NSW Decarbonisation Innovation Study

Scoping Paper

NSW Chief Scientist & Engineer

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SCOPING PAPER

1.1 INTRODUCTION

In September 2019, the Minister for Energy and Environment, the Hon. Matt Kean MP, requested that the NSW Chief Scientist & Engineer undertake a study to assess and provide advice on the challenges and opportunities for meeting emissions targets and adapting to climate change. The Terms of Reference for the study include examining the benefits of decarbonisation and climate adaptation in generating economic development, prosperity and jobs growth in NSW, as well as considering best practice approaches to transitioning industry, including skills development and market access.

This scoping paper provides context on the pathways, opportunities and challenges of decarbonisation and climate adaptation in sectors relevant to the NSW economy. It provides an overview of the technologies and services to reduce carbon emissions and adapt to the impacts of a changing climate. Across these technologies and services, potential economic opportunities for NSW are identified based on NSW's competitive advantages.

The final report will evaluate these potential opportunities in more detail, and identify those that have the greatest potential economic and employment benefit for NSW and that are feasible, suitable, and technically and commercially viable. The final report will also identify potential actions to realise these opportunities.

This scoping paper draws on insights from an expert panel with experience in energy, infrastructure, innovation, sustainability and economics. It also captures insights from initial consultations with stakeholders from industry, government and community organisations in NSW and elsewhere. In preparing the final report, the Office of the NSW Chief Scientist & Engineer and the expert panel will engage further with stakeholders, particularly those who have a role in addressing challenges associated with decarbonisation and climate adaptation.

The changing climate is one of the most significant global challenges of the 21st century – posing risks to existing industries, communities and ecosystems. In response, there is increasing demand from governments, industries, investors and communities for new technologies and services to lower emissions and improve resilience.[1] Many of these technologies and services are already cost-effective and will continue to become more cost-competitive as technology develops and uptake increases. Other solutions require further innovation in technology, deployment or regulatory frameworks that enable their rollout. These technologies and services also offer benefits in improved: energy security, productivity and affordability; food and water security; more resilient natural ecosystems; regional prosperity and job growth; and reductions in air and environmental pollution. Some of these technologies have secondary disadvantages which need to be considered and managed, for example, impacts on the electricity grid.

Industry, innovators and researchers are responding to this growing global demand, and large and small businesses are implementing sustainable technologies and services. Many businesses in NSW and overseas have set decarbonisation targets. Servicing this demand presents socio-economic opportunities for NSW's small, medium and large businesses to develop new technologies and services, apply them locally, and export them internationally.

[1] Through the Paris Agreement, international governments have committed to taking and encouraging action to address climate change through decarbonisation and climate change adaptation. See further *The Paris Agreement*, opened for signature 16 February 2016 (entered into force 4 November 2016).

Establishing a first-mover advantage in decarbonised technologies and services will ensure that NSW becomes an important part of this emerging global supply chain.

The market for decarbonisation technologies and services is broad, cross-sectoral and highly competitive. To realise these opportunities in a competitive and globalised market, NSW should adopt an approach which plays to its competitive advantages. These include NSW's research and development strengths, advanced industries and infrastructure, workforce capabilities and diversity, regulatory environment, capital markets, and geographic and natural advantages. NSW's economic position and competitive advantages will be examined further in the final report.

NSW should also address the challenges that accompany these opportunities, including how to support efficient technology transitions, enable positive workforce and community transitions, maintain international competitiveness and manage unintended consequences. Effective transitions not only make communities and jobs resilient, but also provide increased prosperity. This may be through diversifying and growing regional and urban industries and employment, upskilling local workers, attracting skilled workers and investment, and increasing environmental sustainability. The case for, and progress of, transitions should also be clearly communicated to stakeholders to maintain understanding and support for change.

NSW's $600 billion per year economy is strong in services, including financial, education, tourism, construction and healthcare (Figure 1). NSW has notable manufacturing, mining and agriculture industries. NSW also has industries that are already demonstrating rapid adoption of new technologies to decarbonise, for example, the energy sector is transitioning towards high solar uptake.

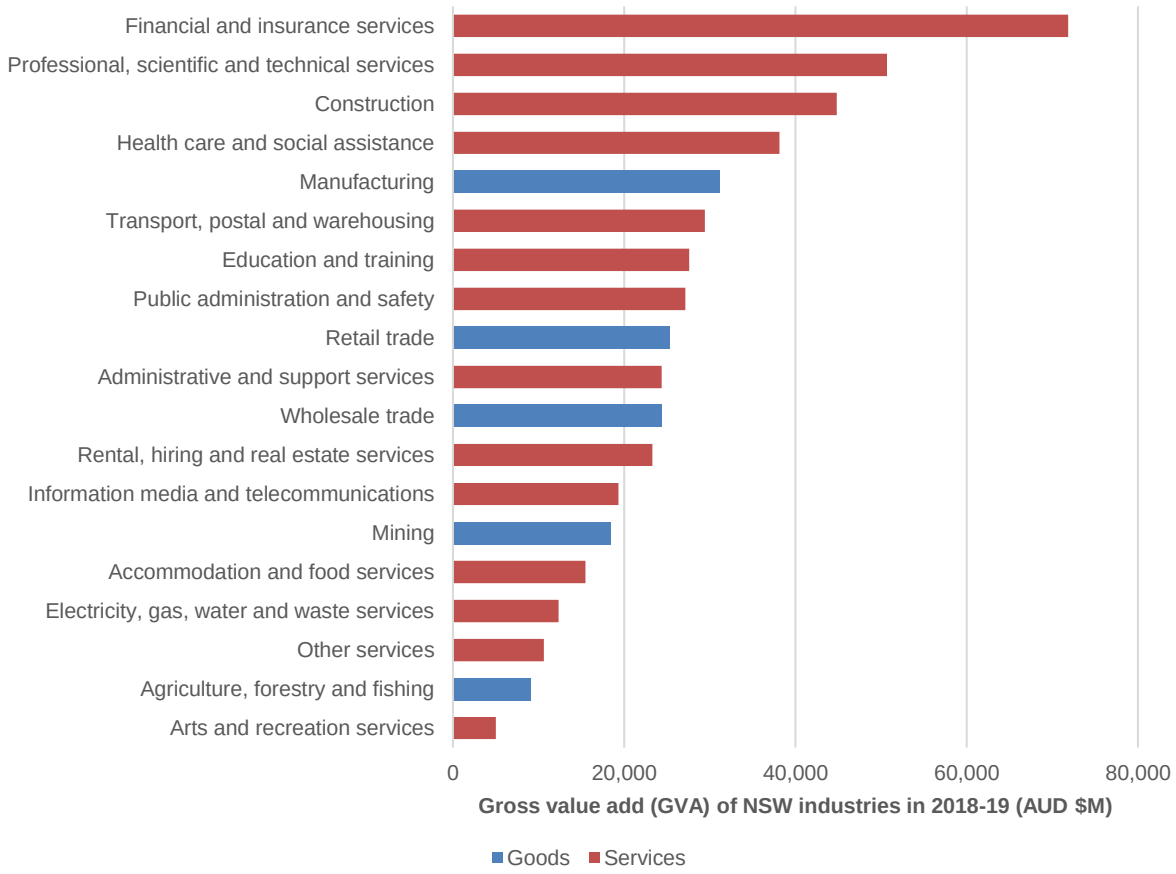

Figure 1: Gross value add (GVA) of NSW's major industries in 2018-19.
Source: (Australian Bureau of Statistics, 2019a)
Note: Ownership of dwellings, and the impact of taxes and subsidies are excluded from this figure.

