



Shaping the future of NSW in science and technology

20-Year R&D Roadmap





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

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Minister's foreword

Research and Development (R&D) is a critical driver of new businesses, jobs and investment. It shapes positive economic and social outcomes and is key to the creation of future industries as we move beyond the COVID-19 pandemic.

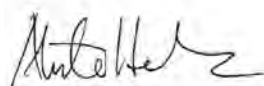
The NSW Government is strongly committed to supporting innovation, research and industry ecosystems. This is why the Premier made the decision to create, for the first time, a portfolio incorporating science, innovation, technology and the skills to advance these fields. Through initiatives like the *Turning ideas into jobs: Accelerating R&D in NSW Action Plan* (the ARDAC Action Plan), the NSW Government has made cutting-edge R&D an economic and social priority for NSW.

The 20-Year NSW R&D Roadmap (the Roadmap) is a recommendation of the ARDAC Action Plan and an important piece of work to understand how best to invest in and support R&D in NSW. The NSW Government invests hundreds of millions of dollars in R&D each year. Given that level of investment, the Roadmap will help us to achieve the best results for economic growth and social wellbeing, and the creation of new jobs, companies and industries in NSW. It will help the NSW Government to work with industry, researchers and entrepreneurs to optimise R&D investment and activities in NSW.

The Roadmap comes from a deep analysis of NSW's competitive advantages in areas such as R&D and industry capabilities, skilled workers, students and education pathways, regulatory frameworks, innovation, university research and natural assets. It was also guided by NSW, Australian and international industry and research leaders, who have real world experience working with innovative technologies, creating new startups and attracting investment. These leaders have first-hand understanding of these opportunities and where NSW should be focusing.

While we already know that NSW R&D is world-leading in many areas, the Roadmap demonstrates the breadth and depth of NSW's competitive advantages. The State Government is committed to ensuring that NSW achieves its potential to create the industries and jobs of the future.

Sincerely,



The Hon. Alister Henskens, SC MP

Minister for Science, Innovation and Technology
Minister for Skills and Training



NSW Chief Scientist & Engineer's foreword

R&D plays a critical role in addressing many of the major challenges facing NSW and the world. Over the next 20 years, issues such as automation, climate change, urbanisation, and demographic and economic power shifts are expected to have major impacts on the labour market, infrastructure, and industrial and economic capacity.

R&D is important because it not only allows us to respond to these challenges but find opportunity in them through new science, engineering and knowledge. Clean energy technologies can help us decarbonise and mitigate the impacts of climate change. Robotics can enhance productivity and create highly skilled jobs in software and advanced manufacturing. Novel medicines and medical technologies can help to manage the economic burdens of an ageing population, while improving our health and wellbeing.

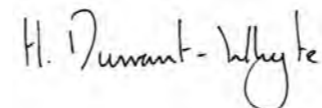
The Roadmap will help NSW to navigate these challenges and seize these opportunities, providing a blueprint for government, industry and research organisations to focus R&D investment and activities to future-proof our economy for the benefit of everyone in our state.

In an increasingly connected global market for goods, services, investment and skills, economies that leverage world-leading R&D dominate industries. Economies that are unable to sustain sufficient R&D capabilities and technology adoption will fall behind international competitors that can. The Roadmap identifies NSW's existing competitive advantages, as well as areas where there are strategic imperatives for NSW to develop capability.

The Roadmap is the culmination of an extensive research and consultation process led by the Office of the NSW Chief Scientist & Engineer (OCSE) over the past six months. I would like to thank all the research, industry and government leaders who provided valuable guidance during this process.

The Roadmap identifies four technology themes – Digital, Materials and Chemistry, Biotechnology, Energy – and 39 applications, which illustrate the wide range of competitive advantages NSW holds. We are in a strong position to strengthen and leverage these advantages to grow future industries in NSW. OCSE is already taking action in some of these areas, including semiconductors and synthetic biology. I look forward to leading further action on the Roadmap and working with NSW businesses, researchers, entrepreneurs and innovators to realise its ambition.

Sincerely,



Professor Hugh Durrant-Whyte
NSW Chief Scientist & Engineer



An R&D Roadmap for NSW has never been more important.

Given the scale of our future challenges and opportunities, NSW needs to effectively focus its R&D investments and activities to maximise the positive impacts of science and technology R&D.

Executive summary

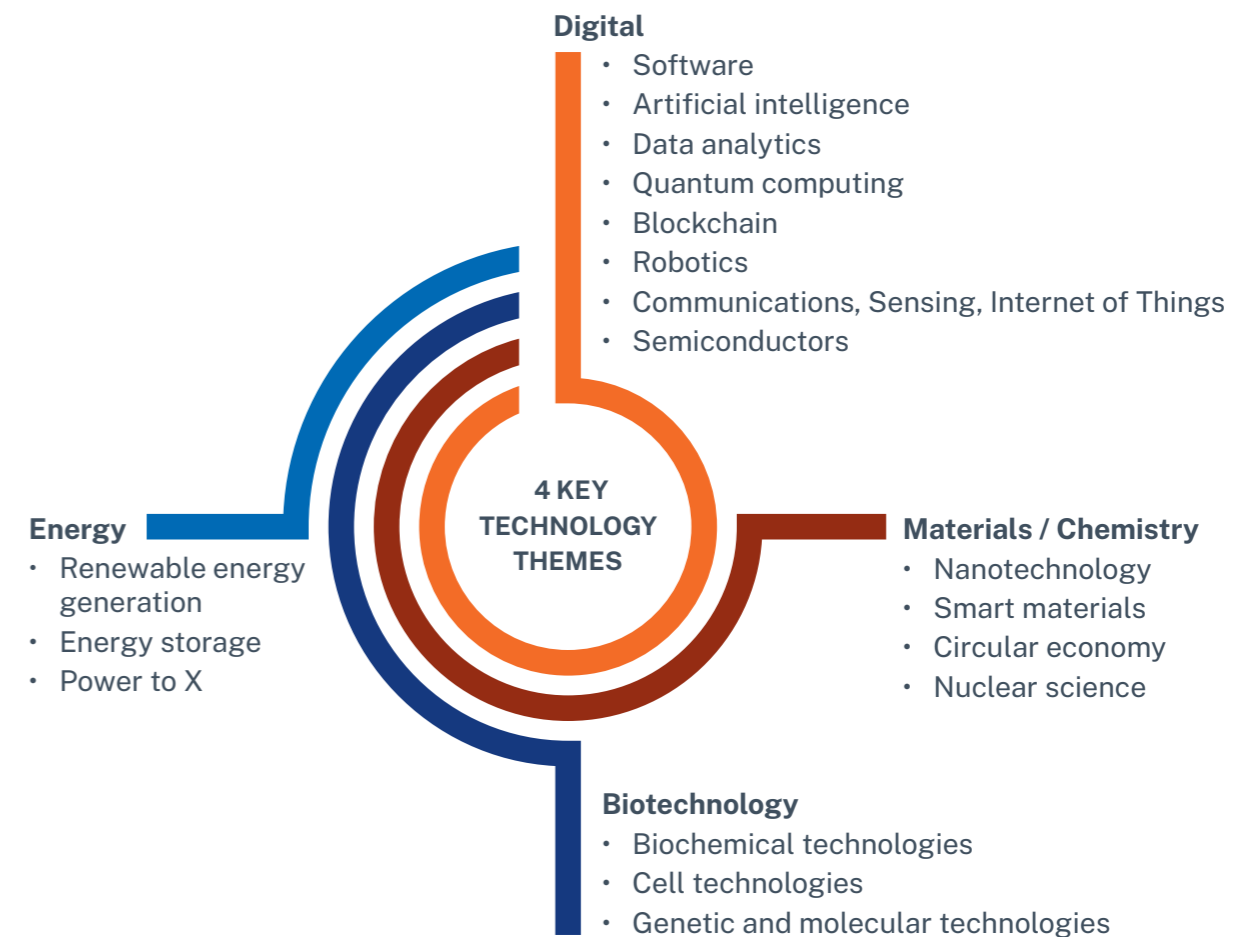
The next 20 years will see rapid and significant disruption in the global economy, with unprecedented challenges and opportunities.

Demographic changes will put pressure on public infrastructure and services, but technologies such as robotics and AI can improve the quality and capacity of social and health services. R&D is critical to address these challenges and realise these opportunities – and many others – to drive economic, social and environmental prosperity.

Given the scale of our future challenges and opportunities, NSW needs to effectively focus its R&D investments and activities to maximise the positive impacts of science and technology R&D. It makes sense to prioritise R&D investment towards technologies and applications where NSW has strategic needs or competitive advantages.

The Roadmap identifies four technology themes where NSW has international or domestic competitive advantages:

Digital | Materials and Chemistry | Biotechnology | Energy



The Roadmap provides a blueprint that will:

- Help the NSW Government direct R&D investments and activities in science and technology, by assessing and prioritising areas where NSW has existing and emerging competitive advantages or strategic needs.
- Identify capabilities NSW needs for strategic reasons, such as cyber security.
- Signal where NSW welcomes private R&D investment and activities from businesses, entrepreneurs, innovators, startups and investors.
- Assist government, industry and universities to coordinate research investment and activities.
- Provide an ongoing evidence-based framework to assess NSW competitive advantages and monitor how they change over 20 years.
- Highlight disruptive technologies that can be leveraged to increase prosperity and address critical economic, social and environmental challenges.

The Roadmap sets out a 20-year vision for NSW to produce more world-leading new technologies, products and services, and develop and sustain globally competitive industries that improve productivity, standards of living, quality of life, and the natural environment.

The Roadmap is a recommendation of the *Turning ideas into jobs: Accelerating R&D in NSW Action Plan*¹. It was developed by OCSE through an evidence-based analysis of data on NSW's competitive advantages and in consultation with NSW, Australian and international industry and research leaders.

These leaders have first-hand experience in translating R&D, working with disruptive technologies, creating new startups and attracting investment. They provided valuable insights on NSW's niche and emerging competitive advantages.

Within the four themes, the Roadmap identifies 39 applications where NSW has competitive advantages. The applications are wide ranging – including FinTech, quantum computing, nuclear science and pharmaceuticals – and are relevant to all sectors of the economy. This presents opportunities to translate leading science and technology capabilities from one sector to another and develop more complete capabilities across supply chains in NSW.

The breadth and depth of capabilities in NSW businesses and universities is too great to summarise in a single document. As such, the Roadmap is not an exhaustive list of NSW capabilities, but instead identifies where NSW has compelling aggregations of competitive advantages in science and technology. The Roadmap takes a 20-year view, recognising that efforts to focus R&D should start now, but will take time to be fully realised at the industry level. Further, given the rapid pace of change and uncertainty in R&D, the Roadmap will be updated periodically to adapt and respond to local and global trends and opportunities.

To implement the Roadmap, action plans will be developed for the identified applications. The action plans will set out specific steps to catalyse and leverage the advantages, focusing on commercialisation and translation of research to enable future industries, as well as broader actions where necessary.



1. Accelerating R&D in NSW Advisory Council, *Turning ideas into jobs: Accelerating R&D in NSW Action Plan* (2021)

R&D drives prosperity

Effective R&D that advances knowledge, science and technology is essential to maximise NSW's prosperity and address local and global challenges. R&D underpins all elements of prosperity, for example:

- Economic prosperity – by driving new technologies that increase productivity, raising aggregate demand by allowing companies that develop or adopt them to offer more competitive goods and services, pay higher wages, and return income to investors. Increased demand stimulates the economy, leading to further business and job creation and growth.
- Social prosperity – by improving quality of life through innovations such as new medical treatments and high quality public services, as well as technologies that increase productivity and allow more time for social, personal, creative and recreational pursuits.
- Environmental prosperity – by improving understanding of the environment, and how to better preserve and enhance it, and live more sustainably.

Disruptive technologies driven by R&D have dramatically increased prosperity and altered economies. For example, the past 150 years of industrialisation has led to significant productivity increases and realignment of employment from the production of basic goods to the delivery of services and production of goods of higher complexity and value. Disruptive technologies like the steam engine, antibiotics, electricity, mass production, and the internet have been transformative – creating new industries, businesses and jobs while upsetting existing ones. R&D and disruptive technologies have also helped to address major economic, social and environmental challenges. For example, vaccines have helped to dramatically reduce the impact of severe diseases.

Further disruptive technologies are inevitable. Robotics, Internet of Things, gene editing and quantum computing are already emerging and disrupting existing industries. However, whether these innovations are developed and applied in NSW is not inevitable. In an increasingly connected global market for goods and services, businesses that invest in world-leading R&D dominate industries. Skills are also increasingly mobile, with highly skilled workers migrating globally to pursue the most attractive jobs at the most innovative businesses. Economies and businesses that are unable to sustain sufficient rates of R&D and technology adoption are likely to fall behind their international competitors that can.

To sustain and improve its economic, social, and environmental prosperity, NSW must leverage R&D in science and technology to accelerate the development and adoption of disruptive technologies across all industries and businesses in NSW. R&D is critical for supporting both:

- Existing industries to leverage disruptive technologies and ensure they remain internationally competitive and support NSW's continued prosperity.²
- 'Future industries' based on disruptive technologies that will sustain long-term prosperity. Future industries arise where the impact of new technologies is sufficiently disruptive and dramatic, such that existing products and services are displaced, and new markets are created.³

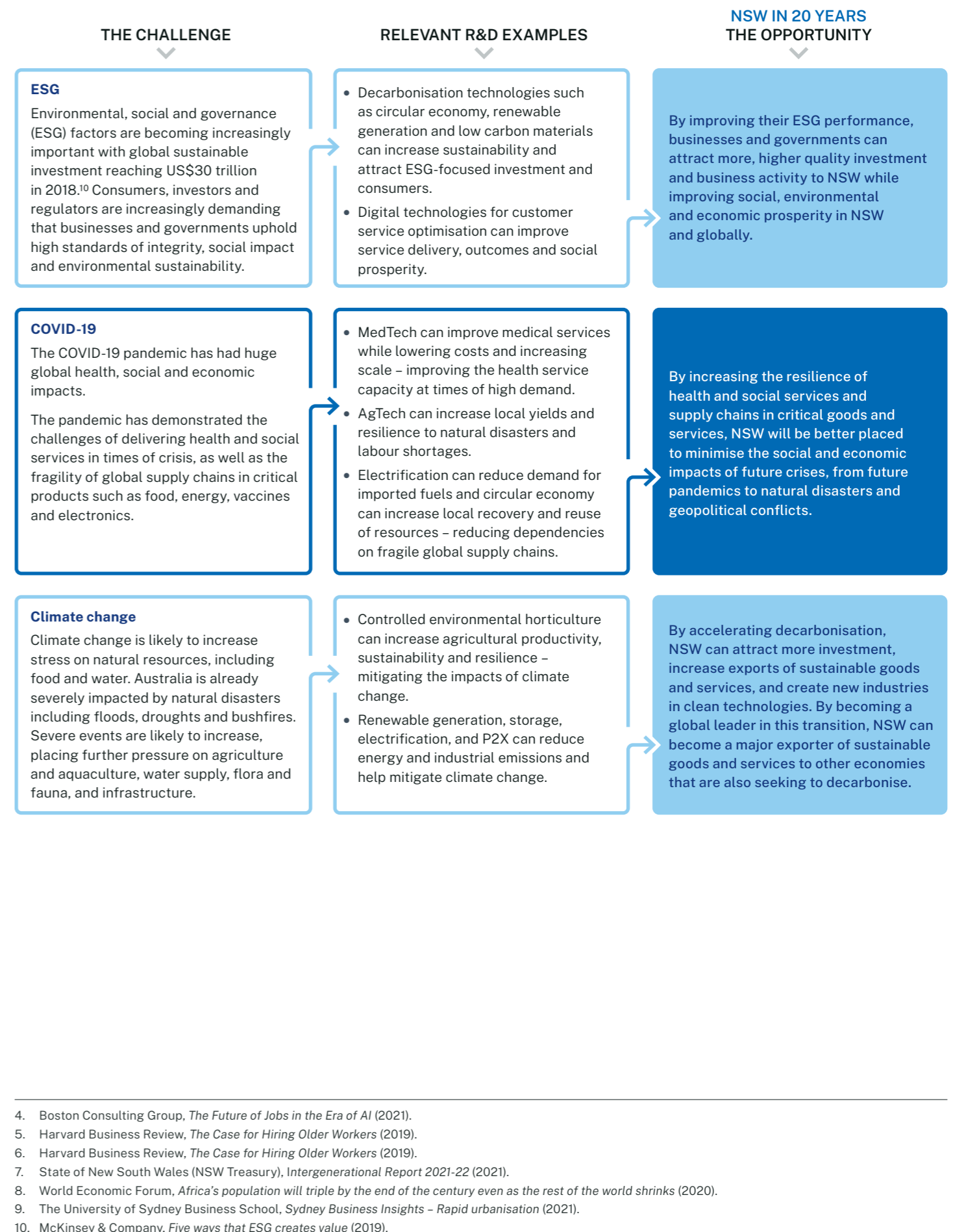
R&D can address fundamental challenges over the next 20 years

The R&D opportunities highlighted in the Roadmap address many of the fundamental economic, social and environmental challenges and megatrends facing NSW and the world over the next 20 years. These challenges also present opportunities for economies and businesses that can respond effectively (Figure 1). R&D is important in understanding and responding to these challenges and megatrends, to maximise benefit and minimise harm. The Roadmap helps government and industry to respond, by identifying where NSW's competitive advantages can be leveraged to meet these challenges.

2. For example, increased energy efficiency and carbon capture technologies could assist heavy industries in transitioning from existing emissions intensive processes to lower emissions processes. However, at a sufficient level of technology development, many existing industries may be completely displaced by future industries.

3. For example, the renewable energy industry, where development and adoption of solar technologies has created new supply chains in solar photovoltaics, and new markets in domestic and commercial energy goods and services. Energy storage products are further accelerating the growth of this industry.

Figure 1: Fundamental challenges and opportunities



4. Boston Consulting Group, *The Future of Jobs in the Era of AI* (2021).
 5. Harvard Business Review, *The Case for Hiring Older Workers* (2019).
 6. Harvard Business Review, *The Case for Hiring Older Workers* (2019).
 7. State of New South Wales (NSW Treasury), *Intergenerational Report 2021-22* (2021).
 8. World Economic Forum, *Africa's population will triple by the end of the century even as the rest of the world shrinks* (2020).
 9. The University of Sydney Business School, *Sydney Business Insights – Rapid urbanisation* (2021).
 10. McKinsey & Company, *Five ways that ESG creates value* (2019).

Why does NSW need an R&D Roadmap?

While the prosperity benefits of R&D are significant, R&D can also be costly and have long incubation periods from idea to commercialisation. The benefits of disruptive technologies often arise after a heavy investment phase that initially drags productivity as resources are directed into R&D and adoption.¹¹ Further, the breadth and diversity of disruptive technologies is large, and international competition is fierce and well resourced. In 2018, approximately \$11 billion or 1.9% of NSW Gross State Product (GSP) was spent on R&D.¹² This represents significant investment, but is still below many global peers.¹³

Given the many opportunities for R&D, the NSW Government, businesses and research institutions need to prioritise and coordinate their R&D investments and activities in science and technology. It makes sense to prioritise R&D by focusing on technologies and applications in which NSW has competitive advantages. Competitive advantages are attributes that allow a business or state to outperform its competitors. By focusing on these areas, NSW is more likely to maximise the benefits of R&D investment, producing more world-leading technologies, products and services, and developing and sustaining globally competitive industries.

NSW also needs capabilities in sectors, technologies and applications that are critical for strategic reasons, such as economics, health and national security. For example, the COVID-19 pandemic has demonstrated the importance of local supply chains in messenger RNA (mRNA) vaccines, testing and personal protective equipment.

The Roadmap sets out how NSW should harness its competitive advantages and target its R&D investments and activities. It provides guidance to government, businesses, entrepreneurs and researchers on areas of R&D that are well aligned with NSW's competitive advantages and strategic needs.

Impact of the Roadmap

The Roadmap provides a comprehensive view of competitive advantage across the NSW economy. It is designed to inform and assist government, businesses, entrepreneurs and researchers to coordinate and optimise their R&D investment and activities in science and technology.

