water Security and Environmental Sustainability (University of Newcastle)	Skills development, training, accreditation
Land	Centre for Water, Climate and Land (University of Newcastle)	Market development - buyers/deal makers
Land	CRC for High Performance Soils	R&D (early stage)
Land	Food Agility CRC	Market development - buyers/deal makers
Land	Future Food Systems CRC	R&D (early stage)
Land	Global Centre for Land-Based Innovation (Western Sydney University)	Commercialising
Land	Global Water Institute (UNSW Sydney)	Commercialising
Land	Grains Research and Development Corporation (GRDC)	R&D (early stage)
Land	Gulbali Agriculture, Water and Environment Institute (Charles Sturt University)	R&D (late stage)
Land	Institute of Agriculture (University of Sydney)	R&D (early stage)
Land	Mining3	Commercialising
Land	National Vegetable Protected Cropping Centre (Western Sydney University)	R&D (early stage)
Land	Priority Research Centre for Advanced Particle Processing and Transport (University of Newcastle)	Commercialising
Land	Queensland University of Technology	Market development - buyers/deal makers
Land	Sustainable Management Accessible Rural Technologies (SMART) Farm (University of New England)	R&D (early stage)
Land	Sydney Institute of Marine Science (SIMS)	Skills development, training, accreditation
Land	Allens Hub for Technology, Law and Innovation (UNSW Sydney)	R&D (early stage)
Land	ARC Centre of Excellence for Climate Extremes	Market development - buyers/deal makers
Land	ARC Centre of Excellence for Electromaterials Science (ACES)	Skills development, training, accreditation
Land	ARC Centre of Excellence for Enabling Eco-Efficient Beneficiation of Minerals	Market development - buyers/deal makers
Land	ARC Centre of Excellence for Quantum Computation and Communication Technology	Commercialising

Sector	Organisation	Primary role
Other	ARC Research Hub for Basin GEodyNamics and Evolution of Sedimentary Systems (GENESIS)	Policy development & strategy
Other	ARC Training Centre for Innovative Bioengineering	Knowledge and information sharing
Other	ARC Training Centre in Data Analytics for Resources and Environments (DARE)	R&D (early stage)
Other	ARC Training Centre in Fire Retardant Materials and Safety Technologies	R&D (early stage)
Other	Australian Centre for Climate and Environmental Law (University of Sydney)	R&D (early stage)
Other	Australian Centre for Field Robotics (University of Sydney)	R&D (early stage)
Other	Australian Nuclear Science and Technology Organisation (ANSTO)	Policy development & strategy
Other	Australian Power and Energy Research Institute (APERI) (University of Wollongong)	Policy development & strategy
Other	Central Queensland University	Funding - equity
Other	Centre for Advanced Energy Integration (University of Newcastle)	Knowledge and information sharing
Other	Centre for Advanced Materials Technology (CAMT) (University of Sydney)	Knowledge and information sharing
Other	Centre for Clean Energy Technology (University of Technology Sydney)	Market development - buyers/deal makers
Other	Centre for Energy (University of Western Australia)	Market development - buyers/deal makers
Other	Centre for Energy Technology (University of Adelaide)	Funding - equity
Other	Centre for Future Energy Networks (CFEN) (University of Sydney)	R&D (early stage)
Other	Centre for Law, Markets & Regulation (UNSW Sydney)	Policy development & strategy
Other	Centre for Renewable Energy and Power Systems (University of Tasmania)	R&D (early stage)
Other	Centre for Sustainable Energy Development (University of Sydney)	R&D (early stage)
Other	Charles Darwin University (CDU)	R&D (early stage)
Other	Charles Sturt University	R&D (early stage)
Other	Climate Change Cluster (C3) (University of Technology, Sydney)	R&D (early stage)
Other	Climate Change Research Centre (CCRC) (UNSW Sydney)	R&D (early stage)
Other	Climate Change, Human Health and Social Impacts Node (University of Sydney)	R&D (early stage)
Other	Climate, Society and Environment Research Centre (C-SERC) (University of Technology Sydney)	R&D (early stage)
Other	ClimateWorks Centre	Innovation servicing and support
Other	Cotton Research and Development Corporation (CRDC)	R&D (early stage)
Other	CSIRO	R&D (early stage)
Other	Curtin University	R&D (early stage)
Other	Electrical Power Systems Research Group (University of Adelaide)	R&D (early stage)
Other	Energy Systems Research Group (UNSW)	Innovation servicing and support
Other	Environmental and Climate Research Group (Newcastle University)	Policy development & strategy
Other	Federation University Australia	Funding - grants
Other	Future Industries Institute (University of South Australia)	R&D (early stage)
Other	Global Challenges Program (University of Wollongong)	R&D (early stage)
Other	Griffith University	R&D (early stage)
Other	Institute of Global Finance (IGF) (UNSW Sydney)	R&D (early stage)
Other	Intelligent Grid Cluster (University of Technology Sydney & CSIRO)	Incubation and acceleration
Other	Melbourne Energy Institute (University of Melbourne)	Policy development & strategy