NSW is a significant exporter of goods and services – mainly to Asia (Figure 2). The NSW economy also has potential in emerging growth industries, including advanced manufacturing, agtech, food production, aerospace and defence, and hydrogen.[2]

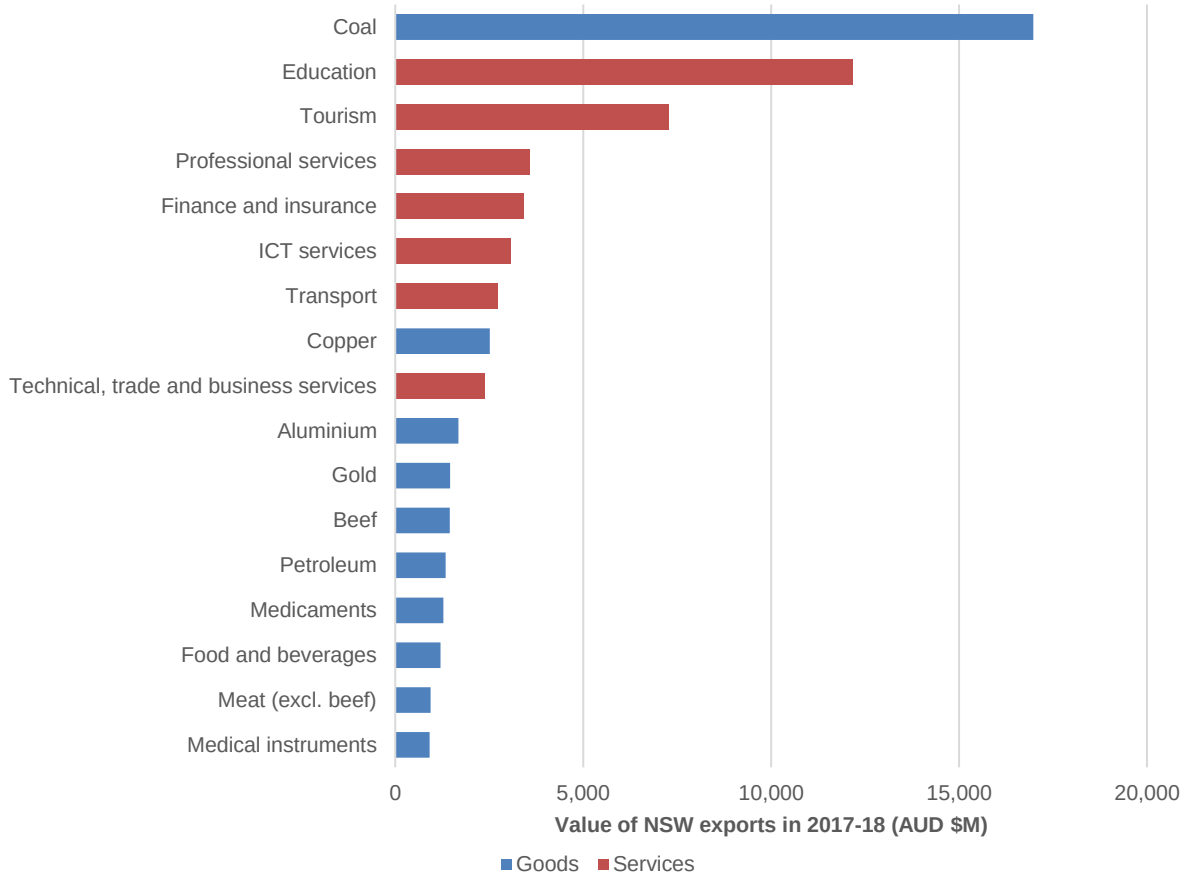

Figure 2: NSW's major exports (financial year 2017-18).
Source: (Department of Foreign Affairs and Trade, 2018).

NSW's current and emerging industries have decarbonisation and climate-resilience challenges and opportunities. Energy, transport, agriculture, industrial processes, and infrastructure are responsible for most emissions in NSW but have a range of economic opportunities in decarbonisation (Table 1). Of NSW exports, resources, tourism and agriculture are carbon intensive and early action on decarbonisation opportunities in these areas would assist to manage carbon risks. Energy, infrastructure, agriculture, conservation and tourism face particular climate resilience challenges and opportunities.

[2] The NSW Economic Blueprint 2040 identifies that NSW has opportunities in industries of the future including advanced manufacturing, agtech and food production, aerospace and defence, space and hydrogen (NSW Treasury, 2019).

Table 1: NSW greenhouse gas (GHG) emissions (2005 – 2017)

Sectors	Major emissions sources / end-use activities in 2017	Contribution to NSW GHG emissions in 2017		Change in annual emissions 2005 to 2017	
		(Mt CO_2-e)	(%)	*(Mt CO_2-e)*	(%)
Electricity generation	Residential electricity use (31%) Commercial services electricity use (25%) Manufacturing electricity use (24%) Energy, water, waste electricity use (10%) Other (9%)	55	42%	-7	-11%
Transport	Cars (47%) Heavy trucks and buses (22%) Light commercial vehicles (16%) Domestic Aviation (10%) Other (5%)	28	21%	+4	+15%
Agriculture	Cattle (44%) Sheep (27%) Agricultural soils (19%) Other (11%)	19	15%	0	-1%
Fugitive emissions	Underground coal mining (80%) Surface coal mining (10%) Oil and natural gas (7%) Other solid fuels (3%)	14	11%	-4	-22%
Industrial processes and product use	Metal industry (50%) Refrigeration, air conditioning (29%) Mineral industry (10%) Chemical industry (9%) Other (1%)	13	10%	-1	-7%
Stationary energy	Manufacturing, construction (52%) Other stationary energy (48%)	11	8%	-2	-17%
Waste	Solid waste (59%) Wastewater (38%)	3	2%	-2	-38%
Land use, land use change and forestry	Forest land (-18.5 Mt CO_2-e) Cropland (1.2 Mt CO_2-e) Grassland (5.9 Mt CO_2-e) Wetland (0 Mt CO_2-e) Settlements (0.1 Mt CO_2-e) Harvested wood products (-1.4 Mt CO_2-e)	-13	-10%	-17	-426%
Total		131	100%	-29	-18%

Note: As values are rounded they may not add to total.

1.2 DECARBONISATION

Decarbonisation is the shift from activities which are greenhouse gas (GHG) emissions-intensive to activities with low or no GHG emissions, or that capture emissions. NSW has a range of productive economic sectors that contribute to emissions (Table 1). No single approach will address this diversity and consequently, NSW must pursue multiple decarbonisation pathways:

Pathway 1: Transition to renewable and low-emission electricity generation

Pathway 2: Electrify transport, industry and infrastructure

Pathway 3: Improve energy and material efficiency and productivity

Pathway 4: Develop new alternative processes for hard-to-abate emissions[3]

Pathway 5: Use emissions capture and sequestration

The pathways are interdependent and should be pursued simultaneously to realise their full decarbonisation potential. This means that businesses must adopt a systems approach to address all sources of carbon emissions in their business, and consider the flow-on effects on decarbonisation by their suppliers, customers and the wider economy.

