# NEW
# SMARTS

Supporting Queensland's knowledge-intensive industries through science, research and innovation

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# EXECUTIVE SUMMARY

Knowledge is an increasingly important driver of Queensland's economy and will support the state in growing and diversifying its industries in the future. Advances in enabling technologies, combined with existing research capabilities and local, national and international market shifts, present opportunities for stakeholders to seed new industries and increase the knowledge-intensification of existing or previously dormant industries. While this future horizon presents new opportunities to provide economic, environmental and social benefits for the state, there are current gaps that will need to be addressed.

This report identifies a set of eight emerging 'knowledge-intensive industries' for Queensland, defined as industries that do, or are predicted to, draw heavily on technology and/or human capital inputs. These industries are driven by shifts in multiple supply and demand trends, where a change in supply provides opportunities to offer new products or services or deliver existing business processes more efficiently, and a change in demand opens up a new market. This report aims to inform future policy and strategy decisions concerning science in Queensland.

## Eight emerging knowledge-intensive industries

| | |
|---|---|
| SUSTAINABLE ENERGY | Drawing upon strengths in renewables research and enabling sensors, platforms and nanotechnologies to provide sustainable, affordable and reliable energy products and services. |
| CYBER-PHYSICAL SECURITY | Responding to the need for improved cybersecurity and leveraging research capabilities in robotics and autonomous systems to provide technical and behavioural solutions. |
| SMART MINING, EXPLORATION AND EXTRACTION | Using enabling remote technologies and deep mining research and industry expertise to enhance the knowledge intensity of the entire mining chain, from exploration to mine remediation. |
| PERSONALISED AND PREVENTATIVE HEALTHCARE | Drawing upon world-class biomedical research facilities and infrastructure, platforms, sensor technologies and 3D printing to provide customised and proactive healthcare services. |
| ADVANCED MATERIALS AND PRECISION ENGINEERING | Leveraging advances in 3D printing and automation and existing strengths in advanced manufacturing research to provide high-value, low-volume customised inputs for a range of sectors. |
| NEXT GENERATION AEROSPACE AND SPACE TECHNOLOGIES | Capitalising on geographical strengths and aerospace businesses and research to grow niche markets in the design, development, testing and maintenance of flight vehicles and Earth observation. |
| ADVANCED AGRICULTURE | Utilising deep food science expertise and enabling technologies to transition a strong and mature agriculture industry into one that produces more sustainable, secure and nutritious products. |
| CIRCULAR COMMODITIES | Leveraging existing biotechnology research and an emerging biofutures sector to transform and reduce existing waste streams from industries and consumer markets. |

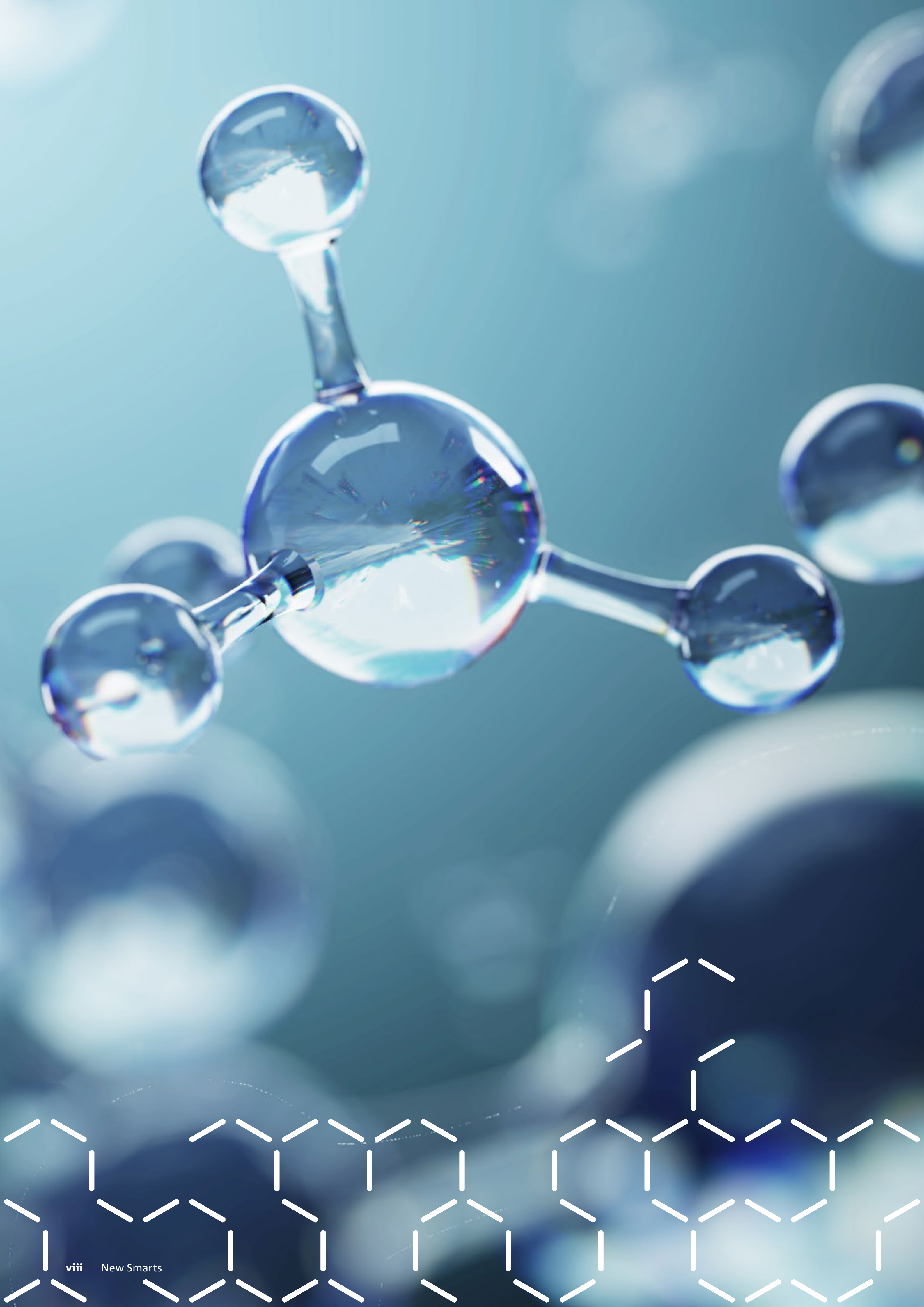
These industries were estimated to be at the 'co-evolutionary' phase of industry emergence – the phase characterised by growth in the number of firms in that industry, where such growth is supported by networks of enterprises, universities, governmental agencies and others. These industries show a strong potential for growth with later phases of industry emergence characterised by employment growth. Knowledge-intensive firms can emerge via a variety of factors, as highlighted in this report by case studies of local and international knowledge clusters.

## Policy implications for science

1. **Improving collaboration between institutions, sectors and disciplines:** Collaboration is a persistent challenge for the research sector at the local and national level, but emerging knowledge-intensive industries will depend upon inputs from multiple sectors, institutions and disciplines. Funding schemes that incentivise joint proposals as well as collaborative research and infrastructure initiatives could help lessen current barriers to collaboration.
2. **Supporting research across the entire pipeline:** Research funding is often skewed towards applied research as it has a clearer economic pathway to impact, but basic research can provide broader environmental, health and social dividends. Basic research is needed to develop new knowledge for applied projects and a short-term focus on applied research funding could have longer-term consequences for growing Queensland's emerging knowledge-intensive industries.
3. **Attracting, training and retaining a skilled and diverse workforce:** Labour and skills shortages could limit future growth for a range of emerging industries, particularly as these industries are predicted to demand new skills or skill combinations. These challenges are compounded in some emerging knowledge-intensive industries which struggle to attract future workers due to outdated perceptions of the industry or which lack sufficient workforce diversity.
4. **Broadening the role of government as a customer, enabler or innovator:** International knowledge clusters demonstrate some instances where new industries emerged as a result of government being an early customer and adopter, and others where government had minimal involvement. While government is often viewed as a key source of funding for emerging industries, there are a variety of roles government can play in facilitating industry growth.
5. **Positioning universities in supporting the advanced knowledge economy:** Universities and research institutes have developed commercialisation entities to improve the translation of research, but they have a broader role to play in enhancing industry–research collaboration and responding to emerging education and workforce requirements. Graduate programs that offer flexibility and on-the-job training and are responsive to industry needs will be necessary in future.

This report presents a set of emerging knowledge-intensive industries that demonstrate the options available to Queensland, drawing upon the state's research capabilities, enabling technologies and emerging sources of supply and demand. Each industry faces a number of challenges to future growth concerning the research sector, infrastructure, education and the workforce, but through a coordinated effort, Queensland can realise the full potential of its growing and evolving knowledge economy.

CSIRO's Data61 was commissioned by the Queensland Government Department of Environment and Science to conduct this strategic foresight project as part of the Q-Foresight program – an initiative under a multi-year Strategic Partnership Agreement between the Queensland Government and Data61. Q-Foresight is Australia's only dedicated strategic foresight program and is designed to provide state government agencies with improved information for decision making about future trends, risks and scenarios.



# 1 INTRODUCTION

The Queensland economy, like many other advanced economies, has seen significant shifts over the past several decades. Advances in technology, changes in consumer preferences and globalisation, among other factors, have increased the focus on the generation of value from knowledge-intensive goods and services. While generation and application of knowledge has played a longstanding role in economic growth, its importance has been intensified by the enhanced connectivity provided by technology, particularly through the internet.[1] As such, knowledge-intensive activities will be a key driver of future growth, job creation and prosperity in Queensland's economy.

The term 'knowledge economies' was first coined by the Organisation of Economic Co-operation and Development (OECD) in 1996, and since then, a range of definitions have been put forward.[2] According to the World Bank, a knowledge economy can be defined as an advanced economy where greater importance is placed on the creation, dissemination and use of knowledge assets over capital or labour assets and wherein there are high levels of knowledge-based activities.[3] 'Knowledge-intensive industries' are the key contributors to a knowledge-based economy and can be defined as industries that draw heavily on technology and/or human capital inputs.[4]

Science, technology, engineering and mathematics (STEM) disciplines can drive innovation in primary, secondary and services-related industries in a number of ways.[5] For instance, the application of fundamental STEM developments or infrastructure in areas such as computing and communications technology can enable significant shifts in the types of services organisations provide and how these services are delivered. Moreover, STEM-related activities can drive innovation internally within organisations (e.g. through the presence of skilled STEM workers or internal STEM-based research) or externally through collaborations between industry, university, research institutes and government.

However, the contributions of science, technology and research to innovation in existing and new knowledge-intensive industries are not always clear-cut. This is because service innovation models are complex and STEM-related outputs can be intangible, limiting their visibility to those outside of the process.[5,6] Consequentially, the value of science, technology and research in emerging knowledge-intensive industries can be understated.[6] As global competition for markets continues to intensify, Queensland's science sector will play an important role in growing new knowledge-intensive industries and increasing the knowledge-intensification of existing or previously declining industries.

But what knowledge-intensive industries are emerging in Queensland? There have been a number of reports that have aimed to explore emerging industries, such as the Queensland Government's industry roadmaps which have highlighted advanced manufacturing, aerospace, mining equipment, technology and services, biofutures, biomedical, defence, food and agriculture, and the screen industries.[7–14] These industry roadmaps pinpoint Queensland's competitive strengths; strengths that provide opportunities to diversify its economy and grow knowledge-intensive jobs.[15] Other reports have similarly identified emerging industries in the Asia-Pacific region[16] and high-potential digital industries for Australia.[17]

What is missing is a clear account of how Queensland's science sector contributes to, or could contribute to, the state's emerging knowledge-intensive industries. Understanding the scientific capabilities that are needed to support the state's areas of competitive advantage and respond to emerging sources of supply and demand is critical to growing and diversifying Queensland's knowledge economy. Extending upon prior industry roadmaps and reports, this report aims to identify a set of emerging knowledge-intensive industries for Queensland and explore the opportunities and challenges for the science sector in growing and developing these industries over the coming decades.

CSIRO's Data61 was commissioned by the Queensland Government Department of Environment and Science to conduct this project as part of the Q-Foresight program – an initiative under a multi-year Strategic Partnership Agreement between Queensland Government and Data61. This initiative is designed to provide state government agencies with improved information for decision making about future trends, risks and scenarios. Using strategic foresight methods, this program aims to support the development of enhanced policies, service delivery strategies and outcomes for the people of Queensland.

This report first provides a snapshot of Queensland's knowledge economy (Chapter 2) and outlines a theoretical framework for identifying different phases of emergence for knowledge-intensive industries (Chapter 3). Chapter 4 presents a set of emerging knowledge-intensive industries for Queensland and the current research, infrastructure, education and workforce gaps that could limit future industry growth. The report concludes with a set of policy considerations for future decisions in the science sector (Chapter 5). Details on the strategic foresight process and quantitative modelling are listed in the appendices.

# 2 SNAPSHOT OF QUEENSLAND'S KNOWLEDGE ECONOMY

Queensland had 816,022 knowledge workers in 2016, representing 39.8 per cent of the state's total workforce.[18] Here 'knowledge workers' are defined as those employed as managers and administrators, professionals and associate professionals.[19] A large number of these knowledge workers were employed in the healthcare and social assistance sector and knowledge workers made up the highest share of the workforces pertaining to professional, scientific and technical services and other services (see Figure 1). When compared to other states, Queensland falls near the lower end in terms of the proportion of its workforce that is working in knowledge-related occupations (see Figure 2).

Queensland is home to 10 of Australia's universities, with the majority of the campuses based in the south-east corner of the state. These universities are recognised nationally and internationally for their strengths in key science domains. For example, according to the World University Rankings, the University of Queensland (UQ) is first in Australia for agriculture and forestry and environmental sciences and the Queensland University of Technology (QUT) places first for communication and media studies.[21] UQ is also the top-ranking Australian institution on Nature's index for international scientific research collaboration.[22] These research strengths provide a strong foundation for growing Queensland's knowledge economy.

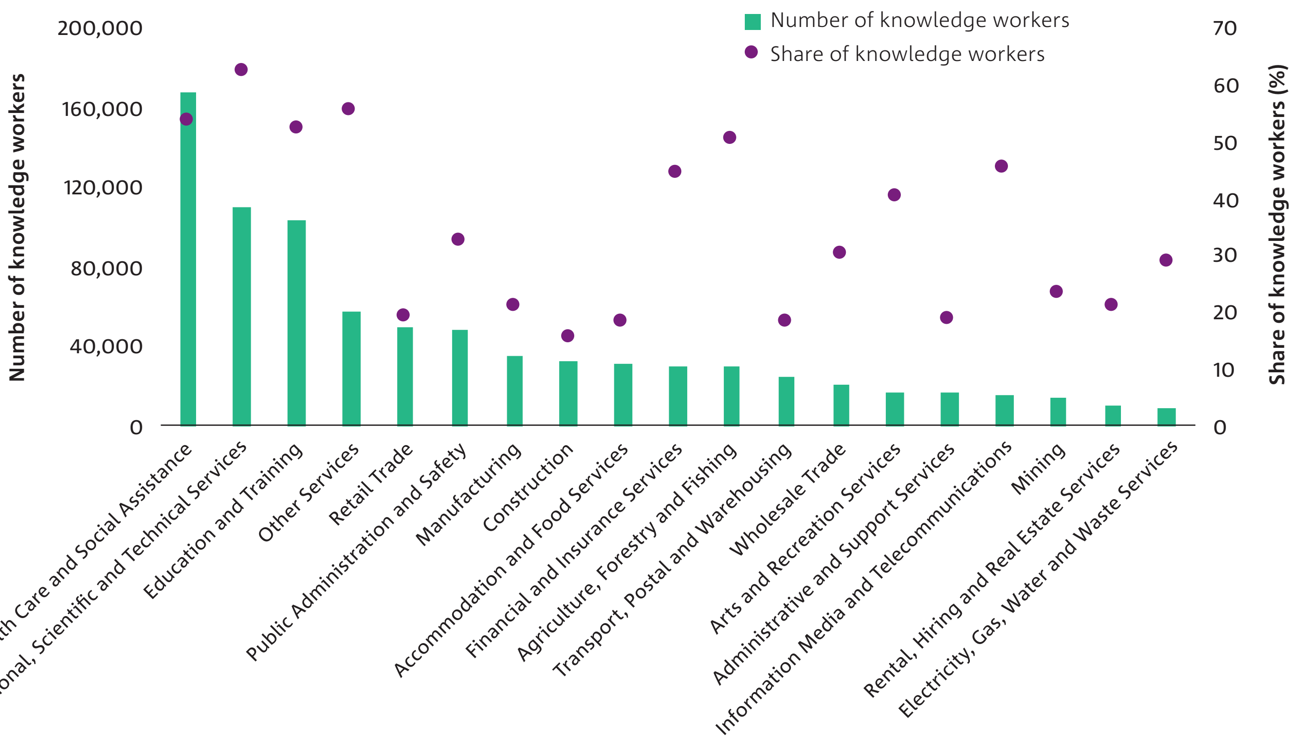



**Figure 1. Number (left axis) and share (right axis) of knowledge workers in Queensland by industry in 2016**

Data source: Queensland Government Statistician's Office[20]

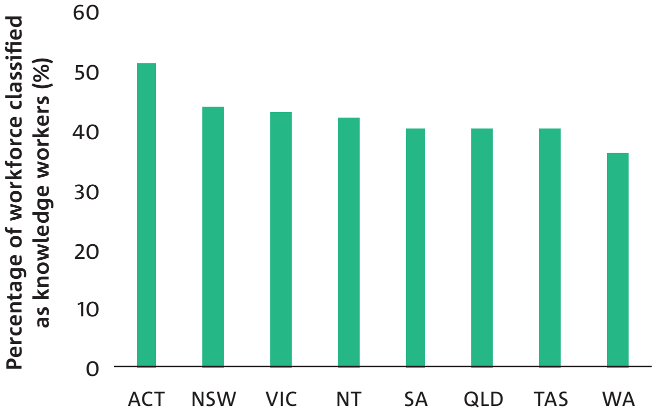



**Figure 2. Share of workforce classified as knowledge workers in Australia, by state and territory, 2016**

Data source: Australian Bureau of Statistics[23]

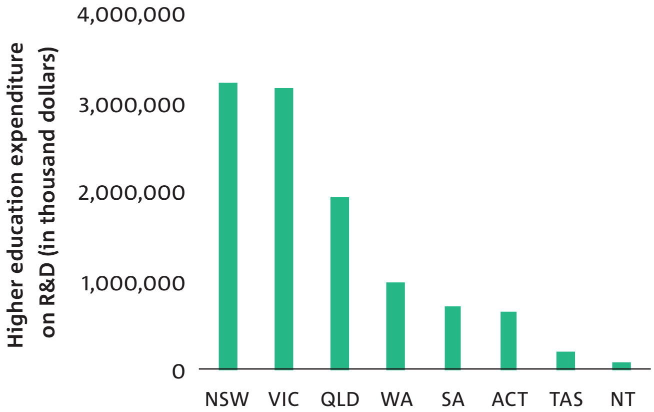



**Figure 3. Higher education expenditure on research and development (R&D, in thousand dollars) in Australia, by state and territory, 2016**

Data source: Australian Bureau of Statistics[24]

Higher education institutions, government and not-for-profit organisations and businesses all contribute to research and development (R&D) activities. Queensland's higher education institutions spent a total of $1.9 billion on R&D in 2016, with the majority of these funds coming from general university funding (60.1 per cent) and Australian Government competitive grants (16.0 per cent).[24] This figure places Queensland's higher-education sector as the third-highest in terms of higher education expenditure on R&D, with New South Wales and Victoria in the top two spots (see Figure 3). The top three fields of research to receive this funding were medical and health sciences (26.2 per cent), engineering (10.4 per cent) and biological sciences (10.0 per cent) and 51.3 per cent of this funding was allocated to applied research.[24]

Businesses expenditure on R&D in Queensland totalled $1.9 billion in 2015–16, the majority of which is concentrated in experimental development (65.2 per cent).[25] Mining (25.8 per cent), professional services (22.1 per cent) and manufacturing (18.5 per cent) were the largest contributors to business expenditure on R&D.[25] In this expenditure, Queensland is on par with Western Australia – where mining contributes double the R&D expenditure compared to Queensland's mining sector – while New South Wales and Victorian businesses invest much more heavily in R&D (see Figure 4). Queensland has one of the lowest shares of business expenditure on R&D as a percentage of gross state product in Australia (see Figure 4) and Australia spent less on business R&D (1.0 per cent of gross domestic product) than the OECD average (1.6 per cent) in 2015.[26]

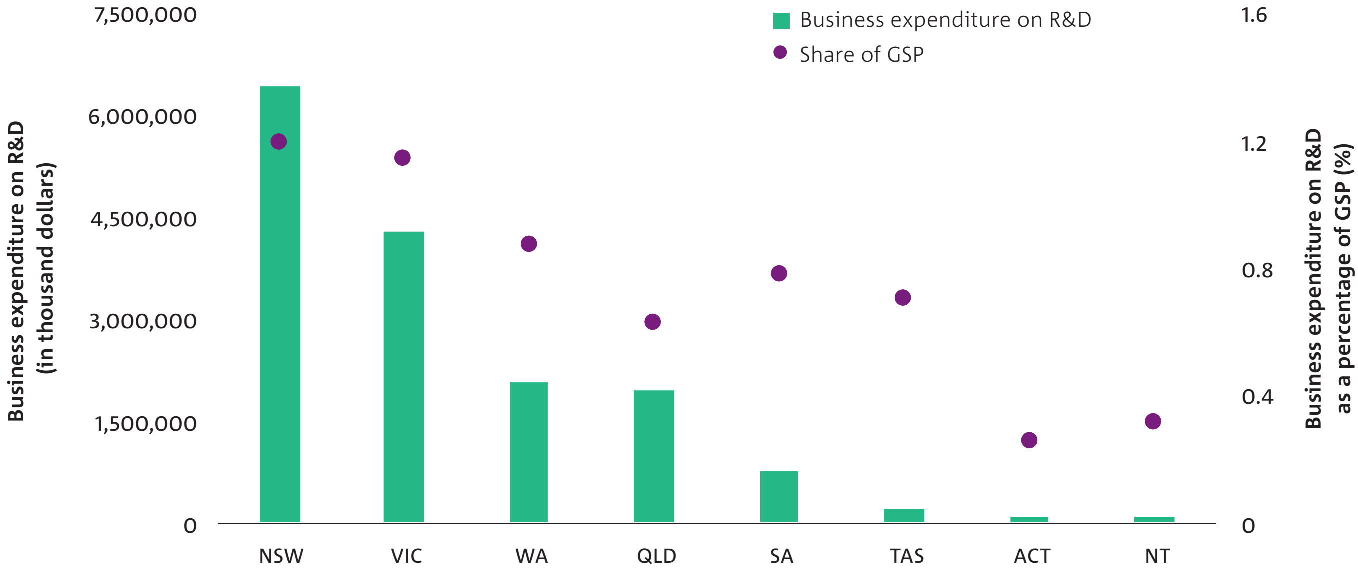



**Figure 4. Business expenditure on research and development (R&D, in thousand dollars) in values (left axis) and as a percentage of gross state product (GSP, right axis) in Australia, by state and territory, 2015–16**

Data source: Australian Bureau of Statistics[25]

A strong supply of STEM-related capabilities will be necessary for growing Queensland's knowledge economy. STEM disciplines account for a small proportion of Queensland higher education degree completions, however, with most completions in the fields of management and commerce, health, and society and culture (see Figure 5). The number of Queensland workers with STEM qualifications is projected to grow at a much slower rate than other fields over the period 2018–22,[28] driven by factors such as a lack of industry collaboration with schools and universities, workforce shortages in qualified STEM teachers, a lack of funding to grow this workforce and poor student engagement in STEM.[29,30] According to the 2016 Census, 15.3 per cent of Queensland's workforce had STEM qualifications[a] – a figure comparable to that of New South Wales and Victoria but slightly below the national average of 17.4 per cent (see Figure 6).