The Roadmap provides a blueprint that will:

- Help the NSW Government direct R&D investments and activities in science and technology, by assessing and prioritising areas where NSW has existing and emerging competitive advantages or strategic needs.
- Identify capabilities NSW needs for strategic reasons, such as cyber security.
- Signal where NSW welcomes private R&D investment and activities from businesses, entrepreneurs, innovators, startups and investors.
- Assist government, industry and universities to coordinate research investment and activities.
- Provide an ongoing evidence-based framework to assess NSW competitive advantages and monitor how they change over 20 years.
- Highlight disruptive technologies that can be leveraged to increase prosperity and address critical economic, social and environmental challenges.

By adopting a 20-year period, the Roadmap acknowledges that the transformative impact of R&D occurs over a long timeframe, particularly for disruptive technologies and future industries. However, the Roadmap should also be viewed as a guide to NSW's R&D opportunities at a point in time.

The Roadmap is designed to be regularly reviewed and updated in recognition of the considerable uncertainty around how disruptive technologies will impact existing industries and create future industries. Forecasting the development and uptake of disruptive technologies is extremely difficult due to their characteristics:

- **Disruptive growth:** Rapid, exponential growth as they disrupt existing markets, often displacing existing technologies and creating new markets.
- **Cross-sector impacts:** Large addressable markets and productivity improvements often occur across multiple industry sectors as applications are discovered and integrated into more supply chains.
- **Catalysts of innovation:** Initially uncertain and often underestimated, as their applications can be unpredictable, they are a platform for further innovative products and services.

Each iteration of the Roadmap will consider what is happening in the local and global economy, as well as new data on NSW's competitive advantages and strategic needs. Over time, some of the advantages identified in the Roadmap will become more important as certain disruptive technologies develop more use cases and future industries are created. New, unanticipated technologies will emerge where NSW could have a competitive advantage. Some advantages will become less important as certain technologies struggle to find practical uses or remain unfeasible.

The Roadmap should not be considered a summary of NSW capabilities. While the Roadmap covers a diverse range of technologies across the whole economy, it is not exhaustive. The breadth and depth of capabilities in NSW businesses and universities is too great to summarise in a single document. Rather, the Roadmap identifies where NSW has a compelling aggregation of competitive advantages – across elements such as R&D, innovation, industry, education and workforce capacity, and natural advantages. Other NSW capabilities not featured in the Roadmap should not be ignored, but rather assessed on their individual merits.

The Roadmap complements and should be read alongside other important NSW Government initiatives, including the:

- *NSW Industry Development Framework*, which details how the NSW Government will support the growth of priority industries in partnership with the private sector, research institutions and other levels of government. Whereas the Roadmap focuses on identifying R&D priorities for NSW, the Framework adopts a priority industries approach.
- *NSW 2040 Economic Blueprint*, which identifies challenges and risks facing our economy and major opportunities for the NSW Government to grow industries, innovate and improve the economy.
- *NSW Innovation and Productivity Scorecard*, published by the NSW Innovation and Productivity Council, which provides a snapshot of NSW's innovation and productivity performance in comparison to other states and international economies.
- *Net Zero Plan Stage 1: 2020-2030*, which outlines the NSW Government's plan to grow the economy, create jobs and reduce emissions over the next decade.

Further detail on the development of the Roadmap is contained in the *20-Year NSW R&D Roadmap – Supplement*.

Roadmap development and methodology

The Roadmap is a recommendation of the ARDAC Action Plan.¹⁴ It provides a framework to guide public and private R&D investment and activities in science and technology in NSW and was developed by OCSE based on a thorough, evidence-based analysis of NSW's competitive advantages in areas such as R&D and industry capabilities, skilled workers, students and education pathways, regulatory frameworks, innovation and natural assets. NSW's competitive advantages were assessed against peer geographies such as other countries, states and cities.

The Roadmap was also developed in consultation with NSW, Australian and international industry and research leaders with first-hand experience of working with disruptive technologies, creating new startups and attracting investment.

These experts provided valuable insights on NSW's niche and emerging competitive advantages as well as on emerging disruptive technologies and industries that were not well captured in current data, which often only reflect existing industry capabilities and strengths.



11. For example, new capital equipment, training and integration costs.

12. R&D investment from business, higher education providers, and state and local government was \$6.8, \$3.8 and \$0.7 billion respectively. Innovation and Productivity Council, *NSW Innovation and Productivity Scorecard 2019* (2019), Australian Bureau of Statistics, *Research and Experimental Development* (2021).

13. For example, Israel and South Korea spent 4.9% and 4.6% of GDP on R&D in 2019, respectively. Organisation for Economic Co-operation and Development, *Gross domestic spending on R&D* (2021).

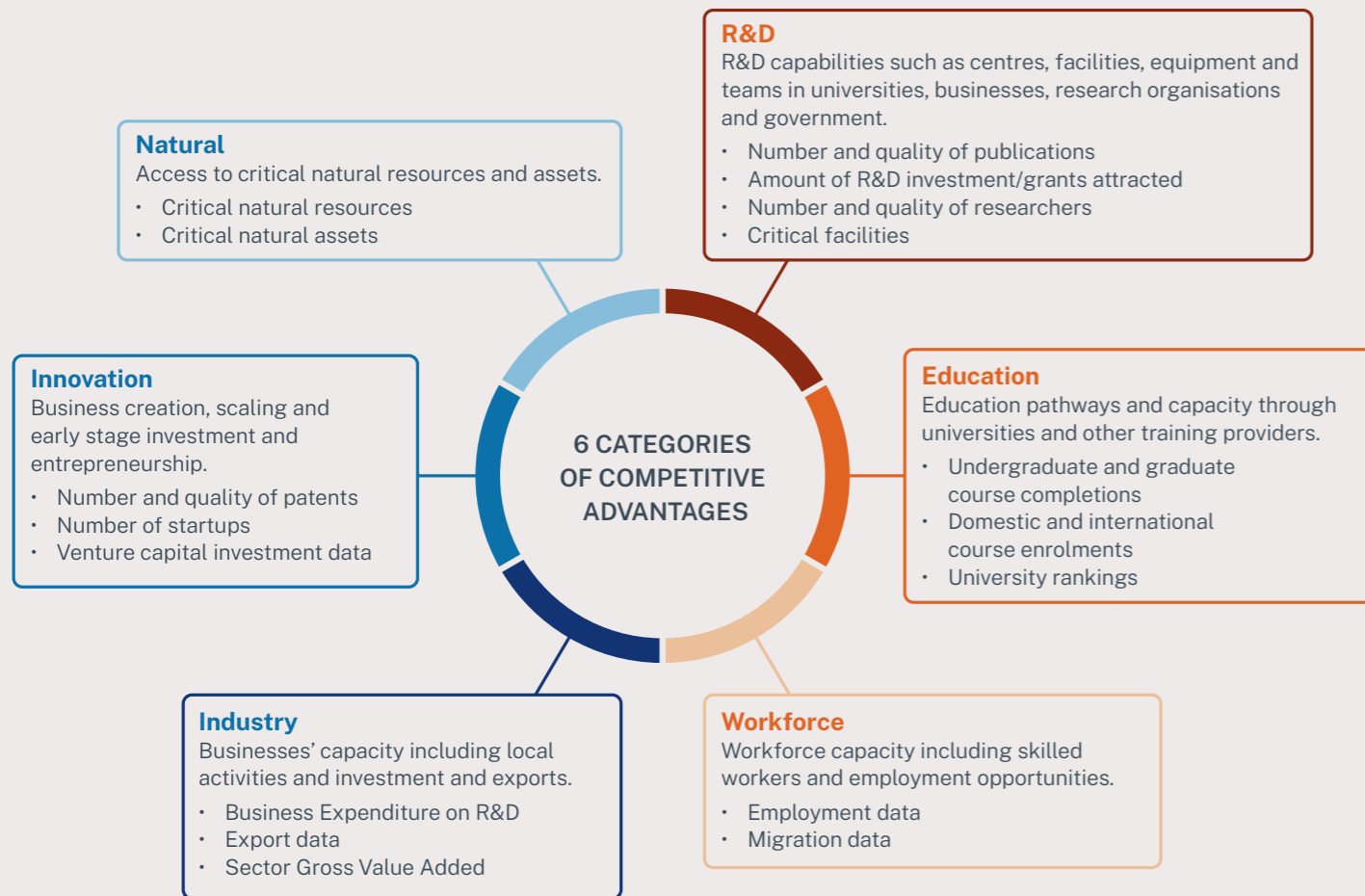
14. The ARDAC Action Plan sets out actions to accelerate the rate at which ideas are translated into new industries, jobs, products and services, and make NSW Australia's R&D leader and a world-class contributor.

NSW's Competitive advantages

Competitive advantages are attributes that allow a business or state to outperform its competitors.

The Roadmap considers six categories of competitive advantages (Figure 2).

Figure 2: Categories of competitive advantage



NSW's Competitive advantages

Science and technology R&D generally focuses on either improving technology platforms or applying specific technologies in different use cases. R&D for technology platforms is generally applicable across multiple sectors.

R&D for applying technologies may only be applicable across a few sectors or a single sector.

Therefore, the Roadmap focuses on identifying NSW's competitive advantages in 'technologies' and 'applications':

Technologies

Methods, systems and devices with common attributes and functions that can be applied in a variety of applications across different sectors. For example, 'software' that describes computer scripts, applications and programs – essentially all virtual function aspects of computers. This can be used for any application involving computers and electronics, from control systems to word processing, video games and graphic design.

Applications

The use of technology for a specified purpose, generally in a specific sector. For example, 'robotic agriculture', which comprises the use of robotics to perform tasks in the agricultural sector such as planting and harvesting.

What are NSW's competitive advantages?

NSW is a major economic hub in the southern hemisphere and Asia-Pacific region, with an economy larger than Hong Kong and Singapore. Sydney is Australia's largest city and ranks 24th globally for the concentration of the world's 2000 largest public companies headquartered in the city.¹⁵ This is a critical competitive advantage in attracting small, medium and large businesses. Many of the Australian offices of international companies are based in Sydney due to its economic strength, access to talent and international transport connections and networks to markets across Asia Pacific.

NSW's economic strength also supports business creation. The World Bank ranks Australia 14th out of 190 countries for ease of doing business, fourth for access to credit, sixth for enforcing contracts and seventh for ease of starting a business.¹⁶ NSW and Sydney in particular have a strong financial services sector, facilitating access to capital markets for new and existing businesses. Nearly 70% of Australia's financial services sector is in NSW,¹⁷ and Sydney is home to the world's 17th largest stock exchange.¹⁸ Australia's superannuation sector, the fifth largest in the world also provides deep pool of capital for local investment.¹⁹

NSW's population of over 8 million people – comparable to London, Israel or Arizona – is highly diverse, with over 35% born overseas and 25% speaking a language other than English at home.²⁰ NSW's diversity is an important competitive advantage – attracting high skilled immigrants, increasing ease of doing business in non-English speaking countries, and providing a domestic market for innovation and product development that is more representative of the global market.

Sydney is internationally highly regarded for its liveability, natural environment and brand.²¹ While the ongoing impacts of COVID-19 are highly uncertain, the increased acceptance and adoption of remote working arrangements are likely to encourage the relocation of global talent to the most liveable cities, towns and regional areas. Sydney and NSW are strongly positioned to attract this talent.

Competitive advantages in technologies and applications

The Roadmap identifies four technology themes and 39 applications across a range of sectors where NSW has an aggregation of competitive advantages – across elements such as R&D, innovation, industry, education and workforce capacity, and natural advantages – versus our domestic and international peers (Figure 3).

15. Forbes, Global 2000 (2021).

16. World Bank Group, Doing Business (2020).

17. Australian Bureau of Statistics, Australian System of National Accounts (2021).

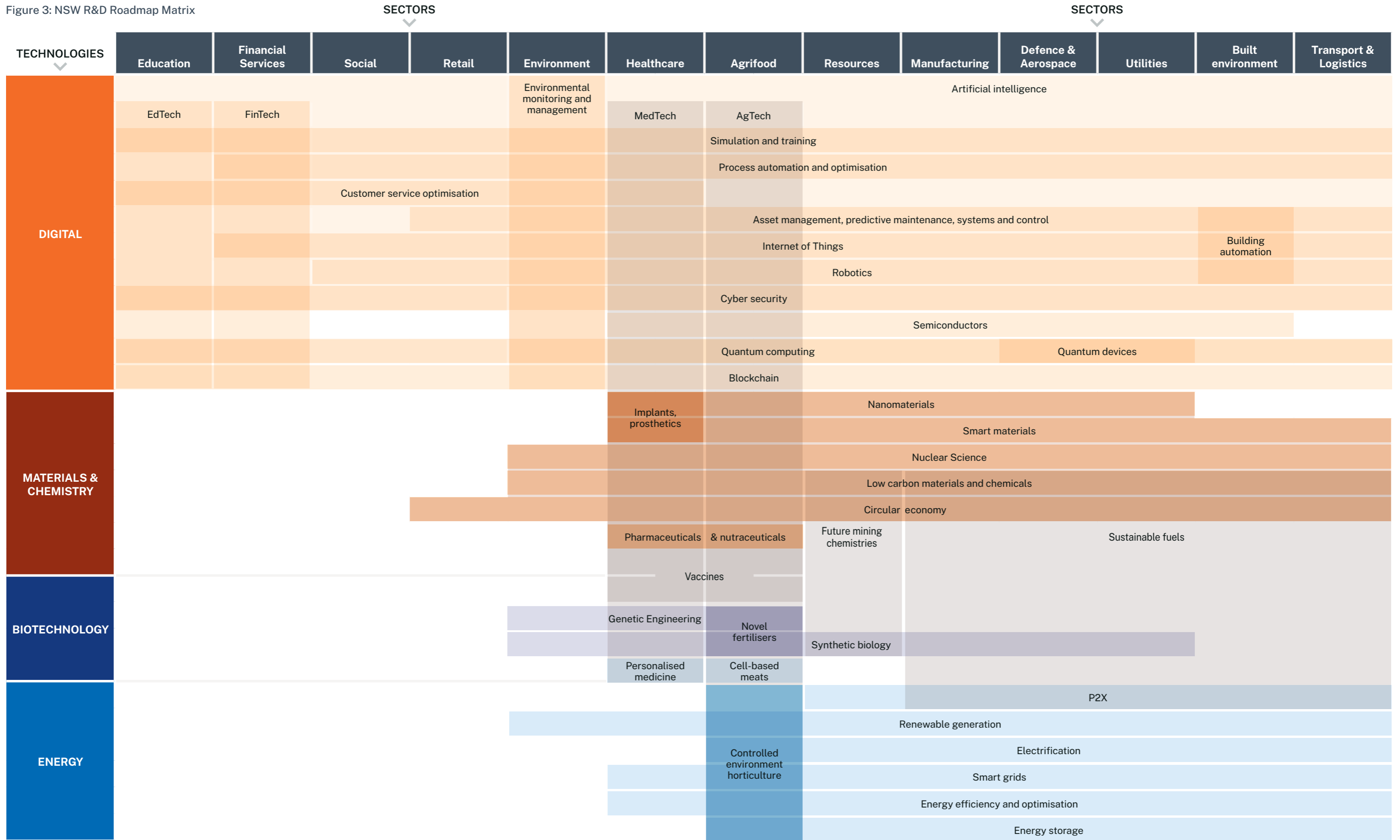
18. Statista, Stock Exchange Operators (2021).

19. Austrade, Australia's pension funds shine in 2021 global rankings (2021).

20. Australian Bureau of Statistics, Census of Population and Housing: Nature and Content (2016).

21. Committee for Sydney, Benchmarking Sydney's Performance (2021).

Figure 3: NSW R&D Roadmap Matrix



NSW's Industry Landscape: Competitive advantages against global peers²²

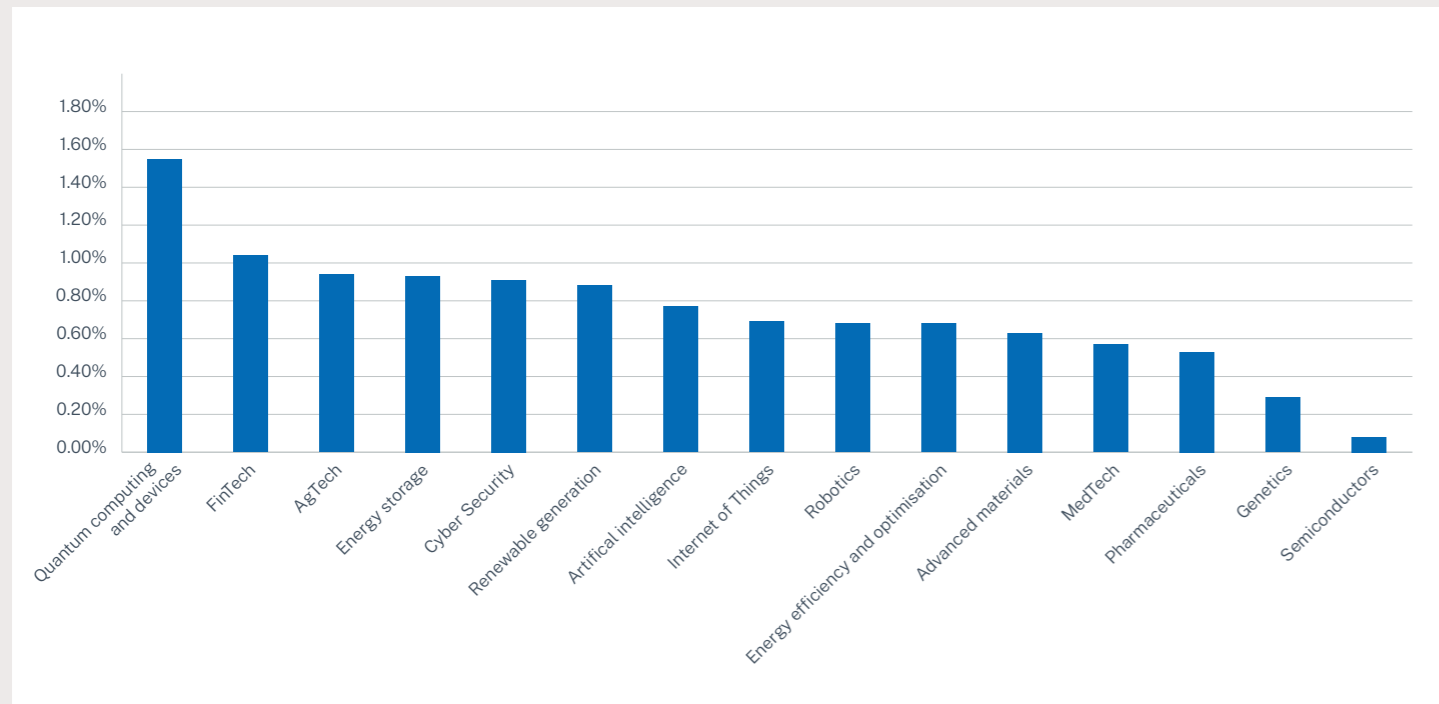
An important category of competitive advantage is the strength of the local industry ecosystem. NSW has strong business clusters in several applications identified in the Roadmap versus our global peers.

Figure 4: Top 3 applications in peer geographies



Based on percentage of all global businesses headquartered in each geography for each application area.