1.3 OPPORTUNITIES

Opportunities in decarbonisation and climate change adaptation exist across NSW's current and emerging industries. Some come about from investing in enabling technologies and capabilities that provide a platform for decarbonisation and climate-resilience. Examples include: digital technologies for full integration of electric mobility into the grid including smart charging; smart electricity systems for buildings, including in new suburbs; sustainable investment to fund new industries or transitions; and a local hydrogen industry to decarbonise multiple industrial processes. Other opportunities are in commercialisation or deploying sector-specific technologies and capabilities – for example, batteries and pumped hydroelectric storage to improve renewable energy utilisation. Some opportunities are emerging and require further development – for example synthetic biology, hydrogen and novel cements.

Some of these opportunities lend themselves to being delivered through a place-based approach around new precincts and major infrastructure developments -- for example, the planned Western Sydney Airport and Aerotropolis and the Special Activation Precincts. Placed-based approaches can be useful to mobilise a connected group of stakeholders to improve collaboration, catalyse joint decarbonisation projects and innovation in technology development, and to increase productivity through shared infrastructure and investment (NSW Innovation and Productivity Council, 2018). These benefits are particularly relevant to decarbonisation transitions, which will require new capital investment, innovative technology development, systems that use multiple interdependent technologies, approaches that reflect local conditions and coordination between stakeholders to develop new supply chains. Successful place-based approaches can provide the catalyst to implement these transitions across the state.

A selection of potential opportunities which NSW could pursue are presented below. Some of these opportunities are already being realised and may need acceleration, while others may require new approaches, policies or investment. Many opportunities are co-dependent and require coordination.[4] The final report will present a strategic and interconnected approach to

[3] For example: enteric emissions from livestock; emissions from the production of cement, iron, steel, plastics and chemicals; and emissions from shipping, aviation and heavy road freight. Although practical emissions reduction approaches exist in many of these sectors, most require further demonstration at scale.

[4] For example, electrification of industry and transport is co-dependent on renewable energy rollout to ensure increased electrification does not lead to greater fossil fuel generation. Further, coordination of policies for electric vehicle uptake and infrastructure encourages investors and companies to accelerate research, development and availability of electric vehicles.

filter and prioritise those opportunities that have the most potential, based on NSW's economic position and competitive advantages. The final report will also contextualise the opportunities in a future NSW economy.

1.3.1 Investment and finance

Finance, including insurance, is the largest industry in NSW and Sydney is already a significant global financial centre. As decarbonisation and climate-resilience technologies are becoming more cost competitive, investment in them is growing. Globally, investors are increasingly allocating capital toward developing and adopting low-carbon technology and business models seeking to take advantage of these growth opportunities, while at the same time moving out of sectors with exposure to climate-related risks. Environmental, Social and Governance (ESG) investments under management in Australia were $980 billion in 2018, representing 44 per cent of professionally managed assets in Australia (RIAA, 2019). Investors and regulators are also increasingly applying multilateral frameworks, such as the recommendations of the Task Force on Climate-related Financial Disclosures (TCFD), when deciding where to direct investment and how to manage and price climate-related risks such as:

- Direct climate risks – for example, rising sea levels and increasing frequency and intensity of extreme weather (including storms, heatwaves and droughts)
- Carbon risks – for example, regulatory shifts, technology disruption and changes in market demand for carbon intensive goods and services like fossil fuels
- Transition risks – for example, disruptive transitions which could impact supply chains and cost of doing business, and international trade rules that preference decarbonised businesses and states.

Investors have recognised that considering climate-related risks improves investment practice and reduces systemic future risks to investments in companies, industries, property, and infrastructure assets (Investor Group on Climate Change, 2019).

These investment trends present domestic and export opportunities for NSW, which has an opportunity to channel this growing investment into industry and intellectual capability-building to develop technologies, products, services and infrastructure for decarbonisation and climate adaptation. There is also a regional investment opportunity, as investment of US$1.7 trillion per year to 2030 will be required to fund these technologies and infrastructure across Asia (Asian Development Bank, 2017).

NSW has an opportunity to build on its existing strengths in financial and environmental services to become a preeminent sustainable finance centre. NSW could leverage its competitive advantages in:

- Sydney being a major global financial centre in Asia[5]
- deep capital markets[6]
- large number of major financial institutions[7]
- best practice in investment management practices and standards[8]
- strength in financial technology ('fintech')[9]

[5] For example, Sydney is ranked as 10th on the Z/Yen Global Financial Centres Index 26 (Financial Centre Futures, 2019).
[6] For example, Australia has the third largest pool of funds under management globally, and the largest in Asia (DPIE, 2014).
[7] For example, Sydney is home to the Australian Securities Exchange (ASX), the headquarters of 59 out of the 63 international financial institutions with a presence in Australia, and nine out of 10 of Australia's largest fund managers, (DPIE, 2014).
[8] For example, 44 per cent of professionally managed assets in Australia (RIAA, 2019), and 83 per cent of green bonds issued in Australia are certified under the Climate Bonds Standard, a leading share globally (Climate Bonds Initiative, 2019).
[9] For example, Australia has been identified as an "up and coming" fintech hub with a high level of collaboration (EY, 2016), and Sydney is home to the Sydney Startup Hub, which includes the Stone & Chalk Fintech incubator.

- Strength in professional services necessary to accredit, manage and operate these investments.[10]

The strength and depth of the financial industry in NSW offers an opportunity and advantage in providing the investment to fund new decarbonised industries and infrastructure in NSW, Australia, Asia and globally. It also provides an opportunity for NSW to grow professional services necessary to decarbonise the economy and manage climate-related risks. For example, the analytics and certification tools, services and standards that investors will use to assess and manage the sustainability of their portfolios. This transition will also support the stability and security of NSW's financial sector and government assets and portfolios.

Potential opportunity 1	Adoption of multilateral climate change risk management initiatives (such as the Task Force on Climate-related Financial Disclosures recommendations) to improve investment practice and incentivise investment flows: • to new technologies, products, services and infrastructure for decarbonisation • to improve the resilience of the NSW economy, including the financial sector, to climate change.
Potential opportunity 2	Secure and strengthen NSW's position as a preeminent regional and global sustainable finance centre, with expertise in sustainable finance and associated services (for example, fintech, advanced sustainable financial instruments, insurance, and environmental and sustainability services), resilient to the risks associated with climate change and leveraging opportunities from decarbonisation transition and climate adaptation.

1.3.2 Energy generation, transmission and storage systems

Energy is the largest source of emissions in NSW. Energy emissions should be addressed through measures to improve energy productivity and efficiency, as well as through reducing emissions from energy generation. Potential opportunities in energy productivity and efficiency are discussed further below. In terms of generation, new build renewable generation from wind (firmed and unfirmed) and utility solar (without firming) are now more cost-effective than new build coal generation on a levelised cost of electricity (LCOE) basis (Figure 3), due to significant recent reductions in the cost and maturity of these technologies (Figure 4). New build solar generation with storage, and rooftop solar, have equivalent LCOEs to new build black coal. These cost comparisons will likely lead to continuous growth in wind and solar generation, with renewable generation comprising 35 to 58 per cent of NSW generation by 2030 depending on policy interventions, technology development and uptake, and investment (AEMO, 2019).