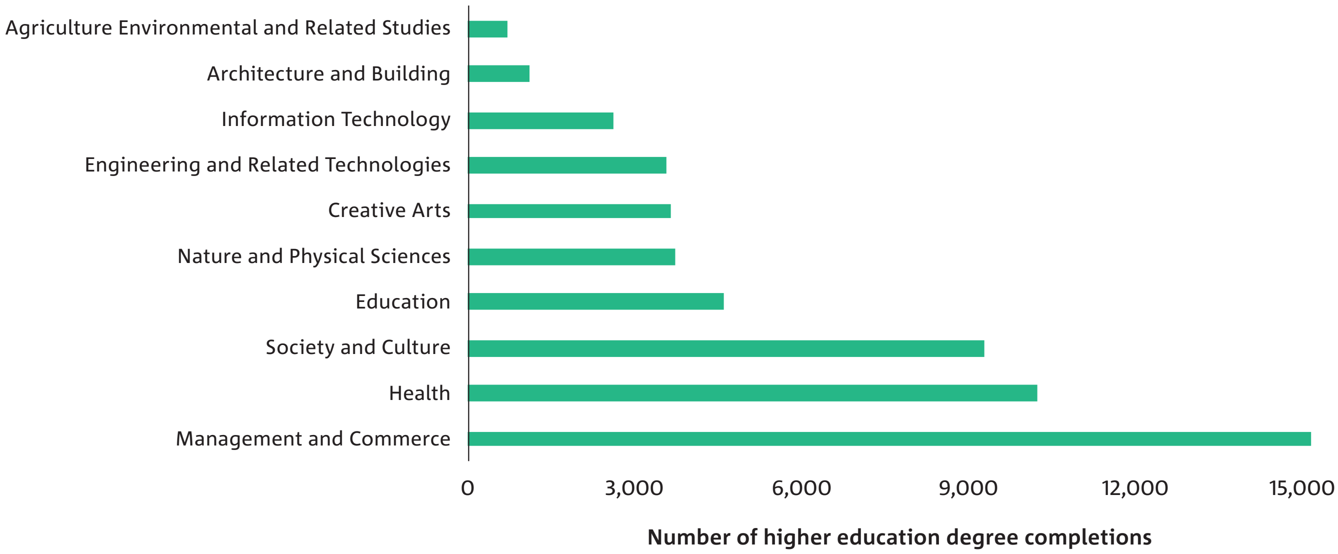



**Figure 5. Number of completed higher education degrees in Queensland, by field of study, 2017**

Data source: Department of Education and Training[27]

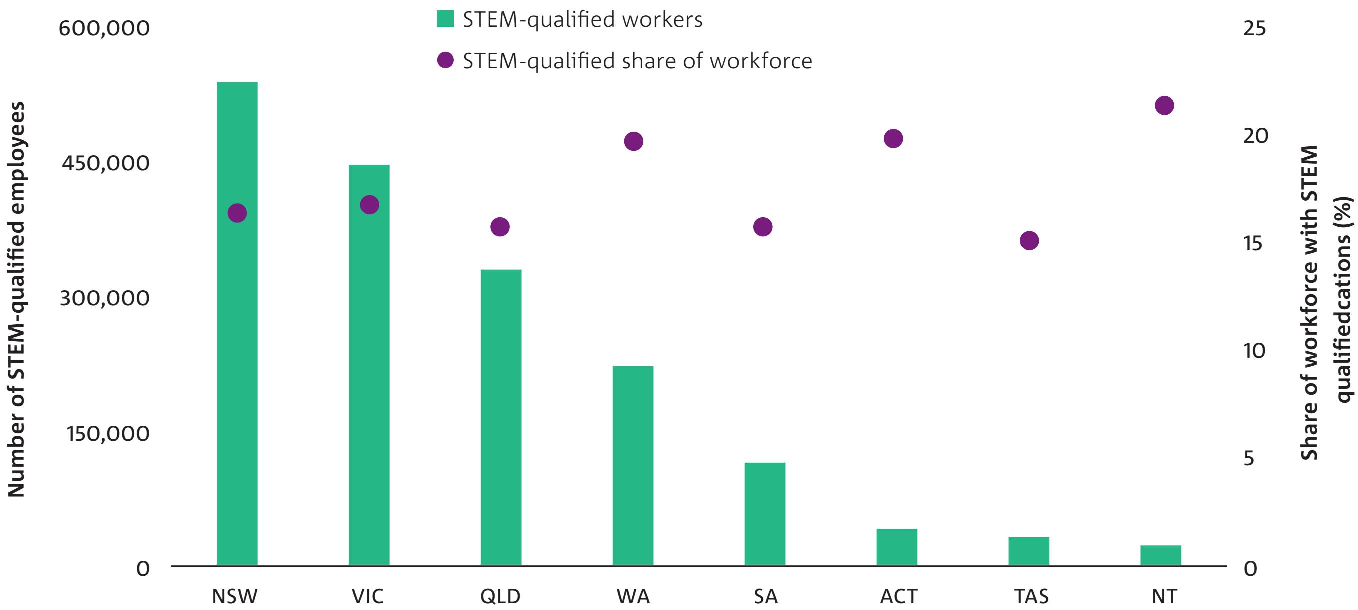



**Figure 6. Number (left axis) and share (right axis) of employed persons with science, technology, engineering and mathematics (STEM) qualifications in Australia, by state and territory, 2016**

Data source: Australian Bureau of Statistics[31]

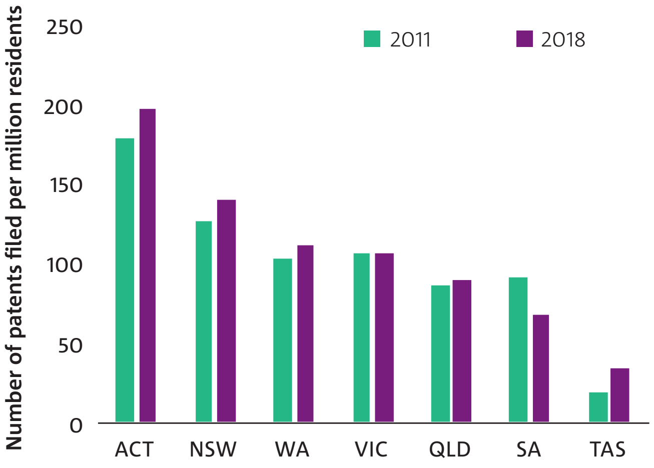



**Figure 7. Number of patents filed per million residents in Australia, by state and territory**

Data source: IP Australia[32,33]

As a measure of knowledge-economy output, the number of patent applications filed in Queensland grew by 16 per cent from 2011 to 2018, compared to an average national growth of 14.5 per cent.[32,33] However, the number of patents filed per million residents is lower in Queensland, with the state consistently among the lowest-performing states and territories over the past decade (see Figure 7). UQ represented a major source of Queensland's patent applications filed in 2017 and was third-highest in Australia for the number of resident patents filed by a single organisation.[34]

Service exports are another output from Queensland's knowledge economy. Services accounted for 15.3 per cent of Queensland exports in 2017–18, with the majority of these being travel services (76.2 per cent).[35] Although the value of Queensland's service exports has grown consistently over the past five years, the value of service exports as a proportion of total exports has declined in recent years (see Figure 8). This decline corresponded to an increase in liquified natural gas (LNG) exports from Queensland.[36] Although primary products accounted for a larger share of Queensland's exports in 2017–18 (51.9 per cent) than for other states (e.g. 35.2 per cent for New South Wales and 30.6 per cent for Victoria),[35] the growth in LNG exports reflects a diversification of Queensland's exports into new resource domains.

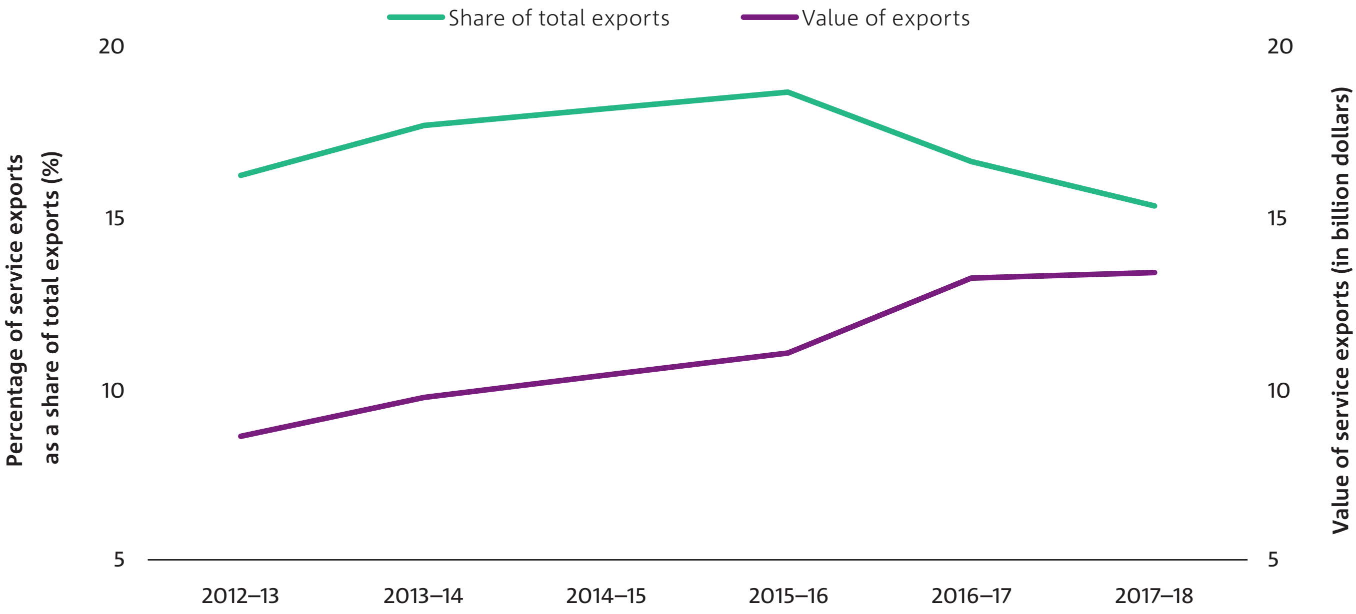



**Figure 8. Service exports as a share of total exports (left axis) and the value of service exports (in billion dollars, right axis) from Queensland**

Data source: Department of Foreign Affairs and Trade[35,37–41]

# 3 DEFINING EMERGING INDUSTRIES

A central aim of this project was to identify a set of emerging knowledge-intensive industries for Queensland. This chapter outlines the different phases of industry emergence, highlighting the specific phase which was used to isolate emerging industries. These industries were defined by emerging sources of supply and demand that may be geopolitical, environmental, social, technological or economic in nature. These new knowledge-intensive clusters were refined and validated through stakeholder consultations and the final set of emerging industries and their associated supply and demand drivers are presented in Chapter 4.

## Phases of industry emergence

Changes in economic, social, technological and geopolitical conditions are reshaping existing industries and giving rise to new industries. The process of identifying emerging industries has generated much interest in academic, government and industry domains, particularly given the positive impact that such industries can have on economic development.[42] Emerging industries reflect the earliest phases of development, where the boundaries between markets, technologies and industry participants are yet to crystallise.[43,44] They may be a sub-sector or technology-driven niche market of an existing industry[45] or an entirely new industry that is born from a new scientific discovery or innovation[46] or the convergence of multiple technologies.[47]

The start of the industry emergence process can be divided into three phases: initial, co-evolutionary and growth (see Figure 9 and Table 1). In the 'initial phase', changes in industry, market or technological conditions become evident, but the novel structure or identity of new industries is not yet clear.[42] While this phase is characterised by high levels of entrepreneurial activity and opportunities for new entrants to enter previously dominated markets,[42] firms that emerge during the initial phase of industry emergence often lack sufficient resources, practices and skills.[48]

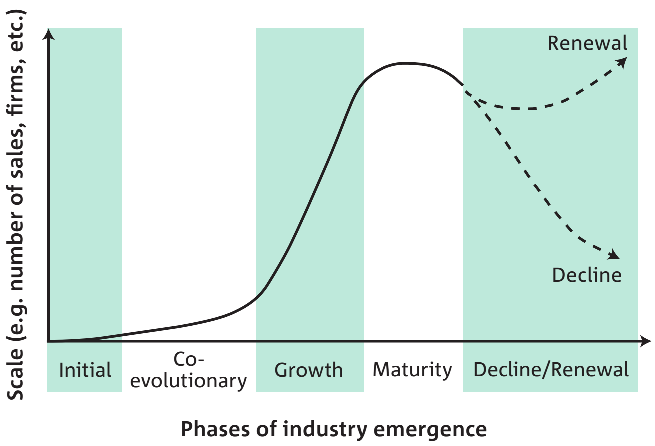



**Figure 9. Key phases of industry emergence**

Source: Adapted from Phaal et al.[44]

In the 'co-evolutionary phase', there is a significant qualitative shift from the initial phase, characterised by rapid imitation of organisational, technical, product and service innovations across firms.[42,49] There is convergence around how markets, products and services are defined and referred to by stakeholders, which opens up a window of opportunity for firms to enter the new industry.[50] The number of firms in the new industry increases,[51] with the establishment of firms and start-ups often supported by networks of existing enterprises, universities, venture capitalists, government agencies and professional associations (e.g. conference organisers).[52] This report considers trends associated with the co-evolutionary phase as indicators of emerging knowledge-intensive industries that have a high potential for future growth.

In the 'growth phase' of industry emergence, there is strong and rapid growth in industry sales and the new industry order that emerged in previous phases takes hold.[42] The number of firms in the new industry reaches its peak and begins to plateau.[51] There is a greater sense of permanency around the new industry through the establishment of a dominant design and broad acceptance of the new industry category among stakeholders.[50] Competition among firms increases too[53] and a clear market leader emerges.[42] In later phases of industry formation, applications, production processes and business models reach maturity.[44]

**Table 1. Challenges and opportunities at each phase of industry formation**

| | INITIAL | CO-EVOLUTIONARY | GROWTH |
|---|---|---|---|
| **Challenges** | • Poorly defined business models and limited resources available to commercialise products<br>• High market uncertainty, making it difficult to develop customer and producer bases<br>• Competition from late-coming free-riders | • Increased competition between technologies, technology designs, value chains and platforms<br>• Lack of accepted industry standards | • Reduction in entrepreneurial activities<br>• Increased firm competition from incumbents and new entrants |
| **Opportunities** | • Openings for new entrants to enter markets<br>• Strong entrepreneurial activity<br>• First-mover advantage in market | • Increased collaboration between firms and with universities and research institutes<br>• Emergence of dominant category, facilitating communications with industry stakeholders | • Improvements in product quality<br>• Rapid growth in firm sales and employment<br>• Common industry and technology standards begin to emerge |

Source: Gustafsson et al.[42] and Horton et al.[16]

There are a range of factors that can trigger or drive an industry to emerge and grow. Scientific or technological developments are among the most prominent factors that challenge the current operating environment or industry structure and can give rise to new products, technologies or services.[44,54] Other key drivers can include cultural or social movements,[55] changes in the regulatory environment,[54] or demand shifts.[56] For example, the emergence of the not-for-profit recycling industry in the United States has been attributed in part to the broader community understanding and practice of recycling behaviours.[57]

Moreover, drivers of industry emergence are subject to the broader socio-economic landscape. When the first digital audio player, MPMan, was released by South Korean firm Saehan in the late 1990s, access to MP3s and broadband internet was poor and as such, the product did not gain market traction.[58] However, when Apple launched the iPod in 2001, MP3s and broadband internet were widely accessible.[58] Enabled by access to technology and its intuitive and seamless interface design, the iPod quickly became the dominant digital audio player on the market, accounting for 48 per cent of the market by 2008.[58] This report takes into account the broader socio-economic landscape and scientific and technological advances in defining a set of emerging knowledge-intensive industries for Queensland.

## The four 'Silicons': Case studies of knowledge clusters

New knowledge clusters can emerge via a variety of factors. This section highlights four case studies of local and international knowledge clusters that have emerged in previous decades or are currently emerging: Silicon Valley in the San Francisco Bay area (United States); Silicon Fen in Cambridge (United Kingdom); Silicon Wadi in Tel Aviv (Israel); and 'Silicon Sunshine' on the Gold Coast (Australia). Local governments, universities, research institutes and enterprises have had different levels of involvement in these emerging knowledge clusters, demonstrating multiple paths to industry formation. These case studies also illustrate the strong role that local scientific and technological capabilities play in emerging knowledge clusters.

### SILICON VALLEY

Silicon Valley, in the San Francisco Bay Area, is arguably the world's most famous example of a successful technology and knowledge-intensive cluster. Innovation and information products and services account for 26.1 per cent of employment in Silicon Valley (2018 figure),[59] with the Bay Area accounting for an estimated 329,200 local tech jobs in 2017 – more tech jobs than in any other city in the United States.[60] In 2017, Silicon Valley generated 12.9 per cent of all patent registrations in the United States[61] and had 636 patents granted per 100,000 people, versus 106 in California as a whole.[62]

Government played a major role in the development of Silicon Valley, beginning in 1913 when the US Navy invested heavily in radio technology and awarded a number of major government contracts to wireless technology firms in the Bay Area.[63] These contracts acted as an incubator for early high-tech firms in the beginning phases of their development.[63] Stanford University was also a critical catalyst in developing new enabling technologies.[63,64] In the 1940s, the university secured several military-sponsored technology projects, which strengthened its reputation and attracted talented researchers[64] and built the Stanford Industrial Park to facilitate industry–research collaborations and commercialisation.[64]

A number of enabling regulatory changes occurred in the 1970s and 1980s too: capital gains tax on stock profits was reduced,[65] universities were granted rights to the commercialisation of intellectual property (IP) generated from federal funding,[66] and citizens were allowed to invest their pension funds in venture capital, which facilitated Silicon Valley's switch from public funding to private equity.[67] Although commercial work and consumer products began to make up a larger percentage of Silicon Valley's ventures, these developments drew on the existing infrastructure, expertise and industry–research–government collaborations that had been developed over the preceding 70 years of government support.

**Image of San Francisco Bay Area, California, United States - the location of the Silicon Valley knowledge cluster**

## SILICON FEN

Silicon Fen refers to the cluster of technology, bioscience and medicine companies that rapidly emerged in Cambridge, United Kingdom – a phenomenon also referred to as the 'Cambridge Phenomenon'. Since 1960, about 5,000 technology companies have been founded in Cambridge[68] and about 1,000 of these companies still operate in the area.[69] Employment in the knowledge-intensive sector in Cambridge was 29 per cent in 2015–16[70] and over the period 2010–11 to 2015–16, the turnover of Cambridge companies grew by 7.5 per cent per annum and employment by 6.6 per cent per annum.[70] The University of Cambridge was a key facilitator in the emergence of Silicon Fen and the cluster emerged without government engineering.

In the early 1950s, Cambridge University established itself as a science and technology leader, building one of the first general-purpose electronic computers.[71] It later founded the Cambridge Science Park in 1970 and allowed faculty members to develop commercial applications and start new businesses outside of the university.[72] This enabled the creation of local knowledge economies. For instance, the information and communication technology (ICT) faculty staff at the University of Cambridge were well placed to anticipate and respond to growing economic demand for ICT-related products and services[72] and one in six Cambridge graduates went on to work for Silicon Fen companies.[73] Many Silicon Fen companies can be traced back to scientific and technological capabilities developed within Cambridge University, either as spin-out companies based on university research or start-ups founded by students or faculty.[74]

The literature on technology-focused industry growth also notes that patterns of high-technology growth are strongly associated with less-urbanised local environments.[75] In Cambridge, the availability of vast tracts of land on which to build the science and technology park was crucial,[73] as were the lifestyle qualities that made Cambridge an attractive place to live.[72] Similar natural advantages likely exist in Queensland too. The Cambridge phenomenon highlights an alternative path to industry emergence from Silicon Valley (i.e. industry supported by university initiatives in the absence of formal government support).