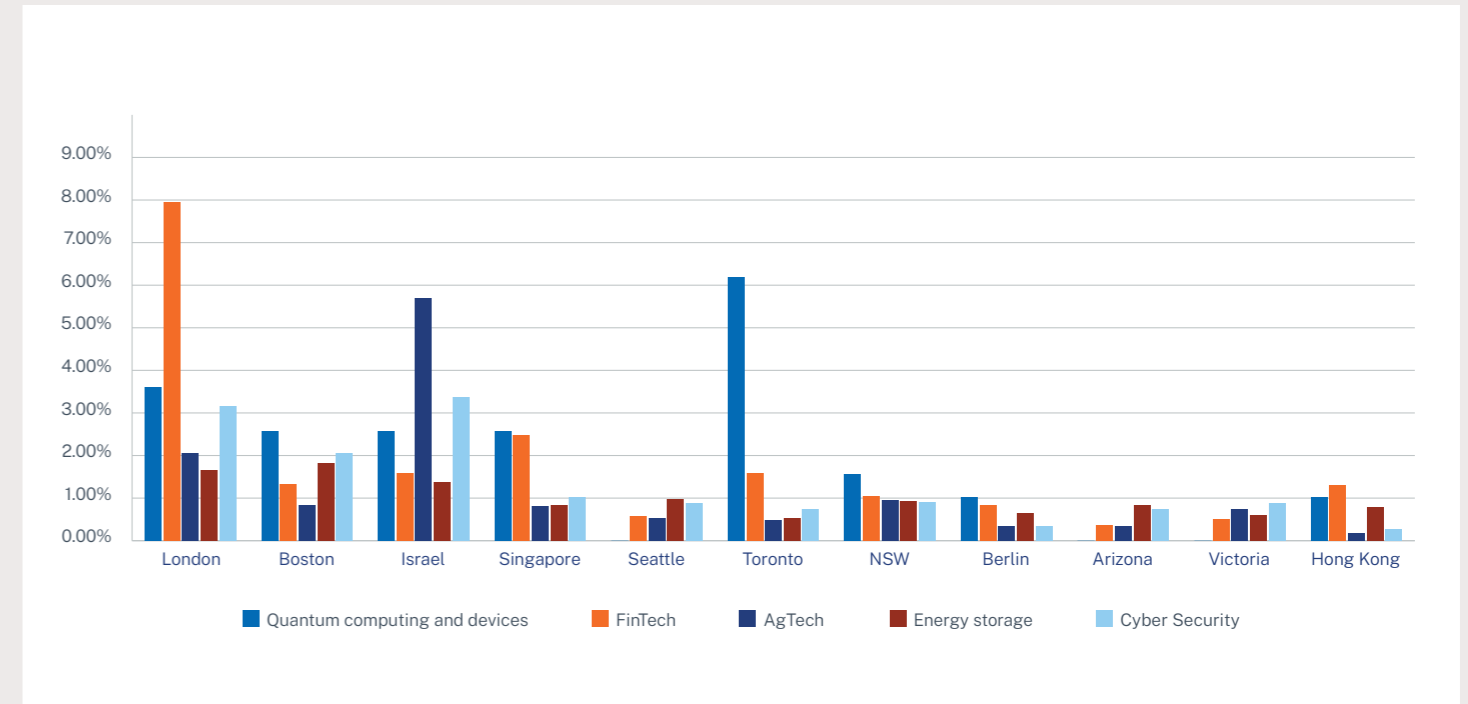
Figure 5: Proportion of all global businesses headquartered in NSW



Based on percentage of all global businesses headquartered in NSW geography for each application area.

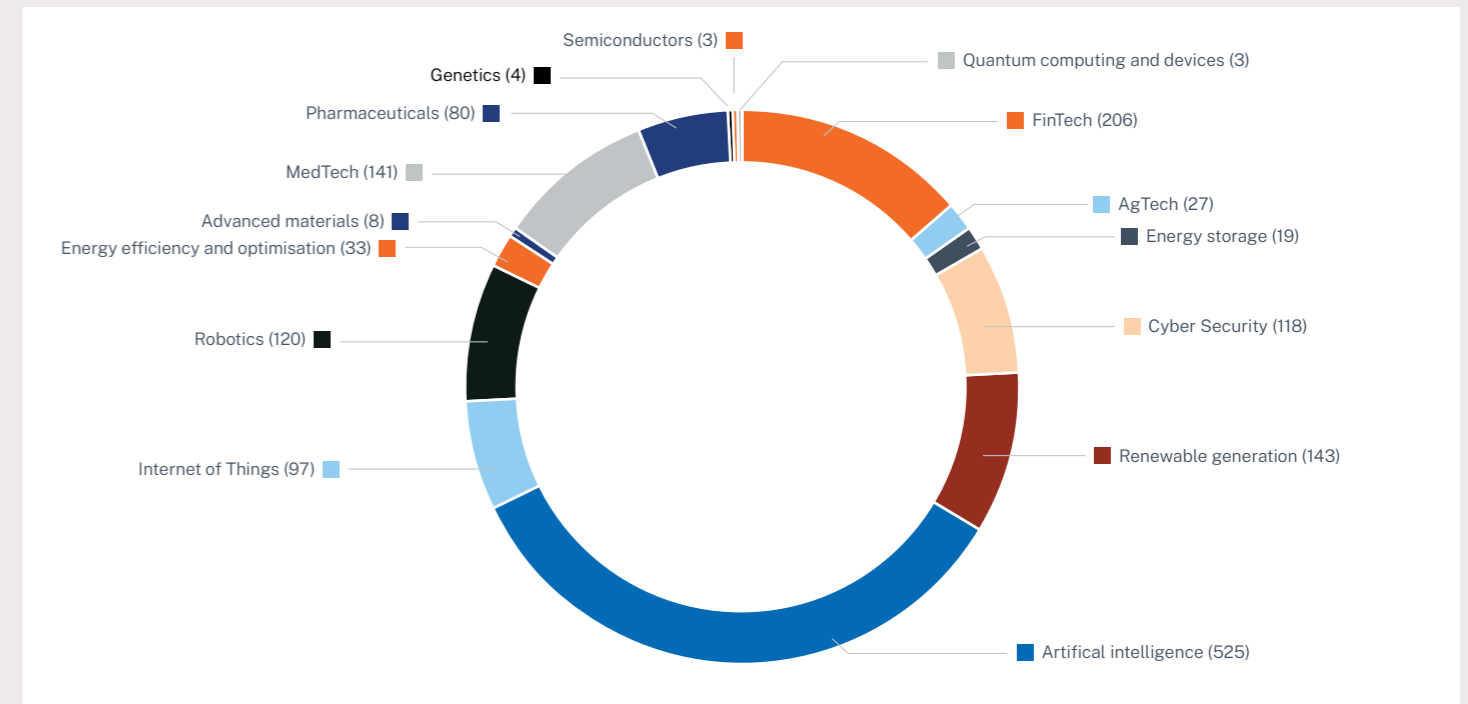
22. Crunchbase (2021); Organisation for Economic Co-operation and Development (2020).

Figure 6: Proportion of global businesses headquartered in each peer geography



Based on percentage of all global businesses headquartered in each peer geography for the five application areas where NSW has the largest percentage of global industry.

Figure 7: Businesses headquartered in NSW



Based on number of businesses specialising in each application area headquartered in NSW.

Next steps: 20-year vision

Action plans to grow and leverage NSW's advantages

In some cases, competitive advantages identified in the Roadmap have already been leveraged in NSW through existing industries. For example, NSW has leveraged its competitive advantages in natural resources, people and skills, technology, regulatory support, infrastructure, markets, industry, and supply chains to develop a world-leading and highly productive resources sector. In other cases, these competitive advantages have yet to be leveraged into future industries. For example, NSW could leverage its competitive advantages in natural and low-cost renewable energy resources, R&D capability, people and skills, infrastructure, markets and supply chains to develop a large and competitive controlled environment horticulture industry.

To grow and leverage NSW's competitive advantages, action plans will be developed for each area of competitive advantage identified in the Roadmap. Each action plan will:

- Provide detailed mapping of NSW's capabilities across the full value chain – identifying gaps and strengths, prioritising opportunities and target outcomes.
- Assess international competitors, partners and market dynamics.
- Set out how to activate the competitive advantage to support the growth of existing and future industries in NSW – particularly focusing on commercialisation and translation of science and technology research.
- Guide public and private R&D investment – focusing on the economic, social and environmental opportunities in end markets.
- Set targets for impact on existing and future industries.

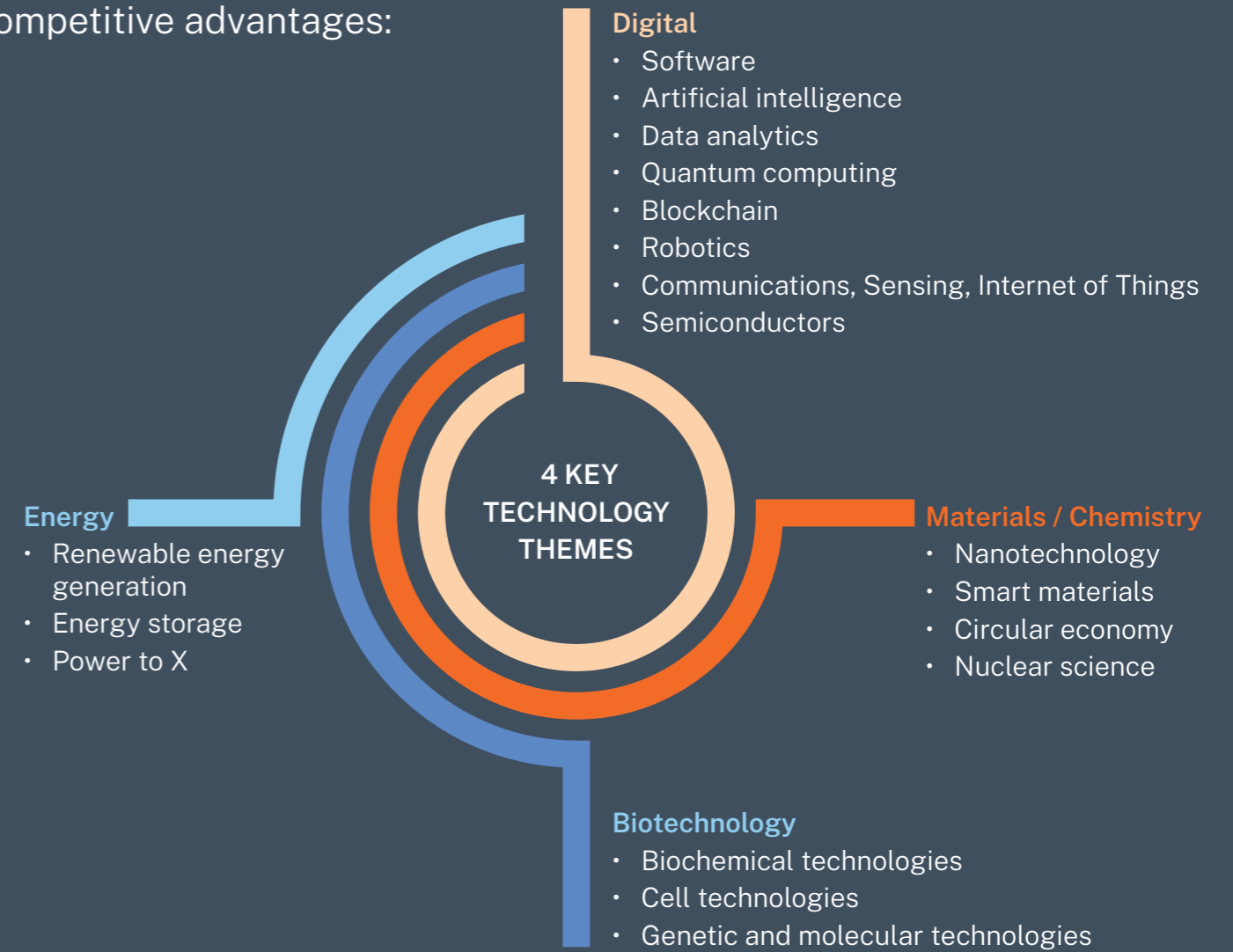
The *Australian Semiconductor Sector Study*, published by OCSE in December 2020, provides an example of an action plan for the NSW semiconductor sector.²³

The action plans will seek to accelerate future industries in NSW, focusing on growing the ecosystem of tangible and intangible assets. Tangible assets such as investment, facilities, equipment and infrastructure in NSW can be quickly created and deployed to accelerate growth. Intangible assets such as entrepreneurship experience, workforce capacity, and the depth and range of skills in NSW, particularly at the mid- and late-career level, take longer and require more organic growth. Like the Roadmap, the action plans will take a 20-year view and will be reviewed and updated periodically to adapt and respond to local and global trends.



Technology themes

The Roadmap identifies four technology themes where NSW has competitive advantages:



23. OCSE, *Australian Semiconductor Sector Study* (2020).



Digital technologies are transforming all sectors of the economy. AI, data and analytics are enhancing the ability to generate insights and use data for decision making. Automation software and hardware enable productivity gains in a range of processes, from administration and building management, to agriculture and manufacturing. Sensors and communication technologies are critical for smart infrastructure, providing the interface and networks to support complex autonomous systems.

The vast and growing digital environment also requires frameworks and protections to build trust and security in digital interactions and infrastructure.

NSW has competitive advantages in digital technology R&D, a strong and growing professional technology and software workforce, a track record of industry investment in this space, and sectors that are already realising the benefits of applying innovative digital technologies.

These strengths should be leveraged to accelerate the development, adaptation and uptake of digital technologies across all sectors.

NSW's competitive advantages in digital technologies

R&D

University capabilities

In the Australian Research Council's (ARC) Excellence in Research Australia (ERA) 2018 report, NSW institutions performed strongly in Fields of Research (FoR)²⁴ underpinning digital technologies.

NSW also had institutions assessed at 'well above world standard' in the following fields:

- Computation Theory and Mathematics (3 institutions, 75%²⁵)
- Computer Software (1, 50%)
- Distributed Computing (1, 50%)
- AI and Image Processing (3, 43%)

Grant funding

Over the 10-year period 2012-2021, NSW attracted a large share of ARC funding in the following FoR:

- Computation Theory and Mathematics (69%²⁶)
- Distributed Computing (51%)
- Communications Technologies (48%)
- Electrical and Electronic Engineering (43%)
- Computer Hardware (42%)
- Quantum Physics (35%)
- AI and Image Processing (34%)

NSW organisations have consistently attracted ARC funding in research fields underlying robotics, AI and data.

University rankings

NSW is the only state represented in the 2021 CWTS Leiden Rankings²⁷ Global top 100 for Mathematics and Computer Science. In this field, NSW leads other Australian jurisdictions in number and proportion of total publications, publications in top 1% cited, and co-publications with industry.

Research centres

NSW has specialist facilities and networks with capabilities underpinning digital technologies including:

- The ARC Centre of Excellence for Quantum Computation and Communication Technology
- Secure Unified Research Environment (Sax Institute)
- Intersect
- The Digital Health Cooperative Research Centre (CRC)
- The ARC Research Hub For Connected Sensors for Health
- Groundwater Infrastructure Project (UNSW Sydney)
- The Australian Centre for Field Robotics
- The Australian Artificial Intelligence Institute (AAIL) at the University of Technology, Sydney (UTS)
- The ARC Research Hub in Intelligent Robotic Systems for Real-Time Asset Management



24. FoR are defined in the Australian and New Zealand Standard Research Classification.

25. Percentage of Australian institutions assessed as 'well above world standard' that are based in NSW.

26. Percentage of all ARC funding in the FoR awarded to NSW administering organisations from 2012 to 2021.

27. The CWTS Leiden Ranking system is based on the publication output of institutions in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index.

EDUCATION

Course completions

Over the period 2015 to 2019, NSW:

- Had the highest number of domestic graduates from all course levels in the broad field of Information Technology (~11,000) followed by Victoria (~9,000)
- Led domestic completions in bachelor-level courses in the narrow fields of Computer Science (~4700, 41%), and Information Systems (~2700, 38%)
- Had the highest shares of domestic doctorate by research completions in Electrical and Electronic Engineering and Technologies (~350, 50%) and Mechanical and Industrial Engineering and Technologies (~170, 40%)

University rankings

Of Australian institutions listed in the QS World University Rankings 2021 top 250 universities by subject area, NSW had:²⁸

- 6 of 14 (43%) for Mathematics
- 5 of 12 (42%) for Statistics
- 6 of 15 (40%) for Electrical Engineering
- 5 of 13 (38%) for Computer Science

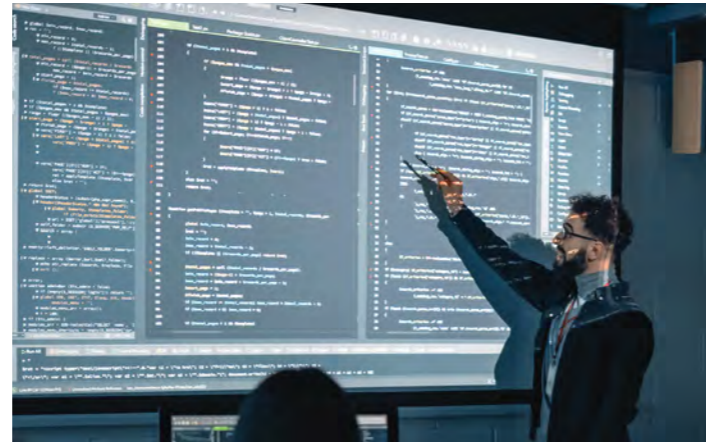
In the top 100, NSW had:

- 3 of 7 (43%) for Computer Science
- 3 of 7 (43%) for Electrical Engineering

University training centres

NSW has specialist training centres in digital technologies, including:

- The ARC Training Centre in Data Analytics for Resources and Environments
- The Sydney Quantum Academy, established in 2019 by a consortium of four NSW universities, aims to educate and train future quantum leaders, specialists and entrepreneurs



WORKFORCE

Employment

As of August 2021, Computer System Design and Related Services was the second highest full-time occupation in NSW, behind School Education.

Of Australians working in the following occupations, NSW employs approximately:

- 52% of ICT Support and Test Engineers
- 46% of ICT Managers
- 41% of ICT Support Technicians
- 41% of ICT Sales Professionals
- 41% of Computer Network Professionals
- 41% of Software and Applications Programmers
- 40% of Database and Systems Administrators, and ICT Security Specialists
- 40% of ICT Business and Systems Analysts
- 40% of Telecommunications Engineering Professionals
- 36% of Electrical Engineers
- 34% of Electronic Engineering Draftspersons and Technicians
- 31% of Electrical Engineering Draftspersons and Technicians

Skilled migration

NSW attracts significant talent in Information Technology occupations, which are consistently represented in the top 10 professions granted Temporary Skills Shortage Visas for entry to NSW.²⁹

28. The Quacquarelli Symonds Limited (QS) World University Rankings 2021 is a global university ranking index based on weighted indicators including academic reputation, employer reputation, citations per faculty, and H-index. Weights are adjusted depending on the subject.

29. Department of Home Affairs, Temporary Resident (Skilled) Reports 2018 to 2021 (2021).

INDUSTRY

Business R&D

Business Expenditure on R&D (BERD) in the Computer System Design and Related Services industry subdivision is consistently higher in NSW than other jurisdictions (ranging from 36% to 42% share from 2011-12 to 2019-20).

Similarly, BERD in Telecommunications Services is consistently higher in NSW than other jurisdictions (ranging from 45% to 100% share from 2011-12 to 2019-20).

Ecosystem

In a Revealed Comparative Advantage (RCA)³⁰ analysis based on global company listings, NSW has RCA internationally and compared to other Australian states in AI, data, sensors, advanced computing, and robotics (based on number of businesses located).