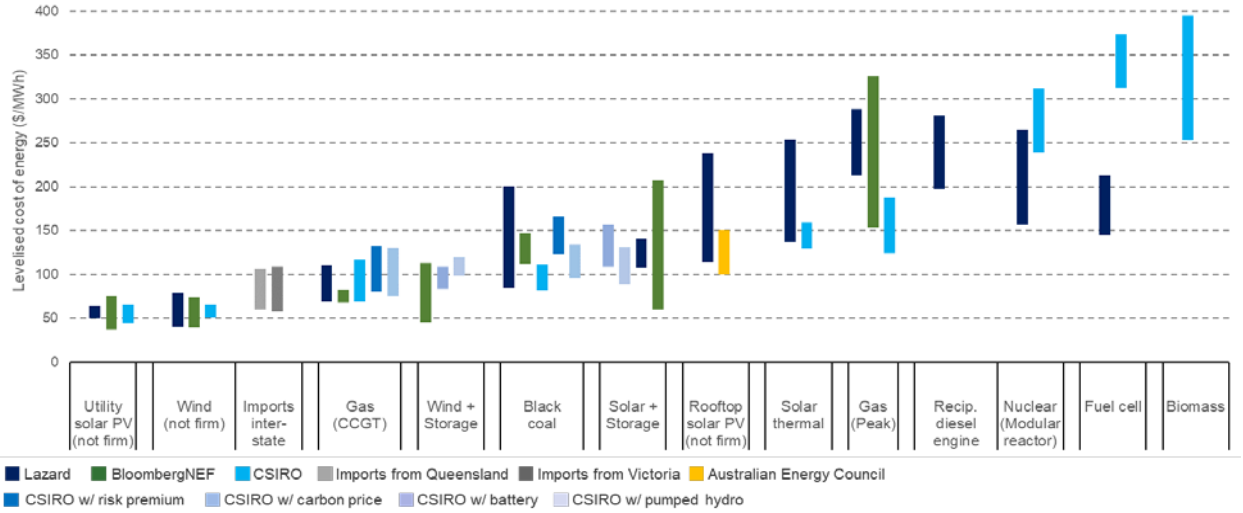

Figure 3: Levelised cost of electricity (LCOE, $/MWh) by generation type based on various reports.
Source: (NSW Government, 2019b).

[10] For example, NSW has strength in environmental services, including applying schemes such as the Building Sustainability Index (BASIX), Green Star and the National Australian Built Environment Rating Scheme (NABERS) (Johnston, 2018).

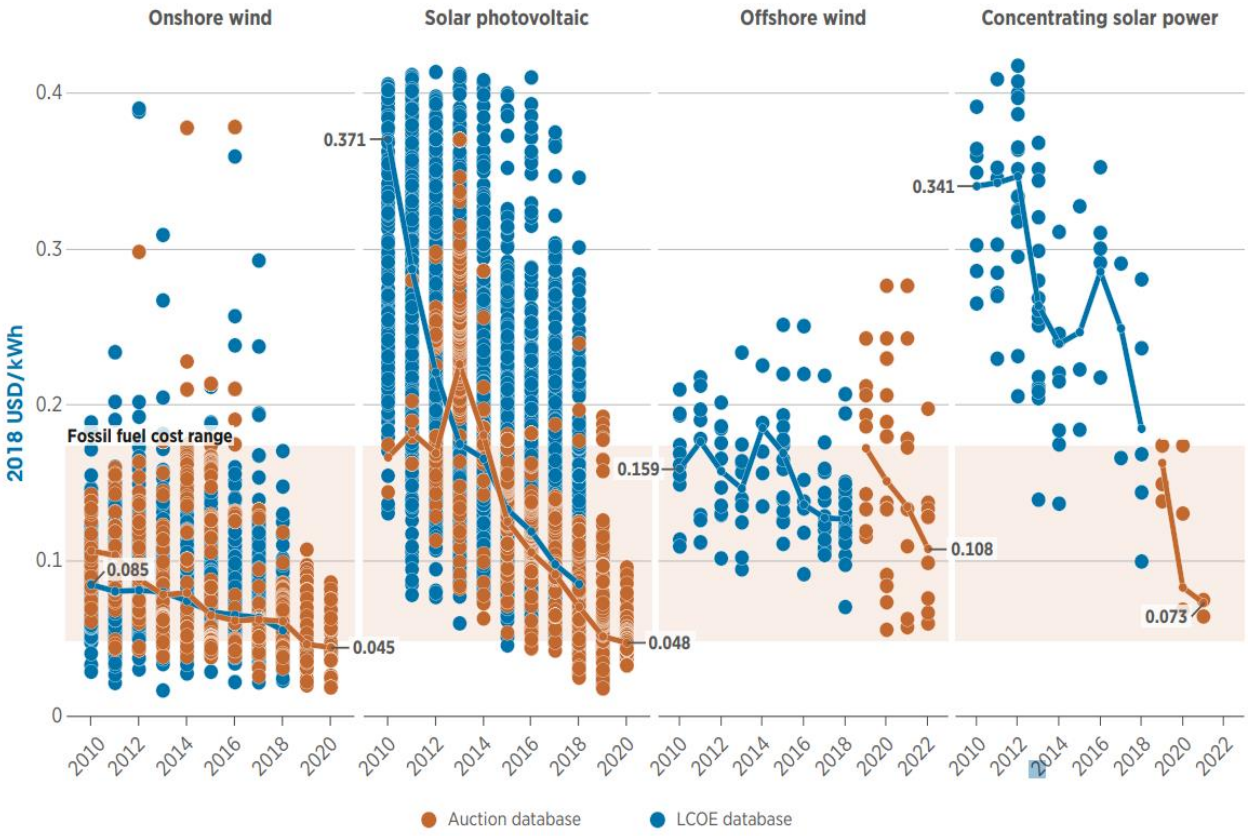

Figure 4: Global LCOE and auction price trends (US$/KWh) for renewables from project and auction data (2010 – 2022).
Source: (International Renewable Energy Agency, 2019).
Note: Each circle represents an individual project or an auction result where there was a single clearing price at auction. The centre of the circle is the value for the cost of each project on the Y axis. The thick lines are the global weighted-average LCOE, or auction values, by year. For the LCOE data, the real WACC is 7.5 per cent for OECD countries and China, and 10 per cent for the rest of the world. The band represents the fossil fuel-fired power generation cost range.

Solar and wind technologies, combined with energy storage, will continue to be the primary mechanism for electricity generation to achieve deeper decarbonisation. Other forms of firmed renewables or low-emissions generation (such as generation from waste heat, geothermal, solar thermal, and hydrogen fuel cells and turbines), could be brought to the market to further diversify the generation mix.

NSW is well placed to lower energy emissions through technologies including renewables and low-emissions energy and storage at large scale due to its competitive advantages in natural resources (e.g. sun and wind) and the existing scale of rooftop solar and utility renewables. The Australian Energy Market Operator (AEMO) has identified nine potential Renewable Energy Zones (REZ) locations in NSW for solar and wind generation, as well as pumped hydro storage, that can be connected to the network (AEMO, 2019). The announced REZs will coordinate development of transmission and grid infrastructure to facilitate the connection of multiple new large-scale renewable generation projects into the grid. This presents opportunities for NSW to accelerate the development and commercialisation of innovative renewable generation technologies, business models for renewables and technologies to improve the secure and reliable integration of renewables into the electricity system.