Sector	Organisation	Primary role
Other	Monash Sustainable Development Institute	Knowledge and information sharing
Other	Monash University	Funding - grants
Other	Murdoch University	Funding - equity
Other	National Climate Change Adaptation Research Facility (Macquarie University)	Incubation and acceleration
Other	Newcastle Institute for Energy and Resources (NIER) (University of Newcastle)	Funding - debt
Other	NSW Decarbonisation Innovation Hub	Funding - equity
Other	Power and Energy Research Group (University of Melbourne)	Standards and regulation
Other	Priority Research Centre for Frontier Energy Technologies & Utilisation (University of Newcastle)	Policy development & strategy
Other	Renewable Energy and Energy Efficiency Research Group (University of Melbourne)	Funding - equity
Other	Solar Energy Technologies Research Group (University of Western Sydney)	Policy development & strategy
Other	Southern Cross University	Incubation and acceleration
Other	Sydney Environment Institute (SEI) (University of Sydney)	Skills development, training, accreditation
Other	University of New England (UNE)	Standards and regulation
Other	University of New South Wales	Incubation and acceleration
Other	University of Newcastle	R&D (early stage)
Other	University of Sydney	Policy development & strategy
Other	UNSW Energy Institute	Funding - equity
Other	Warren Centre for Advanced Engineering (University of Sydney)	Funding - debt
Other	Western Sydney University	R&D (early stage)
Other	Centre for Local Government (University of New England)	R&D (early stage)
Other	Centre for Social Research and Regional Futures (Newcastle University)	Policy development & strategy
Other	Centre for Urban and Regional Studies (University of Newcastle)	R&D (early stage)
Other	CRC for Contamination Assessment and Remediation of the Environment (crcCARE)	R&D (early stage)
Regional	Hunter Research Foundation Centre (Newcastle University)	Market development - buyers/deal makers
Regional	Innovation Campus (iC) (University of Wollongong)	Market development - buyers/deal makers
Regional	Intelligent Polymer Research Institute (IPRI) (University of Wollongong)	Policy development & strategy
Regional	International Collaborative Centre for Carbon Futures (University of Newcastle)	R&D (early stage)
Regional	SMART Infrastructure Facility (University of Wollongong)	R&D (early stage)
Services	Australian National University	Market development - EPCM
Services	Biztech Lawyers	Skills development, training, accreditation
Services	Centre for Corporate Sustainability and Environmental Finance (Macquarie University)	Funding - equity
Services	Data61 (CSIRO)	R&D (early stage)
Services	RMIT University	Policy development & strategy
Services	ARC Research Hub for Integrated Energy Storage Solutions	Funding - equity
Services	ARC Training Centre for Advanced Technologies in Rail Track Infrastructure	Funding - equity
Services	ARC Training Centre for Automated Manufacture of Advanced Composites	Funding - equity
Services	ARC Training Centre for CubeSats, UAVs, and Their Applications	Funding - equity
Transport	Institute of Transport and Logistics Studies (University of Sydney)	Commercialising