INNOVATION

Patents

Based on international patent data, NSW has Revealed Technology Advantage³¹ (RTA) compared to other countries in:

- IT Methods for Management
- Control

Compared to Australia as a whole, NSW has RTA in:

- Telecommunications
- Basic communication processes
- Computer Technology
- IT Methods for Management
- Semiconductors
- Optics
- Control

Innovation entities

NSW has specialist facilities and networks with capabilities underpinning digital technologies including:

- The NSW Smart Sensing Network
- DPI GATE – AgTech incubator
- The Sydney Startup Hub
- The Quantum Terminal at Tech Central

OTHER

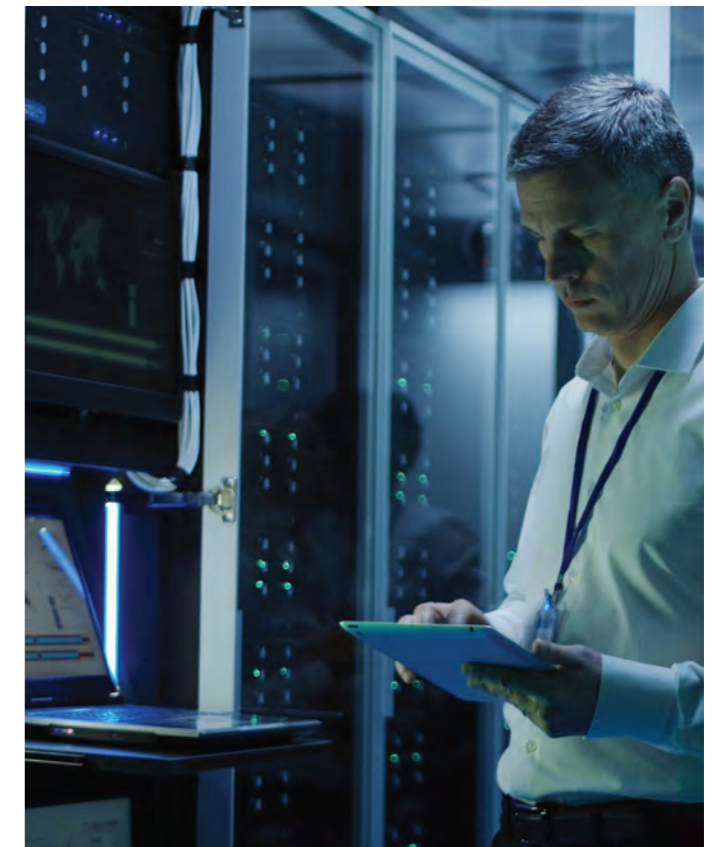
NSW has a strong local consumer base and position as a major hub in the Asia-Pacific region.

NSW has a multicultural, multilingual population that can take advantage of global connections and expertise.

Stakeholders also said...

NSW has competitive advantages in:

- FinTech
- Communication technologies
- Quantum skills and talent
- Blockchain technologies
- Development of data usage standards and Trusted Identify Frameworks
- Use of real-time digital twins
- Digital technologies for management of complex energy grid operations, trading and exports



30. RCA was calculated using Balassa's RCA methodology based on the number of company listings in technology field for NSW compared to global listings. Refer to the 20-Year NSW R&D Roadmap – Supplement for details.

31. Based on RTA analysis using international patent data to compare NSW patent outputs against world patent outputs for technology categories. The RTA index was calculated using Balassa's RCA methodology. Refer to the 20-Year NSW R&D Roadmap – Supplement for details.



Chemistry is foundational to the development of advanced materials and processes required in disruptive technologies, including medical devices, nanotechnology, quantum computers, and energy generation and storage. Increasing the circularity of resource use and decarbonisation of materials will require new ways to design and manufacture the materials used in consumer goods and infrastructure.

Materials and chemistry technologies also have a critical role in the growth of sustainable energy industries in NSW, such as green hydrogen.

Historically, NSW has been strong in exporting unrefined primary resources but could leverage strengths in chemistry and materials to create high-value industries processing these resources for export.

NSW has competitive advantages in materials and chemistry R&D, workforce and industry capabilities.

Together with growing domestic and international demand for solutions in advanced materials, decarbonisation and sustainable resource management, innovation in material and chemistry technologies presents an opportunity with high potential impact and prosperity benefits for NSW.

NSW's competitive advantages in materials and chemistry

R&D

University capabilities

In the ARC's ERA 2018 report, seven NSW institutions were assessed as 'well above world standard' in Macromolecular and Materials Chemistry representing 39% of all institutions in the field assessed at this level. NSW also had institutions assessed as 'well above world standard' in:

- Analytical Chemistry (4 institutions, 44%³²)
- Physical Chemistry (including Structural) (4, 24%)
- Medicinal and Biomolecular Chemistry (3, 27%)
- Chemical Engineering (2, 33%)
- Organic Chemistry (2, 40%)
- Inorganic Chemistry (1, 14%)
- Condensed Matter Physics (3, 30%)
- Materials Engineering (3, 19%)

Grant funding

Over the 10-year period 2012-2021, NSW attracted a large share of ARC funding in the following FoR:

- Resources Engineering and Extractive Metallurgy (70%)
- Materials Engineering (36%)
- Geochemistry (36%)
- Macromolecular and Materials Chemistry (35%)
- Inorganic Chemistry (35%)
- Chemical Engineering (33%)

Materials Engineering is the FoR in which NSW has attracted the largest volume of ARC funding over the period 2012-2021 (approximately \$101 million).

Research centres

NSW has specialist facilities and networks with capabilities underpinning materials and chemistry technologies including:

- The Materials & Embodied Carbon Leaders' Alliance
- The Australian National Fabrication Facility (ANFF) – NSW Node, Materials node and Optofab node
- The ARC Research Hub for Microrecycling of battery and consumer wastes / UNSW Centre for Sustainable Materials Research and Technology
- The ARC Research Hub for Nutrients in a Circular Economy
- The ARC Research Hub for Australian Steel Innovation
- The ARC Centre of Excellence for Enabling Eco-Efficient Beneficiation of Minerals
- The ARC Centre of Excellence for Electromaterials Science
- The Microscopy Australia – NSW Node
- The Australian Centre for Microscopy & Microanalysis

NSW has specialised nuclear science expertise and capabilities in Australian Nuclear Science & Technology Organisation (ANSTO) facilities at Lucas Heights which houses Australia's only operating research reactor. Commonwealth funding for a new nuclear medicine facility has also been committed.

32. Percentage of Australian institutions assessed as 'well above world standard' based in NSW.

EDUCATION

Course completions

Over the period 2015 to 2019, NSW:

- Had the highest number of domestic graduates from all course levels in the narrow field of Chemical Sciences (~850, 54%)
- Led domestic completions in bachelor-level courses in the narrow field of Chemical Sciences (~450, 58%)
- Had the highest shares of domestic doctorate by research completions in the narrow field of Chemical Sciences (~350, 54%)
- Had the highest number of domestic graduates from all course levels in the detailed field of Materials Engineering (~270, 83%) and 89% of doctorate by research completions in the field.

University rankings

In the QS World University Rankings 2021:

- Half of the Australian universities (3 of 6) represented in the top 100 for Materials Science were NSW institutions
- 4 NSW universities are represented in the top 250 for Chemistry
- NSW has 2 institutions in the top 100 for Mechanical Engineering and Chemical Engineering

University training centres

NSW has specialist training centres in materials and chemistry, including the:

- ARC Training Centre for The Global Hydrogen Economy
- ARC Training Centre in Fire Retardant Materials and Safety Technologies

WORKFORCE

Employment

Of Australians working in the following occupations, NSW employs approximately:

- 47% of Chemical and Materials Engineers
- 28% of Chemists, and Food and Wine Scientists

INDUSTRY

Business R&D

The following industries in NSW have seen consistent BERD over the period 2011-12 to 2019-20:

- Fabricated Metal Product Manufacturing (NSW share ranges from 46% to 62%)
- Machinery and Equipment Manufacturing (range 34% to 51%)
- Primary Metal and Metal Product Manufacturing (range 28 to 53%)
- Pulp, Paper and Converted Paper Product Manufacturing (range 46% to 100%)

Exports

NSW has strong RCA in global exports for the following commodities:³³

- Coal
- Copper
- Base metals
- Lead
- Aluminium
- Flat-rolled products of iron or non-alloy steel
- Paper and paperboard

Compared to Australia as a whole, NSW has RCA in a wide variety of material and chemical export products, including:³⁴

- Radioactive materials
- Uncoated flat-rolled iron and steel
- Alcohols, phenols and derivatives
- Pig-iron
- Other inorganic chemicals
- Starches, inulin and wheat gluten
- Paper and paperboard
- Silver and platinum
- Primary vinyl chloride polymers
- Photo and cinematographic supplies
- Plastic tubes, pipes and hoses
- Hydrocarbons and derivatives

Ecosystem

Based on global company listings, NSW has RCA in materials businesses and is on par with other Australian jurisdictions in chemistry technologies.

INNOVATION

Patents

Based on international patent data, compared to other countries, NSW has RTA in:

- Micro-structural and nano-technology
- Civil engineering

Compared to Australia as a whole, NSW has RTA in:

- Macromolecular chemistry, polymers
- Micro-structural and nano-technology
- Thermal processes and apparatus

Innovation entities

NSW has specialist facilities and networks with capabilities underpinning materials and chemistry, including the NSW Circular Economy Innovation Network.

OTHER

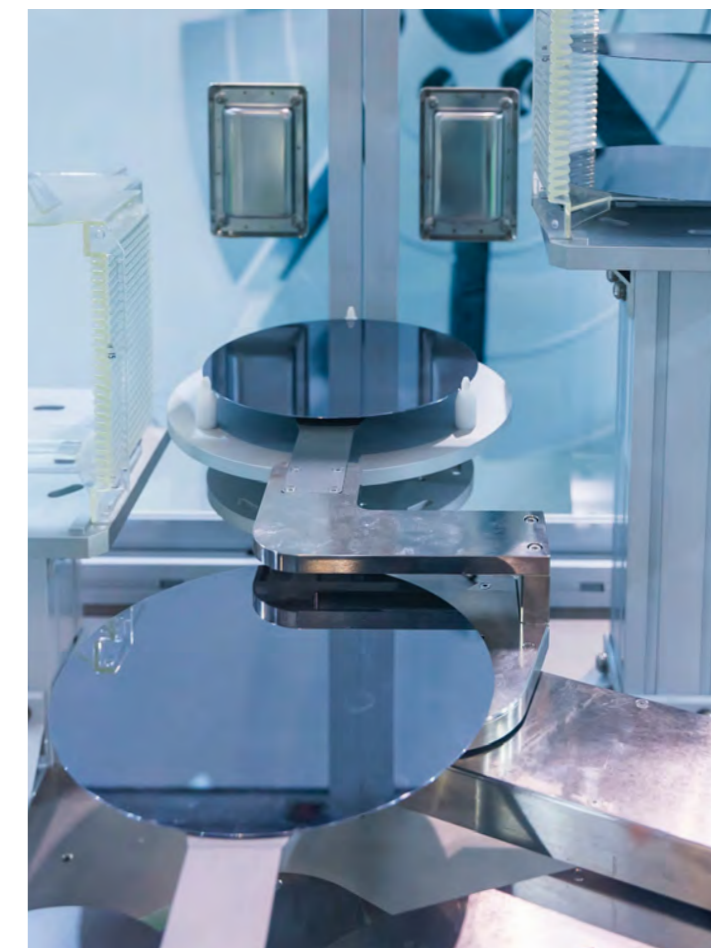
NSW has supportive policy settings, strategy and programs, including:

- The Net Zero Plan Stage 1: 2020-2030
- The Low Emissions Building Materials Program
- Remote and Regional Remanufacture NSW
- Remanufacture NSW
- NSW Waste and Sustainable Materials Strategy 2041 Stage 1 plan: 2021-2027

Stakeholders also said...

NSW has competitive advantages in:

- Water research, which will be important in understanding the sustainability implications of many industries, such as the green hydrogen industry
- Tooling technologies and capabilities to support translation of technologies from R&D to scaled manufacturing
- Geopolymer concrete R&D, with the NSW Government being a large first customer through major infrastructure projects
- There is potential to grow local capability in advanced upstream processes (such as mining and refining) and downstream processes (such as waste treatment and disposal).



33. RCA was calculated using Balassa's RCA methodology based export data for NSW compared to global export data. Refer to the *20-Year NSW R&D Roadmap - Supplement* for details. Department of Foreign Affairs and Trade, Australia's Trade by State and Territory 2018-19 (2020); United Nations, Comtrade (2019).

34. RCA was calculated using Balassa's RCA methodology based export data for NSW compared to Australian export data. Refer to the *20-Year NSW R&D Roadmap - Supplement* for details. Department of Foreign Affairs and Trade, Australia's Trade by State and Territory 2018-19 (2020); United Nations, Comtrade (2019).

Biotechnology has existing and potential applications in a range of sectors, including health and medicine, agriculture and food production, mining and energy.

Applications include diagnostic tests for disease, genetic editing to produce crops with desirable properties (such as drought or pest resistance), production of cell-based protein, microbial bioremediation and fuel production. An ageing population, chronic lifestyle disease burden and climate change drive demand for biotechnology innovation.

NSW contributes substantially to Australia's life sciences industry.³⁵ NSW has competitive advantages in several fields of biological science R&D, and specialist expertise and facilities for synthetic biology. A recently formed NSW RNA Bioscience Alliance is leveraging NSW's academic, industry and public sector expertise to establish the state's first RNA pilot manufacturing facility.

NSW's competitive advantages in biotechnology

R&D

University capabilities

In the ARC's ERA 2018 report, six NSW institutions were assessed as 'well above world standard' in Plant Biology representing 35% of all institutions assessed in the field at this level. NSW also led the number of institutions assessed as 'well above world standard' in:

- Oncology and Carcinogenesis (5 institutions, 36%³⁶)
- Pharmacology and Pharmaceutical Sciences (5, 38%)
- Genetics (5, 45%)
- Microbiology (4, 40%)
- Biochemistry and Cell Biology (3, 43%)
- Immunology (2, 40%)
- Biomedical Engineering (2, 67%)

NSW and Victorian institutions are closely competitive across many fields of research in health and life sciences that underpin biotechnology.³⁷



Grant funding

Over the 10-year period 2012-2021, NSW attracted a large share of ARC funding in the following FoR:

- Medical Biochemistry and Metabolomics (46%)
- Oncology and Carcinogenesis (42%)
- Microbiology (42%)
- Biomedical Engineering (36%)
- Biochemistry and Cell Biology (33%)

Biochemistry and cell biology is the field of research in which NSW has attracted the second largest volume of competitive ARC funding overall over the 10-year period 2012-2021, nearly \$100 million in total.

University rankings

Biomedical and health sciences is the broad field in which NSW institutions publish the largest volume of research, according to the 2021 CWTS Leiden Rankings. However, Victorian institutions lead slightly in total publications, publications in top 1%, and co-publications with industry.

In the broad field of life and earth sciences, NSW has a slight lead over Queensland in total publications, top 1% most frequently cited publications, and industry co-publications.

Research centres

NSW has specialist facilities and networks with capabilities underpinning biotechnology including:

- The ARC Centre of Excellence in Synthetic Biology
- The ARC Research Hub to Combat Antimicrobial Resistance
- Bioplatforms Australia
- The NSW RNA Bioscience Alliance

NSW Department of Primary Industries (NSW DPI) has extensive agricultural and veterinary science research capability at facilities throughout regional NSW.

EDUCATION

Course completions

Over the period 2015 to 2019, NSW had the most domestic graduates in:

- All course levels in the narrow field of Biological Sciences (~6,600, 41%), and Agriculture (~1400, 41%)
- Bachelor-level courses in the narrow field of Biological Sciences (~5600, 47%)
- All course levels in the detailed field of Biomedical Engineering (~560, 65%)
- Doctorate by research courses in Biochemistry and Cell Biology (~110, 53%)

University training centres

NSW has specialist training centres in biotechnology fields:

- The ARC Training Centre for Facilitated Advancement of Australia's Bioactives
 - The ARC Training Centre for Innovative BioEngineering
- The UTS Biologics Innovation Facility provides Good Manufacturing Practice (GMP) teaching and training in cleanroom manufacturing processes and operation.

WORKFORCE

Employment

Of Australians working in the following occupations, NSW employs approximately:

- 20% of Medical Laboratory Scientists
- 29% of Pharmacists
- 26% of Science Technicians
- 17% of Life Scientists

The Health Care and Social Assistance sector employs the largest number of people in NSW (~550,000 or 13% of the workforce).

35. AusBiotech, Australia's Life Science Sector Snapshot 2019 (2019).

36. Percentage of Australian institutions assessed as 'well above world standard' based in NSW.

37. ARC, State of Australian University Research 2018-19: ERA National Report (2018).

INDUSTRY

Exports

Internationally and domestically, NSW has RCA in exports for the following commodities:³⁸

- Instruments and appliances for medical, surgical, dental or veterinary purposes
- Medicaments (including veterinary)

These stand out as complex products among the top 25 RCA commodities, which are dominated by resource and agricultural products.

Ecosystem

Based on global company listings and a RCA analysis, the NSW biotechnology sector is on par with other Australian jurisdictions but has comparative disadvantage on an international scale.

INNOVATION

Patents

Based on international patent data, compared to the world, NSW has RTA in:

- Medical technology
- Biotechnology

Compared to Australia as a whole, NSW has RTA in medical technology.

Venture capital

Since 2005, a significant majority of venture capital funding in the Australian Health Care and Social Assistance sector has been invested in NSW.

Innovation entities

The NSW Health Medical Device Commercialisation Training Program (MDCTP) has been running since 2014 with positive industry impacts being realised.³⁹ From 2022, the program has been expanded to include innovators from the field of biotechnology.

OTHER

NSW has world-class biobanking capability in the NSW Health Statewide Biobank.

Funding of \$96 million has been committed to build an RNA pilot manufacturing facility in NSW.

Development of Westmead Health and Innovation District to enhance existing capabilities in biomedical and life sciences research and innovation, including \$25 million to upgrade viral vector manufacturing facility to commercial scale.

Stakeholders also said...

NSW has competitive advantages in:

- MedTech
- Cell culture R&D capability, primarily in cancer research but transferable to other sector applications such as agriculture and food manufacturing
- 3D printing of plant-based meat alternatives
- Gene editing



NSW is transitioning from centralised emissions intensive energy generation to more distributed and renewable generation. Electrifying assets that currently rely on fossil fuels, such as vehicles and some industrial processes, will require careful planning, coordinated development and management of grid infrastructure.

A major challenge is the intermittent nature of renewable generation from solar and wind, which requires backup from other firming energy generation or storage that can be quickly brought online to maintain a stable grid. Technologies to manage energy generation, distribution, storage and trading are all required to successfully transition from fossil fuels to renewable energy generation. Digital technologies can optimise management of the evolving grid, particularly distributed generation and storage assets (rooftop solar and batteries).

Other energy technologies, such as powerfuels, are required to decarbonise hard-to-abate industries, such as heavy freight, aviation, and heat-intense industrial processes.

NSW has competitive advantages in digital technologies, materials and chemistry, and biotechnology which all have applications in the energy sector. In addition, NSW has world-leading expertise in innovative energy technologies including solar energy, sustainable fuels, smart grids and energy storage. NSW Government strategies and policies also support the implementation of this renewable energy infrastructure, sustainable precinct developments and decarbonisation initiatives.

38. Department of Foreign Affairs and Trade, Australia's Trade by State and Territory 2018-19 (2020); United Nations, Comtrade (2019).

39. STEM Matters, *Impact of the Medical Device Commercialisation Training Program* (2021).

NSW's competitive advantages in energy technologies

R&D

University capabilities

In the ARC's ERA 2018 report, NSW institutions were assessed as 'well above world standard' in fields of chemical and physical sciences and engineering underpinning energy technologies. There is significant overlap with fields required for both the digital, and materials and chemistry technology themes.

Grant funding

Over the 10-year period 2012-2021, NSW attracted a large share of ARC funding in the following FoR:

- Electrical and Electronic Engineering (43%)
- Materials Engineering (36%)
- Macromolecular and Materials Chemistry (35%)
- Inorganic Chemistry (35%)
- Quantum Physics (35%)
- Chemical Engineering (33%)
- Materials Engineering is the FoR in which NSW has attracted the largest volume of ARC funding over the period 2012-2021 (approximately \$101 million).

NSW has attracted a significant proportion of Australian Renewable Energy Agency (ARENA) funding for solar energy R&D.⁴⁰



University rankings

NSW has 2 of 3 Australian institutions ranked in the top 50 for Energy Science & Engineering in the Global Ranking of Academic Subjects 2021.⁴¹

Research centres

NSW has specialist facilities and networks with capabilities underpinning energy technologies, including:

- The ARC Research Hub for Integrated Energy Storage Solutions
- The ARC Industry Transformation Research Hub for Resilient and Intelligent Infrastructure Systems (RIIS) in Urban, Resources and Energy Sectors
- The Centre for Accelerator Science (ANSTO)
- The Australian Centre for Neutron Scattering (ANSTO)
- The Reliable, Affordable, Clean Energy for 2030 CRC
- The Future Fuels CRC

EDUCATION

Course completions

The energy technology theme shares underlying science and engineering fields with both the digital and materials and chemistry technology themes. NSW institutions train and educate Australian-leading volumes of graduates in the key areas of computer, physical and chemical sciences, and engineering.