Potential opportunity 3	Procurement of energy from renewable generation (both from the grid and onsite) for NSW Government infrastructure and landholdings.

Potential opportunity 4	The Renewable Energy Zones (REZs), including: • the Central-West pilot REZ and the NSW Electricity Strategy 2019 • a coordinated and integrated approach for the development of REZs in NSW, learning from the experience with the pilot and following the three phases of development identified by AEMO ISP 2020 as the least cost way of establishing REZs • the three prioritised NSW REZs in Central-West, New England and South-West regions • innovative decarbonised technologies, enabling technologies and operating models across generation, storage, transmission, system and energy users within the REZs in building a low emission energy ecosystem • the trial of new low- and zero-emission technologies in REZ.
Potential opportunity 5	• innovative business models for generation, including models for landowners to lease rooftops for onsite solar generation, and split-incentive solar PV models for tenants and landlords • innovative solar PV technologies, including thin-film and organic solar PV • digital technologies, including sensing and artificial intelligence (AI), to improve and optimise the operation of renewable generation.

NSW electricity generation is likely to continue to become more decentralised and decarbonised, dominated by investment in renewable generation (AEMO, 2019). In future, high amounts of solar photovoltaics and wind would generate electricity at a lower marginal cost than other technologies and the excess diverted to storage. When renewable power is not available, flexible low-emission dispatchable technologies will provide power. AEMO has projected that NSW needs 3 to 10 GW of new utility-scale energy storage by 2040 to complement new renewable generation (AEMO, 2019). Examples include utility-scale pumped hydroelectric storage, utility scale batteries and potentially hydrogen storage. Technologies and standards for infrastructure and industrial processes that control usage to match peak renewable generation could mitigate these storage needs. Demand response and 'behind the meter' batteries will also support increased penetration of renewables. Electric vehicles (EVs), if integrated effectively, can be used to discharge energy into the grid, further supporting a high renewables grid.

To manage this transition, new energy systems technologies and operating models are required. These technologies will enable increased consumer participation in the market through two-way energy flows from distributed energy resources (DER) and EVs, account for renewable energy peaks in how they manage power consumption, while also building grid resilience. These services will span voltage control, system strength, frequency management, power system inertia, dispatchability and demand response (AEMO, 2019). Smart grid technologies, such as intelligent appliances, meters and inverters, control and market platforms, telemetry and sensors, and cyber-security solutions exist, but key opportunities arise in deploying them in integrated systems, improving efficiency and reducing cost. NSW has already successfully trialled and deployed smart grid solutions, for example the Smart Grid, Smart City trial and the Narara Ecovillage on the Central Coast.

NSW has competitive advantages as a major early adopter of DER, with significant capabilities in renewable generation, energy storage, network and integration systems research, digital systems (including artificial intelligence and Internet of Things [IoT]), and some pilot demonstration projects. NSW could leverage these capabilities to: establish a first-mover advantage in technologies and system services to integrate storage (in particular EVs); electrify industry; and operate future grids efficiently and cost effectively.

Estimates suggest that the value of digital innovation across the entire energy value chain (generation, transmission, distribution, trading and retailing) is up to $1.3 billion for Australia (McKinsey & Company, 2018). There are also significant export opportunities for these technologies and services as DER proliferates overseas and technologies such as microgrids become viable for remote and developing communities internationally.

Potential opportunity 6	Current and emerging battery technologies, advanced manufacturing, materials engineering and digital systems for new energy storage technologies and components, and systems for their control and integration into the grid.
Potential opportunity 7	Digital technologies, such as Internet of Things (IoT) and AI, to facilitate the increased penetration of renewable generation and DER. This includes, but is not limited to: • development of digitised energy markets • peer-to-peer (P2P) energy trading platforms • decentralised grid models (e.g. micro-grids) to communities, particularly in regional and remote locations, that have limited access to the main grid • smart grids, energy-as-a-service and associated technology for future areas of development, such as the Special Activation Precincts (SAPs) and the Western Sydney developments and precincts, including the Aerotropolis.
Potential opportunity 8	Demand response, integration of EVs, energy efficiency and conservation, and other emerging technologies, such as Virtual Power Plants, to provide additional effective storage, improving flexibility of demand and lower energy costs (for industrial, commercial and residential consumers).

1.3.3 Hydrogen

Hydrogen from renewable sources ('green hydrogen') offers economic opportunities for NSW in building a new industry, with associated technologies, products, services and a skilled workforce. It also offers benefits in improving energy security and affordability, industry productivity and reducing emissions through lower cost energy and clean hydrogen as a feedstock. Hydrogen has potential to replace current emissions-intensive fuels or feedstocks to reduce emissions in many applications:

- Energy generation – providing peaking power and long-term energy storage, and powering small-scale or distributed power systems
- Transport – enabling a local fuel production industry to supply fuel cell electric vehicles (FCEVs), improving fuel security and reducing fuel imports
- Industry – replacing other chemical feedstocks such as coking coal and methane
- Stationary energy – using existing gas networks to blend hydrogen into gas supplies.

Production of green hydrogen is forecast to become cheaper as the price of renewable generation continues to fall (Arup, 2019). At very low renewable energy costs, hydrogen could be more cost competitive than existing fossil fuel feedstocks in steel and ammonia production (McKinsey & Company, 2018). Several of NSW's major trading partners have set targets for uptake of green hydrogen, an indication of future export demand. There is potential for the Australian hydrogen industry to generate 7,600 new jobs and increase GDP by $11 billion per year by 2050. To develop a local hydrogen supply chain, NSW could leverage its competitive advantages including:

- Existing hydrogen supply chains and workforce – Australia currently produces 0.5 Mt in an overall global market of 70 Mt (COAG Energy Council, 2019) and NSW has an ammonia supply chain using hydrogen produced through steam methane reforming
- Low cost production potential – there are coastal and regional opportunities for green hydrogen production and use in NSW that utilise existing infrastructure and abundant natural resources for renewable generation (Feitz, Tenthorey, & Coghlan, 2019)
- Research and development – NSW has strengths in hydrogen research and development across the value chain, including production, storage and processing
- Hydrogen hubs – the NSW Special Activation Precincts and major export hubs (e.g. Newcastle and Port Kembla) offer opportunities to leverage existing and future infrastructure, as well as industrial and commercial end users, to develop and demonstrate local hydrogen supply chains.

Potential opportunity 9	A hydrogen economy (in energy, industry and transport sectors), including: • demonstration projects and trials that target both production and end use, thus de-risking investment. Opportunities include small scale hydrogen production, using electrolysers located at REZ, which can take advantage of free wind/solar power that would otherwise be curtailed. This could then fuel remote heavy transport and/or remote communities. Other opportunities include power supply for remote areas and microgrids, which would increase regional energy security and, once demonstrated, could provide an export opportunity to self-sufficient communities including Pacific island nations and other overseas markets • market and investment incentives by purchasing hydrogen services in energy (e.g. dispatchable energy or storage) or captive heavy transport fleets (e.g. buses, rail, road freight) • research and development in new methodologies of production, that improve efficiencies in both energy and water expenditure • a provenance scheme that ensures the production process and pathway is codified and documented for green hydrogen • the expansion of renewable generation in areas where there is high potential for hydrogen production • transition of current hydrogen industry to lower-emission pathways, including using existing infrastructure, and building skills and capacity • peripheral industries that would value-add to the hydrogen industry (for example, energy storage, and carbon capture and storage or use from blue hydrogen production).