**Image of Cambridge, United Kingdom - the location of the Silicon Fen knowledge cluster**

## SILICON WADI

Tel Aviv, Israel, is home to a cluster of high-tech start-up companies known as Silicon Wadi. In 2016, 1,883 high-tech companies were based in the Tel Aviv–Yafo Municipality, representing a quarter of all Israeli high-tech companies and around 64 per cent of these were start-ups.[76] Tel Aviv's high-tech industry employed 38,091 people in 2016, which equated to 12 per cent of Israel's total workforce.[76] The majority of these companies are focused on big data and cloud computing, the Internet of Things and financial technology.[76]

The success of Silicon Wadi and Israeli's broader technology industry has been attributed to several factors. Firstly, a relative lack of capital and resources in Israel relative to other OECD countries pushed it to invest heavily in high-technology industries.[77] Reliable telecommunications infrastructure and a highly educated workforce played a role in ensuring the success of this investment.[77] The Israeli military also recruits talented high school graduates who spend long periods in elite military technology units and are trained in state-of-the-art military technologies that can later be spun off into commercial applications.[77] Israel's mandatory military service helped foster collaborations between Israelis within the innovation ecosystem.[78]

The Israeli Government has played an active role in enabling the success of Silicon Wadi. The Israeli Innovation and Technology policy adopted during the 1990s promoted R&D within the business sector, provided tax incentives for venture capital through the Yozma Program and encouraged entrepreneurial activity through a Technological Incubators Program.[79] The Israeli Government also prioritised investment in science and technology education.[77] Today, the Israel Innovation Authority is a central government agency responsible for fostering innovations across a broad range of sectors[78] and there remains a strong feedback loop between the military, the start-up sector and the Technological Incubators Program.

**Image of Tel Aviv, Israel - the location of the Silicon Wadi knowledge cluster**

## ‘SILICON SUNSHINE’

Queensland is home to the Gold Coast Health and Knowledge Precinct, which reflects the emergence of a new knowledge cluster for the state – a cluster for which this report has coined the term ‘Silicon Sunshine’. It is a 10 to 15-year project that will result in a 200-hectare hub for high-tech development and research collaboration in the health and biomedical sector. The Precinct has already provided 9,200 jobs and is anticipated to contribute 11,000 more.[80] It is also expected to contribute $1.4 billion to Queensland’s economy upon completion.[81] This is one of the various biomedical-knowledge clusters that have emerged across South East Queensland, with others including the Herston Health Precinct, Health City Springfield Central and the Sunshine Coast Health Precinct.[10]

The Gold Coast Health and Knowledge Precinct is a highly planned project, with a master plan designed by the Queensland Government[80] and $2.4 million of the 2019 state budget dedicated to its development.[82] The Precinct capitalises on its proximity to Griffith University’s Gold Coast campus and also encompasses the Gold Coast University Hospital, Gold Coast Private Hospital, the Institute for Glycomics and Griffith University’s Menzies Health Institute Queensland.[80]

The Gold Coast Health and Knowledge Precinct is well-connected to other knowledge hubs in Brisbane and the Gold Coast, benefiting from recent infrastructure developments in the Gold Coast’s light rail, creating a ‘knowledge corridor’ in South East Queensland.[80]

This concentration of experts and world-leading research institutes is a crucial factor supporting the Precinct’s development. For example, Griffith University partnered with the Gold Coast Health and Hospital Service in 2017 to use the Griffith University Clinical Trial Unit to conduct trials with Gold Coast clinicians as lead investigators.[83] More than 100 trials have been undertaken or completed to date, rapidly building the Gold Coast Health and Knowledge Precinct’s clinical trial capacity and reputation.[84] The Precinct is already attracting international firms too: for instance, Materialise – a world-leading additive manufacturing company – plans to locate its Australian headquarters within the Precinct to capitalise on the facilities and its existing partnerships with local universities and hopsitials.[85]

**Image of the Gold Coast, Queensland, Australia - the location of the ‘Silicon Sunshine’ knowledge cluster**

# 4 THE EMERGING KNOWLEDGE-INTENSIVE INDUSTRIES

This report identifies a set of emerging knowledge-intensive industries that could provide significant social, environmental and economic benefits for Queensland. These industries fall at the intersection of multiple emerging supply and demand trends and drivers, which can cover changes in local, national and global markets, new technologies and innovations, and competitive advantages in science and research expertise. Here a change in supply presents opportunities for firms to offer new products or services or provide existing products and services more efficiently and at lower cost. Conversely, a change in demand can create new markets or customer preferences and can drive firm activity in response to this demand.

This report outlines eight emerging knowledge-intensive industries for Queensland. But these industries and their underlying firms will not evolve in isolation; rather they will likely co-evolve together in an emerging ecosystem of knowledge-intensive industries in Queensland. In some cases, the downstream activities associated with an existing or emerging industry (e.g. the development of new technology products or materials) could support upstream activities in the supply chain of another industry. Emerging digital technologies and knowledge generated across scientific domains can have broad applications too, with the potential to support growth in multiple industry sectors (see Table 2).

Each emerging knowledge-intensive industry is supported by the application and convergence of multiple enabling technologies. Below is a high-level summary of enabling technologies that fall at the intersection of other social, environmental, political and scientific trends, supporting the growth of Queensland's emerging knowledge-intensive industries. The identification of these industries and the trends that underpin them were informed by desktop research and stakeholder consultations across government, industry and academia (see Appendix A for further methodology details). Each emerging knowledge-intensive industry (and its broader industry structure) is quantified in terms of the number of employees and firms (see Appendix B for modelling methodology details). Here, firm growth is taken as a lead indicator of industry emergence, with employment growth occurring at later phases of formation.

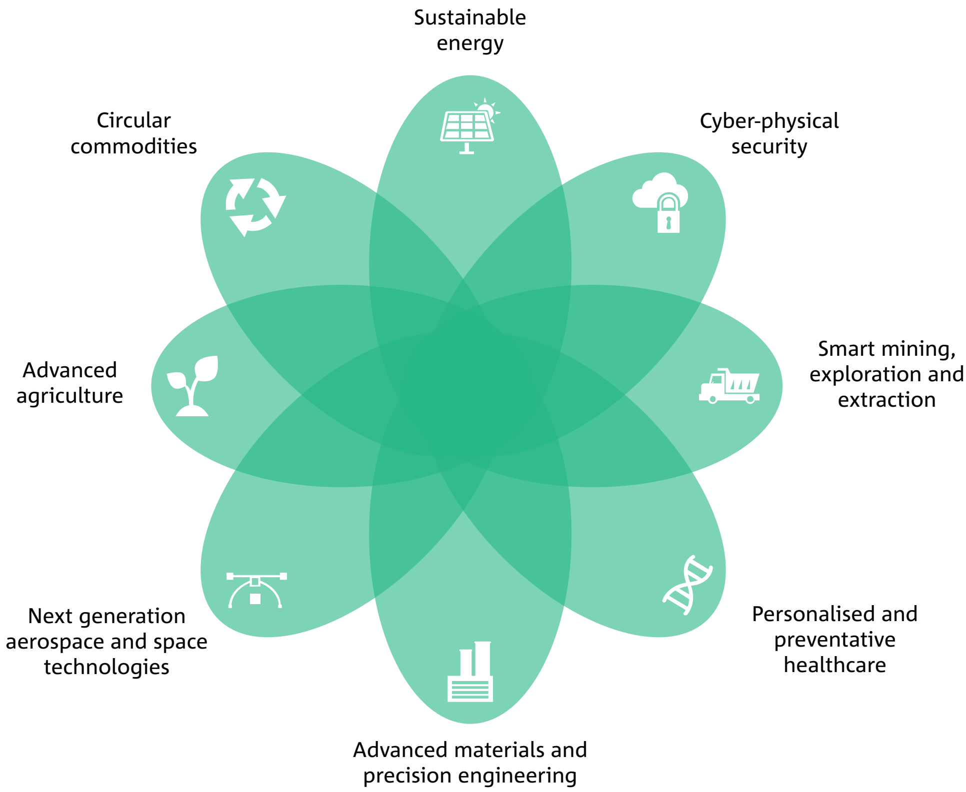


**Table 2. Enabling technologies that are applied and integrated across emerging knowledge-intensive industries**

| | | QUEENSLAND'S EMERGING KNOWLEDGE-INTENSIVE INDUSTRIES | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Sustainable energy | Cyber-physical security | Smart mining, exploration and extraction | Personalised and preventative healthcare | Advanced materials & precision engineering | Next generation aerospace and space technologies | Advanced agriculture | Circular commodities |
| ENABLING TECHNOLOGIES | Remote sensors/Internet of Things | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| | Robotics & autonomous systems | | | ✓ | ✓ | ✓ | ✓ | ✓ | |
| | Artificial intelligence & machine learning | | ✓ | ✓ | ✓ | | ✓ | ✓ | |
| | Big data analytics & platforms | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Satellites & geospatial mapping | | ✓ | ✓ | | | ✓ | ✓ | |
| | Privacy & security technologies | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Distributed ledger technologies | ✓ | ✓ | | | | | ✓ | |
| | High performance computing | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Genome sequencing | | | | ✓ | | | ✓ | ✓ |
| | Synthetic biology | | | | ✓ | ✓ | | ✓ | ✓ |
| | Advanced manufacturing / 3D printing | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Nanotechnology | ✓ | | | ✓ | ✓ | ✓ | | |
| | Virtual & augmented reality | | | ✓ | ✓ | ✓ | | | |
| | Computer vision | | | ✓ | | ✓ | ✓ | | |
| | Social & behavioural sciences | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ |

Source: Informed by stakeholder consultations and desktop research

## Sustainable energy

The sustainable energy industry is comprised of firms that design, manufacture, install and manage products to store and distribute energy in a reliable and affordable manner. With a focus on renewable energy sources, firms offer products such as solar photovoltaic (PV) panels, wind turbines, batteries, smart grid and micro-grid technologies and household 'smart' devices. This industry is driven by geopolitical and environmental pressures to transition towards a low-carbon economy; consumer demand for sustainable, reliable and affordable energy solutions; and advances in enabling sensors, platforms and nanotechnologies. The sustainable energy industry will grow as the cost of batteries reduces and as demand for sustainable energy products and services (e.g. electric vehicles and distributed solar PV systems) increases.

This emerging industry consists of start-ups, small-to-medium-sized enterprises (SMEs) and established firms capable of large-scale energy generation and distribution. Some firms develop and commercialise cutting-edge technologies designed to reduce energy consumption and reliance on non-renewable energy sources. Queensland's existing strengths in renewable energy, advanced manufacturing and environmental sustainability will support these R&D activities. Other firms adopt existing technologies to provide new energy management and distribution products or offer advisory services or online platforms for businesses and households looking to make the switch to more reliable, cheaper and sustainable energy sources.

The current firm and employment trajectories associated with this industry are shown in Figure 10 (see Appendix B for industry categories associated with this industry definition). Based on the most recent data available for this calculation, it is estimated that approximately 55.2 per cent of the sustainable energy workforce in 2016 were knowledge workers.

### WHY QUEENSLAND?

**Queensland is transitioning to a low-carbon economy.** Higher global energy demand is driving increases in carbon emissions,[88] which are associated with a rise in global temperatures and a range of environmental pressures.[89–91] This is driving global concerns around climate change. Queensland has increased its use of renewable energy, with the share of energy generated from renewable sources growing from 3.9 per cent in 2008–09 to 6.9 per cent in 2016–17.[92] In line with the Paris Agreement, the Queensland Government has also committed to reducing greenhouse gas emissions to net zero by 2050.[93] The Queensland Government has established its $1.16 billion Powering Queensland Plan, which includes a $150 million investment into strategic transmission infrastructure in North and North-West Queensland, to support a clean energy hub.[94] Moreover, the Queensland Government has launched a state-owned, 100 per cent renewable energy generator, which is expected to reduce power prices for consumers.[95] These initiatives and developments will support the continued growth of Queensland's sustainable energy industry.

**Queensland's renewable energy sector is supported by strong R&D capabilities.** UQ is home to the Australian Institute for Bioengineering and Nanotechnology (AIBN) and the Dow Centre for Sustainable Engineering and Innovation, who have developed flexible, ultra-thin batteries that could be used to power small-scale medical devices, wearables and larger devices.[96] Moreover, Griffith University hosts the Centre for Clean Environment and Energy, which conducts research into a range of environmental sustainability domains, including energy storage devices.[97] According to Web of Science citations, energy and fuels was the second fastest growing field of research across Queensland universities and research institutes from 2008 to 2018 (see Figure 11). This strong basis in R&D around renewable energy technologies could present future commercialisation opportunities for Queensland's sustainable energy sector.

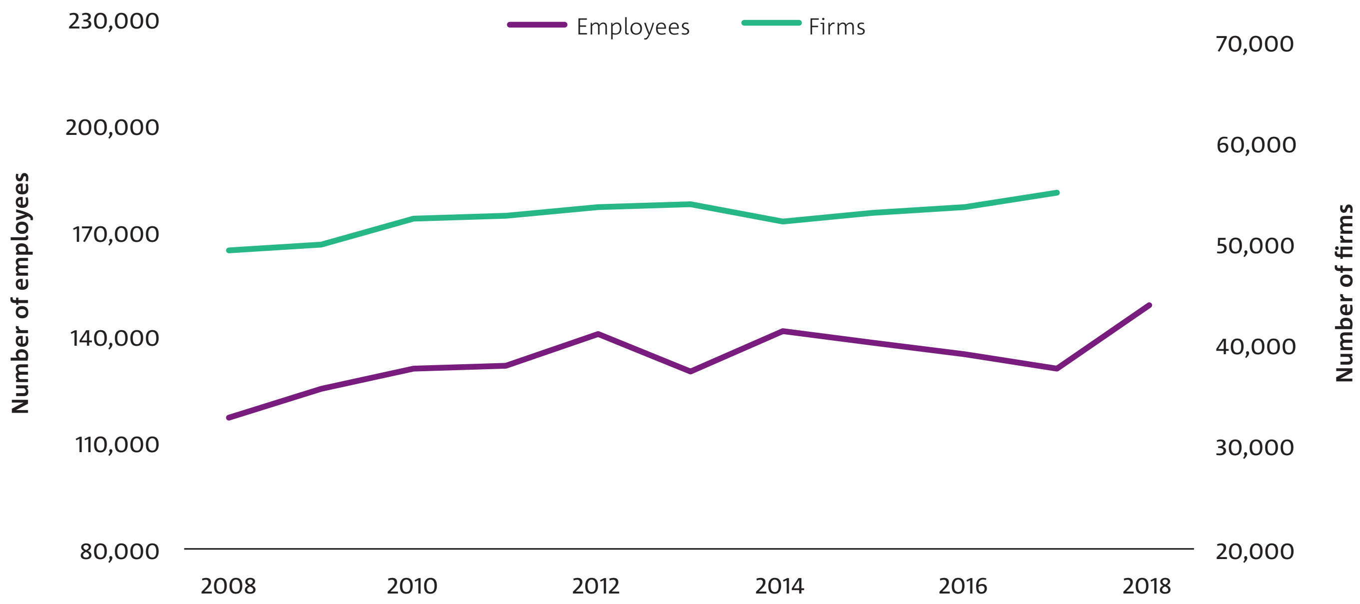



**Figure 10. Number of employees (left axis) and firms (right axis) in the sustainable energy sector in Queensland**

Data source: Australian Bureau of Statistics[86,87]

*Note: Employment and firm estimates are based on historical data aggregated across a subset of ANZSIC industry categorises that are assumed to correspond to this industry (see Appendix B for more details). These ANZSIC codes cover the emerging niche industry as well as the broader industry structure. Employment estimates covers both knowledge and non-knowledge workers, reflecting the predicted size of the entire workforce of the emerging industry and its associated industry sub-sectors.*

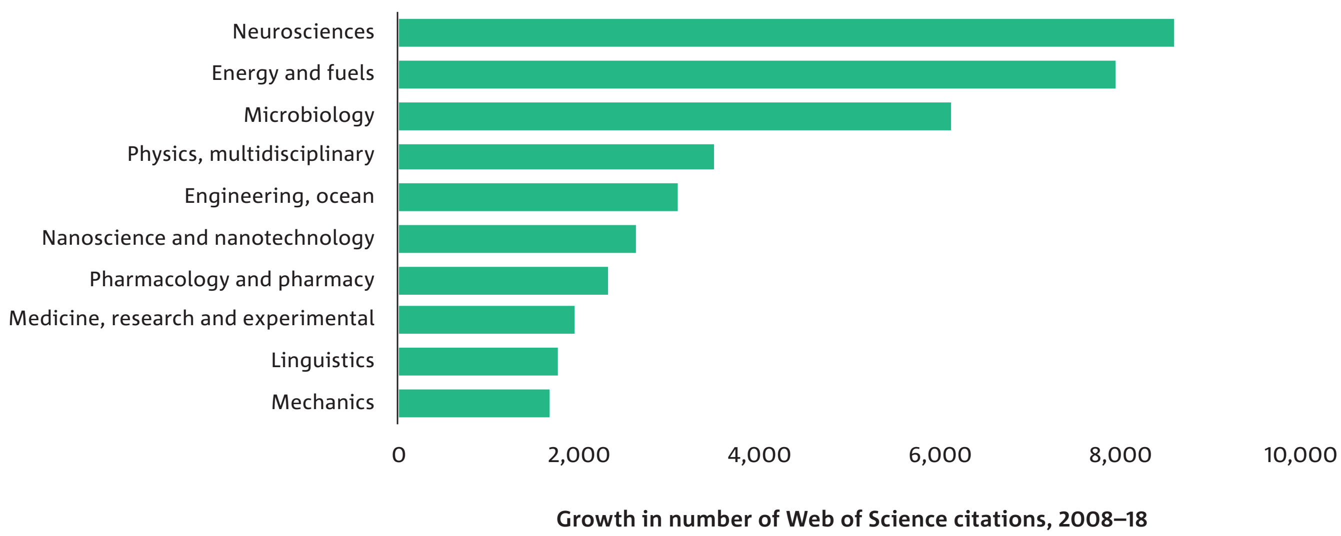



**Figure 11. Growth in number of publications on the Web of Science across top 10 fastest growing fields of study in Queensland from 2008–18**

Data source: InCites, Clarivate Analytics[98]

**Queensland is leading Australia's uptake and generation of solar power.** Queensland has the largest share of rooftop solar PV installations in Australia[99] and generates the largest amount of solar electricity (see Figure 12). With an average of 8.2 hours of sunshine per day in Brisbane, Queensland has a natural solar advantage over other states (e.g. Sydney averages 7.1 and Adelaide averages 8.1 hours per day).[100] Declining costs of renewable technologies and rising electricity costs are driving uptake of solar systems across Australia[101] and it is estimated that Queensland will generate 17 per cent of its annual energy consumption through rooftop solar PV systems by 2035.[102] Strong growth in demand for renewable energy could generate up to 6,000 jobs for Queensland by 2030 in areas such as the construction, operation, maintenance and development of solar PV plants, solar PV panel production and other activities.[103]

**Renewable energy technologies are improving while electricity prices rise.** Queensland's wholesale electricity prices increased by 57 per cent between 2015–16 and 2016–17,[105] driving consumer demand for more affordable energy. At the same time, renewable energy technologies are becoming more affordable and attractive for consumers, with the cost of lithium-ion batteries – a key component of the cost of renewable energy solutions – on the decline (see Figure 13). Lithium-ion battery installation costs are similarly anticipated to fall between 50 per cent and 66 per cent by 2030.[106] Solar PV technologies are becoming more efficient too,[107] and the capacity of batteries[106] and types of battery storage solutions available[108,109] are improving. These technology advances, in conjunction with growing consumer demand for these solutions, will drive future firm activities in the sustainable energy sector.

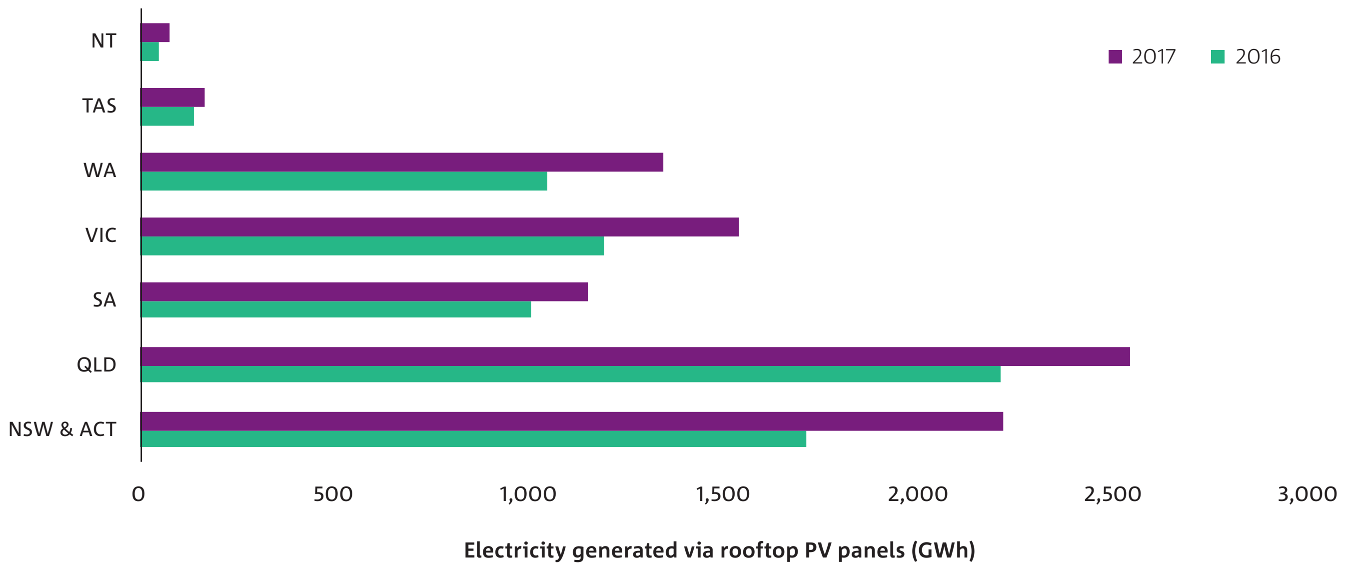



**Figure 12. Amount of electricity generated via rooftop PV panels (in GWh) in Australia, by state and territory**

Data source: Australian Energy Council[104]

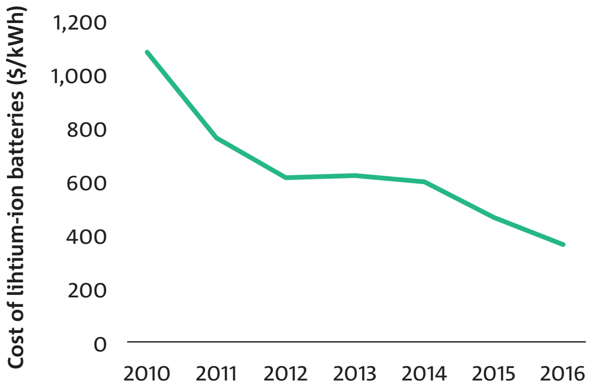



**Figure 13. Cost of lithium-ion batteries worldwide (in dollars per kWh)**

Data source: Bloomberg New Energy Finance[110]

**Demand reduction technologies can help reduce energy usage.** Small-scale, smart energy technologies manage energy supply relative to demand and can reduce energy costs and usage.[111] In particular, 'smart grid' technologies provide fine-grained and real-time information about energy consumption,[112–115] helping consumers to reduce consumption during peak periods and allowing the grid to adjust load demand rather than generation supply.[116] Smart energy technologies can also improve uptake of renewable energy.[117] Smart grids are currently being trialled across Victoria, New South Wales and South Australia[118] and the Queensland Government has launched Yurika – a virtual power plant which sources around 135 MW of excess electricity from large energy users to boost supply during peak periods.[119] Firms in the sustainable energy industry would offer these types of smart grid and energy management products and services.