University rankings

NSW has world-class universities that are internationally competitive in the physical, chemical and computer sciences and branches of electrical, chemical and mechanical engineering relevant to energy technologies.⁴²

University training centres

NSW has specialist training institutions in energy technologies, including:

- The ARC Hydrogen Training Hub
- The ARC Training Centre for The Global Hydrogen Economy
- The ARC Training Centre in Energy Technologies for Future Grids

WORKFORCE

Employment

Of Australians working in the following occupations, NSW employs approximately:

- 47% of Chemical and Materials Engineers
- 41% of Computer Network Professionals
- 41% of Software and Applications Programmers
- 40% of Database and Systems Administrators, and ICT Security Specialists
- 36% of Electrical Engineers
- 34% of Electronic Engineering Draftspersons and Technicians
- 31% of Electrical Engineering Draftspersons and Technicians



INDUSTRY

Ecosystem

Based on global company listings, the NSW energy sector has slight RCA on an international scale.

INNOVATION

Patents

Based on international patent data, compared to the world, NSW has RTA in:

- Control
- Civil engineering

Innovation entities

NSW has specialist facilities and networks with capabilities underpinning energy technologies including:

- The NSW Decarbonisation Innovation Hub
- The NSW P2X Alliance
- The NSW Energy and Resource Knowledge Hub
- The Hydrogen Technology Cluster Australia Newcastle Cluster

Disruptive energy technologies developed in NSW at post-R&D and early commercialisation stage include the LAVO hydrogen storage system, plasma-driven ammonia generation and wastewater electrolysis.⁴³

OTHER

Along with other Australian jurisdictions, NSW is a world leader in solar energy generation with high uptake of residential rooftop solar.

NSW has abundant access to renewable energy, and supporting road, rail and port infrastructure for potential interstate and international exports.

NSW has supportive policy settings, strategy and programs for energy technologies, including:

- The NSW Electricity Infrastructure Roadmap including development of Renewable Energy Zones (REZ)
- The Net Zero Plan Stage 1: 2020-2030
- The Clean Technology Research and Development Grants Program
- The NSW Decarbonisation Innovation Hub
- The NSW Hydrogen Strategy

Stakeholders said...

NSW has a presence in the commercialisation and supply chain for a variety of clean energy technologies that are critical in the global landscape. For example, photovoltaics, long duration energy storage, flow batteries, and hydrogen and P2X.

40. ITP Renewables, *In the spotlight: Australian solar energy R&D outcomes and achievements in a global context* (2018).

41. The Global Ranking of Academic Subjects 2021, also known as the ShanghaiRanking, are based on weighted indicators including research output, research influence, international collaboration, research quality, and international academic awards.

42. QS World University Rankings (2021).

43. UNSW Sydney, *NSW Power to X (P2X) Pre-Feasibility Study* (2021).

Applications

Applications that use a similar technology platform have been grouped into ‘application clusters’ for ease of description.

Within the four technology themes, the Roadmap identifies 39 applications where NSW has competitive advantages.

Application	Description	Multi-sector	Strategic Priority	Technology Theme/s			
				Digital	Materials/Chemistry	Biotechnology	Energy
EdTech	Use of digital technologies to deliver education services			D			
FinTech	Use of digital technologies to deliver financial services			D			
Environmental monitoring and management	Technologies and approaches that assess the quality of the environment to improve environmental management			D			
Simulation and training (application cluster)	Use of digital technologies to imitate real world processes or systems for design, optimisation and training purposes	•		D			
Process automation and optimisation	Practices, technologies and systems that increase the efficiency and productivity of a process	•		D			
Asset management, predictive maintenance, systems and control	Systems to monitor system or asset health and address issues, reduce risks, and optimise performance	•		D			
Internet of Things (application cluster)	Systems of internet-connected physical objects including everyday devices, machines, and sensors	•		D			
Robotics (application cluster)	The use of automated or human controlled machines to perform functions	•		D			
Building automation	Systems that control electric, electronic and mechanical systems in buildings			D			
AI (application cluster)	Methods, systems and devices to simulate intelligent behaviour (learning and problem solving) in machines	•		D			
Customer service optimisation (application cluster)	Technologies and practices that improve customer experience through more efficient, customised and high quality services	•		D			
Blockchain (application cluster)	Distributed, unanimous and immutable digital ledgers for recording information	•		D			
Cyber security (application cluster)	Hardware, software, processes, and practices for protecting networks, devices, and data from digital threats	•	•	D			
Quantum computing and devices (application cluster)	Systems that use quantum properties or phenomena to perform computation or a function	•		D			
Semiconductors (application cluster)	Electronic components, either discrete devices or integrated circuits, critical to the functioning of almost all technology applications	•	•	D			
MedTech (application cluster)	Technologies that address patients’ medical conditions or improve the quality, efficiency and experience of their treatment			D	M	B	
Pharmaceuticals and nutraceuticals	Compounds manufactured for medicinal purposes	•	•		M		
Nanomaterials (application cluster)	Materials that are constituted at the nanoscale	•			M		
Implants and prosthetics	Artificial body parts or devices implanted in the body for medical purposes				M		
Smart materials (application cluster)	Designed materials with properties that can be modified in a controlled way	•			M		
Nuclear science (application cluster)	The study of nuclear matter and its applications	•			M		

For example, robotics, which incorporates a range of applications from autonomous vehicles, to mining robots and robotic agriculture. Many of the identified applications are relevant to a range of sectors and intersect with each other, demonstrating the depth and clusters of competitive advantage in NSW (Figure 3).

This presents opportunities to translate leading capabilities from one sector to another, and to develop more complete capabilities across supply chains in NSW. The Roadmap also identifies capabilities that NSW needs for strategic reasons. For example, cyber security to ensure NSW has sovereign capability to protect critical virtual and physical infrastructure.

Within the four technology themes, the Roadmap identifies 39 applications where NSW has competitive advantages.

Application	Description	Multi-sector	Strategic Priority	Technology Theme/s			
				Digital	Materials/Chemistry	Biotechnology	Energy
Low carbon materials and chemicals (application cluster)	Materials and chemicals produced with low or zero carbon emissions or energy inputs	•			M		
Circular economy (application cluster)	Technologies and approaches for production and consumption that reduce, reuse, repair, refurbish and recycle existing materials and products	•	•		M		
Novel fertilisers	Innovative fertilisers that improve agricultural productivity or reduce cost and environmental impact compared to conventional fertilisers	•			M	B	
Vaccines	Used to stimulate the production of antibodies and provide immunity against disease		•		M	B	
Future mining chemistries	More productive, efficient and sustainable chemical products for mining applications				M	B	
Genetic engineering (application cluster)	Manipulating the DNA of existing organisms with the aim of altering their physical characteristics or products	•				B	
Synthetic biology (application cluster)	The application of engineering principles to design or redesign organisms de novo from biological components, including enzymes, proteins and DNA, for useful purposes	•				B	
Personalised Medicine	Medical care where treatment is customised for the patient by analysing their genetic information to guide the most appropriate treatment					B	
Cell-based meats	Animal meat produced using animal cell culture technology					B	
AgTech	Use of advanced technologies in agriculture			D	M	B	
Sustainable Fuels (application cluster)	Power fuels produced from sustainable feedstocks and renewable energy	•	•		M	B	E
Controlled environment horticulture	Production of crops using indoor production systems						E
Power to X (P2X) (application cluster)	Technologies and processes producing green power fuels and clean chemicals using renewable energy and sustainable materials	•					E
Electrification (application cluster)	Energy from electricity replacing other power sources, especially fossil fuels	•					E
Smart grids	Advanced electricity grids and localised power systems, especially decentralised grids with advanced control, automation, and other digital technologies.	•		D			E
Renewable generation (application cluster)	Energy collected from renewable resources that are naturally and constantly replenished	•	•				E
Energy storage (application cluster)	Storage of energy for later use, to mitigate imbalances between energy demand and supply	•	•				E
Energy efficiency and optimisation (application cluster)	Systems to optimise energy generation, transmission, storage and consumption	•		D			E

Competitive advantages in identified applications

EdTech

What is it?

- Use of digital technologies to deliver education services.
- Examples: Apps for learning, student collaboration, classroom management and automated grading.

Why is it a competitive advantage?

- Education has historically been one of NSW's largest sectors and service exports. The school, vocational education and university sector is quality assured through regulation.
- Six NSW universities are ranked in the global top 200⁴⁴ and prior to COVID-19, Sydney had the third highest number of international students among 48 top global cities.⁴⁵
- NSW has a large and skilled digital technology workforce, including software and application programmers.⁴⁶
- 41% of Australia's EdTech companies are based in NSW.⁴⁷

What is the opportunity?

- NSW could expand its international market for education exports through affordable, quality education solutions that can be accessed through online delivery.
- Domestically, EdTech can enhance educational opportunities for remote and regional communities and make access to reskilling and professional development opportunities more equitable.

FinTech

What is it?

- Use of digital technologies to deliver financial services.
- FinTech leverages a variety of digital technologies such as AI, data analytics, blockchain.
- Examples: Digital wallets, mobile payments, peer-to-peer lending, cryptocurrency.

Why is it a competitive advantage?

- NSW's strength in FinTech arises from the intersection of its strong digital technologies and financial services sectors.
- Financial services is NSW's largest sector.⁴⁸
- NSW has strong R&D capabilities in digital technologies including AI and data, advanced computing, quantum and blockchain.⁴⁹
- NSW has a large software industry and particularly strong cluster of FinTech start-ups and incubators, with Sydney's FinTech ecosystem ranked number 14 globally.⁵⁰
- NSW has a relative competitive advantage in the number of local digital technology companies, including versus other Australian states.
- NSW educates a disproportionate amount of software and computing students (undergraduate and postgraduate, domestic and international) compared to other states.⁵¹
- NSW has large software and finance workforces compared to other states.⁵²

What is the opportunity?

- NSW has a well-developed FinTech ecosystem, with scaled companies.
- Sydney has an opportunity to become the leading FinTech hub in the Asia-Pacific.
- FinTech applications in investment and capital markets can drive growth in other sectors.

Competitive advantages in identified applications



Environmental monitoring and management

What is it?

- Technologies and approaches that assess the quality of the environment to improve environmental management.

Why is it a competitive advantage?

- NSW has a strong environmental goods and services sector and established regulatory regimes for regulating and valuing environmental assets.
- NSW has strong R&D capabilities in environmental science, with eight NSW universities well above world standard and three ranked in the global top 100 – more than any other Australian state.⁵³
- NSW has strong R&D capabilities in Internet of Things, sensing, robotics, AI and data analytics, with applications in environmental monitoring and management.
- Major NSW sectors provide deep markets for these services, including agriculture and tourism.

What is the opportunity?

- NSW is well suited to develop this industry with access to diverse terrain and climate extremes for design and validation of technologies.
- Improved data on the status of environmental assets will assist decision making in areas such as resource management and allocation.
- Quality data will enable better predictions of how environmental systems might respond to stresses and shocks and improve the design and implementation of interventions.

Simulation and training

What is it?

- Use of digital technologies to imitate real-world processes or systems for design, optimisation and training purposes.
- Examples: Augmented and virtual reality training systems.

Why is it a competitive advantage?

- NSW has strong R&D and industry capabilities in digital technologies and software.
- Education has historically been one of NSW's largest sectors and service exports.
- NSW has a relative advantage in the use of technologies to deliver education with 41% of Australia's EdTech companies based in NSW.⁵⁴
- NSW has strong R&D capabilities in areas such as data science, AI and sensors, which can be applied in simulation and training systems.

What is the opportunity?

- Providing global access to high quality simulation and training services, leveraging digital technologies and NSW's reputable education sector, could significantly increase the NSW industry.

44. QS World University Rankings 2022.

45. Mori Memorial Foundation, Global Power City Index Yearbook (2020).

46. Australian Bureau of Statistics, Labour Force (2020).

47. EduGrowth, Sector Overview and Statistics (2022).

48. Australian Bureau of Statistics, Australian System of National Accounts (2021).

49. ARC, State of Australian University Research 2018–19: ERA National Report (2018).

50. Startup Genome, Global FinTech Ecosystem Report (2020).

51. Department of Education, Skills and Employment, Australian Higher Education Completions Data (2020).

52. Australian Bureau of Statistics, Labour Force (2020).

53. ARC, State of Australian University Research 2018–19: ERA National Report (2018); ShanghaiRankings, The Global Ranking of Academic Subjects (2021).

54. EduGrowth, Sector Overview and Statistics (2022).

Competitive advantages in identified applications

Process automation and optimisation

What is it?

- Practices, technologies and systems that increase the efficiency and productivity of a process.
- Examples: automation of key processes such as machining and welding, industry facility monitoring, supply chain control, factory layout optimisation.

Why is it a competitive advantage?

- NSW has strong R&D capabilities in AI and data analytics, and manufacturing and mechanical engineering technologies, attracting a disproportionate amount of funding (35%, 40% and 51% respectively from 2014 to 2020).⁵⁵ Capabilities include specialist centres in areas such as automated welding and fabrication, collaborative robotics and predictive maintenance.
- NSW has a relative advantage versus Australia in patents filed in critical process optimisation technologies.⁵⁶
- 45% of Australia's businesses specialising in AI and data analytics are in NSW.⁵⁷
- NSW has a relative advantage in advanced processes and optimisation, with an ecosystem of similar size to leading industrial hubs such as Arizona and Seattle.⁵⁸

What is the opportunity?

- Process automation and optimisation can increase productivity in industries such as manufacturing – improving economic competitiveness.

Asset management, predictive maintenance, systems and control

What is it?

- Systems to monitor system or asset health and address issues, reduce risks, and optimise performance.
- Examples: enterprise asset management, structure health monitoring and alerts.

Why is it a competitive advantage?

- NSW has strong R&D capabilities in AI and data analytics, and civil and mechanical engineering technologies, attracting a disproportionate amount of funding (35%, 35% and 51% respectively from 2014 to 2020).⁵⁹
- NSW has world-leading performance in commercial building energy efficiency through programs such as the National Australian Built Environment Rating System (NABERS).⁶⁰

What is the opportunity?

- NSW has a large building and services sector, with proactive customers particularly in the commercial building industry and government.
- There is potential to deliver this capability across the Asia-Pacific region as it experiences significant infrastructure and construction growth.



55. ARC, National Competitive Grants Program Dataset (2020); ShanghaiRankings, The Global Ranking of Academic Subjects (2021).

56. IP Australia, Intellectual Property Government Open Data (2021).

57. Crunchbase (2021).

58. Crunchbase (2021).

59. ARC, National Competitive Grants Program Dataset (2020); ShanghaiRankings, The Global Ranking of Academic Subjects (2021).

60. Australian Sustainable Built Environment Council, Growing the Market for Sustainable Homes (2019).

Competitive advantages in identified applications

Robotics

What is it?

- The use of automated or human controlled machines to perform functions.
- Examples: service robots, robotic surgery, robotic agriculture, robotic mining, autonomous vehicles.

Why is it a competitive advantage?

- NSW has strong R&D capabilities in robotics. For example, NSW attracts a disproportionate amount of ARC funding in robotics-related fields of research including AI and image processing, electrical and electronic engineering and mechanical engineering (35%, 40% and 51% respectively from 2014 to 2020).⁶⁴
- NSW also has a competitive advantage in robotics-related R&D, with five universities ranked in the top 100 in the world for automation and control, and three for electrical and electronic engineering.⁶⁵
- NSW has a strong cluster of robotics businesses, with a local ecosystem of similar size to leading global innovation hubs such as Seattle, Singapore and Toronto, and larger than Hong Kong, Berlin and Arizona. Over 40% of Australia's robotics businesses are in NSW.⁶⁶
- NSW has a relative advantage versus Australia and other countries in robotics patents filed.⁶⁷
- NSW educates a leading volume of electrical, electronic and mechanical engineering and computing students (undergraduate and postgraduate, domestic and international) compared to other states.⁶⁸

What is the opportunity?

- Robotics is both a future growth industry and an enabler of productivity uplift in other industries such as agriculture, advanced manufacturing and mining.



Internet of Things

What is it?

- Systems of internet-connected physical objects including everyday devices, machines and sensors.
- Examples: Connected appliances, smart home systems, smart cities.

Why is it a competitive advantage?

- NSW has strong R&D capabilities in Internet of Things-related technologies including AI, data analytics, communications and sensors. For example, NSW attracts a disproportionate amount of ARC funding in AI and image processing, electrical and electronic engineering, distributed computing and chemical engineering (35%, 40%, 66%, and 31% respectively from 2014 to 2020).⁶¹
- NSW has a relative advantage versus Australia in patents filed in Internet of Things technologies such as communications, electronics, semiconductors, optics and control.⁶²
- Forty-five per cent of Australia's businesses specialising in sensing, AI and data analytics are in NSW.⁶³
- NSW has good deployment case studies of Internet of Things technologies in public transport, the built environment and the public sector.

What is the opportunity?

- NSW has a technology-ready consumer base, with a large pipeline of significant infrastructure and precinct development projects that could leverage Internet of Things technologies.

61. ARC, National Competitive Grants Program Dataset (2020); ShanghaiRankings, The Global Ranking of Academic Subjects (2021).

62. IP Australia, Intellectual Property Government Open Data (2021).

63. Crunchbase (2021)

64. ARC, National Competitive Grants Program Dataset (2020)

65. ShanghaiRankings, The Global Ranking of Academic Subjects (2021).

66. Crunchbase (2021).

67. IP Australia, Intellectual Property Government Open Data (2021).

68. Department of Education, Skills and Employment, Australian Higher Education Completions Data (2020).

Competitive advantages in identified applications

Building automation

What is it?

- Systems that control electric, electronic and mechanical systems in buildings.
- Examples: Building energy management systems, smart lighting systems, automated surveillance and security.

Why is it a competitive advantage?

- NSW has strong industry and R&D capabilities in Internet of Things, robotics, AI and data analytics (see previous). These capabilities have been widely demonstrated in NSW's commercial building sector to deliver world-leading performance in building operational efficiency.
- NSW has a relative advantage versus Australia and other countries in civil engineering patents filed.⁶⁹
- The NSW regulatory environment, with programs such as NABERS, has incentivised uptake of building automation systems and supported the growth of significant local industry capability.

What is the opportunity?

- NSW is at the global forefront of sustainable building design, certification and operation and continues to drive innovation in sustainable building technologies. These technologies are being exported overseas and will help local and global decarbonisation efforts.



AI (Artificial intelligence)

What is it?

- Methods, systems and devices to simulate intelligent behaviour (learning and problem solving) in machines.
- Examples: computer vision, speech recognition, decision making, language translation.

Why is it a competitive advantage?

- NSW has strong R&D capabilities in robotics. For example, NSW attracts 35% of all ARC funding in AI and image processing and 65% in computational theory and mathematics.⁷⁰
- NSW has a strong local cluster of AI businesses, of a similar scale to Berlin and close to Singapore and Toronto. 45% of all Australian AI businesses are based in NSW.⁷¹
- NSW has world-leading AI capabilities within its universities, with three of Australia's seven world-leading AI universities based in NSW.⁷²
- NSW has a large and skilled digital technology workforce, with 41% of Australia's software and application programmers based in NSW.⁷³
- NSW has a large multicultural and multilingual community – 35% of the population were born overseas and 25% speak a language other than English at home.⁷⁴ This assists the development of inclusive AI products that can be more readily applied globally.

What is the opportunity?

- NSW has a skilled AI workforce, deep AI R&D capabilities, and a technology-ready, diverse multicultural consumer base ideal for AI product development, testing and insight generation.

Competitive advantages in identified applications

Blockchain

What is it?