1.3.4 Transport

Market penetration of new transport technologies, such as EVs and hydrogen FCEVs, is increasing rapidly. Falling battery costs have already reduced the total cost of ownership of some EVs in Australia, to equivalent to that of some internal combustion engine (ICE) vehicles (ICEVs) (RACV, 2019). In markets with EV incentives, such as the UK, 90 per cent of EVs have a lower total cost of ownership than equivalent ICE vehicles (LeasePlan Corporation NV, nd). EV uptake is expected to rapidly increase as these battery costs continue to fall (Energeia, 2019). These cost reductions will also improve the commercial viability of other novel electrified transport modes, for example electric scooters and electric Vertical Take-off and Landing (VTOL) aircraft. However, upfront costs of EVs remain higher than ICE vehicles which dissuades consumers (RACV, 2019). Model availability in Australia is also lower than in other markets. Increased procurement of EVs for government and industry fleets is one mechanism to reduce EV cost and improve model availability as it encourages manufacturers to bring EVs into the local market and increases secondary EV markets as these fleet EVs are sold (Energeia, 2019).

The NSW Electric and Hybrid Vehicle Plan identifies the infrastructure opportunities and challenges arising from the growth of EVs, particularly around charging infrastructure. Widespread adoption of EVs offers significant opportunities for energy storage capacity and stability services.[11] However, if all EVs are connected and charging during peak demand this will lead to additional grid stress and could increase non-renewable generation (Energeia, 2019).[12] Therefore, intelligent grid integration systems and operating models for charging and discharging power from EVs and other DER are essential to leverage the benefits of EVs and

[11] For example, if 50 per cent of the current NSW car fleet was EVs, this would provide energy storage capacity of approximately 130 GWh. Although the practical storage capacity would be lower than this (as not all EVs would be simultaneously connected to the grid and would not be able to provide their full battery capacity) the scale of energy storage would still be significant. This analysis assumes that 50 per cent of the current NSW car fleet of 4.3 million cars were EVs with an average battery capacity of 60 kWh (Australian Bureau of Statistics, 2019c; Electric Vehicle Database, 2019).

[12] If 50 per cent of the current NSW car fleet and 90 per cent of the current bus fleet were electric, this would contribute approximately an extra 9 TWh or 13 per cent to annual electricity consumption in NSW. This analysis assumes that 50 per cent of the current NSW car fleet of 4.3 million cars were EVs, 90 per cent of the current NSW bus fleet were electric, that 30 per cent of the Australian annual car fuel consumption of 654 PJ is in NSW and 28 per cent of Australian annual bus fuel consumption of 29 PJ is in NSW, and that EVs are three times more efficient than vehicles with internal combustion engines in converting energy into motion (Smit, Whitehead, & Washington, 2018; Australian Bureau of Statistics, 2019c; Australian Energy Regulator, nd).

DER.[13] NSW has strong capabilities in digital technologies and is an early adopter of DER through rooftop PV. These advantages combined with increasing EV uptake, could present NSW with a significant export opportunity if these systems can be developed and successfully demonstrated in NSW.

New decarbonised technologies, such as EVs powered by renewable energy, combined with new enabling technologies and operating models are also creating new 'Mobility as a Service' (MaaS) ecosystems. For example, EVs, autonomous systems, advanced communications and 5G technology, navigation and machine learning technologies, combined with sharing economies are creating new autonomous, connected, electric and shared urban transport ecosystems. NSW can develop the technologies and workforce skills to enable these ecosystems, demonstrate them in NSW through government adoption and incentivising early uptake, and ultimately export these technologies to other international transport markets.

As NSW makes significant infrastructure investments, for example around the Western Parkland and Central River Cities, consideration must be given to how transport infrastructure and the built environment supports these MaaS ecosystems. Transport infrastructure is generally high cost and challenging to modify. This can lock in particular transport modes and pathways. As technology advances, consideration needs to be given to future transport modes, cost-effectiveness, and industry and community growth to ensure transport infrastructure preserves choice, retains its efficiency and capacity, is resilient to climate risks, and is compatible with current and future decarbonised transport modes. Well planned infrastructure can reduce pressure on energy and transport networks, while accelerating decarbonisation outcomes by incentivising consumers to choose public transport, EVs, FCEVs, MaaS options, cycling and walking.

Potential opportunity 10	Government and industry EV fleet and infrastructure procurement.
Potential opportunity 11	Skills transition from internal combustion engine vehicles and infrastructure, to those required for EVs and hydrogen fuel cell electric vehicles (FCEVs).
Potential opportunity 12	Digital and systems expertise, and high penetration of renewable generation, to develop technologies, operating models and regulatory frameworks that support the effective integration of EVs into the electricity grid. Benefits would include stabilising the grid, increasing the energy storage capacity in NSW, increasing the utilisation of renewable power and potentially improving energy affordability. These technologies could also be exported to markets with increasing EV and DER uptake.
Potential opportunity 13	FCEVs that complement a local hydrogen industry.
Potential opportunity 14	Digital technologies, (e.g. autonomous systems) and public infrastructure (e.g. smart EV charging infrastructure from renewables) which enable automated, connected, electric and shared transport ecosystems (MaaS). These technologies and infrastructure could significantly improve the operational efficiency of transport networks as well as assisting decarbonisation of transport in NSW and elsewhere.

Promoting the use of next generation biofuels, that can be produced on land that is not used for food production, could provide new industry opportunities for regional and remote communities and reduce demand for imported oil. NSW has a competitive advantage in biofuels as it is one of only two states nationally that have a biofuel mandate and has strong capabilities in related research such as synthetic biology. Further, the agricultural sector has the potential to 'produce and consume' its own fuel to build agricultural circular economies and improve resilience. There are also economic opportunities in the maritime and aviation

[13] Technology to manage demand by load shifting charging throughout the day and night could decrease the potential additional peak demand of EVs on the grid by up to 450 per cent by 2040 (Energeia, 2019).

industries, which are seeking technologies to reduce emissions and pollution.[14] Supply chains for aviation biofuels would need to be strengthened, however the greenfield Western Sydney Airport and Aerotropolis provides a potential opportunity to establish infrastructure at the point of distribution with future supply chains throughout NSW.

Potential opportunity 15	Biofuels, including maritime, aviation and on-farm opportunities.