Sector	Organisation	Primary role
Transport	Research Centre for Integrated Transport Innovation (rCITI) (UNSW Sydney)	Commercialising
Transport	Transport and Logistics Knowledge Hub	R&D (early stage)
Transport	Transport and Road Safety Research (UNSW Sydney)	Market development - manufacturing

4. NSW Decarbonisation Innovation 2023 Study Consultation

The Office of NSW Chief Scientist & Engineer (OCSE) conducted an extensive consultation process with various stakeholders representing industry, research, and Government agencies. This consultation process consisted of two stages. Through these consultations, OCSE sought to gather insights, perspectives and expertise from a wide array of stakeholders, ensuring a holistic and inclusive approach to developing effective decarbonisation strategies for NSW.

Stage 1 Consultation

Stage 1 Consultation (Figure 3): The primary objective of this stage was to identify approaches and methodologies that would be utilised throughout the consultation process. Additionally, the goal was to map out key stakeholder groups for the subsequent Stage 2 consultation. This stage also involved an examination of major studies conducted in NSW and Australia since the 2020 Study. The Stage 1 Consultation took place through a series of interviews, meetings and workshops with groups such as the NSW Net Zero Emissions and Clean Economy Board, NSW Renewable Energy Sector Board, as well as various NSW Government departments and agencies responsible for implementing net-zero policies and programs. Informed by the insights gathered from this, the 2023 Study aimed to address several key objectives. Firstly, it involved a comprehensive review of the opportunities outlined in the 2020 Study. The purpose was to review progress made on the 65 opportunities. This included examining how Government policies and programs have contributed to supporting and overcoming challenges and barriers associated with these opportunities.