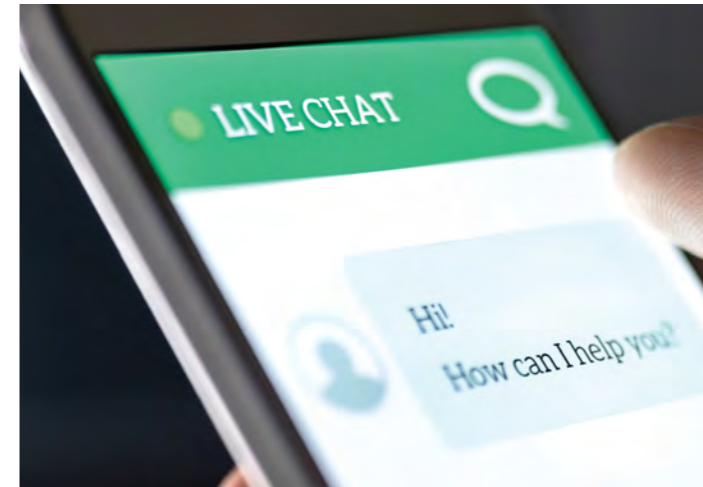
- Distributed, unanimous and immutable digital ledgers for recording information.
- Examples: digital currency, secure information exchange, asset tracking and collection, digital identification, supply chain management, decentralised autonomous organisations.

Why is it a competitive advantage?

- NSW has strong R&D in software and advanced computing. For example, NSW attracts a disproportionate amount of all ARC funding in computational theory and mathematics and distributed computing (65% and 66% respectively from 2014 to 2020).⁷⁶
- Several NSW universities have world-leading computer science capabilities, with three NSW universities ranked in the global top 100.⁷⁷
- NSW has a local cluster of businesses working on blockchain products and services, of similar magnitude to the Greater Seattle or Boston areas. Over 65 companies headquartered in NSW are working on blockchain products and services, representing nearly 50% of all Australian blockchain businesses.⁷⁸
- NSW educates a leading volume of software and computing students (undergraduate and postgraduate, domestic and international) compared to other states.⁷⁹
- NSW has a relatively large software and finance workforce compared to other states. Many of the earliest applications of blockchain technology are in the financial services sector.

What is the opportunity?

- Blockchain technology is attracting a large amount of investment globally, driven by increased investor and major corporate interest in the sector. Seventy-seven per cent of global senior executives in the financial services industry believe their organisations will lose competitive advantage if they do not adopt blockchain and digital assets.⁸⁰



Customer service optimisation

What is it?

- Technologies and practices that improve customer experience through more efficient, customised and high quality services.
- Examples: chatbots, service robots, self-service systems.

Why is it a competitive advantage?

- NSW has strong capabilities in AI, data analytics and robotics (see previous).
- Services represent almost 80% of the economy in NSW, with customer service intensive sectors representing at least 40%, such as health care, social assistance, retail, education and accommodation.⁷⁵

What is the opportunity?

- NSW has a technology-ready, diverse multicultural consumer base ideal for product development, testing and insight generation across all demographics.
- NSW has the necessary R&D capabilities to develop these products and services, combined with large and diverse end markets in its services sectors to test and apply them.

69. IP Australia, Intellectual Property Government Open Data (2021).

70. ARC, National Competitive Grants Program Dataset (2020); ShanghaiRankings, The Global Ranking of Academic Subjects (2021).

71. Crunchbase (2021).

72. ARC, State of Australian University Research 2018–19: ERA National Report (2018).

73. Australian Bureau of Statistics, Labour Force (2020).

74. Australian Bureau of Statistics, Census of Population and Housing: Nature and Content (2016).

75. Australian Bureau of Statistics, Australian System of National Accounts (2021).

76. ARC, National Competitive Grants Program Dataset (2020); ShanghaiRankings, The Global Ranking of Academic Subjects (2021).

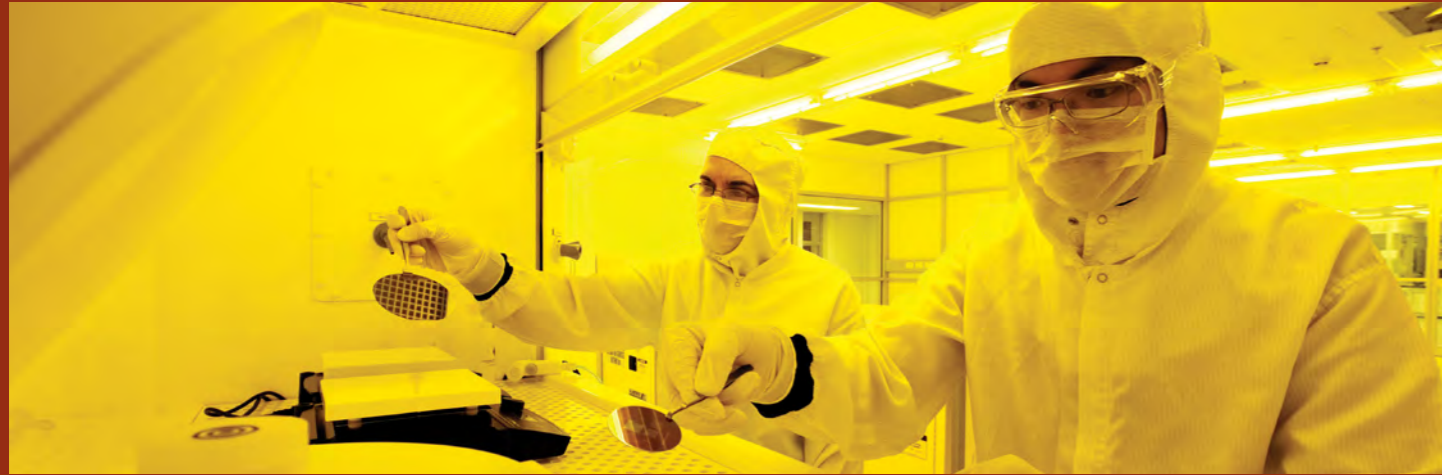
77. ARC, State of Australian University Research 2018–19: ERA National Report (2018); ShanghaiRankings, The Global Ranking of Academic Subjects (2021).

78. Crunchbase (2021).

79. Department of Education, Skills and Employment, Australian Higher Education Completions Data (2020).

80. Deloitte, Global Blockchain Survey (2021).

Quantum Technology



With appropriate investment and sector collaboration, CSIRO projects that the Australian quantum technology industry could generate over \$4 billion and 16,000 jobs for Australia by 2040 in the fields of computing, sensing and measurement, and communications.¹⁵⁵

Market size

Globally, quantum technologies could be worth at least \$86 billion by 2040.¹⁵⁶

There are several NSW-based startups in quantum technologies attracting significant interest and venture capital investment.

These include:

- **Q-CTRL** – a spinout from the University of Sydney which produces quantum control firmware for quantum computing and other applications that reduces susceptibility to noise and error.
- **Silicon Quantum Computing** – a spinout from UNSW Sydney with the short term objective to develop a 10-qubit prototype quantum integrated processor by 2023.

- **LuciGem** – a spinout from Macquarie University producing nanomaterials, including fluorescent nanodiamonds, which can be used in quantum technologies.
- **Redback Systems** – a spinout from Macquarie University producing high-resolution spectrographs to support quantum technology research.
- **h-bar: Quantum Technology Consultants** – a quantum information and quantum technology advisory firm which is a joint spinout between partners from RMIT University & UTS.

Larger corporations involved in the quantum technology R&D in NSW include Microsoft and Google.

Industry sectors and applications – Quantum technologies have promising applications in many sectors, including:



Defence

Quantum positioning and navigation tools, ultra-secure communication methods.



Health

Sensors for imaging and disease detection, computing to optimise drug design and precision medicine.



Transport

Performance optimisation for complex transport networks.



Finance

Quantum computing for targeting and prediction, trading optimisation, and risk profiling.

NSW's competitive advantages

NSW has many competitive advantages, with strong R&D capability in universities and examples of commercialisation activity in emerging quantum technologies. NSW has hosted the ARC Centre of Excellence for Quantum Computing and Communication Technologies since 2011 and is a major partner in the ARC Centre of Excellence for Engineered Quantum Systems.

Four of NSW's universities with world-leading expertise in quantum technologies have collaboratively formed the Sydney Quantum Academy (SQA), Australia's first major coordinated approach to quantum training.¹⁵⁷ The SQA delivers postgraduate and industry-based education and training in quantum technology, and develops the pipeline of talent to support the growing industry.

The NSW Government has established the Quantum Terminal in Sydney's Tech Central precinct to attract innovation activity and create an active quantum ecosystem. The first tenants include Q-CTRL, Sydney Quantum Academy, and Quantum Brilliance. Transport for NSW has also committed to establish a Centre for Quantum Technologies, having already formed a Quantum Technology Expert Advisory Council.

Other industry activity includes Google's recent announcement of a \$1 billion investment to establish Google Research Australia in Sydney. This includes a strengthened partnership with Macquarie University in quantum computing research.

In recognition of the impact and value that quantum technologies will have in the global economy, the Commonwealth has committed \$111 million towards the sector, including \$70 million for an Australian Quantum Commercialisation Hub.



155. CSIRO, Growing Australia's Quantum Technology Industry (2020).

156. CSIRO, Growing Australia's Quantum Technology Industry (2020).

157. Australian Strategic Policy Institute, An Australian Strategy for the Quantum Revolution (2021).

Competitive advantages in identified applications

Cyber security

What is it?

- Hardware, software, processes and practices for protecting networks, devices and data from digital threats.
- Examples: application and network security, cloud security, endpoint protection.

Why is it a competitive advantage?

- NSW has a strong local cluster of cyber security businesses, of similar magnitude to Singapore and Greater Seattle.⁸¹
- There are over 120 cyber security companies headquartered in NSW, representing 37% of all Australian cyber security businesses.⁸²
- NSW has strong R&D in software and advanced computing. For example, NSW attracts a disproportionate amount of all ARC funding in computational theory and mathematics and distributed computing (65% and 66% respectively from 2014 to 2020).⁸³
- NSW has a large and skilled digital technology workforce, with 41% of Australia's software and application programmers and computer network specialists based in NSW.⁸⁴
- The NSW Government is a global leader in the development and implementation of the Trusted Digital Identity Framework.

Why is it a strategic priority?

- An established local cyber security industry is essential to ensure NSW has sovereign capability to protect critical virtual and physical infrastructure.

What is the opportunity?

- Cyber security is a secular growth industry, growing at 9% annually since 2017.⁸⁵
- Cyber security threats continue to grow, with a 45% increase in intrusions in 2021.⁸⁶
- A well-established cyber security industry can protect digital infrastructure in NSW and Australia and offers significant export opportunities to allied countries.

Quantum computing and devices

What is it?

- Systems that use quantum properties or phenomena to perform computation or a function.
- Example: quantum computers for drug design, quantum gravimeters for surveying or navigation.

Why is it a competitive advantage?

- NSW has strong R&D capabilities in quantum computing and devices. For example, NSW attracted 40% of all ARC funding in quantum science from 2014 to 2020.⁸⁷
- NSW has world-leading quantum science capabilities within its universities, with four of Australia's eight universities with world-leading quantum science capabilities based in NSW.⁸⁸
- Quantum computing is a small but emerging industry, and NSW has several leading quantum computing businesses. Almost all of Australia's quantum industry is based in NSW and the ACT.⁸⁹
- The Quantum Terminal and Sydney Quantum Academy, both within the Tech Central precinct, provide a globally competitive quantum and advanced computing ecosystem for quantum training, R&D and commercialisation.
- See Case Study (pg 46): *Quantum Technology*

What is the opportunity?

- NSW has globally-competitive capabilities in quantum computing and devices, as well as major businesses investing in R&D, pilots and early adoption approaches.



81. Crunchbase (2021).
 82. Crunchbase (2021).
 83. ARC, National Competitive Grants Program Dataset (2020); ShanghaiRankings, The Global Ranking of Academic Subjects (2021).
 84. Australian Bureau of Statistics, Labour Force (2020).
 85. AustCyber, Australia's Cyber Security Sector Competitiveness Plan (2020).
 86. CrowdStrike, Global Threat Report (2022).
 87. ARC, National Competitive Grants Program Dataset (2020); ShanghaiRankings, The Global Ranking of Academic Subjects (2021).
 88. ARC, State of Australian University Research 2018-19: ERA National Report (2018).
 89. Crunchbase (2021).

Competitive advantages in identified applications

Semiconductors

What is it?

- Electronic components, either discrete devices or integrated circuits, critical to the functioning of almost all technology applications.
- Examples: microprocessors, memory chips, photonics devices.

Why is it a competitive advantage?

- Most Australian semiconductor businesses are based in NSW.⁹⁰
- NSW has a relative advantage versus Australia in patents filed in semiconductors.⁹¹
- NSW has a large and skilled digital technology workforce, with 41% of Australia's software and application programmers based in NSW.⁹²
- NSW has a strong local cluster of advanced computing businesses, of similar magnitude to Singapore, Hong Kong, Toronto and Seattle, as well as several other advanced manufacturing businesses which could provide a local customer base for a larger semiconductor industry.⁹³
- NSW has three universities ranked in the top 100 in the world for electrical and electronic engineering.⁹⁴
- NSW educates a leading volume of electrical, electronic and mechanical engineering and computing students (undergraduate and postgraduate, domestic and international) compared to other states.⁹⁵

Why is it a strategic priority?

- Semiconductors are indispensable to many global supply chains and all electronic technologies in both commercial and defence applications. Semiconductor supply chain risks have major economic and national security implications for NSW.

What is the opportunity?

- NSW can capture more of the global supply chain of this rapidly growing sector, particularly in the intellectual property and design segments.
- Given its competitive advantages, NSW is the best place in Australia for investment in the semiconductor sector.

90. Crunchbase (2021).
 91. IP Australia, Intellectual Property Government Open Data (2021).
 92. Australian Bureau of Statistics, Labour Force (2020).
 93. Crunchbase (2021).
 94. ShanghaiRankings, The Global Ranking of Academic Subjects (2021).
 95. Department of Education, Skills and Employment, Australian Higher Education Completions Data (2020).
 96. Research 2018-19: ERA National Report (2018); ShanghaiRankings, The Global Ranking of Academic Subjects (2021).

MedTech

What is it?

- Technologies that address patients' medical conditions or improve the quality, efficiency and experience of their treatment.
- Examples: hearing implants, pacemakers, defibrillators, medical software.

Why is it a competitive advantage?

- NSW has relative R&D strengths in science and engineering fields that underpin medical technologies including sensors, communications, AI, data analytics, electrical and mechanical engineering, materials and chemistry.⁹⁶
- NSW has three nodes of ANFF and extensive public health infrastructure.
- NSW has a relative competitive advantage in exports of medical equipment.⁹⁷
- NSW attracts the most venture capital investment in Australia in the health care and social assistance sector.⁹⁸
- The NSW Government has established longstanding investment and skills programs to support the MedTech sector, such as the Medical Devices Fund (MDF) and MDCTP.
- See Case Study (pg 50): *MedTech*

What is the opportunity?

- The Australian MedTech sector is projected to reach \$18 billion⁹⁹ and add 28,000 jobs by 2025.¹⁰⁰
- NSW is strategically positioned as a high-value MedTech R&D and manufacturing hub for MedTech in the Asia-Pacific region.
- NSW has a diverse, multicultural trial population, well suited to supporting development and testing of MedTech that can be applied globally.

97. Department of Foreign Affairs and Trade, Australia's Trade by State and Territory 2018-19 (2020); United Nations, Comtrade (2019).
 98. Department of Industry, Science, Energy and Resources, Venture Capital Dashboard (2021).
 99. MTPConnect, MedTech, Biotechnology and Pharmaceutical Technology Sector Competitiveness Plan (2016).
 100. MTPConnect, MedTech, Biotechnology and Pharmaceutical Technology Sector Competitiveness Plan (2020).

MedTech

MedTech contributes about \$2 billion to the NSW economy.

Market size

In Australia, three NSW-based companies hold a substantial share of the medical and surgical equipment manufacturing industry:

- ResMed Holdings (43.9% Australian market share)
- Cochlear (17%)
- Baxter Healthcare (7.3%)

The rest of the market is characterised by smaller players. Most firms employ fewer than 20 staff, and only a small percentage (1.9%) generate over \$10 million in revenue. NSW has about 33% of industry enterprises, with Victoria following (approximately 27%). The MedTech sector in NSW employs around 7,000 people and contributes substantially to the Australian economy, generating \$4.8 billion in revenue annually.

Industry sectors and applications

MedTech spans simple to complex products and is enabled by digital technologies (such as sensors, communication, AI and analytics), advanced materials and biotechnology. MedTech includes products such as electronic pacemakers, wearable monitoring devices, smart implants and prosthetics, diagnosis and treatment support tools, point-of-care testing, robotic surgery, and organ printing. Quality medical devices are highly valued in international markets and demand for such technologies will be driven domestically by an ageing population, increasing lifestyle disease burden and the need to bolster public health capability.



NSW's competitive advantages

NSW's competitive advantages in medical technology, across multiple factors, are reflected in strong historical export results. NSW produces 80% of all Australian exports of medical instruments and electrodiagnostic equipment, with the value of NSW's exports exceeding \$1 billion in recent years.

NSW also has a strong MedTech startup sector. The MDF competitive grant and the MDCTP were established by the NSW Government to boost NSW's medical technology sector. These programs have assisted NSW MedTech entrepreneurs to progress innovation in the field and realise commercial benefits. For example, over the period 2015 to 2020, the MDCTP has trained more than 1,000 participants, enabled participants to attract \$14 million in grant funding, raised \$55 million in capital investment, and founded 19 new startups. Recipients of MDF grants have raised more than \$800 million in private capital investment, completed over 211 clinical trials, and have more than doubled their collective employment. More than 48,000 patients around the world have been treated as a result of MDF-funded products.

Three NSW-based organisations were funded through the first round (2018) of BioMedTech Horizon's program to conduct commercialisation projects in the areas of 3D Anatomical Printing and Precision Medicine. As a result of their projects, Garvan Medical Research Institute sold their cancer genomics platform to SydPath, and Indee Labs generated over \$1 million in revenue from top tier pharmaceutical companies for their gene delivery technology.

NSW has several existing medical innovation precincts, such as Macquarie Park, Westmead and Randwick, where research organisations and large commercial players are in proximity. Large funding commitments have been made to enhance development of ecosystem infrastructure in Macquarie Park and Westmead Health & Innovation District.



158. Investment NSW, MedTech, invest.nsw.gov.au/sector-opportunities/medtech.

159. IBISWorld, Medical and Surgical Equipment Manufacturing in Australia (2021).

160. IBISWorld, Medical and Surgical Equipment Manufacturing in Australia (2021).

161. IBISWorld, Medical and Surgical Equipment Manufacturing in Australia (2021).

162. NSW Government, NSW medical technology industry development strategy (2018).

163. Department of Foreign Affairs and Trade, Australia's Trade by State and Territory 2018-19 (2020).

164. STEM Matters, Impact of the Medical Device Commercialisation Training Program (2021).

165. MTPConnect, A summary of the progress and impact of new Australian medical technologies supported by Round One of the BMTB Program (2021).

Competitive advantages in identified applications

Pharmaceuticals and nutraceuticals

What is it?

- Compounds manufactured for medicinal purposes.
- Examples: drugs, biologics, vitamins and supplements.

Why is it a competitive advantage?

- NSW has relative R&D strengths in chemical sciences, pharmacology and pharmaceutical sciences and biochemistry.¹⁰¹
- NSW has a unique GMP training facility at the Biologics Innovation Facility.
- NSW has a cluster of international pharmaceutical corporations headquartered in Macquarie Park, with development planned to leverage the precinct's strengths.
- 28% of Australian clinical trials are conducted in NSW, similar to Victoria (30%).¹⁰² Together they account for most clinical trial activity in Australia.
- NSW has a large domestic consumer base and access to Asia-Pacific markets.

Why is it a strategic priority?

- Local production capability in critical pharmaceutical products improves resilience when global supply chains are disrupted and delivery of drugs and medicines might be delayed, difficult to source, or expensive due to high demand.

What is the opportunity?

- NSW can become a manufacturing and export hub to the Asia-Pacific region, with access to land for production and storage facilities, and the 24-hour Western Sydney Airport.

Nanomaterials

What is it?