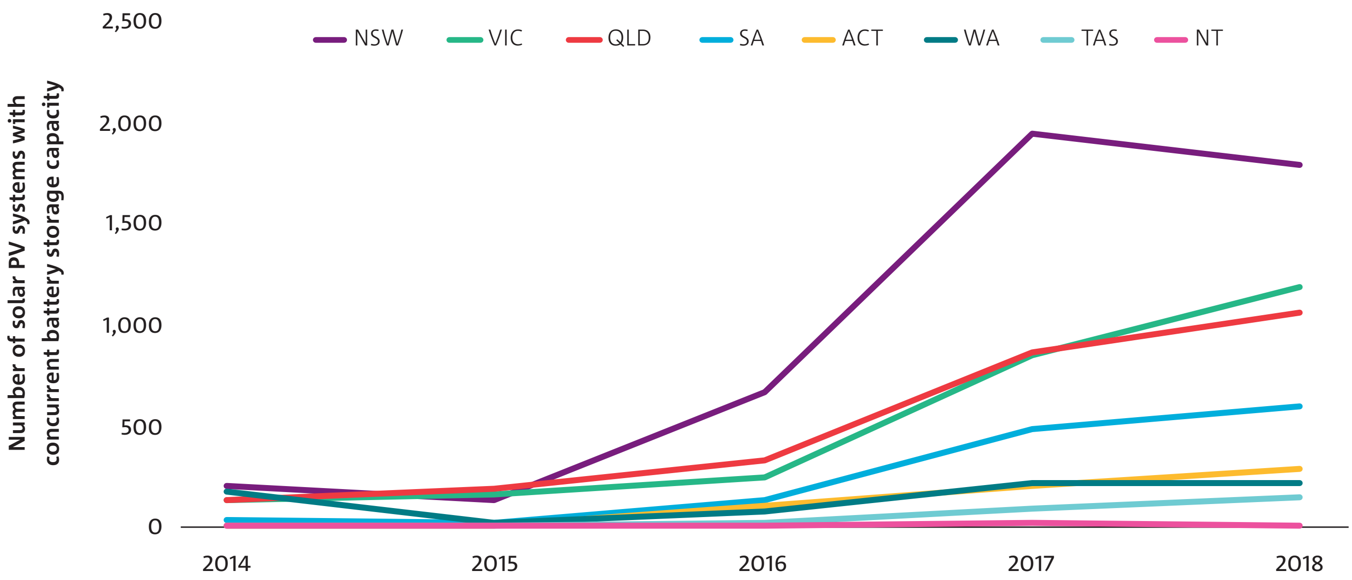



**Figure 14. Number of solar PV systems with concurrent battery storage capacity in Australia, by state and territory**

Data source: Clean Energy Regulator[99]

**There is growing interest in peer-to-peer energy trading worldwide.** Applications of peer-to-peer trading in the energy sector allow grid-connected parties to trade electricity, usually in the form of excess power generated from solar PV systems.[120] This supports locally generated renewable energy, reduces transmission and distribution costs,[120] increases grid independence[121] and can improve grid reliability.[121] One survey of international energy companies found around 45 per cent were trialling peer-to-peer trading[122] and the number of peer-to-peer energy trading projects, trials and platforms is growing worldwide.[123] Solar PV systems with concurrent battery storage are already on the rise in Queensland (see Figure 14), and the Australian Energy Market Operator predicts that Australia could overtake Germany to become the world leader in decentralised generation by 2025.[124]

**Queensland could be a key player in Australia's lithium-ion battery industry.** The Queensland Government committed $3.1 million to assess the feasibility of a lithium-ion battery manufacturing facility in Townsville[125] and QUT has already developed a purpose-built facility for manufacturing lithium-ion batteries.[126] Queensland is also home to innovative start-ups such as Pure Battery Technologies – a start-up that plans to commercialise its patented selective acid leaching process developed at UQ for cheap and efficient extraction of nickel and cobalt for battery materials[127] – and Lithium Australia – a Brisbane-based company that uses its 'SiLeach' process to source battery materials from mine waste[128]. Manufacturing of lithium-ion batteries and their materials could emerge as a niche area of the sustainable energy sector.

**Hydrogen energy represents a new opportunity for Queensland.** Hydrogen is an energy carrier that can be used in transportation, power, industry and buildings and has significant potential to reduce energy-related greenhouse gas emissions,[129] and countries such as Japan and South Korea are looking to import hydrogen to reduce energy-related emissions.[130] A recent breakthrough by CSIRO in membrane technology means that hydrogen can be safely transported and used as a mass production energy source.[131] Queensland's natural gas and coal reserves, carbon capture and storage capability and strong solar potential position it well as a future hydrogen supplier.[130] Hydrogen projects are already being planned and developed in Gladstone[130,132] and the Queensland Government has developed a Queensland Hydrogen Industry Strategy.[133] Queensland's existing research centres (e.g. Griffith University's National Hydrogen Materials Reference Facility) could provide supporting national and global capabilities in hydrogen technologies.[134]

## OPPORTUNITIES FOR GROWING SUSTAINABLE ENERGY

### Research

The commercialisation of research outputs is a challenge in many fields of science, but this is particularly salient for renewable energy research given the strong geopolitical and environmental pressure to reduce greenhouse gas emissions. A historical analysis of energy-related technologies found that these innovations take a median duration of 32 years from invention to widespread commercialisation.[135] Access to funding for commercialisation activities can be a key barrier for researchers, who often need to demonstrate a commercially viable prototype or product to secure funding from investors.[136] Initiatives such as the Commercialisation of R&D Funding Initiative Pilot by the Australian Renewable Energy Agency are designed to support the translation of research into commercial opportunities.[136]

While Queensland has a number of universities and research institutes focused on renewable energy research, the state could improve its national and international standing to be more competitive in this field. Monash University is the top-performing Australian university in energy science and engineering according to ShanghaiRanking's Global Ranking of Academic Subjects in this field, and it was ranked at 30th place worldwide in 2018.[137] UQ ranks between 51st and 75th in the world.[137] Stakeholders consulted as part of this research highlighted that growth in the sustainable energy sector would be supported by greater connections with leading national and international industry partners. Indeed, the Western Australian Government has secured a new Future Battery Industries Collaborative Research Centre (CRC), which aims to bring together industry, research and government partners, including QUT.[138,139]

## Infrastructure

The sustainable energy industry supplies products and services that rely on distributed energy resources (e.g. solar PV systems, smart grids, peer-to-peer trading), but these could require significant changes to grid design and operation.[140] In particular, technical challenges are likely to emerge from the shift from unidirectional power flows to two-way power flows, as energy consumers become producers (e.g. through peer-to-peer energy trading systems).[140] These new modes of energy distribution and management can be supported by advanced metering infrastructure, which typically consists of an integrated system of smart meters, communications networks and meter data management systems.[141] Energy companies are currently limited in their ability to access data generated by advanced metering infrastructure, therefore restricting the types of products and services they can provide for consumers.

Storage will be another integral part of the sustainable energy industry. Through its planned Kidston solar project in Far North Queensland, Queensland is already leading nationally with what will be Australia's first renewable energy project combining solar power with pumped hydro storage to produce energy during peak demand.[142] Other renewable energy infrastructure initiatives across Queensland include the feasibility studies around the proposed lithium-ion battery manufacturing facility in Townsville[125] and the $150 million investment in transmission infrastructure in North Queensland.[94] If these feasibility studies deem the infrastructure developments suitable, they could provide new employment opportunities for regional Queensland, particularly for workers currently employed in high-emitting industries.

## Education and the workforce

As Queensland transitions away from fossil fuels and diversifies its energy mix, there will be some degree of job displacement in regions with coal-fired power stations and other carbon-intensive industries. It will be important to identify education and employment transition strategies for these workers, either within the sustainable energy industry or other sectors. Research from the United States has shown that a relatively minor investment in retraining coal workers would allow the vast majority to transition into roles in the solar PV industry.[143] The Queensland Government has established the Just Transition program which is designed to support workers and communities impacted by the state's transition to a low-carbon economy, and this will be an important consideration in growing Queensland's sustainable energy sector.

Enabling technologies and service models will also shift the capability requirements of the current and emerging sustainable energy workforce. There is a role for both the vocational education and training (VET) and university sectors in responding to these changing skill requirements. Previous work conducted by CSIRO and Energy Networks Australia have identified critical gaps that exist between the current electricity workforce and future industry requirements in areas such as systems thinking, ICT skills, data security, and customer-focused service skills.[140] Electricians and solar installers also increasingly need to be accredited for rooftop PV installations and consumers will demand this to ensure eligibility for government rebates.[144]

| QUEENSLAND'S SUSTAINABLE ENERGY INDUSTRY IN A GLANCE | |
|---|---|
| **Supply drivers** | • Advanced scientific and technological capabilities in renewable energy, advanced manufacturing, environmental sustainability and hydrogen energy<br>• Declining cost of renewable technologies and advances in technology capabilities (e.g. the case of lithium-ion batteries)<br>• Existing and emerging facilities for local lithium-ion battery production |
| **Demand drivers** | • Environmental and geopolitical pressures to transition to a low-carbon economy<br>• Consumer demand for affordable and renewable energy solutions, including peer-to-peer trading, decentralised energy systems and hydrogen<br>• Strong solar potential and uptake of solar technologies |
| **Research opportunities** | • Providing access to funding for the commercialisation of energy-related innovations in the absence of a commercially viable prototype or product<br>• Improving national and international competitiveness in renewable energy research |
| **Infrastructure opportunities** | • Ensuring infrastructure supports bi-directional flows of distribution and management of energy<br>• Enabling storage of renewable energy to meet demand during peak periods and in regional areas |
| **Education and the workforce opportunities** | • Transitioning workers impacted by changes in carbon-intensive industries into this or other low-carbon sectors<br>• Responding to skill requirements in new technology domains, systems thinking and customer service |

## Cyber-physical security

The cyber-physical security industry provides cybersecurity products and services for cyber-physical systems (i.e. systems that consist of both software and physical components), protecting them against cybersecurity vulnerabilities. Cyber-physical security companies offer security solutions for devices, digital supply chains, data platforms and autonomous systems, among others. Some firms also provide business consulting services that help organisations train their staff and customers in cyber-secure practices. Demand for this industry will grow domestically and internationally as adoption of technologies and cyber-physical systems increases along with the frequency of cybersecurity breaches.

The cyber-physical security industry will enable growth in other digitally driven industries in Queensland and respond to their cybersecurity requirements.[145] For instance, the provision of personalised and preventative healthcare will require diagnostic platforms that could contain data sourced from electronic health records, wearable devices, medical imaging and genome sequencing – highly sensitive data that could be subject to security breaches.[145] Similarly, as the smart mining, exploration and extraction industry uses sensors and autonomous systems to perform more operations remotely, cybersecurity solutions will be needed to reduce the risk of hacking.[146] Queensland's strong foundations in defence and research into robotics and autonomous systems will act as key inputs into this emerging knowledge-intensive industry.

The current firm and employment trajectories associated with this industry are shown in Figure 15 (see Appendix B for industry categories associated with this industry definition). Based on the most recent data available for this calculation, it is estimated that approximately 50.7 per cent of the cyber-physical security workforce in 2016 were knowledge workers.

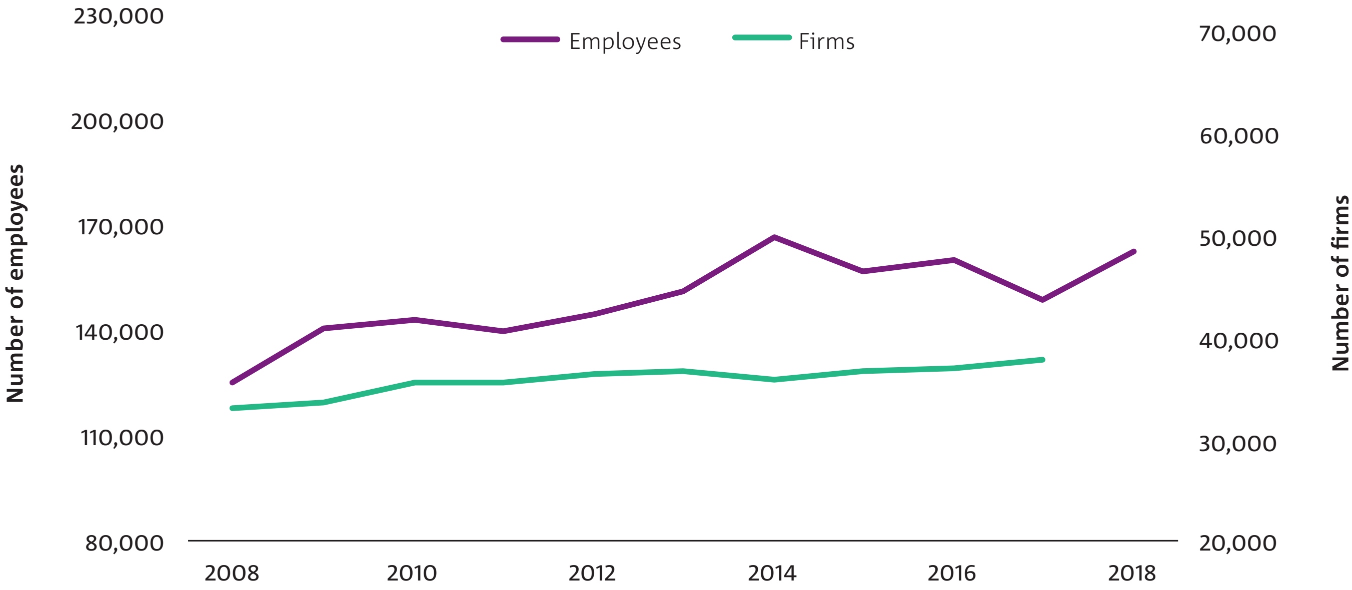



**Figure 15. Number of employees (left axis) and firms (right axis) in the cyber-physical security sector in Queensland**

Data source: Australian Bureau of Statistics[86,87]

*Note: Employment and firm estimates are based on historical data aggregated across a subset of ANZSIC industry categorises that are assumed to correspond to this industry (see Appendix B for more details). These ANZSIC codes cover the emerging niche industry as well as the broader industry structure. Employment estimates covers both knowledge and non-knowledge workers, reflecting the predicted size of the entire workforce of the emerging industry and its associated industry sub-sectors.*

## WHY QUEENSLAND?

**Global demand for cybersecurity solutions remains strong.** Norton estimates that almost 6.1 million consumers in Australia were impacted by cybercrime in 2017 – an increase of 13 per cent from 2016.[147] Demand for cybersecurity will likely grow as technologies continue to develop, particularly in countries where the level of investment in digital innovation outpaces cybersecurity readiness.[17] For instance, Asia-Pacific region firms take an average of 1.7 times longer to detect a breach relative to the global median and spend 47 per cent less on information security than North American firms.[148] AustCyber estimates that global expenditure on cybersecurity will increase from $170 billion in 2017 to $347 billion by 2026,[149] with spending in the Indo-Pacific region increasing at an accelerated rate (see Figure 16). Queensland's proximity to the Indo-Pacific region places it well in meeting this emerging demand.

**Queensland has research capabilities and industry collaborations in robotics and autonomous systems.** Queensland is home to QUT's Robotics and Autonomous Systems group, CSIRO's Data61 Robotics and Autonomous Systems group and the Brisbane-based Australian Centre for Robotic Vision. These research groups form part of the Sixth Wave Alliance – a national industry, government and research collaboration in robotics and automation technologies.[150] Data61 also opened its Robotics Innovation Centre in Brisbane in March 2019 – a facility open to industry and collaborative robotics and autonomous systems projects.[151] The Queensland Government plans to open an AI Hub in Brisbane too, which builds upon its existing artificial intelligence (AI) capabilities and hopes to attract world-leading AI experts.[152] These research strengths and collaborations will support ongoing R&D in the emerging cyber-physical security industry.

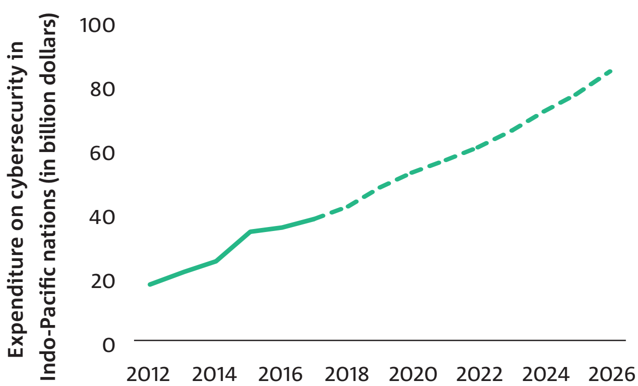



**Figure 16. Expenditure on cybersecurity in Indo-Pacific nations (in billion dollars)**

Data source: AustCyber[149]

*Note: Actual values are denoted by a solid line and predicted values are denoted by a dashed line.*

**Queensland is a critical player in growing Australia's cybersecurity industry.** The Australian Government has committed more than $230 million from 2016 to 2020 to enhance Australia's cybersecurity capabilities and support the delivery of new initiatives.[153] In collaboration with the Western Australian Government, the Australian Government has also established the Cybersecurity CRC, which is jointly funded by federal and state government, industry, university and research participants, including QUT.[154] As part of the Australian Government's Cybersecurity Strategy, Brisbane was the first to launch a Joint Cyber Research Centre in February 2017[155] with others now established in Melbourne, Sydney, Perth and Adelaide. Queensland's role in growing Australia's cybersecurity capabilities provides strong foundations for its local industry.

**Queensland is positioned at the frontline for defence in Australia.** Queensland is home to the largest Royal Australian Air Force (RAAF) base in Australia[156] and the defence industry generates approximately $6.3 billion in state revenue (2015–16 figures).[14] Queensland's defence industry is supported by the state's existing research strengths in advanced materials and manufacturing, along with its capabilities in robotics and autonomous systems.[14] These strengths are reflected in the $5.2 billion LAND 400 Phase 2 contract, which will see Rheinmetall Defence Australia base its Australia–New Zealand headquarters and Military Vehicle Centre of Excellence in South East Queensland.[14] Moreover, the national headquarters for the first Defence CRC for Trusted Autonomous Systems based in Queensland will aid the development of robotics and autonomous systems for defence and other Queensland industries.[14]

**Queensland's existing base of cybersecurity firms could grow in response to other emerging industries.** Queensland is home to cybersecurity companies such as Arkose Labs – which has developed engaging tools that can distinguish human users from spammers – and CyberMetrix – which helps organisations identify, understand and mitigate their cybersecurity risks. Emerging cyber-physical security firms will likely be responsive to growing cybersecurity needs of other knowledge-intensive and technology-intensive industries, such as healthcare and medical technologies, mining, advanced manufacturing and agriculture.[145] According to AustCyber, Australia has unique competitive advantages in (i) software, (ii) services in the protection stack (i.e. services that protect organisational networks, applications and endpoints), and (iii) services in underlying processes (i.e. services that increase awareness of cybersecurity risks in organisations).[149]

## OPPORTUNITIES FOR GROWING CYBER-PHYSICAL SECURITY

### Research

One approach to growing Queensland's research capabilities could be to focus on key applications that align closely with emerging industry cyber-physical security needs. This is the approach taken by the Joint Cybersecurity Centre based in Western Australia, where cybersecurity of mining companies is a key research focus.[157] Other institutes, such as the Australian National University's Cyber Institute, have chosen to focus on research into multidisciplinary and cross-sector cyber challenges.[158] Limiting research efforts to a discrete set of research areas (e.g. cyber-physical security for robotics and autonomous systems in health, agriculture or mining) could help focus efforts to grow Queensland's cyber-physical security industry and attract government research funding.[149]

Distributed ledger technologies were also highlighted by stakeholders as another key area in which Queensland could grow its research capabilities. This research could explore the feasibility of different applications for distributed ledger technologies in existing and emerging knowledge-intensive industries and the necessary cybersecurity measures needed to protect the information and data stored on these systems. However, stakeholders consulted as part of this project emphasised the key role of the social sciences in growing Queensland's cyber-physical security research capabilities too. Understanding the intersection between human behaviour and cybersecurity and the ethics underpinning data and technology use will be important in developing supporting services that help organisations become more cyber-savvy.

Cybersecurity firms also struggle to identify clear export pathways for their services. Surveys of Australian cybersecurity services companies have found that just 12 per cent have customers outside Australia.[149] Although access to quality digital infrastructure likely plays a role here, the challenges around cybersecurity export markets are also influenced by the types of services being provided and the local regulatory requirements of recipient countries.[149] For example, education services have a clear export market and fewer barriers than other services such as data analytics or compliance support services.[149] There will be a role for the research sector, in collaboration with industry and government, to help define and develop exportable cybersecurity products and services.