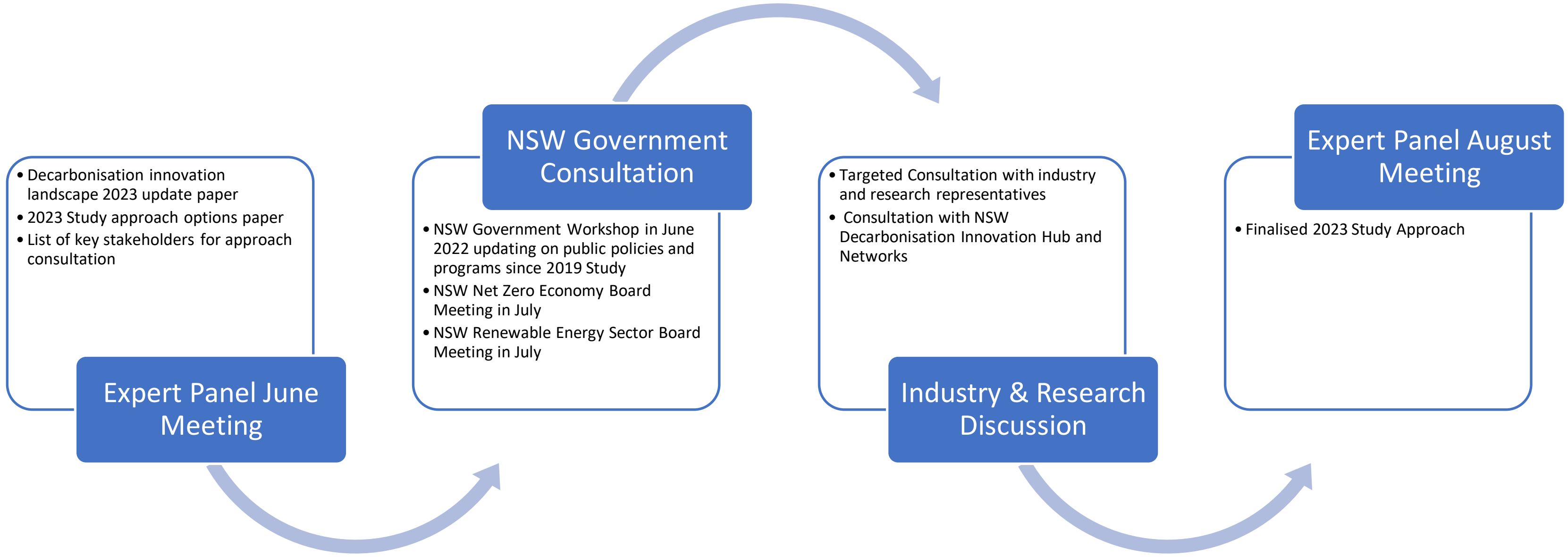

Figure 3 Stage 1 Consultation Overview

Stage 2 Consultation

The Stage 2 Consultation (Figure 4) shifted towards discussing and identifying the key opportunities for decarbonisation in NSW. It also aimed to identify any barriers or challenges that may impede the realisation of these opportunities. Stage 2 Consultation involved a range of activities, including one-on-one interviews, face-to-face and online industry roundtable sessions, and technology workshops. These engagements took place in late 2022 and were designed to facilitate comprehensive discussions with stakeholders.

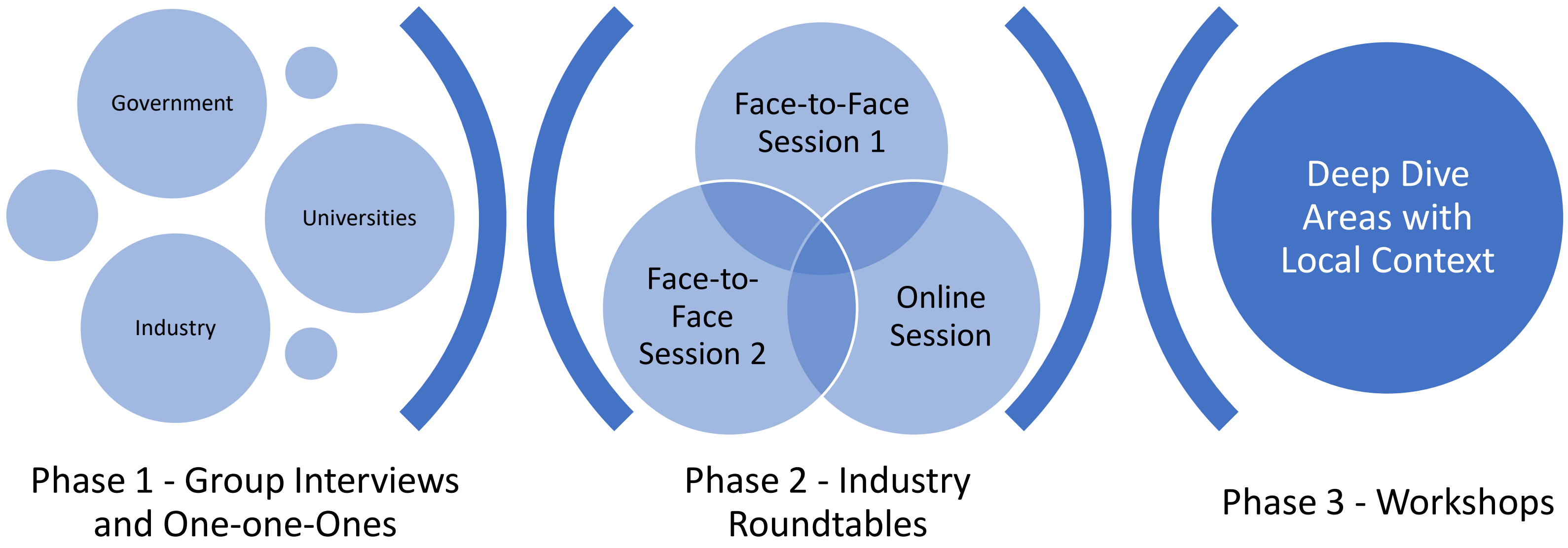

Figure 4 Stage 2 Consultation Overview

Consultation process – Roundtables

OCSE convened stakeholders within research and academia, industry groups, businesses and Government agencies to participate in roundtables to discuss decarbonisation opportunities, barriers and challenges. The Expert Panel supporting the Decarbonisation Innovation Study were also invited to attended, with all attending at least one session.