- Materials that are constituted at the nanoscale.

Why is it a competitive advantage?

- NSW has relative R&D, education and workforce strengths in material and chemical sciences and engineering.¹⁰³
- NSW has expertise in nanofabrication in three NSW-based branches of ANFF, established under the Commonwealth National Collaborative Research Infrastructure Strategy (NCRIS) in 2007.
- NSW has specialist capabilities in microscopy and microanalysis, with the headquarters of Microscopy Australia based in Sydney.

What is the opportunity?

- Growing industries such as quantum technologies, medical devices and communications will require nanoscale components. NSW can leverage its leading nanomaterials capabilities to grow these industries while supporting growth in the local market for nanotechnology.

Competitive advantages in identified applications

Implants and prosthetics

What is it?

- Artificial body parts or devices implanted in the body for medical purposes.
- Examples: arm or leg prostheses, hearing aids, artificial eyeballs, pacemakers.

Why is it a competitive advantage?

- NSW has industry and workforce strengths in developing and commercialising MedTech and specifically implants, with examples of successful companies such as Cochlear.
- The NSW Government has established longstanding investment and skills programs to support the MedTech sector, such as the MDF and MDCTP.
- NSW has a domestic consumer base for medical devices, and access to the Asia-Pacific market.

What is the opportunity?

- NSW can consolidate and capitalise on existing industry and workforce competitive advantages in this area.
- MedTech draws on inputs from across the technology clusters and can be a large domestic customer for other advanced emerging technologies such as semiconductors.

Smart materials

What is it?

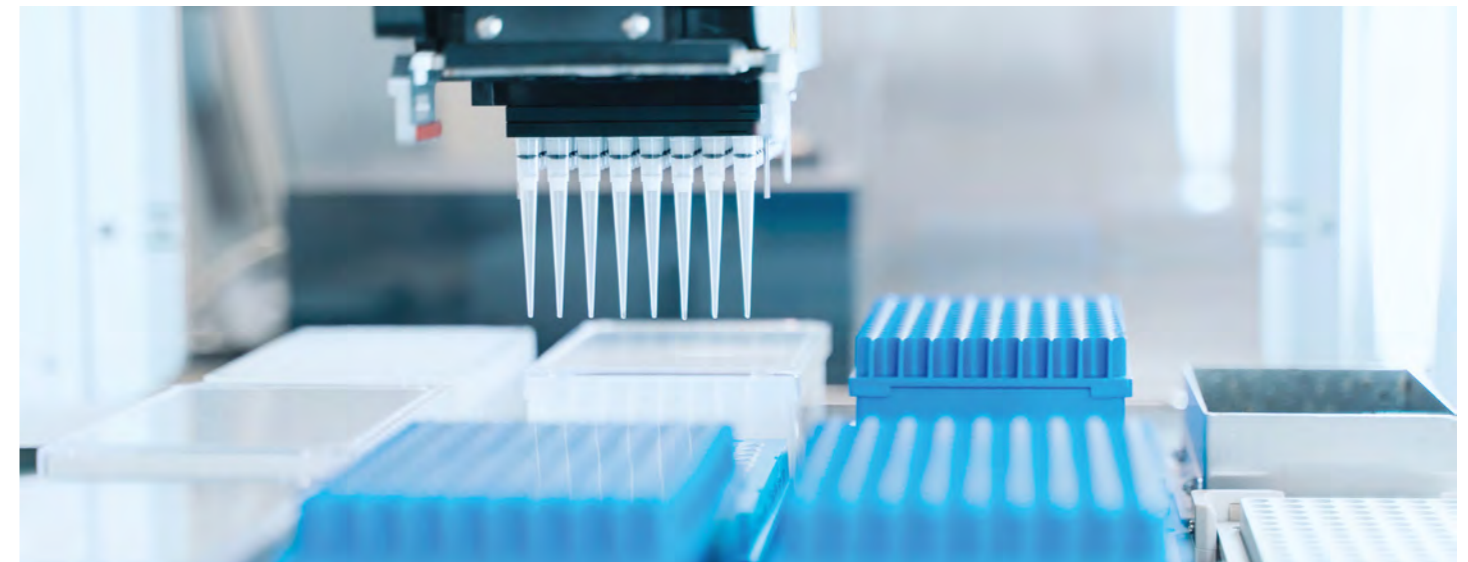
- Designed materials with properties that can be modified in a controlled way.
- Examples: protective clothing, light-responsive surfaces, building control and environmental monitoring.

Why is it a competitive advantage?

- NSW has relative R&D, education and workforce strengths in fields of material and chemical science and engineering.¹⁰⁴
- NSW hosts the headquarters of the SmartCrete CRC, which is developing smart concrete, and the ARC Centre of Excellence for Electromaterials Science.
- NSW has expertise in materials fabrication in three NSW-based branches of the ANFF.

What is the opportunity?

- Smart materials are a growing technology platform that has compelling use cases in many of NSW's strongest sectors, including healthcare and MedTech, energy and the built environment.



101. ARC, State of Australian University Research 2018–19: ERA National Report (2018).

102. MTPConnect, Australia's Clinical Trials Sector (2021).

103. ARC, State of Australian University Research 2018–19: ERA National Report (2018).

104. ARC, State of Australian University Research 2018–19: ERA National Report (2018).

Competitive advantages in identified applications

Nuclear science

What is it?

- The study of nuclear matter and its applications.
- Examples: nuclear medicine and radiology, radionuclides for locating mineral deposits, irradiation for destroying bacteria, isotopic tracers for environmental science, nuclear forensics.

Why is it a competitive advantage?

- NSW has Australia's only major nuclear science facility at ANSTO, including most of Australia's nuclear science equipment and infrastructure. ANSTO provides nuclear science products and services for all of Australia and is the most advanced facility in the South East Asia and Pacific Region.
- NSW hosts the Open Pool Australian Lightwater reactor, one of a limited number of research reactors globally.
- Through ANSTO and its NSW capabilities, Australia holds a permanent position on the International Atomic Energy Agency board of governors and is engaged in many of its initiatives.

What is the opportunity?

- Demand for and investment in nuclear science capabilities may increase from both the private and public sector through initiatives such as the AUKUS Alliance.
- NSW – having the only major nuclear science facilities – is well placed to attract that investment in nuclear science in Australia and the South East Asia and Pacific Region.



105. ARC, State of Australian University Research 2018–19: ERA National Report (2018).

Competitive advantages in identified applications

Circular economy

What is it?

- Technologies and approaches for production and consumption that reduce, reuse, repair, refurbish and recycle existing materials and products.
- Examples: recycled wastewater, manufactured goods from recycled plastic, textile reuse.

Why is it a competitive advantage?

- NSW has strengths and capability in materials and chemistry R&D, including for sustainable material reuse, recycling and repurposing.
- NSW has established a Circular Economy Innovation Network, which brings together researchers, industry and government to strengthen NSW's circular economy ecosystem and capabilities.
- NSW Special Activation Precincts including Parkes, Wagga Wagga and Moree are being planned with circular economy principles and offer the potential to demonstrate these practices at scale.

Why is it a strategic priority?

- The need to mitigate the environmental impacts of consumption through improved energy and resource use and reuse requires a transformational shift in the way industry and household waste is handled.
- Restructuring waste streams is essential for NSW and other countries to achieve net-zero targets.

What is the opportunity?

- NSW can grow its domestic industry, creating skilled jobs in trades like electrical, carpentry, textiles and materials manufacturing as well as diverting high-value resources from waste and reclaiming them for use in new products and materials manufactured in NSW.



Novel fertilisers

What is it?

- Innovative fertilisers that improve agricultural productivity or reduce cost and environmental impact compared to conventional fertilisers.
- Examples: fertiliser capsules with release stimulated by soil conditions, biological seed coatings.

Why is it a competitive advantage?

- NSW has relative R&D, education and workforce strengths in fields of material and chemical science and engineering.
- NSW has five out of 12 Australian universities with world-leading R&D strengths in agricultural and veterinary sciences.¹⁰⁶
- NSW has the largest share of agribusinesses in Australia (30%).¹⁰⁷
- The CRC for High Performance Soils is headquartered in NSW, working on novel approaches to fertiliser formulation and application.
- NSW has substantial local manufacturing expertise in biological inoculants.¹⁰⁸ The quality assurance program for Australian inoculant manufacturers is managed by NSW DPI's Australian Inoculant Research Group.

What is the opportunity?

- Novel fertilisers can improve productivity and efficiency of the agricultural sector and also reduce environmental impacts, including the emissions impact of fertiliser use.

106. ARC, State of Australian University Research 2018–19: ERA National Report (2018).

107. IBISWorld, Agribusiness in Australia (2021).

108. Biological inoculants improve yields of legume crops through symbiotic relationships with nitrogen-fixing rhizobial bacteria.

Competitive advantages in identified applications

Vaccines

What is it?

- Used to stimulate the production of antibodies and provide immunity against disease.
- Examples: mRNA, protein-based and viral vector vaccines.

Why is it a competitive advantage?

- NSW has R&D strengths in fields of biochemistry, genetics, microbiology and immunology, which underpin vaccine technologies.¹⁰⁹
- NSW universities have formed the NSW RNA Bioscience Alliance to leverage expertise in RNA R&D.
- NSW has a unique GMP training facility at the Biologics Innovation Facility.
- NSW is establishing a local RNA pilot manufacturing facility.
- NSW is expanding its advanced viral vector manufacturing capabilities at the Westmead Health & Innovation District.

Why is it a strategic priority?

- The ability to produce vaccines locally will enhance the public health response to emerging infectious diseases, reducing dependence on international supply chains.

What is the opportunity?

- NSW can be a regional leader in medical vaccine production, leveraging existing world-class vaccine manufacturing infrastructure and investment in RNA capabilities.



109. ARC, State of Australian University Research 2018–19: ERA National Report (2018).

110. ARC, National Competitive Grants Program Dataset (2020).

111. NSW Government, Critical minerals and high-tech metals strategy (2021).

Future mining chemistries

What is it?

- More productive, efficient and sustainable chemical products for mining applications.

Why is it a competitive advantage?

- NSW has attracted a significant amount of R&D funding in resources and extractive metallurgy to establish the ARC Centre for Excellence for Enabling Eco-Efficient Beneficiation of Minerals.
- NSW has strong capabilities in chemistry, including attracting over 40% of ARC funding for analytical and inorganic chemistry from 2014 to 2020.¹¹⁰
- NSW has relative export strengths in mined resources.
- NSW has endowments of high-tech metals such as antimony, cobalt, copper, titanium and rare earths that have a strong global demand for use in advanced technology manufacturing.¹¹¹
- A Critical Minerals Hub will be established in Dubbo and will be a centre for value-added processing and mineral recycling, strategically positioned near high-tech mineral developments.

What is the opportunity?

- Combined with abundant renewable energy, these technologies could unlock opportunities to both mine and refine high-value resources, capturing more of the supply chain for these products in NSW.
- The international demand for precious metals and rare minerals is increasing, driven by increasing demand for advanced technologies.

112. ARC, State of Australian University Research 2018–19: ERA National Report (2018).

113. Agricultural Biotechnology Council of Australia, The Official Australian Reference Guide to Agricultural Biotechnology and GM Crops, (2015).

114. ARC, National Competitive Grants Program Dataset (2020).

Competitive advantages in identified applications

Synthetic biology

What is it?

- The application of engineering principles to design or redesign new organisms from biological components, including enzymes, proteins and DNA, for useful purposes.
- Examples: bacteria designed to breakdown pollutants in the environment, produce useful products such as pharmaceuticals or fuels, detection of environmental conditions.

Why is it a competitive advantage?

- NSW has relative R&D strengths in several fields of biological sciences underpinning synthetic biology technologies.
- NSW attracts over 36% of all ARC funding in biochemistry and cell biology.¹¹⁴
- NSW hosts the headquarters of the ARC Centre of Excellence in Synthetic Biology, and the NCRIS-funded Bioplatforms Australia facilities, with expertise in Omics and Bioinformatics.
- NSW has large industries in relevant end markets for synthetic biology including in agriculture, health, resources and industrial processing.

What is the opportunity?

- Synthetic biology can improve productivity and sustainability in many areas from energy to food production, manufacturing, environmental protection and healthcare.
- Major investments are being made by leading research nations as they recognise synthetic biology's potential as a future industry and enabler of other critical industries.
- By 2025, the economic impact of synthetic biology in the biofuels, chemicals, agriculture and health care sectors is expected to reach US\$0.7 to 1.6 trillion.¹¹⁵



Genetic engineering

What is it?

- Manipulating the DNA of existing organisms with the aim of altering their physical characteristics or products.
- Examples: pesticide-resistant crops, vitamin-enriched produce, microbial production of human insulin.

Why is it a competitive advantage?

- NSW has relative R&D strengths in genetics, microbiology, biochemistry and cell biology that underpin genetic engineering methods.¹¹²
- NSW has strong industry-based life science capabilities in the health and agricultural sectors.
- NSW has large industries in relevant end markets for genetic engineering including in agriculture, health, resource and industrial processing.

What is the opportunity?

- Genetic engineering of organisms has the potential to climate-proof valuable industries and improve resource use efficiency, including water, fertilisers, pesticides and energy.
- Strong uptake of genetically modified organisms by farmers globally offers export opportunities.¹¹³

112. ARC, State of Australian University Research 2018–19: ERA National Report (2018).

113. Agricultural Biotechnology Council of Australia, The Official Australian Reference Guide to Agricultural Biotechnology and GM Crops, (2015).

114. ARC, National Competitive Grants Program Dataset (2020).

115. McKinsey Global Institute, Disruptive Technologies: Advances that will Transform Life, Business and the Global Economy (2013).

Competitive advantages in identified applications

Personalised medicine

What is it?

- Medical care where treatment is customised for the patient by analysing their genetic information to guide the most appropriate treatment.
- Examples: personalised cancer treatment, replacement cell transfusion, targeted drug delivery.

Why is it a competitive advantage?

- NSW attracts over 36% of all ARC funding in biochemistry and cell biology.¹¹⁶
- NSW has relative strengths and capability in cancer research and omics R&D.
- NSW-based organisations led the Zero Childhood Cancer Program, a highly successful, world-first trial of personalised medicine which has led to several breakthroughs in the diagnosis and tailored treatment of children with cancer.
- NSW has world-leading supporting infrastructure for personalised medicine including the NSW Statewide Biobank and Children's Medical Research Institute ProCan library.
- NSW is establishing an RNA pilot manufacturing facility that will produce both synthetic RNA (sRNA) and mRNA therapeutics.
- NSW is expanding its advanced viral vector manufacturing capabilities at the Westmead Health & Innovation District.

What is the opportunity?

- NSW can be the Australian leader in personalised medicine, developing advanced treatments and approaches that improve health services in NSW, attract private patients to seek care in NSW, and international talent to train and work in NSW.



Cell-based meats

What is it?

- Animal meat produced using animal cell culture technology.

Why is it a competitive advantage?

- NSW has relative R&D strengths in biochemistry and cell biology.¹¹⁷
- NSW has a substantial food manufacturing industry and RCA in food products.¹¹⁸
- NSW has tangential capabilities – such as a well-regarded nutraceuticals and pharmaceuticals industry with a trusted regulatory framework and large, skilled workforce.

What is the opportunity?

- NSW could leverage its existing food manufacturing, biotechnology and nutraceuticals industry and skills to develop a trusted cell cultured meat industry that exports product globally.

AgTech

AgTech is a vital part of the economy and is predicted to become a \$100 billion industry in Australia by 2030.¹⁵⁰

Market size

NSW's agriculture sector already contributes \$17.2 billion to state income and has substantial opportunities to develop and deploy AgTech through NSW agribusinesses.¹⁵¹

Industry sectors and applications

NSW has a diverse primary industry sector comprising agriculture, fisheries and forestry that offers a strong foundation for AgTech. For example, the agriculture sector was an early adopter of robotic and automation technologies, already widely deploying off-the-shelf robots, autonomous navigation systems, irrigation management and custom robots for seeding, spraying, weeding and livestock caring.¹⁵² The sector continues to use innovation to drive productivity and efficiency improvements.

NSW's competitive advantages

NSW's competitive advantages in AgTech rest on significant public and private investments made in R&D and successful commercialisation, as well as existing industry capabilities. Access to research infrastructure, weather and soil data and diverse agriculture products provides a strong foundation for NSW's AgTech R&D. NSW DPI is Australia's largest R&D supplier, with over 600 researchers across 25 research stations and 13,000 hectares of trial farms.¹⁵³ Orange's Global Agri-Tech Ecosystem (GATE) offers AgTech startups and agribusinesses end-to-end AgTech commercialisation services including ideation, incubation, acceleration and investment attraction.

Emerging AgTech hubs are being established to leverage NSW's pipeline of freight infrastructure that connects 'farms to markets'. New road transport, logistics hubs and inland rail projects could unlock new markets for AgTech and agribusinesses. Building on existing agriculture industries and R&D capabilities, emerging AgTech clusters are being established. The Wagga Wagga AgTech Cluster is a successful example that now is becoming a leading technology and education supplier in regional NSW. Another example is the Agribusiness Precinct at the Western Sydney Aerotropolis, which expected to contribute up to 2,500 direct jobs, 12,000 indirect jobs and \$2.8 billion in revenue over 10 years.¹⁵⁴



116. ARC, National Competitive Grants Program Dataset (2020).

117. ARC, State of Australian University Research 2018–19: ERA National Report (2018).

118. Department of Foreign Affairs and Trade, Australia's Trade by State and Territory 2018-19 (2020); United Nations, Comtrade (2019).

150. Investment NSW website – AgTech.

151. Regional NSW website – Agribusiness and food.

152. Australian Information Industry Association, *Growing Globally Competitive Industries* (2021).

153. Regional NSW website – Agribusiness and food.

154. Investment NSW website – AgTech.

Competitive advantages in identified applications

AgTech

What is it?

- Use of advanced technologies in agriculture.
- Examples: automated farm equipment, AI-assisted remote sensing, in-field disease testing, real-time soil monitoring.

Why is it a competitive advantage?

- NSW has relative R&D strengths across digital technologies, materials and chemistry, biotechnology and energy that support AgTech innovation.
- NSW has five out of 12 Australian universities with world-leading R&D strengths in agricultural and veterinary sciences.¹¹⁹
- NSW has RCA in a diverse range of agricultural products, and there is strong international demand for quality produce from trusted exporters like Australia.¹²⁰
- NSW has the largest share of agribusinesses in Australia (30%).¹²¹
- See Case Study (pg 59): *AgTech*

What is the opportunity?

- The broad range of NSW competitive advantages have many AgTech applications.
- Developing and deploying AgTech innovations in NSW's competitive and diverse agriculture sector can further improve productivity, quality and resilience, and grow the industry and its exports.



119. ARC, State of Australian University Research 2018–19: ERA National Report (2018).

120. Department of Foreign Affairs and Trade, Australia's Trade by State and Territory 2018-19 (2020); United Nations, Comtrade (2019).

121. IBISWorld, Agribusiness in Australia (2021).

Competitive advantages in identified applications

Controlled environment horticulture

What is it?

- Production of crops using indoor production systems.
- Controlled environment horticulture (CEH) improves yields and water efficiency but is highly energy intensive.
- Examples: high-technology greenhouses, vertical farms, hydroponic growing systems

Why is it a competitive advantage?

- NSW has access to abundant, low-cost renewable energy that can make CEH more cost competitive and environmentally sustainable in NSW versus other countries.
- NSW has RCA in a diverse range of agricultural products and there is strong international demand for quality produce from trusted exporters like NSW.¹²²
- NSW has a trusted ecosystem of high quality agriculturalists, farmers and food manufacturers. NSW has the largest share of agribusinesses in Australia (30%).¹²³
- NSW has strong R&D capabilities in agriculture. NSW has five out of 12 Australian universities with world-leading R&D strengths in agricultural and veterinary sciences.¹²⁴
- NSW has several specialist R&D capabilities such as the Future Food Systems CRC and National Vegetable Protected Cropping Centre.

What is the opportunity?