## Infrastructure

Access to quality and reliable digital infrastructure and connectivity will be a necessary requirement for Queensland's emerging cyber-physical security industry. At present, Australia places poorly relative to other countries on measures of broadband connectivity: according to the Ookla Speedtest Global Index, Australia ranks in 62nd position worldwide on measures of fixed broadband connection speed in April 2019 – a decline of three places from the previous year.[159] Moreover, according to the Australian Digital Inclusion Index – a 100-point measure that covers internet access, affordability and digital literacy skills – Queensland sits below the national average for digital inclusion (58.9 versus 60.2 points, respectively) and the gap between Brisbane and rural Queensland has grown from 5.8 to 8.6 points from 2017 to 2018.[160]

Digital infrastructure challenges could impact the capacity of Queensland cyber-physical security firms to provide products and services. Moreover, these infrastructure shortcomings could limit uptake of digital technologies in other emerging knowledge-intensive industries and domestic demand for cyber-physical security solutions, particularly in sectors with a strong regional basis. There could be a role for innovations emerging in other industries (e.g. the space sector) to provide remote monitoring and communication capabilities in facilitating the creation of demand for new cyber-physical security products and services.

## Education and the workforce

Queensland has a relatively small information media and technology services workforce, accounting for 1.4 per cent of the workforce (2018 figure)[86] and 4.8 per cent of completed higher education degrees (2017 figure).[27] Access to skilled professionals could hinder Queensland's capacity to grow its cyber-physical security industry. AustCyber estimates that the Australian cybersecurity workforce could grow to 26,500 workers by 2026 under business-as-usual or 31,600 workers if there are modest improvements in Australia's areas of competitive advantage.[149] However, the cybersecurity industry already faces skill shortages, as evidenced by higher wage premiums, unfilled vacancies and long recruitment times associated with cybersecurity occupations relative to other ICT occupations.[149]

The cyber-physical security industry might be able to meet its growing workforce requirements by sourcing workers currently employed in other industries and defining career transition pathways for these workers. Some cybersecurity roles do not require specialised technical backgrounds and draw upon multidisciplinary skills from law, communications and psychology.[149] The education sector has already begun to respond to this challenge with various universities and TAFE providers across Australia providing courses and programs in cybersecurity.[149] It will be important to align education courses with industry skill needs, ensuring they provide a blend of technical and social skills (e.g. systemic thinking, teamwork and communication skills).[161]The homogeneous nature of the cybersecurity workforce could present another challenge for this emerging industry. Women and older people are generally underrepresented in Australia's ICT workforce, making up 28 per cent and 12 per cent of the ICT workforce, respectively (versus 44 per cent and 16 per cent in other professional industries).[162] This lack of diversity could impact the types of cyber-physical security products and services that are developed. For example, research suggests that AI systems can be biased if they are designed by a very narrow subset of the population that does not reflect the broader society.[163] Increasing diversity in the cyber-physical security workforce will be an area of attention in growing this industry.

| QUEENSLAND'S CYBER-PHYSICAL SECURITY INDUSTRY IN A GLANCE | |
|---|---|
| **Supply drivers** | • Growing research capabilities and industry collaboration in robotics and autonomous systems and an emerging base of cybersecurity firms<br>• Supporting research and industry connections to Australia's growing cybersecurity industry<br>• Strong foundations in the local and national defence industry |
| **Demand drivers** | • Increasing connectivity leading to increased demand for protection against cybersecurity attacks<br>• Growing global expenditure on cybersecurity solutions, particularly in the Indo-Pacific region |
| **Research opportunities** | • Focusing future research efforts on cyber-physical security solutions that are relevant for Queensland's industries<br>• Balancing research focus on specialised technical domains with the need for research into cyber-secure behaviours and ethics of data and technology use<br>• Importance of cross-sector collaborations in R&D in developing exportable cyber-physical security solutions |
| **Infrastructure opportunities** | • Addressing digital connectivity gaps, particularly in regional Queensland, to remain globally competitive<br>• Drawing upon innovations from other emerging industries (e.g. the space sector) to address infrastructure gaps |
| **Education and the workforce opportunities** | • Addressing existing shortages in skilled professionals for Australia's growing cybersecurity workforce<br>• Sourcing labour supply from other disciplines like law, communications and psychology<br>• Ensuring the industry responds to broader population needs by encouraging workforce diversity |

## Smart mining, exploration and extraction

The smart mining, exploration and extraction industry combines Queensland's strengths in the resources and mining equipment, technology and services (METS) sectors with enhanced digital technologies to achieve greater efficiency, safety, productivity and sustainability. This industry is driven by the growing pressures placed on extractive industries due to declining productivity and ore grade quality, as well as rising commodity price uncertainty and community and environmental concerns around mining impacts. Companies in this industry use machine learning, sensor, drone and platform technologies and advanced automation to provide supporting services from exploration and discovery to remediation and closure.[146]

Smart mining, exploration and extraction firms will benefit from the outputs of other knowledge-intensive industries such as the next generation aerospace and space technologies and cyber-physical security sectors in running, managing and protecting remote operations. The whole mining value chain will become more knowledge-intensive through greater use of end-to-end optimisation tools, smart warehousing, predictive analytics and real-time sensors for drilling and exploration activities. Some companies may specialise in the design and manufacturing of advanced automation systems, including unmanned aerial vehicles (UAVs) and robotics to improve worker safety. Other companies are focused on monitoring and evaluating the environmental, social and community impacts of mines and end-of-life mine rehabilitation services.

The current firm and employment trajectories associated with this industry are shown in Figure 17 (see Appendix B for industry categories associated with this industry definition). Based on the most recent data available for this calculation, it is estimated that approximately 47.3 per cent of the smart mining, exploration and extraction workforce in 2016 were knowledge workers.

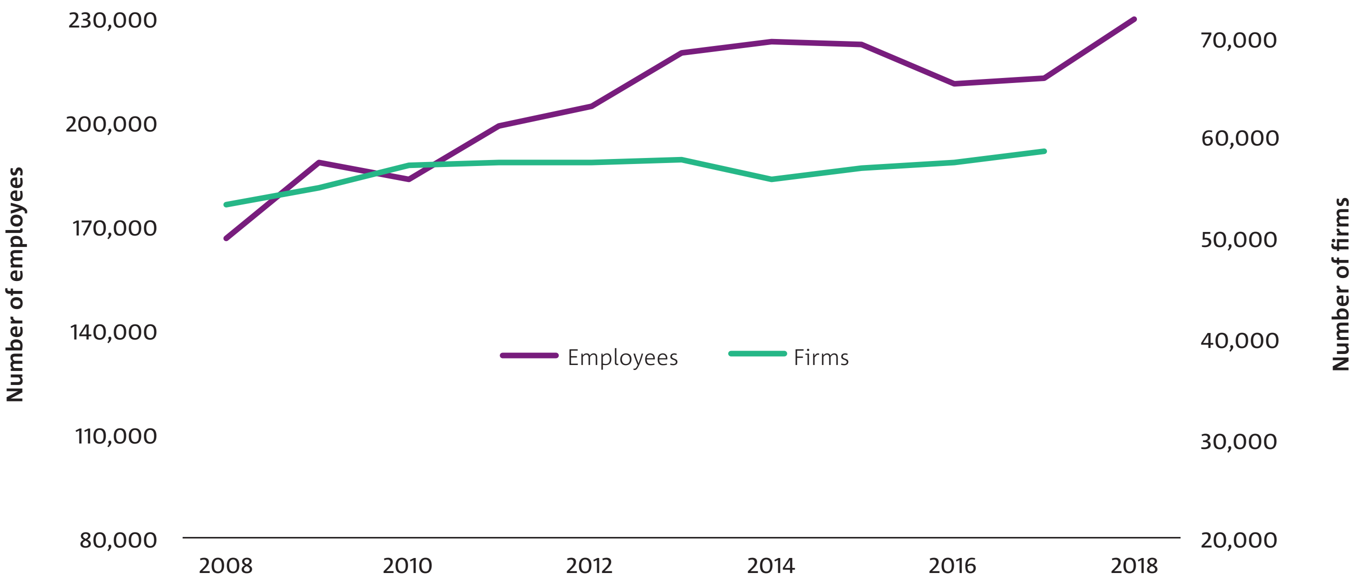



**Figure 17. Number of employees (left axis) and firms (right axis) in the smart mining, exploration and extraction sector in Queensland**

Data source: Australian Bureau of Statistics[86,87]

*Note: Employment and firm estimates are based on historical data aggregated across a subset of ANZSIC industry categorises that are assumed to correspond to this industry (see Appendix B for more details). These ANZSIC codes cover the emerging niche industry as well as the broader industry structure. Employment estimates covers both knowledge and non-knowledge workers, reflecting the predicted size of the entire workforce of the emerging industry and its associated industry sub-sectors.*

## WHY QUEENSLAND?

**Queensland has strong foundations in the resources and METS sectors.** Queensland is home to an abundant supply of natural resources and has a strong mining sector, accounting for 11.8 per cent of gross state product and employing 61,000 people in Queensland in 2017–18.[164,165] Queensland also has world-class programs and expertise in mining and mineral engineering, with UQ placed first out of 100 universities worldwide in 2018, according to the ShanghaiRanking Global Ranking of Academic Subjects.[166] These strengths have given rise to a growing METS sector in Queensland, which currently consists of more than 800 companies.[7] These firms specialise in a diverse range of activities, from large-scale applications of imported technologies to the design and development of boutique technology solutions.[167]

**Declining ore grade quality and price volatility signal future uncertainties.** The quality of ore grades in Australia are declining.[168] While technological advances may improve productivity in the short term, low-grade ores are resource-intensive to mine and rehabilitation technology may not keep pace with modern mining.[168] The value of metallic and non-metallic minerals are already declining, down 11.6 per cent from 2015–17.[169] Commodity price volatility is another concern. In 2017, the Reserve Bank of Australia warned of increasing volatility around mineral exports due to uncertainty in the Chinese market[170] and in early 2019, China's northern port of Dailan banned Australian coal imports.[171] These challenges signal the need for continued innovation and diversification to make Queensland's resources industry more resilient.

**Queensland's resources sector is becoming increasingly knowledge-intensive.** The mining sector makes up the largest share of business expenditure on R&D in Queensland (see Figure 18). Queensland is also home to a concentration of resources-related research and commercialisation institutes, including UQ's Sustainable Minerals Institute, Griffith University's Environmental Futures Research Institute and Mining3 (a collaboration between CRCMining and the CSIRO Mineral Resources group).[7] There are a number of industry–research partnerships (e.g. between UQ and Newcrest Mining[172]) and research collaborations (e.g. between the Sustainable Minerals Institute and the University of Tasmania, CSIRO, Imperial College London, the University of Toronto, and other partners[173]). These collaborations strengthen the competitive advantage of Queensland's resources sector, combining operational expertise with deep science.

**Australia's mining operations are becoming safer through automated systems.** Autonomous vehicles have been deployed in Queensland[174] and Western Australia,[175] providing significant safety and productivity benefits,[176] and BHP Billiton plans to use autonomous vessels for dry bulk shipping.[177] Other remote innovations include Hovermap, developed by Queensland-based Emesent, which uses drones to collect data in dangerous underground mine sites;[178] ReMoTe, developed by Data61's Robotics and Autonomous Systems Group, which is a hands-free, wearable technology that connects remote experts with mining site operators to provide real-time assistance;[179] and new robotic vision technology for autonomous underground mining vehicles developed at QUT.[180] Brisbane-based Interlate is also developing data systems that provide companies with real-time insights that utilise the wealth of data generated on mining sites.[181]

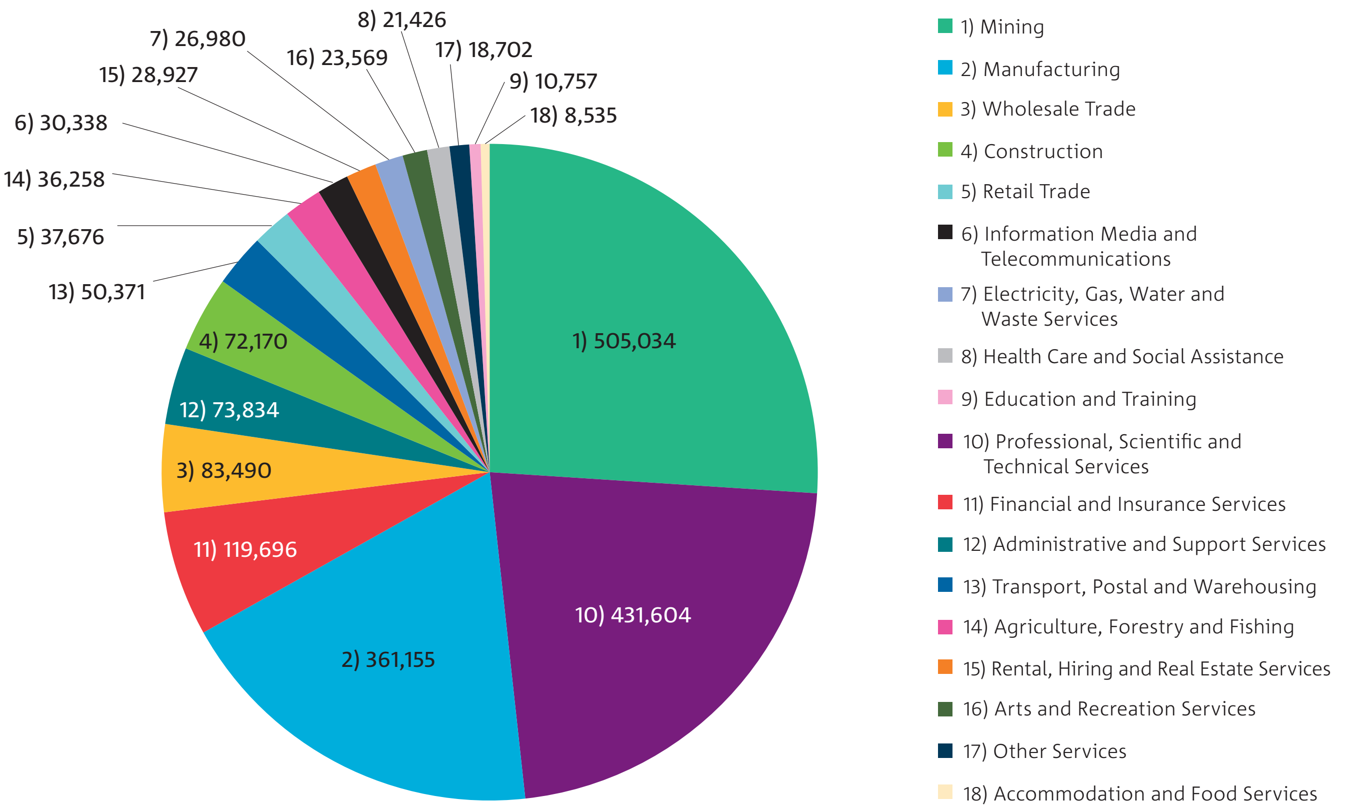



**Figure 18. Business expenditure on research and development in Queensland by industry (in thousand dollars), 2015–16**

Data source: Australian Bureau of Statistics[25]

**Sustainable mining practices have become a priority for mining companies.** A 'social license to operate' is the top risk facing the mining and metals sector[182] and public surveys have found that trust in mining companies is low.[183] In response, companies are implementing mine closure and remediation plans to ensure projects are sustainable across the whole lifecycle.[146] While Queensland's abandoned coal mines might be too shallow for carbon storage,[184] they could be used for further mineral extraction via secondary mining, industrial archaeological heritage conservation and tourism, biodiversity enhancement and contamination research.[185] The research expertise housed at UQ's Centre for Mined Land Rehabilitation could inform future efforts to improve mine rehabilitation outcomes,[186] as could Indigenous knowledge around environment and land management practices.[187,188]

**Demand for rare earth elements is growing with technology demand.** New technologies developed within the clean energy, military and consumer electronics sectors require rare earth elements[189] and average annual growth in demand for rare earth elements is predicted to range between 3.7 per cent and 8.6 per cent from 2010–35.[190] Globally, rare earth element production is concentrated in China and Australia.[191] Queensland has stores of several rare earth elements, including rhenium, scandium, tin, tungsten and graphite, some of which are very high quality.[192] Given the concern that there may be insufficient global supply to meet future demand,[190] Queensland could supply the elements needed for countries to transition to a lower carbon economy[193] and grow their emerging technology sectors.

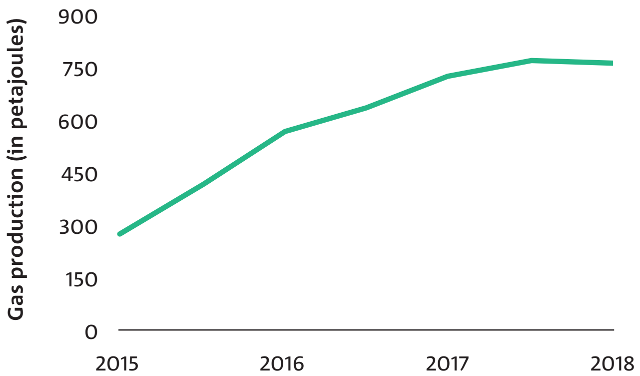



**Figure 19. Aggregate quantity of coal seam gas, condensate, crude oil, liquefied petroleum gas and natural gas produced in Queensland (in petajoules)**

Data source: Queensland Government[194]

**The research sector could support a more sustainable gas sector in Queensland.** Queensland's gas production has been generally increasing since 2015 (see Figure 19). While LNG emits 50–60 per cent less carbon dioxide than coal,[195] gas exploration can damage local ecosystems and methane (which is more effective at trapping heat than carbon dioxide) can be leaked during gas extraction.[195] The three LNG plants in Gladstone operated at an average of 82 per cent capacity in 2018 and it is predicted that one-third of the Queensland industry will close due to reserve shortages by 2025.[196] Gas prices are also linked to declining oil prices.[197] UQ's Centre for Coal Seam Gas – part of the national Gas Industry Social and Environmental Research Alliance – could assist the gas sector in addressing these challenges.

## OPPORTUNITIES FOR GROWING SMART MINING, EXPLORATION AND EXTRACTION

### Research

Queensland has strong capabilities in a broad range of resource-related research, but future research efforts and commercial applications will increasingly focus on the social and environmental impacts of mining activities.[7] Areas identified by stakeholders included in-situ leeching (a fluid-based extraction process for valuable metals from existing ore deposits[198]), mine remediation, and the rapid treatment of contaminated mining wastewater (e.g. for hydrogen production). Some of these areas are already being addressed by Queensland research groups (e.g. Mining3,[198] CSIRO[199] and UQ's Sustainable Minerals Institute[200]). Future resource-related research could also cover advanced digital applications in mining sites through greater use of operational data, predictive analytics and advanced automation.

The fragmented and transactional nature of research collaborations between universities, research institutes and industry has been identified as a challenge for Queensland's – and indeed Australia's – resources and METS sectors.[7,146] A 2015 survey of METS companies found that just 42 per cent of them collaborated with universities on R&D.[201] This can hinder the translation of mining research into commercial applications and the alignment of industry needs with research projects and educational courses.[146] Stakeholders also identified low levels of international collaboration and a disconnect between mining-related research and state priorities as other limiting factors – shortcomings which have been addressed in other states (e.g. through the Minerals Research Institute of Western Australia).[202]

## Infrastructure

Stakeholders consulted as part of this research noted that a significant proportion of mining infrastructure such as ports and rail, is privately owned, which can limit access and employment opportunities for other smaller companies. Given the high costs associated with these infrastructure developments and the potential for duplication, there could be value in adopting dual-use models for mining infrastructure, as has been done with the railway network in Central Queensland's coal-mining region.[203] For example, LNG pipelines can also be used to transport hydrogen,[204] supporting growth in the sustainable energy industry and reducing upfront infrastructure costs.

Reliable and responsive digital infrastructure will be a necessary foundation for increased knowledge intensification of Queensland's mining sites and connectivity issues in regional Queensland[160] present a barrier to this. This affects use of sensor technologies, advanced wireless communication technologies and other fixed and mobile assets.[146] There will be a role for government as well as companies in this industry and other knowledge-intensive industries (e.g. next generation aerospace and space technologies and cyber-physical security) to design, develop, implement and maintain this digital infrastructure. As with physical infrastructure, mining companies could benefit from access to shared digital infrastructure, such as data platforms for analytics, to better utilise sector-wide operational data and insights.

## Education and the workforce

An industry survey reported that 82 per cent of Australian mining companies found it difficult to recruit skilled candidates for vacancies, particularly for management, professional and technical and trades positions.[205] In addition, stakeholders identified capabilities in commercialisation, risk management, supply-chain logistics and scientific literacy, as well as 'soft' skills (e.g. communication and stakeholder engagement) as critical in addressing social and environmental impacts of the sector and improving translation of research outcomes. These skill shortages could be addressed through targeted reskilling programs for existing workers in the mining sector and other industries, as well as embedding these skills in current VET and university courses and programs for emerging job seekers.