The roundtables occurred over three sessions, two face-to-face (on 9 November 2022) and one online (on 25 November 2022). Stakeholders were also invited to provide written feedback to OCSE.

The face-to-face roundtables consisted of an open discussion and breakout sessions. At the open session stakeholders were asked:

1. What opportunities present the greatest emission reductions and economic benefit to NSW, especially in respect to technologies, services and industrial development?
2. What areas or sectors does NSW need to address to continue to reduce emissions?
    a. Are there potential technology solutions?
    b. What economic benefit will they provide?

For the breakout sessions participants were divided into four subject groups, electrification & energy systems, power fuels including hydrogen, land and primary industries and built environment. Participants were asked:

1. What are the potential sectoral opportunities?
2. What are likely to provide export opportunities?
3. What places NSW at a competitive advantage to deliver on those opportunities?
4. What are the key barriers and challenges to achieving progress on the opportunities?

Roundtable outcomes

A summary of opportunities, barriers and challenges identified during the in-person and online roundtable meetings is presented in Table 3.

Table 3 Roundtable outcome summary

Sector	Opportunities	Barriers and Challenges
Electrification and energy systems	• Offshore wind • Use of existing infrastructure to assist energy transition • Storage and network management to address grid stability issues • Decentralised distribution and coupling of renewable energy technology such as wind and solar • Use of 5G and IoT on grid to detect and solve energy system problems	• Carbon price • Supply chain • High investment on infrastructure cost • Grid innovation and change is slower than the technology innovation • Absence of testing and innovation infrastructure for universities and SMEs to demonstrate technology

Sector	Opportunities	Barriers and Challenges
	• Hydrogen for export • Waste-to-energy systems	• Government funding to academic institutions bypassing the industry • Poor adoption of home electrification • Capacity constraints • Complexity and dynamics of renewable energy systems and network
Power Fuels including Hydrogen	• Sustainable aviation fuel (SAF) and green ammonia for export • Conversion of green hydrogen to ammonia for transport and storage • Precincts to co-locate industries (e.g. Renewable Energy Zones)	• Regulation • Lack of understanding where specific fuel sources should be used • Lack of whole-of-system assessment in relation to power fuels, from production, distribution, use and export • Availability and access to feedstock • High cost for new technology implementation • Fluctuation in export market
Land and Primary Industries	• Electrification of agriculture (e.g. electric water pumps, hydrogen-powered tractors) • Use of technology to drive efficiency in agriculture (e.g. frequency and timing of irrigation and nitrogen fertilisation) • Service industry to help implement sustainable agriculture practices, which can be used for export • Methane oxidation • Wetlands as carbon sink • Blue carbon (small potential) • Biochar • Cultivated meat to complement meat export • Native species as bioenergy feedstock • Carbon farming knowledge/service for export • Feed additives to reduce enteric methane emission, such as 3-NOP and Asparagopsis	• Communicating carbon abatement benefits to farmers • Carbon footprint calculation is often inaccurate • Feed additives are hard to adopt, except for intensive systems • Lack of measurement across the system to optimise farm use • Supply chain issues • Cost of renewable energy to meet the energy intensity for cultivated meat • Absence of NSW legislation for carbon storage

Sector	Opportunities	Barriers and Challenges
Built Environment	• Government infrastructure projects and procurement policies to drive innovation and implementation • Circular economy and recycling of building materials • Electrification on a precinct scale and sharing renewable utilities • Integration of energy generation and storage with building design (e.g. rooftop solar panels, battery storage in lifts) • Implementation of NABERS energy efficiency to mandate minimum temperature to ensure adaptive comfort • 3D-printing for building materials • Low carbon materials such as geopolymer concrete and green steel for export • Embodied carbon measurement standard • Retrofitting with low carbon materials and electrification • Business model innovation (e.g. leasing building façade instead of buying) • Sustainable finance innovation in relation to built environment • Repurposing existing buildings	• Reliance on overseas supply chain • Lack of manufacturing capacity for green materials in NSW which requires high capital investment • Grid stability • Lack of technical standards for green building certifications • Cost of electricity storage is high • Tenants have no incentives to reduce emissions in commercial development