- NSW can improve the climate resilience of the agriculture sector and increase productivity of exurban and regional land that would not be suitable for broadacre cropping.
- CEH can be an end-user of captured emissions, contributing to decarbonisation.
- NSW can access growing export markets for high-quality produce to Asia. For example, the Aerotropolis Agribusiness precinct will be a prime location for CEH with access to domestic and international cold chain logistics.

122. Department of Foreign Affairs and Trade, Australia's Trade by State and Territory 2018-19 (2020); United Nations, Comtrade (2019).

123. IBISWorld, Agribusiness in Australia (2021).

124. ARC, State of Australian University Research 2018–19: ERA National Report (2018).

125. ARC, State of Australian University Research 2018–19: ERA National Report (2018).

Power to X (P2X)

What is it?

- P2X is an umbrella term for technologies and processes producing green power fuels and clean chemicals using renewable energy and sustainable materials.
- P2X products include green hydrogen, ammonia, synthetic hydrocarbons such as methane, methanol and aviation fuels.

Why is it a competitive advantage?

- NSW has strong R&D capabilities in electrical and chemical engineering,¹²⁵ specifically in P2X production, storage, distribution and use across downstream industries.
- NSW has access to abundant, low-cost renewable energy that can make P2X more cost competitive and environmentally sustainable in NSW versus other countries.
- NSW has coordinated planning and strategic investment in energy infrastructure to enable low cost energy for P2X production, for example the NSW Renewable Energy Zones.
- NSW has extensive transport and logistics infrastructure to connect production hubs with local demand and overseas markets.
- Supportive policies and incentives have been introduced under the NSW Hydrogen Strategy and Net Zero Plan.
- See Case Study (pg 62): *Power to X (P2X)*

What is the opportunity?

- P2X enables NSW to extend its competitive advantages from renewable energy generation to the local manufacturing and export of commodities produced from renewables.
- P2X displaces fossil fuels, assisting local decarbonisation, and growing exports (of P2X commodities) to meet increasing international demand for green commodities.

Power to X (P2X)

P2X is an umbrella term for technologies and processes producing green power fuels and clean chemicals using renewable energy and sustainable materials.

Market size

P2X products include green hydrogen, ammonia, and synthetic hydrocarbons such as methane, methanol and aviation fuels.

The global hydrogen market alone – just one potential P2X product – was worth US\$141 billion in 2019 and is forecasted to reach US\$168 billion in 2026, a compound annual growth rate of 6.25%.¹⁴² The hydrogen industry in Australia is expected to generate approximately \$200 million in additional GDP annually by 2030.

Secondary P2X fuels and chemicals also have potentially substantial markets:

- Every percentage point of increase in global market share of ammonia production would be equivalent to an extra \$102 million in ammonia exports for NSW.¹⁴³
- Markets for synthetic ethanol and methanol are expected to be worth tens of billions as they displace fossil-based fuels and chemicals.¹⁴⁴

Industry sectors and applications

P2X processes and technologies enable the conversion of renewable energy into various forms of chemical energy carriers, which can be used as industrial feedstocks and fuels for power supply. This indirect-electrification pathway enables the decarbonisation of hard-to-abate sectors such as chemical manufacturing, heavy industry and aviation. Renewable hydrogen and P2X products are versatile energy carriers and feedstocks that have applications in many industry sectors. Using water and waste materials as feedstock and renewable energy for production, P2X is a good example of the nexus between energy, water and waste for sustainable development with competing resource demands.

NSW's competitive advantages

NSW has a \$11.3 billion chemical manufacturing industry and employs over one-third of Australia's chemical industry workforce (2017-2018). Increased and sustained demand for P2X products will displace fossil fuels and reduce NSW's reliance on fossil fuels, specifically imported petroleum and crude oil. Some major P2X projects in NSW have already received public and private investment. For example, the Tallawarra B Power Station will be Australia's first and largest hydrogen gas capable power plant.¹⁴⁶

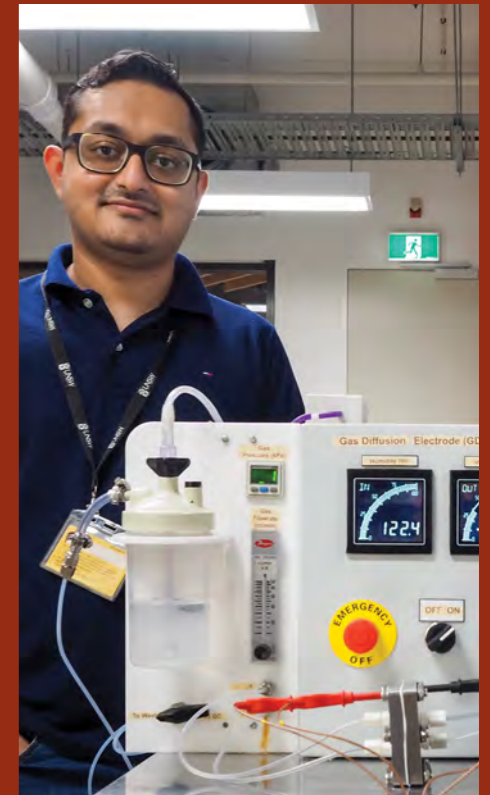
NSW hosts universities and research institutions with excellent P2X technology development and commercialisation capabilities.

For example:

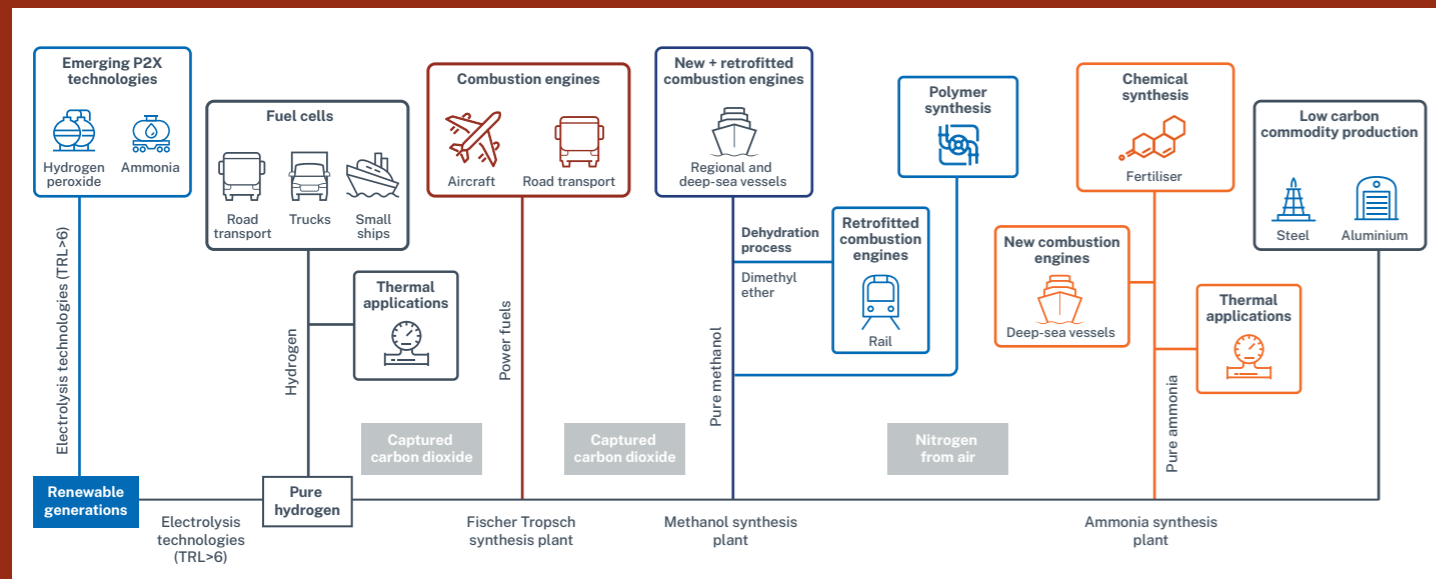
- Plasma Leap Technologies (a spinoff from University of Sydney) has developed a plasma assisted production system to convert Nitrogen Oxides (NOx) emissions to ammonia.
- HydGene Renewables (spinoff from Macquarie University) is commercialising hydrogen generation from biomass with a patented bioreactor and a suite of advanced technologies.
- Hysata (spinoff from University of Wollongong) is developing a novel electrolyser that could significantly reduce the production cost of green hydrogen with catalytic reactions.

The NSW Government is sending clear policy signals to support the development of future clean hydrogen and P2X industries. The NSW Hydrogen Strategy provides up to \$3 billion in financial incentives and exceptions on government charges to support hydrogen projects.¹⁴⁷ The NSW P2X Industry Pre-Feasibility Study, commissioned by OCSE, outlines a roadmap to deploy emerging technologies and build a foundation for local production capability.¹⁴⁸

Recent NSW Government policies have also identified NSW P2X and hydrogen hubs for large scale production. These locations have access to renewable energy and low-cost electricity, abundant feedstock, aggregated and co-located demand, major technology users and export infrastructure. Techno-economic assessments and modelling have identified clear business cases for priority applications (such as synthetic methanol and green hydrogen) that could accelerate the adoption and deployment of P2X.¹⁴⁹



P2X applications¹⁴⁵



142. Global Market Insights, Hydrogen Generation Market (2019).

143. Department of Planning, Industry and Environment, NSW Hydrogen Strategy (2021).

144. KPMG, NSW: A Clean Energy Superpower (2020).

145. UNSW Sydney, NSW Power to X (P2X) Pre-Feasibility Study (2021).

146. Department of Planning, Industry and Environment, NSW Hydrogen Strategy (2021).

147. Department of Planning, Industry and Environment, NSW Hydrogen Strategy (2021).

148. UNSW Sydney, NSW Power to X (P2X) Pre-Feasibility Study (2021).

149. UNSW Sydney, NSW Power to X (P2X) Pre-Feasibility Study (2021).

Competitive advantages in identified applications

Electrification

What is it?

- Energy from electricity replacing other direct power sources, especially fossil fuels.
- Examples: electric engines, heat pumps.

Why is it a competitive advantage?

- NSW has R&D capabilities in renewable energy supply chain and downstream electrification applications across transport, heavy industry, manufacturing and other sectors.
- NSW attracts a disproportionate amount of ARC funding in electrical and electronic engineering and civil engineering (40% and 35% respectively from 2014 to 2020).¹²⁶
- NSW also has a competitive advantage in electrification-related R&D, with five universities ranked in the top 100 in the world for automation and control, and three for electrical and electronic engineering.¹²⁷
- NSW has RTA versus Australia and other countries in control and civil engineering patents filed.¹²⁸
- NSW has abundant inland renewable energy sources (particularly solar and wind), water resources for pumped hydro and land for large-scale energy projects supporting cost-competitive and environmentally sustainable electrification.
- The NSW regulatory environment, with systems such as NABERS, has incentivised and rewarded uptake of electrification in the built environment and supported significant local industry capability in building sustainability.
- NSW is coordinating strategic investment and development of transmission and distribution infrastructure to enable low-cost electricity generation, transmission and distribution.
- Supportive policies and incentives have been introduced under the NSW Electricity Roadmap and NSW Renewable Energy Zones to stimulate private investment and planning in renewable energy projects.



Why is it a strategic priority?

- Electrification is critical for both decarbonising and improving the productivity of the built environment, transport and manufacturing sectors.
- Electrification also reduces demand for imported fuels, reducing NSW's sensitivity to international supply chains and the price of oil.

What is the opportunity?

- Electrification technologies of several heat-intensive processes and light transportation modes is already cost competitive – delivering both cost savings for businesses and environmental benefits for NSW.
- As the world decarbonises, demand for electrification solutions is rapidly expanding. NSW can develop local electrification products and services and export them globally. The exponential growth of the global electric car industry (43% from 2019 to 2020),¹²⁹ is an early indication of how demand for electrification solutions is likely to grow.

Competitive advantages in identified applications

Smart grids

What is it?

- Advanced electricity grids and localised power systems, especially decentralised grids with advanced control, automation, and other digital technologies.
- Examples: smart grids, microgrids, stand-alone power systems that have advanced control and monitoring systems.

Why is it a competitive advantage?

- NSW has technology and R&D capability in systems and control, building automation, AI and blockchain and their applications for energy systems management and control.
- NSW attracts 40% of all ARC funding in electrical and electronic engineering.¹³⁰
- NSW has a competitive advantage in smart grid-related R&D, with five universities ranked in the top 100 in the world for automation and control, and three for electrical and electronic engineering.¹³¹
- NSW has RTA versus Australia and other countries in control patents filed.¹³²
- NSW has rich and dispersed renewable energy sources, particularly solar for decentralised power generation.
- NSW has high penetration of distributed energy resources such as rooftop solar photovoltaics (PV) – one in four homes have solar PV¹³³ – as well as a growing penetration of home battery storage and electric vehicles.
- NSW has coordinated government planning of the upgrade to existing electricity infrastructure.
- NSW has policies and programs incentivising the uptake of microgrids and other forms of decentralised electricity systems to increase local demand.

What is the opportunity?

- NSW can use smart grids to increase the stability and security of its electricity infrastructure while decarbonising the grid through the integration of renewable energy resources. Future smart grids will also increase productivity by improving energy efficiency.
- Smart grid capabilities such as better energy data visibility, digital asset energy management and demand response, are likely to be in increased demand as other countries follow a similar decarbonisation pathway.

Renewable generation

What is it?

- Energy collected from renewable resources that are naturally and constantly replenished.
- Examples: solar (PV and thermal), wind geothermal.

Why is it a competitive advantage?

- NSW has significant R&D capability in new and improved solar power generation technologies, for example passivated emitter and rear cell, silicon wafer cell and flexible solar and paintable materials, and R&D in improving solar cell lifetime, efficiency and recyclability.
- NSW has abundant, geographically dispersed renewable energy sources and a relatively balanced solar and wind portfolio compared to other states.
- Government policies and incentive programs support small household and commercial solar projects.
- Supportive policies and incentives have been introduced under the NSW Electricity Roadmap and NSW Renewable Energy Zones, attracting significant private investment and planning in renewable energy projects in NSW.¹³⁴

Why is it a strategic priority?

- Low-cost, reliable renewable energy can uplift productivity and is essential for decarbonisation across the whole economy, from energy intensive computing and data infrastructure, to electrification of buildings, manufacturing facilities, and the transport and logistics sectors.
- Renewable generation is essential to replace NSW's fossil fuel power stations as they retire. Several planned plant closures are being brought forward due to changing market dynamics.
- Strong renewable generation industries can provide alternative employment opportunities for regions experiencing structural economic transitions away from fossil fuel-based industries.

What is the opportunity?

- NSW can harness its world-leading R&D and significant private investment interest in renewable generation to accelerate commercialisation and uptake of low-cost renewable generation technologies in NSW. This would deliver productivity benefits to downstream industries and households.

126. ARC, National Competitive Grants Program Dataset (2020).

127. ShanghaiRankings, The Global Ranking of Academic Subjects (2021).

128. IP Australia, Intellectual Property Government Open Data (2021).

129. International Energy Agency, Global EV Outlook (2021).

130. ARC, National Competitive Grants Program Dataset (2020).

131. ARC, State of Australian University Research 2018–19: ERA National Report (2018); ShanghaiRankings, The Global Ranking of Academic Subjects (2021).

132. IP Australia, Intellectual Property Government Open Data (2021).

133. CSIRO, Australia installs record-breaking number of rooftop solar panels (2021).

134. NSW Government, \$100 billion of investment potential for Hunter-Central Coast Renewable Energy Zone (2022).

Competitive advantages in identified applications

Energy storage

What is it?

- Storage of energy for later use, to mitigate imbalances between energy demand and supply.
- Examples: batteries, virtual power plants, chemical energy carriers such as hydrogen, pumped hydro storage.

Why is it a competitive advantage?

- NSW has innovation and R&D capability in novel energy storage materials, energy conversion efficiency improvement, demand control technologies and storage integration to energy systems.
- NSW has strong R&D capabilities in electrical and chemical engineering.¹³⁵
- About 40% of Australian businesses developing battery, energy storage and fuel cell technologies are based in NSW.¹³⁶
- NSW has abundant deposits of rare earth metals and critical minerals for battery manufacturing including cobalt, zinc, magnesium and lithium.
- NSW has vertically integrated high-tech metal mining, production and processing facilities and will build Australia's first Critical Minerals Hub at Dubbo.
- NSW has supportive government policies, funding programs and incentive levers for the deployment of long-duration energy storage projects, commercial-scale battery projects and behind-the-meter home batteries.
- Major pumped hydro projects are underway, with financial support from the government (such as Snowy 2.0) and private investment.

Why is it a strategic priority?

- Energy storage technologies are essential to stabilise the grid and increase penetration of intermittent renewable generation as the grid decarbonises.

What is the opportunity?

- Surplus energy storage technologies and capacity can enable renewable energy and P2X export industries such as green hydrogen and ammonia.
- Local electrical and electronics industry and R&D capabilities and access to natural resources can support a local battery manufacturing industry.

Energy efficiency and optimisation

What is it?

- Systems to optimise energy generation, transmission, storage, and consumption.
- Examples: demand response and control, virtual power plants, smart appliances and meters, digital energy management and trading.

Why is it a competitive advantage?

- NSW attracts a disproportionate amount of ARC funding in electrical and electronic engineering and civil engineering (40% and 35% respectively from 2014 to 2020).¹³⁷
- NSW also has a relative competitive advantage in energy efficiency-related R&D, with five universities ranked in the top 100 in the world for automation and control, and three for electrical and electronic engineering.¹³⁸
- NSW has a relative advantage versus Australia and other countries in control and civil engineering patents filed.¹³⁹
- NSW has a large and skilled digital technology workforce, with 41% of Australia's software and application programmers and computer network specialists based in NSW.¹⁴⁰
- NSW has high penetration of distributed energy resources such as rooftop solar PV – one in four homes have solar PV¹⁴¹ – as well as a growing penetration of home battery storage and electric vehicles.
- The NSW regulatory environment, with systems such as NABERS, has incentivised and rewarded uptake of energy efficiency technologies and approaches in the built environment and supported the growth of significant local industry capability.

What is the opportunity?

- Energy efficiency and optimisation technologies and approaches can reduce energy costs for businesses and households – improving overall productivity.
- Energy efficiency and optimisation technologies and approaches can also reduce overall energy demand and increase system flexibility, improving the stability and security of electricity infrastructure.
- Energy efficiency and optimisation technologies are likely to be in increased demand as other countries seek to increase productivity and reduce emissions.

135. ARC, State of Australian University Research 2018–19: ERA National Report (2018).

136. Crunchbase (2021).

137. ARC, National Competitive Grants Program Dataset (2020).

138. ShanghaiRankings, The Global Ranking of Academic Subjects (2021).

139. IP Australia, Intellectual Property Government Open Data (2021).

140. Australian Bureau of Statistics, Labour Force (2020).

141. CSIRO, Australia installs record-breaking number of rooftop solar panels (2021).

Acronyms

AI	Artificial Intelligence
ANFF	Australian National Fabrication Facility
ANSTO	Australian Nuclear Science & Technology Organisation
ARC	Australian Research Council
ARDAC	Accelerating Research & Development Advisory Council
ARENA	Australian Renewable Energy Agency
ASCED	Australian Standard Classification of Education
BERD	Business Expenditure on R&D
CEH	Controlled Environment Horticulture
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ERA	Excellence in Research Australia
ESG	Environmental, Social and Governance
GDP	Gross Domestic Product
GMP	Good Manufacturing Practice
GSP	Gross State Product
MDCTP	Medical Device Commercialisation Training Program
MDF	Medical Devices Fund
mRNA	Messenger RNA
NABERS	National Australian Built Environment Rating System
NCRIS	National Collaborative Research Infrastructure Strategy
NSW DPI	NSW Department of Primary Industries
P2X	Power to X
PV	Photovoltaic
QS	Quacquarelli Symonds
R&D	Research and development
RCA	Revealed Comparative Advantage
REZ	Renewable Energy Zone
RNA	Ribonucleic Acid
RTA	Revealed Technology Advantage
SQA	Sydney Quantum Academy
sRNA	Synthetic RNA
UNSW	University of New South Wales, Sydney
UTS	University of Technology, Sydney