But addressing workforce challenges extends beyond education and training. Public perceptions of the resources sector reflect a traditional and outdated view of the industry and this can limit future recruitment and retainment. A survey of Australian senior high school and undergraduate university students found that 45 per cent had never thought about a career in the mining sector and 59 per cent reported no knowledge about mining careers.[206] Moreover, 35 per cent of respondents felt the mining sector was using leading-edge technology and 34 per cent identified the sector as innovative.[206] Informing the public around modern-day mining practices and the diversity of career pathways in the industry – for example, using the career vignettes developed by the Queensland Resources Council as part of their 'Oresome Resources' project[207] – will be necessary in growing the smart mining, exploration and extraction workforce.

| QUEENSLAND'S SMART MINING, EXPLORATION AND EXTRACTION INDUSTRY IN A GLANCE | |
|---|---|
| **Supply drivers** | • Strong existing research and industry expertise and international connections in a broad range of resources and METS domains<br>• New technologies and innovations enabling more remote operations, and improved productivity, safety and sustainability outcomes |
| **Demand drivers** | • Declining ore grade quality and volatility in commodity prices, signalling the need for innovation and diversification into new markets<br>• Growing social pressures for mining and extraction companies to be mindful of community and environmental impacts and their social license to operate<br>• Demand for rare earth elements needed in emerging technologies and consumer devices |
| **Research opportunities** | • Strengthening research in new domains, such as in-situ leeching, mine remediation and wastewater treatment<br>• Exploring digital applications in mining sites to increase the utilisation of operational data and automated processes<br>• Moving beyond transactional cross-sector collaborations and aligning research with broader state priorities |
| **Infrastructure opportunities** | • Adopting dual-use models for mining infrastructure to support needs of smaller companies and other industries<br>• Providing access to reliable digital infrastructure as a necessary prerequisite for remote mining operations |
| **Education and the workforce opportunities** | • Equipping workers with 'soft' skills that are necessary in managing the social and environmental impacts of the sector<br>• Shifting outdated public perceptions around mining careers to reflect modern and innovative mining practices |

## Personalised and preventative healthcare

The personalised and preventative healthcare industry could reduce pressure on existing hospital and health services and offer efficient, customised and proactive healthcare services for patients and health professionals. An ageing population and rising healthcare expenditure have created demand for innovative healthcare approaches both within Australia and for many countries abroad. Present-day consumers also have greater access to information around their health choices and can be more proactive in managing their own health. Queensland's strengths in biotechnology, biomedical research and advanced manufacturing places it in a strong position to grow its personalised and preventative healthcare industry.

This industry consists of firms ranging from innovative start-ups to large-scale pharmaceutical companies. These firms offer products and services such as wearables and in-home monitoring devices; bionics and implants; medical diagnostic platforms and decision support for health professionals; and the design, production, preclinical and clinical testing and manufacturing of high-value pharmaceuticals, vaccines and 'nutraceuticals'. Queensland has a growing network of world-leading pharmaceutical companies, medical research and translation institutes, clinical trial facilities and medical technology start-ups. The state could leverage these strengths and provide social and economic benefits for domestic and international markets.

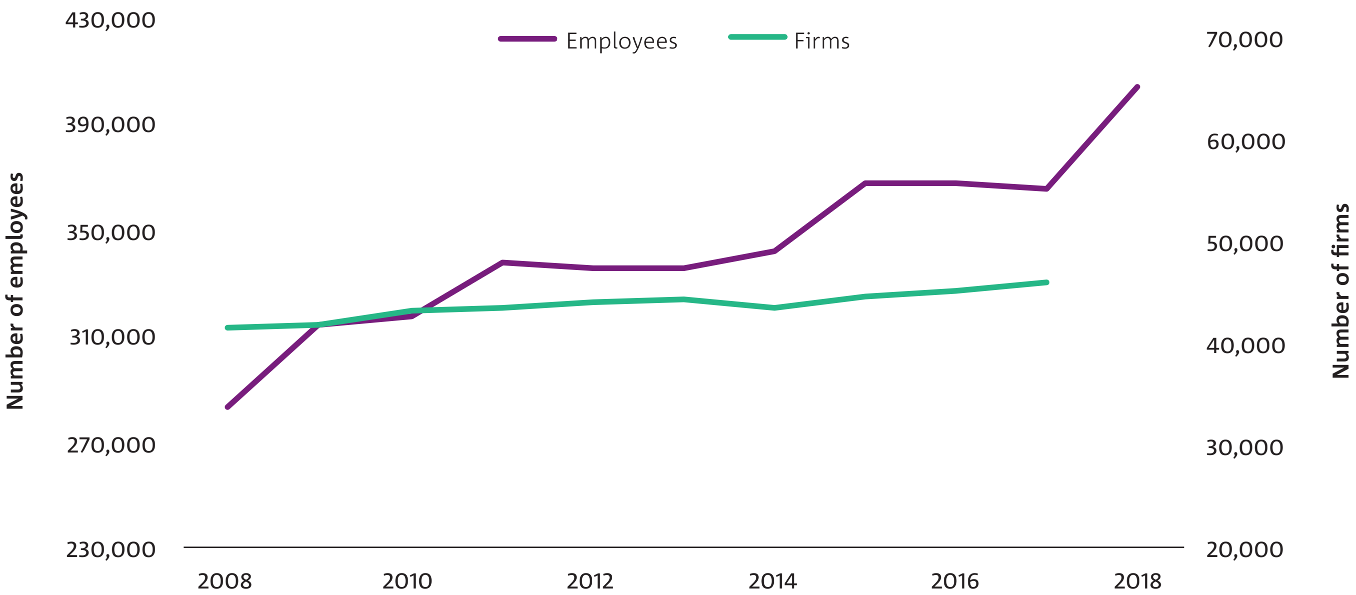



**Figure 20. Number of employees (left axis) and firms (right axis) in the personalised and preventative healthcare sector in Queensland**

Data source: Australian Bureau of Statistics[86,87]

*Note: Employment and firm estimates are based on historical data aggregated across a subset of ANZSIC industry categorises that are assumed to correspond to this industry (see Appendix B for more details). These ANZSIC codes cover the emerging niche industry as well as the broader industry structure. Employment estimates covers both knowledge and non-knowledge workers, reflecting the predicted size of the entire workforce of the emerging industry and its associated industry sub-sectors.*

The current firm and employment trajectories associated with this industry are shown in Figure 20 (see Appendix B for industry categories associated with this industry definition). Based on the most recent data available for this calculation, it is estimated that approximately 58.3 per cent of the personalised and preventative healthcare workforce in 2016 were knowledge workers.

## WHY QUEENSLAND?

**The cost of healthcare continues to rise.** Healthcare accounted for 36 per cent of Queensland Government expenditure in 2017–18 and it has grown at a faster rate from 2004–15 than the national average over the past decade (4.8 versus 4.2 per cent, respectively).[208] Similar trends are observed across other economies (see Figure 21). These rising costs are driven by ageing populations, with 19 per cent of the Queensland population expected to be aged 65 years or older by 2030.[209] The number of hospital admissions in Queensland grew by 2.3 million from 2005–06 to 2015–16 and these are projected to reach 3.7 million per year by 2026 – half of which will be aged 65 years or older.[208] New approaches to healthcare will be needed in the future to effectively manage domestic and international healthcare sectors.

**Advances in technology are enabling personalised medicine.** Personalised medicine uses individual clinical, genetic, genomic and environmental information to guide medical decision making.[210] The cost associated with genome sequencing has dropped dramatically in recent years (see Figure 22), contributing to a major shift in patient treatment and care.[210] 3D printing also provides opportunities to generate replacement tissues and organs that are customised for patients – innovations that QUT's Herston Institute for Biofabrication are pioneering in Queensland.[211] Further advances in personalised medicine are supported by Queensland's world-leading genomics research, including the Australian Translational Genomics Centre – one of the largest genomic diagnostic service programs in Australasia[212] – the UQ Centre for Clinical Genomics – the largest genomics facility in Australasia[213] – and the collaboration between Griffith University, James Cook University (JCU), CSIRO and BGI Group (the world's largest genomic organisation).[214]


**Figure 21. Healthcare expenditure as percentage of GDP in East Asia and the Pacific, across OECD (Organisation for Economic Co-operation and Development) countries and in Australia, 2005–2015**

Data source: World Bank[215] and OECD[216]

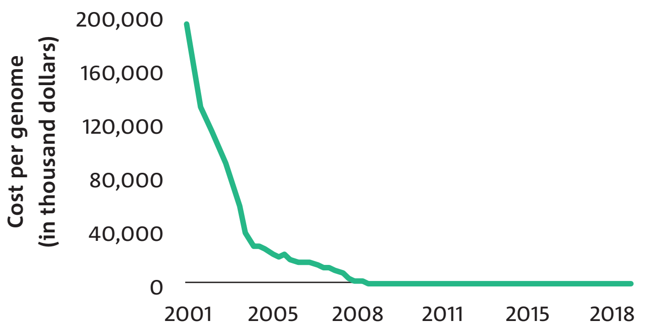



**Figure 22. Cost of sequencing a human-sized genome, in thousand dollars**

Data source: National Human Genome Research Institute[217]

**Queensland has a portfolio of successful biomedical knowledge clusters.** Queensland is home to world-class health and biomedical precincts including the Herston Health Precinct, the Translational Research Institute (TRI) and the broader Princess Alexandra Health Precinct, the Gold Coast Health and Knowledge Precinct, Health City Springfield Central and the Sunshine Coast Health Precinct.[10] These institutes have leading capabilities in cancer immunotherapy, biomarker and target discovery, human genetics, tropical medicine, biopharmaceutical manufacturing and clinical trials.[218,219] The planned development of Boggo Road Station as part of the Cross River Rail project presents opportunities to create a biomedical 'super precinct',[220] which could assist in attracting experts and promoting world-class research and innovation.

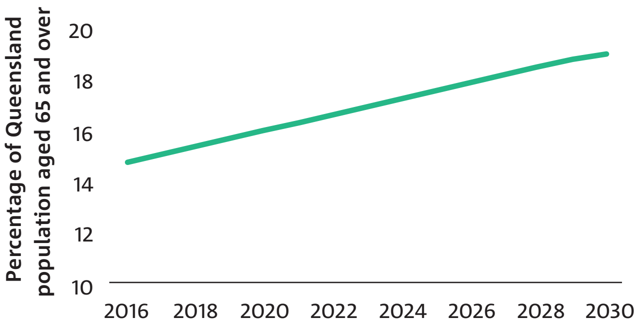



**Figure 23. Projected percentage of the Queensland population aged 65 years and older (medium series)**

Data source: Queensland Government Statistician's Office[209]

**An ageing population increases demand for pharmaceuticals and medical technologies**. The share of Queensland's population aged 65 years or older is increasing (see Figure 23), as is the incidence of chronic diseases – up 30.8 per cent from 2007–08 to 2017–18.[221] These factors will drive future demand for pharmaceuticals and medical technology solutions from consumers, governments and healthcare providers, both to reduce the strain on the public healthcare system and to provide higher quality care and better health outcomes.[222] These trends will be key drivers of future demand in the personalised and preventative healthcare industry.

**Queensland has research strengths in infectious disease.** Epidemic-prone diseases[223] and antimicrobial resistance (i.e. the resistance of bacteria, parasites, viruses and fungi to antimicrobial drugs)[224] are emerging public health threats. Queensland is home to significant clinical expertise on infectious diseases, vaccines and other solutions. For example, the Australian Infectious Diseases Research Centre conducts research into viral, parasite and vector-borne diseases, microbial infections and antimicrobial resistance[225] and recently uncovered mutations of the Zika virus that could fast-track research into the virus and vaccines.[226] Researchers at the University of the Sunshine Coast (USC) have also developed rapid test kits for tropical diseases, with planned applications for the Zika virus,[227] and Griffith University has partnered with various German research institutes to explore new anti-infective therapies.[228]

**Queensland has unique strengths in tropical disease research and applications.** Queensland's access to tropical biodiversity, dedicated tropical health infrastructure and proximity to relevant markets gives it a competitive advantage in the field of tropical health.[10] In 2009, scientists from UQ made a breakthrough in limiting the lifespan of dengue fever-spreading mosquitos[229] and in 2013, JCU researchers developed a new diagnostic test for the tropical disease melioidosis.[230] Paragen Bio – a spinoff from JCU's Australian Institute of Tropical Health and Medicine – applies its tropical disease expertise to develop new treatments for autoimmune disease.[231] As climate change sees tropical disease become a growing threat globally,[232] demand for tropical disease solutions will likely grow.

**Queensland has a strong medical technology sector with room to expand.** A range of medical device and technology companies have grown out of Queensland's strong healthcare and biomedical research sectors, including Factor Therapeutics, Melcare Biomedical, ImpediMed, Ellume, Vaxxas and Magnetica.[233] Queensland is home to Cook Medical – the largest privately held medical device manufacturing company in the world – which specialises in custom-made minimally invasive devices.[233] International medical technology and biopharmaceutical companies such as LuinaBio and Patheon Biologics are also based in Queensland. There are opportunities to further develop Queensland's reputation as a biomedical research and innovation hub in Australia and strengthen its medical technology exports.

**Queensland hospitals are becoming increasingly digital.** Brisbane's Princess Alexandra Hospital was the first large-scale digital hospital in Australia[234] and its introduction of electronic medical records has reduced the length of patient stays, pathology turnaround times and the number of emergency re-admissions within 28 days of discharge.[235] The Wesley Hospital has also introduced two da Vinci surgical robotic systems for training purposes and was accredited as Australia's first Centre of Excellence in Robotic Surgery.[236] Other hospitals such as the Royal Brisbane and Women's Hospital[237] and Greenslopes Private Hospital[238] have also adopted surgical robots. There are opportunities for Queensland to become a leader in education and training for robotic surgery[237] and other digital health initiatives.

**Queensland is a leading adopter of telehealth in Australia.** Queensland has a highly dispersed population[239,240] and the majority of health professionals are based in densely populated areas.[241] Telehealth can be a more cost-efficient way of treating patients, with a one-year trial of home telemonitoring systems in Australia finding a 46.3 per cent reduction in the rate of Medicare Benefits Scheme expenditure, saving each patient $611 on average.[242] Queensland has been a strong adopter of telehealth, accounting for the largest share of telehealth services in Australia (see Figure 24). UQ's Centre of Research Excellence in Telehealth[243] and TRI[244] have active telehealth research programs and this research could inform the design of healthcare services that cater for regional and remote populations.

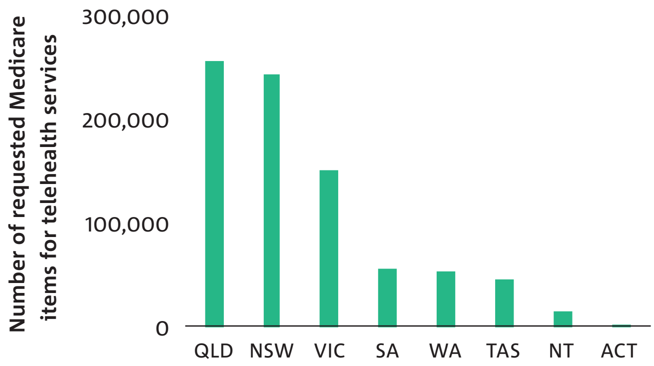



**Figure 24. Number of requested Medicare items for telehealth services in Australia, by state and territory, 2008–18**

Data source: Department of Health[245]

**Demand for supplementary health products is growing.** Domestic and global demand for nutraceuticals (i.e. vitamins or mineral supplements) and other high-value nutrition products is growing. A 2017 study of Australian consumers found that two-thirds of respondents had used some form of complementary and alternative medicines in the previous 12 months.[246] The Australian complementary medicines industry grew by $2 billion over the past five years (valued at $4.9 billion in 2018).[247] The Asia-Pacific region currently accounts for the largest share of the global nutraceutical market and this is expected to grow at a compound annual growth rate of 6.4 per cent from 2019–27.[248] Queensland's proximity to Asia, existing base of world-leading pharmaceutical companies, and strengths in genomics present opportunities to meet this growing demand.

**Queensland could grow its strengths in synthetic biology.** Synthetic biology involves the application of engineering principles to biology, enabling biological systems or their components to be built to design.[249] For instance, in the realm of healthcare and medicine, synthetic biology can be used for diagnostics, therapeutics and 'theranostics' (i.e. diagnostics linked directly to therapeutic outcomes), particularly for human cancer immunotherapy.[249] UQ has the largest number of synthetic biology publications of any Australian university and hosts one of two nodes of the National Biologics Facility.[249] UQ plans to partner with CSIRO to build a world-class synthetic biology research program at the AIBN[250] – a move that would expand Queensland's research strengths in synthetic biology in healthcare and beyond.

## OPPORTUNITIES FOR GROWING PERSONALISED AND PREVENTATIVE HEALTHCARE

### Research

Although Queensland's biomedical research sector has diverse and world-recognised technical and scientific expertise, its ability to translate research into commercial outcomes remains a challenge.[10] Australia represents 3 per cent of the world's biomedical research[222] but only about 1 per cent of global pharmaceutical and medical device sales.[10] Queensland's biomedical sector also performed poorly in recent national funding rounds, gaining 8 per cent of the Medical Research Future Fund grants awarded in 2019.[251] Research has suggested that funding in Queensland's health and biomedical sector has been ad hoc and future commercialisation efforts would benefit from more focused research translation activities and stronger linkages between research discoveries and clinical applications.[252]

A lack of collaboration between clinicians, industry and researchers – both domestically and internationally – was identified as a barrier impacting growth in the sector too. Greater connectivity across the sector could increase the potential for cross-disciplinary discoveries and innovations and improve commercialisation pathways.[10] Cook Medical Australia's Asia-Pacific Commercialisation and Development Centre combines access to world-class facilities, equipment and knowledge with commercialisation expertise and is designed to help innovators develop exportable medical devices.[10] TRI is also working to improve collaboration and translation of research between hospital and health services and universities and aligning objectives for clinicians and researchers.

### Infrastructure

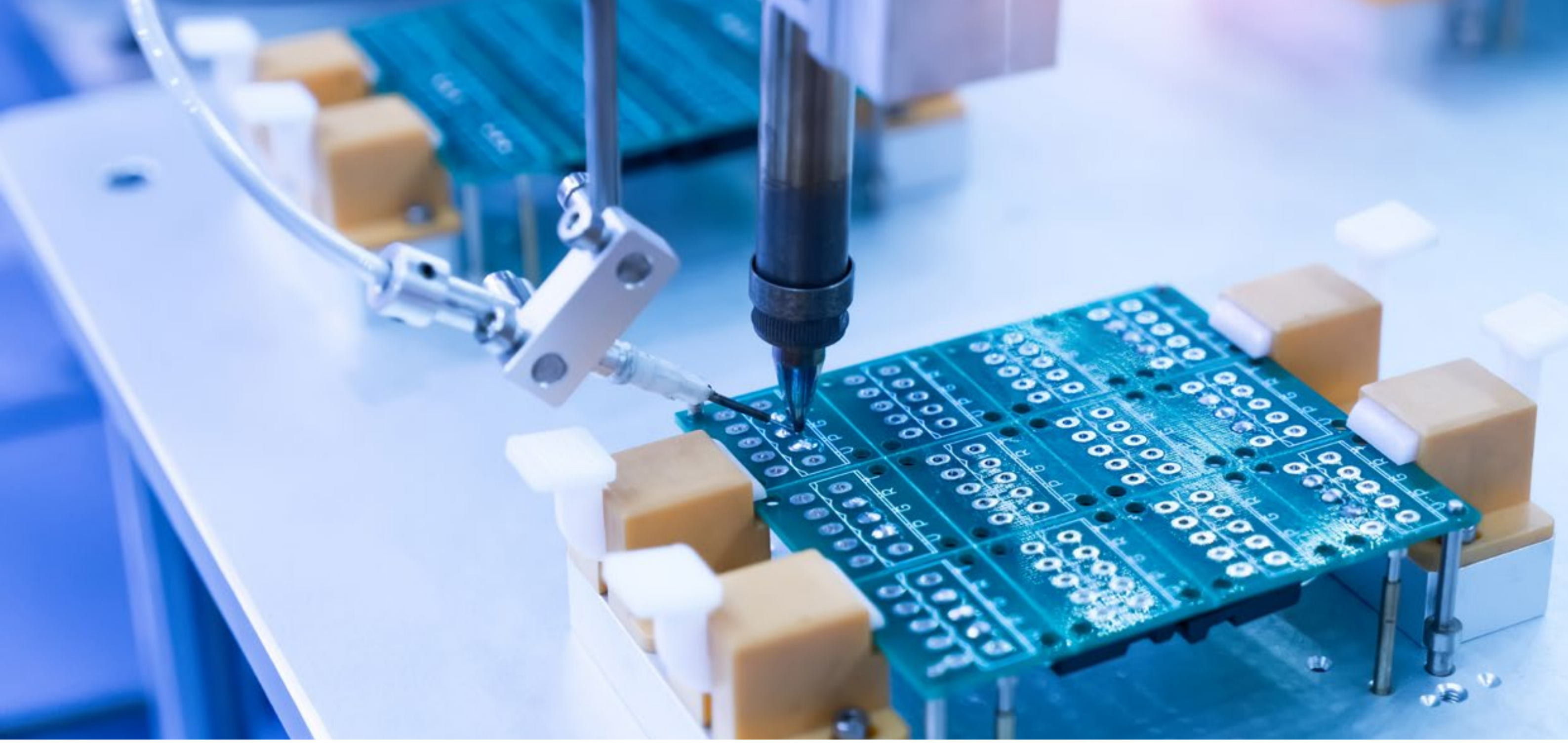
Although Queensland's biomedical infrastructure is a drawcard for international collaborators and investors,[10] stakeholders consulted as part of this research noted that the lack of coordination across institutes can lead to duplicated and underutilised assets. Addressing the aforementioned collaboration challenges could improve sharing of infrastructure and use of research funding. There is a key opportunity for state and federal governments in incentivising collaboration and shared use of biomedical infrastructure, for example, through the prioritisation of research grants that reflect cross-institutional or cross-sector collaborations. Having a clear strategy around the use of biomedical infrastructure in Queensland could also enable more effective planning and use.

Queensland lags in its integration of health data: an analysis of articles using hospital data linkages found that the majority came from Western Australia (51 per cent) and New South Wales (32 per cent), with 3.9 per cent from Queensland.[253] This represents a missed opportunity for Queensland to use health data to develop new technologies, products and services for better patient and systems-level outcomes.[253] Siloing between hospital and health services and their data management systems was identified as a factor contributing to this issue. In the future, ethical issues around ownership and use of medical data will need to be considered, particularly in areas such as privacy, consent, transparency and biases.[254] Establishing a common local or national ethical framework for health data could guide future use and applications.