1.3.5 Agriculture and land use

Agriculture is a critical economic driver for NSW, a major export industry, and a driver of regional employment and business activity. In 2018, NSW agricultural production was $13.3 billion and meat exports were $2.4 billion (Australian Bureau of Statistics, 2019b). Agriculture is heavily dependent on reliable and stable climatic conditions and is of vital importance to food security and regional economies. Changing climatic conditions will require changes to agricultural practices through adaptation and innovation. Emissions from livestock and agricultural soils are also a global challenge which many nations are attempting to address through technologies such as feed supplements, breeding practices, synthetic biology and vaccines.[15] As a major agricultural producer with large livestock herds, NSW has both the need and market scale necessary to pursue promising opportunities in developing and commercialising technologies for reducing methane emissions. There is further potential to leverage NSW's industry and research expertise in advanced agricultural production and climate change adaptation approaches for agriculture, to develop technologies and practices to:

- Create complementary income streams – for example through carbon farming supported by carbon markets
- Reduce emissions from agricultural soils – for example through improved land management practices and regenerative farming
- Improve farm productivity and increase on-farm water and energy efficiency – for example through controlled environment horticulture
- Support climate change adaptation – for example through applying synthetic biology to develop drought-resilient crops
- Incorporate renewable energy sources – for example through utilisation of low-cost on-farm solar or wind and bio-waste conversion.

This is also an important regional opportunity, given the diverse range of climate regions, ecosystems, agricultural types and production scales in NSW. As climate change impacts global agricultural production, NSW expertise can be exported to assist overseas agricultural producers to make their businesses resilient to extreme climatic conditions including drought and heat.

Potential opportunity 16	Emission reduction technologies, aligning with the NSW DPI Climate Change Research Strategy. Promising opportunities include technologies to reduce livestock emissions (for example, feed supplements, breeding, and vaccinations) and emissions from agricultural soils; and partnerships with overseas research initiatives such as the Global Research Alliance on Agricultural Greenhouse Gases.

[14] For example, new 'Low Sulphur Fuel' regulations from the International Maritime Organisation, aiming to reduce marine pollution from ships and respond to climate change, will come into effect on 1 January 2020 (Bioenergy Australia, 2019). In 2009, the International Air Transport Association set targets of carbon neutral growth from 2020 and a 50 per cent reduction in net emissions by 2050 compared to 2005 levels (IATA, 2019). Some airlines have already trialled biofuels and are investing in further research, development and implementation (Qantas, 2019).

[15] For example, in New Zealand, emissions from livestock account for approximately 36 per cent of all emissions (NZ Ministry for the Environment, 2019a) and the New Zealand government has committed to a number of strategies to reduce agricultural emissions (NZ Ministry for the Environment, 2019b). California has a herd of approximately 5.15 million cattle and has a target of reducing methane emissions by 40 per cent by 2030 (Kahn, 2017; NCBA, 2019; RNZ, 2019). As a result, California is an early target market for commercialisation of emissions reduction technologies for livestock (RNZ, 2019). By comparison, NSW has a cattle herd of 5.3 million cattle (MLA, 2018).

Potential opportunity 17	Controlled environmental horticulture to reduce the emissions intensity and improve the climate change resilience and productivity of the NSW agricultural sector; and to build local supply chains for the necessary infrastructure, technologies and services.
Potential opportunity 18	The application of climate models and data to agricultural lands to aid sustainable land management and assist with making agricultural enterprises more resilient to climate change.
Potential opportunity 19	New agricultural and manufacturing opportunities building local supply chains for plant-based protein products, as well as reducing the emissions impacts of traditional meats to protect the NSW agricultural sector from competition from novel agricultural products, including cultured meats.
Potential opportunity 20	Agtech and digital transformation in agriculture.

Activities within the land use, land use change and forestry sector can capture carbon in vegetation and soils. In NSW, this presents opportunities for landowners, including farmers and the forestry industry, to participate in carbon offsetting programs that provide alternative or additional economic benefits to their current primary use of land, and to generate income from land which is less productive for traditional agriculture. These programs also provide opportunities to improve the climate change resilience of the native environment, protecting 'nature-based' tourism. The efficacy of these programs relies on well-functioning carbon markets, supported by robust and transparent carbon accounting.

Potential opportunity 21	Innovative approaches to land use and management to capture carbon in vegetation and soils. This is supported by carbon offset programs to enable greater use of carbon credits, and participation in international carbon markets. This has the potential to: • deliver increased economic prosperity for regional communities, through new or additional sources of income for landholders, farmers and the forestry industry • provide opportunities for restoring and maintaining native environments (e.g. national and state parks), thereby improving the climate resilience of 'nature-based' tourism • grow the NSW environmental services sector which provides the services necessary to enable offsetting and effective carbon markets.

1.3.6 Industrial processes and feedstocks

Industrial processes are energy and resource intensive. To meet the demands of increasing economic growth and sustainability, demand for sustainable products with decarbonised supply chains continues to grow. NSW can develop technologies and services to decarbonise these industrial supply chains by focusing on:

- increasing electrification and improving the energy efficiency and productivity of industrial facilities and processes
- optimising processes, in particular in industries where NSW already demonstrates world-leading process efficiency, such as mining
- increasing material efficiency, durability, reuse and substitution to extend material, product and building lifecycles
- implementing alternative decarbonised processes and feedstocks such as green hydrogen for steel and ammonia production.

As electricity, fossil fuels and materials are major costs in industrial processes, these decarbonised processes could be more cost-effective than existing carbonised processes. For example, at low renewable energy costs, green hydrogen leveraging abundant solar resources in NSW could be more cost competitive than existing coal and methane feedstocks in steel and ammonia production (McKinsey & Company, 2018). This could simultaneously improve the productivity of NSW industry and enable NSW to become a major global supplier of advanced, value-added sustainable products. NSW should particularly target areas where it has competitive advantages but where solutions are yet to

be widely commercially available. For example, NSW's major investment in public infrastructure, and research capabilities in cement chemistries and circular economies, offer an opportunity to develop and demonstrate novel cements and other materials at scale.

Potential opportunity 22	Cost-effective electrification and alternative heat technologies for industry.
Potential opportunity 23	Efficient mining operations including: • electrified, autonomous and optimised extraction, processing and transport technologies for mining • on-site renewable generation and microgrids • highly efficient on-site beneficiation plants utilising low cost and abundant renewable energy resources. These technologies (including enabling digital technologies) will both support the prosperity of the local mining industry and offer exportable mining services and technologies.
Potential opportunity 24	Expand on NSW's environmental services capability and expertise (in building efficiency standards and management) to improve the energy efficiency of industrial infrastructure and processes.
Potential opportunity 25	Technologies, products and services, produced in NSW, for: • improved material efficiency through design and manufacturing processes • material substitution for new low-emission and embodied carbon products (including manufacturing timber) • repurposing, recycling and reuse of existing materials.
Potential opportunity 26	A stronger wood-products manufacturing sector for the building industry using plantation wood and developing laminated wood materials for the construction, furniture and related industries. This would reduce demand for imported wood and emissions intensive construction materials by supporting increased use of wood in low, medium and high-rise construction in NSW.
Potential opportunity 27	Opportunities for new low-emission hydrogen production to target industries that could move to hydrogen as a feedstock such as in metal and chemical production.
Potential opportunity 28	Novel cement products, produced in NSW, including local demonstration of novel cement chemistries in infrastructure.

1.3.7 Fugitive emissions

NSW's large number of legacy coal mines, associated infrastructure, and experience in technologies for detection and abatement of fugitive emissions means that it is well placed to develop and commercialise viable technologies. The NSW Government has made investments in these technologies through Coal Innovation NSW. These technologies also offer export opportunities interstate and overseas.

Potential opportunity 29	Innovative and cost-effective: • ventilation air methane (VAM) abatement technologies for coal mines • novel detection technology for fugitive emissions from gas wells.