Consultation process – Technology Workshops

OCSE Decarbonisation Team consulted with a number of stakeholders from research and academia to track progress and identify emerging decarbonisation opportunities to assist with reducing emissions and providing economic benefit to NSW. The universities consulted are as follows:

- University of Wollongong
- University of Sydney
- University of Newcastle
- University of New England

- University of Technology Sydney

Workshop outcomes

A summary of opportunities, barriers and challenges that were identified by stakeholders during the workshops is presented in Table 4.

Table 4 Workshop outcome summaries

Sector	Finding summary
Electrification and energy system	Electrification is tracking well toward net zero. There are opportunities for wind energy manufacturing at the Illawarra and the Hunter, both of which are known for heavy manufacturing industries with availability of skills and land needed for renewable energy generation. However, connecting, firming and storing the energy system require further efforts. These can be accomplished through: • decentralised smart grids and community storage system to create clusters of load and supply • energy integration, electricity connection infrastructure to adapt with technological change • chemical storage • gravity-based storage at disused mine shafts for medium duration storage and pumped hydro for long-duration storage. There is great interest in hydrogen opportunities across NSW, yet there are uncertainties around hydrogen standards and offtake, as well as overlapping work across Government agencies and universities.
Industry	Decarbonising industries require reliable renewable energy and high investment. <u>Orica</u>: Immediate action taken by Orica is to decrease nitrous oxide scope 1 emission by leveraging proven technology. The next step is to substitute up to 30 per cent methane feedstock with green hydrogen and adding flexibility in ammonia plants through electrification modification or using a low pressure catalyst. The carbon dioxide produced can be captured and stored through mineralisation by partnering with MCi. <u>Biomanufacturing</u>: Locking carbon into bioproducts by using seaweed and microalgae. <u>UTS</u>: direct air capture (Green Genie) captures seven tons of carbon dioxide per year, which can be used as feedstock through algae biofactory to produce textile, plastics and building products. The process involves circular economy principles which can be integrated with other industry to decarbonise their sector (study case: Young Henrys/MLA/C3 to develop microalgae bioreactor fed with carbon dioxide from beer fermentation process. The microalgae strain will be screened and harvested as feedstock additive to reduce enteric methane emission from livestock.

Sector	Finding summary
Land and Primary Industries	Enteric methane emission from cattle can be reduced through feedstock additives, genetic selection and herd management. Current research shows that Asparagopsis and 3-NOP can reduce methane by up to 95 per cent, but their costs are prohibitive. Tier-two additives are less effective but can be more readily adopted from an economic point of view. Further work is underway to investigate additive mixture effectiveness. Suppression of methane through genetic selection is less efficient but accumulative and permanent (i.e. one per cent reduction per year), whereas the vaccination pathway has had little success so far. Floodplains or wetlands can be used as carbon sinks with appropriate water management. There are opportunities in carbon markets with co-benefits for the ecosystems. However, risks associated with carbon products need to be managed and carbon credits should be verifiable. The University of New England has a whole system glasshouse project with the company Costa. Renewable energy will be used to power the operation. The controlled environment is related to pollination, waste management and circular economy. The large green waste produced can be composted or converted to biochar. One issue is the use of pesticide that ends up in the green waste.
Built Environment	The importance of the Electrify 2515 program at Wollongong (as part of the Rewiring Australia initiative) to accelerate full electrification of Australian households.
Enablers	Coordination between government, industries and universities, The importance of the innovation through co-locating universities and industries and open-access infrastructure to provide education/ training facilities.