### Education and the workforce

Queensland has a strong education system and health represents the second largest share of higher degree completions (16.3 per cent in 2017).[27] While this has produced a highly skilled, technical workforce, researchers and research-founded start-ups often lack the business skills needed to translate their research into a commercial product or service, or to navigate the regulatory requirements of international markets.[10] Furthermore, as the healthcare sector becomes more digital, the workforce will require new capabilities in big data analytics, advanced manufacturing, biomedical engineering and health economics.[222] Existing training programs could incorporate modules that address these skill gaps, offering shorter options for existing workers looking to expand their skillset.

| QUEENSLAND'S PERSONALISED AND PREVENTATIVE HEALTHCARE IN A GLANCE | |
|---|---|
| **Supply drivers** | • Advances in personalised medicine technologies (e.g. genome sequencing, 3D printing), enabling individualised healthcare solutions<br>• Existing base of world-leading biomedical research clusters, institutes and infrastructure and a growing number of medical technology firms<br>• Research strengths in a broad range of biomedical domains including infectious and tropical diseases, cancer immunotherapy, biomarker and target discovery, human genetics, biopharmaceutical manufacturing, synthetic biology and clinical trials |
| **Demand drivers** | • Rising healthcare expenditure and an ageing population, placing increased strain on the healthcare system<br>• Shift towards greater digitisation of the healthcare sector (e.g. electronic medical records, robotics for surgical training)<br>• Need for telehealth services to meet demands of a geographically dispersed population<br>• Growing demand for nutraceuticals and other high-value nutrition products, particularly from Asian markets |
| **Research opportunities** | • Improving commercialisation through focused research translation and linkages between discovery and application<br>• Strengthening connectivity between sectors and research fields, both domestically and internationally, to facilitate cross-disciplinary discoveries and innovations |
| **Infrastructure opportunities** | • Utilising existing assets better, potentially through funding incentives or a biomedical infrastructure strategy<br>• Breaking down silos around data management and use of health data to improve patient and systems-level outcomes<br>• Establishing a local or national ethical framework for health data to address issues around ownership and use |
| **Education and the workforce opportunities** | • Equipping the current and emerging healthcare workforce with translation and commercialisation skills<br>• Broadening workforce capabilities to cover big data, health economics, biomedical engineering and advanced manufacturing |



## Advanced materials and precision engineering

The advanced materials and precision engineering industry covers both the development of new materials and the design and production of precise, highly individualised machines, systems or parts. It supplies low-volume, high-value goods and services to other knowledge-intensive sectors such as aerospace, biomedical, energy, mining and agriculture. This industry has become increasingly focused on pre-production activities such as R&D and design, and post-production services including marketing and customer service.[255] The convergence of enabling digital technologies (e.g. sensors, 3D printing, robotics and automation)[255] and the state's advanced manufacturing research expertise has enabled Queensland's existing manufacturing base to diversify and become more knowledge-intensive.

Demand for the advanced materials and precision engineering industry is driven by the need for unique and bespoke products across a broad range of industries and the desire to preserve resources and minimise waste.[11,255] Manufacturing has been a long-standing pillar of Queensland's economy, providing a sizeable skilled manufacturing workforce, deep manufacturing expertise and a strong international reputation for quality and standards.[11] The majority of manufacturing firms are SMEs[87] and can use their size advantage to respond quickly to market demand.[255] Growth in other knowledge-intensive industries will drive future demand for high-value materials and bespoke inputs.

The current firm and employment trajectories associated with this industry are shown in Figure 25 (see Appendix B for industry categories associated with this industry definition). Based on the most recent data available for this calculation, it is estimated that approximately 63.3 per cent of the advanced materials and precision engineering workforce in 2016 were knowledge workers.

### WHY QUEENSLAND?

**Queensland is positioned well to meet the growing demand for customised products.** The traditional assembly-line model of manufacturing is becoming less relevant in a world where customers increasingly demand customised products.[255] This demand is supported by enabling technologies (e.g. 3D printing, robotics and automation, augmented and virtual reality, and sensors) and fuelled by the globalisation of supply chains and challenges around resource scarcity.[255] Queensland's SME-dominant manufacturing base grants it a comparative advantage in mass customisation and there are opportunities to expand into niche markets where quality (e.g. strength, durability and weight) is valued over quantity or cost.[255]

**Queensland's roboust manufacturing base is diversifying.** Manufacturing is Queensland's sixth-largest employing industry (7 per cent of the workforce in 2018), the largest share of which are employed in food product manufacturing (26.1 per cent) and machinery and equipment manufacturing (13.7 per cent).[11] Queensland was home to 16,406 manufacturing firms at the end of 2018, 99.8 per cent of which were SMEs.[87] The manufacturing sector accounts for the third-largest share of Queensland's business expenditure on R&D – totalling $361 million in 2015–16[25] – which, along with a supportive policy environment, has helped the sector become more knowledge-intensive. Indeed, a 2017 survey found that 57.5 per cent of Queensland manufacturing firms are already halfway or more through their transition to advanced manufacturing (see Figure 26).

**Queensland has extensive research capabilities in advanced manufacturing and materials.** Queensland has more than 70 institutes, facilities, precincts, laboratories and other organisations currently involved in advanced manufacturing and design research.[257] For example, the Australian Research Council's (ARC) Research Hub for Advanced Manufacturing of Medical Devices – a collaboration between UQ, USC, Queensland-based companies Cook Medical, QMI Solutions and Heat Treatments Australia and other interstate collaborators – develops cutting-edge technologies for custom medical devices.[258] Other research capabilities exist across UQ, QUT, Griffith University, CSIRO, University of Southern Queensland (USQ), JCU, Central Queensland University, USC and TRI.[11]

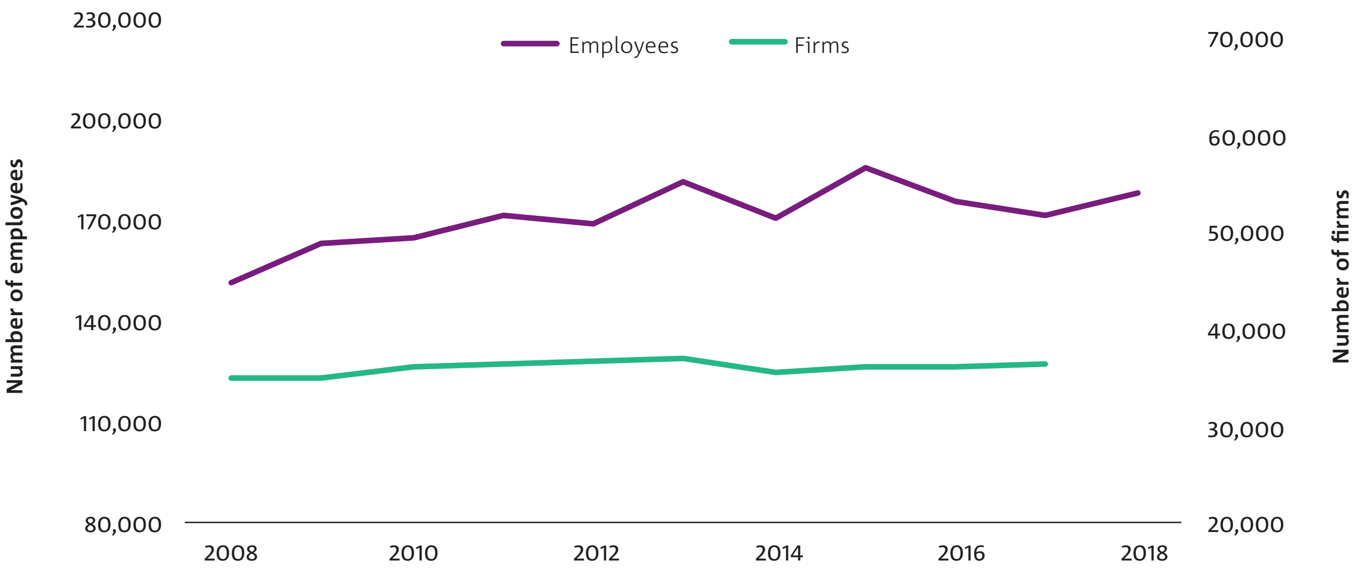



**Figure 25. Number of employees (left axis) and firms (right axis) in the advanced materials and precision engineering sector in Queensland**

Data source: Australian Bureau of Statistics[86,87]

*Note: Employment and firm estimates are based on historical data aggregated across a subset of ANZSIC industry categorises that are assumed to correspond to this industry (see Appendix B for more details). These ANZSIC codes cover the emerging niche industry as well as the broader industry structure. Employment estimates covers both knowledge and non-knowledge workers, reflecting the predicted size of the entire workforce of the emerging industry and its associated industry sub-sectors.*

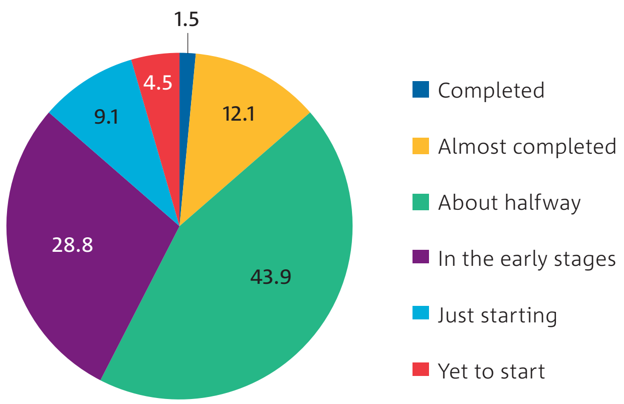



**Figure 26. Share of manufacturing firms in Queensland by progress to advanced manufacturing, 2017**

Data source: Jobs Queensland[256]

**Queensland applications of advanced manufacturing extend to the creative arts.** QUT is leading a five-year design robotics project – a partnership with Urban Arts Project (UAP), the Innovative Manufacturing CRC, RMIT University and construction company Laing O'Rourke – which uses robots to create large-scale bespoke public art pieces.[259] UAP is a world-leading supplier of products and manufacturing services for architecture, design and art projects.[260] The robotic system brings the cost of manufacturing the art pieces down significantly, meaning that they can be manufactured in Brisbane and provide local employment.[259] The project forms part of an $8 million QUT design robotics research project aimed at developing vision-enabled robots accessible for use by manufacturing SMEs.[259]

**Growth in defence and aerospace signals growth in advanced materials.** A key source of future demand for advanced manufacturing will be driven by global supply chains in aerospace and defence.[255] For instance, the defence sector will require tougher, more durable and lightweight advanced materials and compact and high-powered components that can be used in communication, navigation and management systems of flight vehicles.[261] The emerging space industry similarly requires advanced manufacturing processes that are able to recycle and repurpose materials from existing systems and develop new lightweight materials for rockets and payloads.[262] These sectors are emerging as key growth opportunities for Queensland and will fuel future demand for the advanced materials and precision manufacturing sector.

## OPPORTUNITIES FOR GROWING ADVANCED MATERIALS AND PRECISION ENGINEERING

### Research

Queensland has a wide breadth of universities and institutions focused on advanced materials and manufacturing research, however, the majority of these are focused on earlier stages of the commercialisation pathway (e.g. principles, methodologies and materials).[263] While research into product development is typically led by industry, this industry in Queensland is largely SME-based and might have limited R&D capacity. Commercialisation and innovation centres such as Cook Medical's Asia-Pacific Commercialisation and Development Centre or the Queensland node of the Australian National Fabrication Facility could help promote more industry–research and business-to-business collaborations and provide opportunities for smaller firms to pool resources and participate in technology and innovation activities.

Stakeholders felt Queensland's advanced materials and precision engineering industry could benefit from further research into composite materials (i.e. materials made from two or more materials that are physically and chemically different and which, when combined, create a material with superior structural or functional properties).[264] These materials are critical inputs into other emerging knowledge-intensive industries including aerospace, defence, agriculture and renewable energy.[11] Queensland also has access to high-quality resources which could serve as feedstock into new advanced materials (e.g. using coal in novel composite polymers to produce biodegradable plastic applications.[265])

### Infrastructure

Queensland is home to world-class infrastructure for advanced manufacturing research, but stakeholders commented that there were gaps in access to incubators and development hubs. Arc is a privately owned hub for hardware-focused start-ups that has recently been established in Brisbane, providing access to cutting-edge equipment, industry expertise and advice to assist firms in developing and commercialising products.[266] The Queensland Government also plans to invest $30 million in developing similar manufacturing hubs in regional areas, including Cairns, Townsville and Rockhampton.[11] These facilities could support advanced manufacturing SMEs, particularly at the later stages of commercialisation.

It is critical that Queensland's advanced materials and precision manufacturing firms participate in global supply chains given the small size of the domestic market.[267] This depends on access to reliable and fast internet, but as noted in response to the emerging cyber-physical security industry, Australia's fixed broadband speeds are poor relative to other global competitors.[159] Gaps in digital infrastructure including access to new enabling technologies (e.g. 3D printers, robotics and sensor technologies) could slow the transition from manufacturing to advanced manufacturing for Queensland firms.

### Education and the workforce

The closure of various car-manufacturing factories across Australia has contributed to the public perception of manufacturing as a declining industry and this can hinder its ability to attract new talent.[255] Promoting greater awareness around the diverse range of high-skilled and technology-rich careers that are available in the advanced materials and precision engineering sector will be important in attracting and retaining a skilled workforce. Stakeholders consulted as part of this research suggested that this could be achieved through greater use of industry internships and placements and education programs targeted at primary and secondary school students.

The skills bar for the advanced materials and precision engineering workforce is rising too. A recent Jobs Queensland survey found that both employers and employees in the sector see the need for enhanced capabilities in engineering trades and technical skills, critical thinking and sustainability.[256] Given the pace of technology change impacting the industry, ongoing skill and workforce development will be necessary to remain globally competitive. While 75.7 per cent of workers in Queensland's manufacturing sector would be open to participating in further education and training, only 28 per cent of employers felt the current training system was tailored to the industry's emerging skill requirements.[256]

| QUEENSLAND'S ADVANCED MATERIALS AND PRECISION ENGINEERING INDUSTRY IN A GLANCE | |
|---|---|
| **Supply drivers** | • Robust manufacturing industry that is already transitioning to advanced manufacturing<br>• Strong and diverse research capabilities in advanced manufacturing and materials science<br>• Convergence of key enabling technological advancements (e.g. sensors, 3D printing, robotics and automation) that enable automated production |
| **Demand drivers** | • Consumer demand for customised products is growing<br>• Increased industry demand for advanced materials and devices in sectors such as aerospace, biomedical, energy, mining, agriculture and the creative arts<br>• Pressures to reduce waste and optimise use of resources |
| **Research opportunities** | • Broadening the focus of advanced manufacturing R&D to cover all stages of the commercialisation pathway<br>• Drawing upon collaborative innovation centres to enable smaller firms to participate in research activities<br>• Growing research capabilities in composite materials with superior structural or functional properties |
| **Infrastructure opportunities** | • Improving access to incubators and development hubs in regional and metropolitan areas to support commercialisation activities of smaller firms<br>• Enabling firms to transition to advanced manufacturing and participate in global supply chains through good digital connectivity and access to enabling technologies |
| **Education and the workforce opportunities** | • Using industry placements and targeted school programs to shift public perceptions around the industry as declining<br>• Aligning current industry skill needs with education and training to ensure a globally competitive workforce |

## Next generation aerospace and space technologies

The next generation aerospace and space technologies industry covers the design, development, testing, surveillance and maintenance of flight vehicles, including UAVs (also known as drones or remotely piloted aircraft systems), rockets and missiles, and spacecraft (e.g. satellites).[12] Firms in this industry are also involved in the design, development and implementation of space-enabled services such as data analytics, geospatial mapping, Earth observation and remote communications provided by satellites and other space systems. Niche markets may emerge in areas such as UAV testing and applications, high-value customised maintenance, repair and overhaul services, and applied hands-on education and training programs.[12]

Queensland's natural geography is well suited for a range of aerospace- and space-related launch activities and ground systems.[268] It also has an existing base of aerospace, space and aviation contractors, businesses, research groups and industry–research collaborations. Emerging knowledge-intensive industries will benefit from the products and services developed by this industry, for example, remote-guidance systems for drones and autonomous vehicles or satellites for communications in remote areas. Equally, the next generation aerospace and space technologies industry will benefit from advanced materials and products developed in other emerging industries.

The current firm and employment trajectories associated with this industry are shown in Figure 27 (see Appendix B for industry categories associated with this industry definition). Based on the most recent data available for this calculation, it is estimated that approximately 66.0 per cent of the next generation aerospace and space technologies workforce in 2016 were knowledge workers.

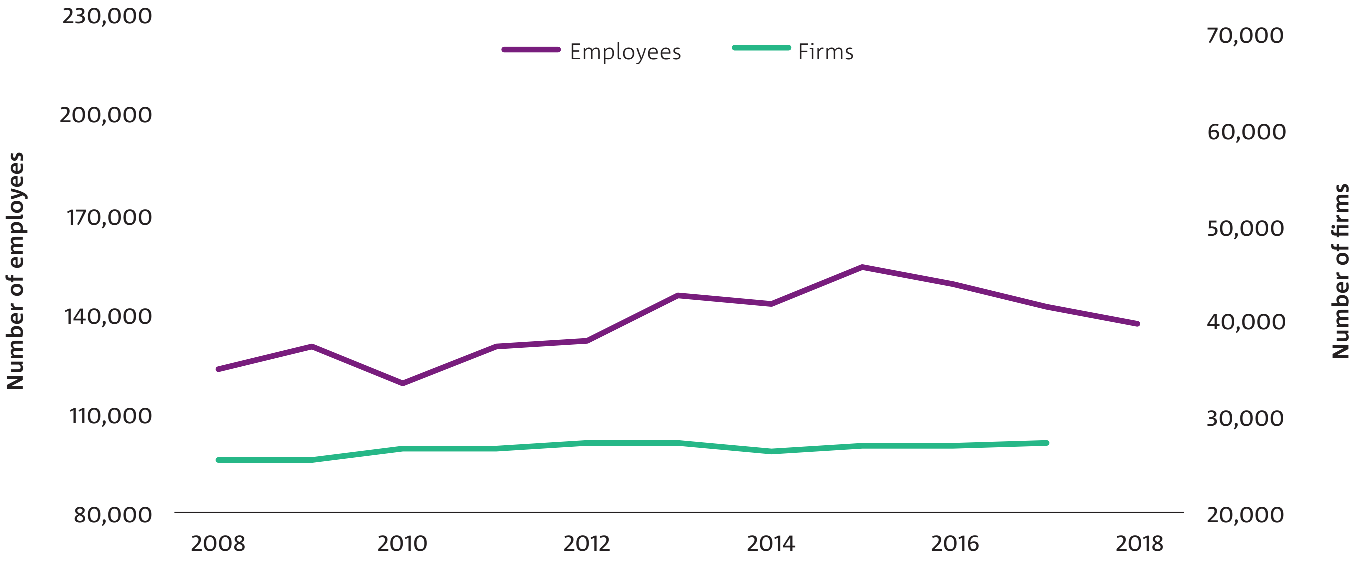



**Figure 27. Number of employees (left axis) and firms (right axis) in the next generation aerospace and space technologies sector in Queensland**

Data source: Australian Bureau of Statistics[86,87]

*Note: Employment and firm estimates are based on historical data aggregated across a subset of ANZSIC industry categorises that are assumed to correspond to this industry (see Appendix B for more details). These ANZSIC codes cover the emerging niche industry as well as the broader industry structure. Employment estimates covers both knowledge and non-knowledge workers, reflecting the predicted size of the entire workforce of the emerging industry and its associated industry sub-sectors.*

## WHY QUEENSLAND?

**Queensland has a rich aviation and aerospace business community.** Many aerospace contractors have based their Australian headquarters in Queensland, including Boeing Defence Australia, Airbus Helicopters, Raytheon, Sikorsky, GE Aviation and Northrop Grumman. Queensland is also home to a number of Tier 2–5 companies (e.g. Ferra Engineering, L3 Micreo, TAE Aerospace, Flying Colours, Heat Treatment Australia) who provide services to the aerospace industry.[12] Queensland's strong defence presence – including the Army Aviation Centre at Oakey and RAAF bases in Amberley, Townsville and Scherger – provides opportunities for smaller firms to contribute to large-scale, international defence contracts (e.g. the LAND 400 Phase 2 contract with Rheinmetall Defence Australia[14]) and the Defence CRC for Trusted Autonomous Systems in aerospace and other defence technology domains.

**Queensland has become a hub for aerospace and aviation research.** UQ established the Boeing Research and Technology Australia Centre in 2017, which provides training and opportunities for researchers to collaborate on aerospace-related projects,[269] and QUT has formed an Aviation Innovation Network which fosters industry–research collaborations around user-driven research.[12] Queensland is also home to a number of hypersonic flight research programs including collaborations between UQ, the United States Air Force Research Laboratories, the Australian Defence Science and Technology Group (DSTG) and Boeing[12] and between USQ and DSTG.[12] USQ also has Australia's only wind tunnel facility that can be used for supersonic and hypersonic experiments.[12] QUT, UQ, Griffith University and CSIRO are also engaged in research around robotics, advanced materials and manufacturing for the space sector.[270]

**The drone industry is a significant growth opportunity for Queensland.** UAVs are attracting substantial investment due to their applications for infrastructure monitoring, disaster mitigation, search and rescue, mining, agriculture and the creative industries.[11] Goldman Sachs estimates that the global UAV market could reach $140 billion by 2025.[271] The Queensland Government has developed the Queensland Drones Strategy to drive future investment and job creation in Queensland's drone sector[272] and has partnered with Boeing Defence Australia to build Boeing Defence's largest international autonomous vehicle program in Queensland.[273] Queensland's strengths in robotics and autonomous systems research, its geography and its proximity to key markets places it well to grow its drone capabilities and exports.

**Australia's space capabilities are dispersed, creating domestic competition.** The establishment of the Australian Space Agency in 2018[274] reflects a renewed national effort to grow Australia's share of the $461.8 billion global space industry.[275] South Australia has a concentration of space-related firms and a growing defence sector,[274] as well as the South Australian Space Industry Centre.[276] New South Wales is home to the UNSW Canberra Space Research Centre[277] and the Australian Capital Territory has the CSIRO-operated NASA Canberra Deep Space Communication Complex, the Space Environment Research Centre, and leading satellite programs and space firms.[278] To explore Queensland's role in Australia's growing space capabilities, the Queensland Parliament commissioned an enquiry into Queensland's capabilities in areas such as communications, Earth observation, position, navigation and timing.[279]

**Queensland has a geographical comparative advantage for aerospace-related activities and services.** Queensland has one of the lowest population densities in Australia (see Figure 28), areas free of radio interference, and land and airspace close to the equator. This combination of factors is ideal for launch activities and ground processing[268,270] and Deloitte's recent assessment of Queensland's space capabilities identified this geographical advantage as an underutilised opportunity for the state.[268] There are also opportunities for Queensland to diversify into the design and manufacturing of space systems and their components, along with space-enabled services for agriculture and farming, disaster and environmental management and other industry applications.[268] Queensland currently has 59 space-related firms with the majority focused on space systems and their operating components (see Figure 29).