1.3.8 Infrastructure and the built environment

Infrastructure and the built environment consume approximately 50 per cent of electricity in NSW. Improving the construction, energy and material efficiency of infrastructure and the built environment can reduce emissions, and energy and material costs. At present, significant investment is being directed into infrastructure and building construction in NSW,[16] and the population of NSW is forecast to grow from 7.9 million to between 9.6 million and 10.2 million by 2035 (Australian Bureau of Statistics, 2018). As demand for decarbonised and sustainable infrastructure increases rapidly, NSW has an opportunity to leverage

[16] The NSW Government has committed $97.3 billion to public infrastructure over four years from financial year 2019-20 (NSW Government, 2019a), and major planned projects include the Western Sydney Airport and Aerotropolis, the Western Harbour Tunnel and Beaches Link, and Sydney Metro West.

capability in a decarbonised built environment to export products and services, as well as to improve the sustainable design, productivity and resilience of NSW infrastructure.

A particular opportunity exists around the planned Western Sydney Airport and Aerotropolis, which could be used to demonstrate innovative technologies and approaches to decarbonised infrastructure at scale. This precinct will be operating in a net zero environment past 2050 and could be used to catalyse innovative decarbonised technologies and services for transport infrastructure, commercial and residential buildings, industry and manufacturing, and public spaces, across NSW. The Special Activation Precincts offer similar opportunities.

A range of technologies and services could be developed and deployed in NSW infrastructure, including: design for urban heat mitigation, climate control and natural lighting; appliance, heating and lighting efficiency; integrated renewable generation, storage and microgrids; modular design and construction; novel materials such as geopolymer cements; advanced manufacturing processes such as additive manufacturing; novel designs for low carbon materials such as medium and high-rise timber buildings; sensing for predictive maintenance; digital twins; and repurposing and refurbishment.

Government has a critical and central role in channelling investment to decarbonised infrastructure, by incorporating sustainability and climate resilience considerations into the infrastructure pipeline and procuring these technologies and services. This is a major driver for investment, innovation, cost-reduction, workforce up-skilling and the creation of supply chains for these products and services. It can also accelerate their wider uptake beyond government, and can lead to improved affordability for consumers – for example through lower energy costs and mortgage costs.[17] It can also lead to financial benefits for government, for example by reducing additional demand on utilities from new energy and water efficient infrastructure.

NSW has competitive advantages in decarbonised and climate-resilient infrastructure and built environment. These include research and development capabilities, supportive standards and regulations such as the National Australian Built Environment Rating Scheme (NABERS) and the Building Sustainability Index (BASIX), as well as sustainable finance capabilities and products. As demand for decarbonised infrastructure in Asia increases rapidly, NSW has an opportunity to leverage local capabilities in these technologies and services for export.

Potential opportunity 30	Decarbonised and climate-resilient infrastructure and new housing stock with improved construction, energy and material efficiencies including demonstrations at scale in major greenfield precincts in NSW.

1.3.9 Sustainable products and services

There is an increasing demand for sustainable products and services as companies and consumers seek to reduce their emissions and adopt more sustainable approaches through design, resource recovery, substitution, repurposing and recycling. NSW could become a major global supplier of value-added sustainable products and services, and expertise in both development and implementation. Robust regulatory frameworks and best practice circular economy demonstration locally can support this growth.

Potential opportunity 31	Policy incentives, procurement and piloting of sustainable products and services in NSW.

1.3.10 Carbon Capture and Storage and utilisation

Carbon Capture and Storage (CCS) and Carbon Capture and Utilisation (CCU) technologies are the most practical and cost-effective method to eliminate residual emissions in some hard-to-abate sectors. Further investment and deployment of these technologies is

[17] For example, interest rate discounts for climate-resilient homes are already available.

necessary to improve the efficacy and cost effectiveness of these technologies as they will be necessary to meet emissions reduction targets set by international industry and governments, and will help to protect emissions-intensive sectors in NSW from carbon and transition risks. NSW has the potential to commercialise CCS and CCU technologies, leveraging competitive advantages in research and development, investment, pilot testing facilities, geological storage potential and capacity, and existing export relationships in industries which will require CCS.

Potential opportunity 32	CCS and CCU technologies, as well as extraction and use or storage of biomethane from waste and landfill sites, including: • research, development and demonstration of CCS and CCU technologies, including industrial processes that lead to the production of concentrated CO_2 or solid carbon for applications in other industries • deployment of CCS and CCU technologies in industry • procurement of materials produced using CCU technologies to replace emissions-intensive materials where practicable. As the viability of most CCS and CCU technologies is impacted by the cost-effectiveness and practicality of alternative zero-emissions processes, it is critical that CCS and CCU is targeted towards hard-to-abate emissions processes that have no cost-effective or practical zero-emissions alternatives in the medium to long-term.

Carbon dioxide removal, if deployed on sufficient scale, may be a necessary approach to reach net zero emissions. Further research and development of these technologies is necessary to realise this decarbonisation pathway. Combined with well-functioning international carbon markets, this would enable NSW, particularly in regional and remote areas, to provide a globally marketable carbon dioxide removal industry and offer new sources of income to NSW.

Potential opportunity 33	Carbon dioxide removal (CDR) approaches, in particular: • land management approaches including forestation and carbon farming • bioenergy with CCS and direct air capture of CO_2 where technologies can demonstrate potential medium and long-term viability and competitiveness with zero emissions alternatives • well-functioning carbon markets and robust and transparent carbon accounting approaches to enable and incentivise CDR.

1.3.11 Synthetic biology

Synthetic biology offers significant opportunities to decarbonise and improve climate resilience in multiple sectors. For example, synthetic biology provides opportunities in:

- Agriculture – to create highly productive and resource-efficient crops suited to specific and changing environments
- Industry – to optimise the activity, yield and quality of industrial enzymes to produce better food and chemicals, with less waste and energy
- Energy – to optimise the genes of plants and microorganisms to increase the efficiency of the biofuel production process.

These approaches can improve productivity while lowering emissions. NSW has strong research capabilities in synthetic biology including a recently announced ARC Centre of Excellence in Synthetic Biology.

Potential opportunity 34	Synthetic biology for commercial applications in agriculture, industrial processing, manufacturing and bioenergy.

1.4 NEXT STEPS

The changing climate poses risks to existing industries, communities and ecosystems. However, these risks also present opportunities to develop the decarbonisation and adaptation technologies and services to grow NSW's existing industries and establish new industries and export markets for NSW. The potential opportunities presented in this paper represent an initial survey of technologies and services which could generate economic development, prosperity and jobs growth in NSW.

NSW will benefit most from an approach that focuses on a clearly defined range of technologies and services supported by NSW's competitive advantages – for example in research and development, workforce, regulatory environment, capital markets and geography. NSW's competitive advantages support potential opportunities raised in this paper. However, these opportunities require further analysis to select those which are most feasible, suitable, and technically and commercially viable for NSW.

In analysing these potential opportunities, the Office of the NSW Chief Scientist & Engineer and the expert panel will engage further with industry, government, researchers and decarbonisation and climate change adaptation experts. The final report will identify opportunities that have the greatest potential economic and employment benefit for NSW, and potential actions to realise these opportunities – for example, new strategies, regulations, policies and investment.

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