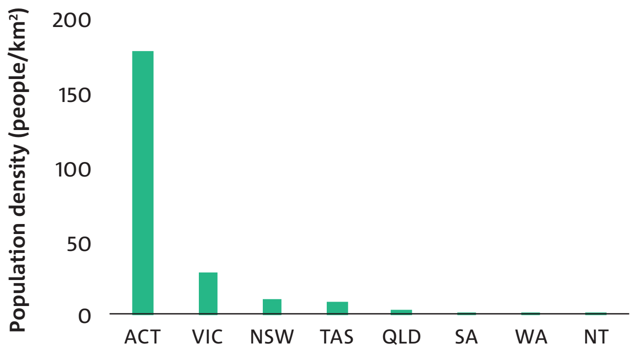



**Figure 28. Population density (people per square kilometre) in Australia, by state and territory**

Data source: Australia Bureau of Statistics[239] and Geosciences Australia[240]

**Queensland's aviation sector could support the workforce needed to meet the demand for air travel**. The number of travellers to Australia has grown at an accelerated rate and a key driver of this growth is travellers coming from the Asia-Pacific region (see Figure 30). With more people transitioning into the middle-income bracket,[280] a greater share of the population in the Asia-Pacific region will be able to afford higher-value purchases such as air travel. Asia's aviation sector will likely expand in the future in response to this demand. This presents opportunities for Queensland to draw upon its expertise in aircraft design and technologies to provide training for pilots and technicians and high-value niche maintenance, repair and overhaul services to the region and beyond.[12]

**The space industry could grow in conjunction with other emerging industries.** Queensland's space industry will be both a consumer and supplier to other knowledge-intensive industries. For instance, the autonomous systems, robotics and remote asset management developed for operation in remote and harsh mining and agricultural environments can be applied to space-related activities.[282] Moreover, advanced manufacturing and materials outputs could be used in developing launch vehicles.[282] The reverse is also true, with mining and agriculture able to use technologies developed in the space industry. For example, space-derived data and services, such as Earth observation from space, can be used to predict the water system, enabling precise water and production management practices.[262]

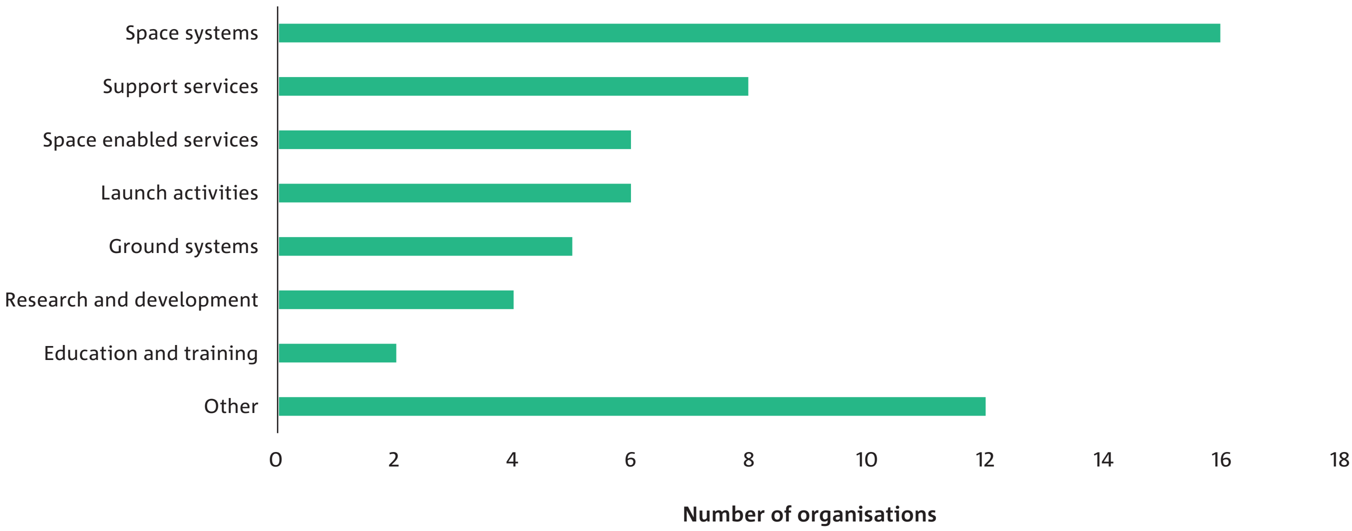



**Figure 29. Number of organisations in the Queensland space economy by sub-sector, 2019**

Data source: Deloitte[268]

*Note: Organisations may be private companies, university and research organisations, government bodies, or industrial organisations*

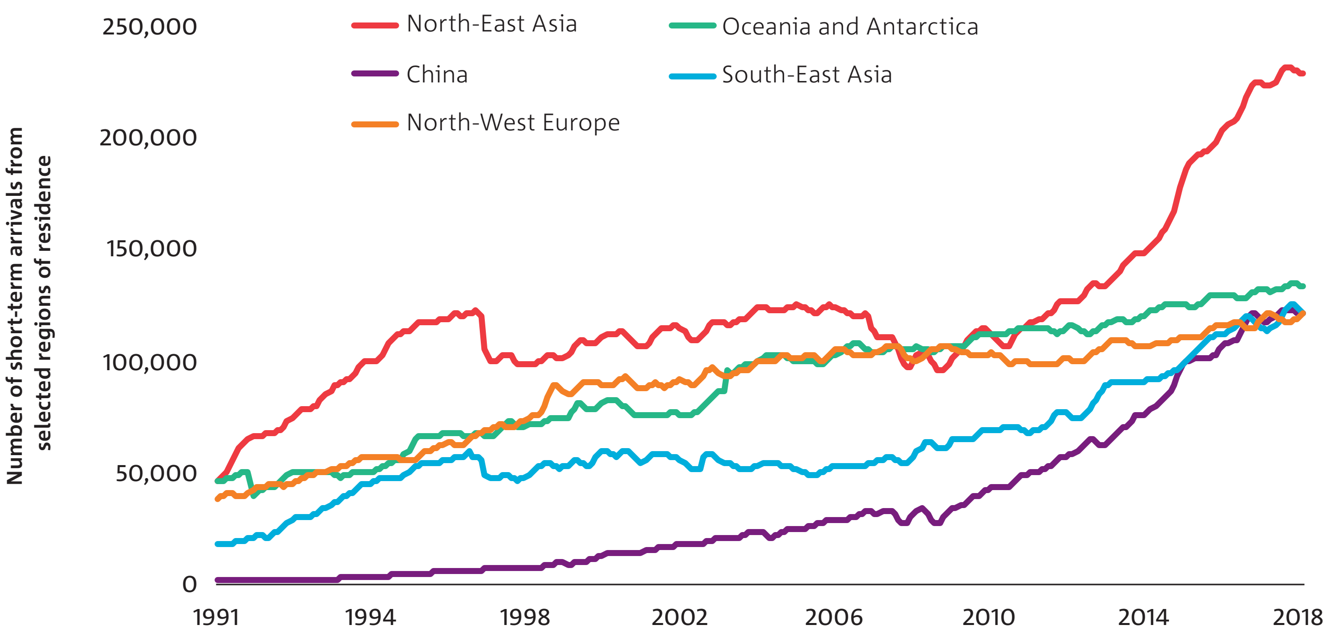



**Figure 30. Number of short-term arrivals to Australia across top five regions of residence (right axis)**

Data source: Australia Bureau of Statistics[281]

## OPPORTUNITIES FOR GROWING NEXT GENERATION AEROSPACE AND SPACE TECHNOLOGIES

### Research

Most of Queensland's major universities are actively involved in aerospace-related research and due to the limited number of experts in specialised domains, the sector has a good track record of international collaborations. For example, USQ's Centre for Astrophysics has collaborated with the NASA Exoplanet Science Institute and the Harvard-Smithsonian Centre for Astrophysics to explore other planets that could support life.[283] But local and national demand for this expertise is limited[268] and could be underutilised due to the small nature of the domestic industry. Continuing to strengthen the existing collaborations between industry and the research sector will ensure projects continue to address industry-relevant problems and fuel local demand for these products and services.

Queensland's next generation aerospace and space technologies industry would mutually benefit from the aforementioned expansion of Queensland's research capabilities in composite materials, advanced materials and precision engineering. Given the multidisciplinary nature of space-related research and its potential applications (e.g. mining, agriculture), there would be value in research programs that combined multidisciplinary local, domestic and international research capabilities. This would ensure that R&D activities conducted in next generation aerospace and space technologies respond to challenges facing other emerging knowledge-intensive industries.

### Infrastructure

Infrastructure needed for the space sub-sector of this industry is expensive and Queensland currently lacks the sufficient physical infrastructure needed to ground this sector in the state.[268] South Australia's aerospace company Southern Launch is developing Australia's first commercial orbital launch facility to deploy nanosatellites[284] and Equatorial Launch Australia in the Northern Territory will be Australia's first commercial spaceport.[285] Given research has identified Queensland's geographical location as an underutilised area of comparative advantage for the space industry,[268] investment in infrastructure needed for launch and ground systems activities (e.g. a launch port) could incentivise more firms to base themselves in Queensland and could attract international researchers and investors.

### Education and labour force

The next generation aerospace and space technologies sector draws upon skilled graduates and workers from a range of STEM fields, but stakeholders consulted in this research noted that these individuals often lack sufficient on-the-job training. There could be potential labour shortages in the aerospace industry in the future – with the global aircraft and maintenance workforce expected to have a shortfall of 30 per cent in needed supply by 2025 – particularly at the senior technician, graduate and post-graduate levels.[12] While higher degree completions in STEM fields have grown by 50.1 per cent in Queensland from 2007–17, this sector is competing for prospective graduates with other rapidly growing sectors, such as health which saw enrolments increase by 96.4 per cent over the same period.[27]

Queensland has limited to moderate human capital across a range of space-related sub-sectors, meaning that firms often source these skills internationally.[268] But there are opportunities for the state to source talent from other emerging industries such as manufacturing, agriculture, mining and defence. The industry may benefit from targeted, industry-led education and training programs that are tailored for common career transitions from other sectors. Industry also reports that engineers and technicians often lack the necessary business and management skills needed in the aerospace workforce. Professional practice and work experience as part of these education and training programs could help to address this skills gap.

| QUEENSLAND'S NEXT GENERATIONAL AEROSPACE AND SPACE TECHNOLOGIES INDUSTRY IN A GLANCE | |
|---|---|
| **Supply drivers** | • Rich ecosystem of global and domestic aviation, aerospace and defence businesses, research groups and industry–research collaborative partnerships<br>• Natural geographical advantages (e.g. low population density, areas free of radio interference and proximity to equator) for a range of aerospace- and space-related activities<br>• Existing expertise and capabilities in remote management and operations and advanced materials and manufacturing |
| **Demand drivers** | • Demand for drone applications in areas such as infrastructure monitoring, disaster mitigation, search and rescue, mining, agriculture and the creative industries<br>• Increasing domestic competition for space capabilities across Australia<br>• Expanding air travel is creating demand for high-value aviation services training for an emerging aviation workforce<br>• Demand for aerospace and space technologies from other knowledge-intensive industries |
| **Research opportunities** | • Encouraging local and national industry–research collaborations to fuel domestic demand for this industry<br>• Acknowledging the value of multidisciplinary collaborations in broadening the scope of space-related research and applications |
| **Infrastructure opportunities** | • Leveraging Queensland's geographical strengths and investing in infrastructure (e.g. a launch port) to attract international investors and researchers |
| **Education and the workforce opportunities** | • Providing on-the-job training for science, technology, engineering and mathematics (STEM) graduates to address business and management skill gaps<br>• Developing education and training programs that can help workers transition their skills from other industries |

## Advanced agriculture

The advanced agriculture industry is made up of knowledge-rich food and agriculture businesses offering high-quality products and services that are sustainable, secure and nutritious. Value is added to food and agriculture outputs through the method of processing (e.g. crops produced with enhanced nutritional value or using less resources) or production (e.g. organic produce or free-range livestock)[286] or other intangible attributes (e.g. assurance around food provenance and safety). This industry is comprised of start-ups, SMEs and large agribusinesses that design and develop products and services that support the entire agricultural supply chain as well as primary producers.

Queensland has a long agricultural history, diverse climatic zones, easy access to natural resources and close proximity to Asian export markets. Australia's high biosecurity and environmental standards and reputation works to Queensland's advantage too. The knowledge-intensification of Queensland's agriculture sector is supported by its thriving and world-leading agriculture and food science research and enabling digital technologies. Demand for advanced agriculture is fuelled by growing consumer demand for healthy, sustainable and trusted food from domestic and international markets. Furthermore, climate-change-related events such as droughts, floods and severe storms continue to threaten production, creating an imperative for the agriculture sector to become more environmentally sustainable and resilient.

The current firm and employment trajectories associated with this industry are shown in Figure 31 (see Appendix B for industry categories associated with this industry definition). Based on the most recent data available for this calculation, it is estimated that approximately 59.8 per cent of the advanced agriculture workforce in 2016 were knowledge workers.

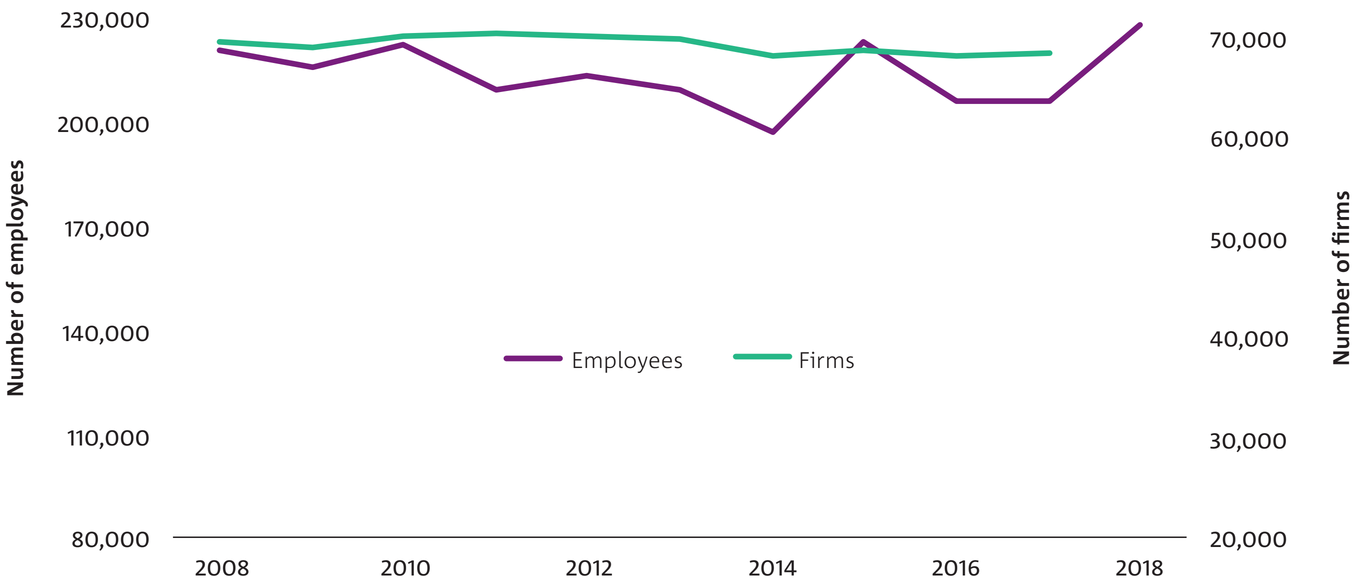



**Figure 31. Number of employees (left axis) and firms (right axis) in the advanced agriculture sector in Queensland**

Data source: Australian Bureau of Statistics[86,87]

*Note: Employment and firm estimates are based on historical data aggregated across a subset of ANZSIC industry categorises that are assumed to correspond to this industry (see Appendix B for more details). These ANZSIC codes cover the emerging niche industry as well as the broader industry structure. Employment estimates covers both knowledge and non-knowledge workers, reflecting the predicted size of the entire workforce of the emerging industry and its associated industry sub-sectors.*

## WHY QUEENSLAND?

**Research and development activities have long been a key driver of agricultural productivity.** The Australian agriculture industry has historically drawn upon new knowledge and technologies to improve productivity, using more sophisticated farm equipment, improved herbicides and genetic modification.[287] As a result, the sector has seen stronger productivity growth than the rest of the economy (see Figure 32). It is estimated that the value of Australian agriculture could increase by 25 per cent from 2014–15 levels through greater uptake of digital technologies, equating to a $20.3 billion increase in the gross value of production.[288] Given the Queensland accounts for the highest share of agricultural land in Australia (35 per cent in 2016–17),[289] it has a natural advantage in leveraging the new opportunities in the agriculture sector.

**Queensland's maturing AgTech sector is supported by world-class research.** Queensland accounts for 26 per cent of Australian AgTech start-ups, just under half of which are based in regional Queensland.[290] Examples include Swarm Farm, which uses small and agile farm robots to increase agricultural productivity,[291] and Hydrox Technologies, which has developed an environmentally friendly plastic mulch film.[292] The AgTech sector is supported by Queensland's strong agricultural and food research sector, including UQ which placed first in Australia and fourth worldwide for scientific papers in agriculture in 2019.[293] CSIRO has also developed new decision-making applications such as Graincast[294] and Yield Prophet[295] and Griffith University was recently awarded $5 million to develop an ARC Industrial Transformation Research Hub, which will use new AI to increase farm production and prevent diseases.[296]

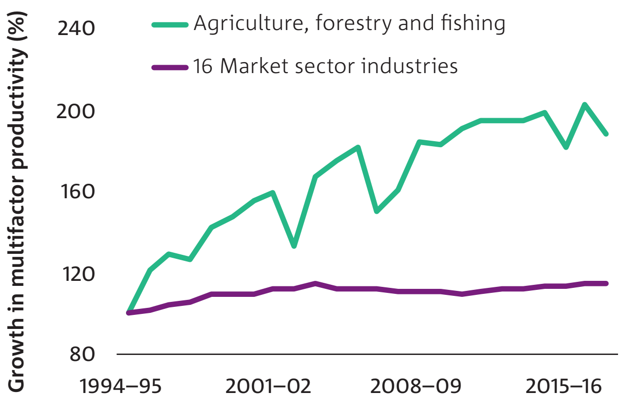



**Figure 32. Growth in gross value added based multifactor productivity indexes across Australia (index, 1994–95 = 100)**

Data source: Australia Bureau of Statistics[297]

**Queensland's deep food science expertise could help the sector become more climate resilient.** Growth in annual crop yields has been slowing worldwide (see Figure 33) and future production systems will need to meet production and environmental targets while helping farmers adapt to water shortages, pesticide resistance, declining yields and other challenges.[298–300] Queensland's world-leading research capabilities in agriculture and food science could add value here. For example, UQ 's Queensland Alliance for Agriculture and Food Innovation has developed a pest-resistant genetic variant for sorghum,[301] QUT's Future Farming research centre explores a range of agriculture-related digital applications (e.g. big data, blockchain and 3D printing),[302] and Griffith University's Institute for Integrated Intelligence Systems uses AI to assess strawberry quality and count larvae.[303] Queensland start-ups, such as Nexgen Plants, are already using plant-breeding technologies in local markets to produce drought and disease resistant crops.[304]

**Asian consumers continue to demand high-value nutrition.** The Asia-Pacific share of the global middle-class population is expected to reach two-thirds by 2030[280] and with this growth in wealth comes increased demand for higher-value goods and services. Indeed, consumption of protein and fat has grown rapidly in Asian economies (see Figure 34). Asian economies have also experienced an increase in the rates of chronic diseases: the number of deaths attributable to non-communicable diseases in China grew from 81.6 to 89.3 per cent from 2000–16.[306] Asian consumers are increasingly health conscious, with a survey finding 93 per cent of Asian respondents would pay more for foods with health attributes.[307] With its proximity to Asia, Queensland's agriculture industry is well placed to respond to this demand for high-value nutrition.

**Demand for functional foods from Asian consumers present opportunities to grow new niche markets**. Functional foods are foods that are fortified, enriched or enhanced to provide health benefits beyond basic nutrition.[308] Functional food sales in the Asia-Pacific region are expected to reach $917.6 million by 2026 – 28.7 per cent of which is accounted for by Japan.[309] Queensland's research capabilities in functional foods (e.g. USQ's Functional Foods Research Group and UQ's Institute for Molecular Bioscience), its existing base of biotechnology businesses and research groups, and its access to diverse tropical vegetation biodiversity are unique advantages for developing functional foods. Queensland firms such as Natural Evolution – which uses unwanted green bananas to develop green banana flour[286] – and Qponics – which plans to produce omega-3 essential oils from algae[310] – are already pursuing these opportunities.

**Synthetic biology and high-tech foods could disrupt Queensland's traditional agriculture markets.** Demand for non-animal products is increasing: Australia is the third-fastest growing vegan market in the world – with China in top place[311] – and 11.2 per cent of Australian adults reported eating a vegetarian diet all or most of the time in 2015–16 – up from 9.7 per cent in 2011–12.[312] Companies such as US-based Impossible Foods are already manufacturing 'meat' made from plant-based ingredients,[313] Perfect Day has developed animal-free dairy products from fermented microflora[314] and Just and Finless Foods creates lab-grown meat from cultured tissue.[315] While this presents a risk for animal exports, which made up about 36 per cent of Queensland's agriculture production in 2018,[316] there are opportunities to diversify into new high-value food markets, drawing upon Queensland's research capabilities in synthetic biology.[250]

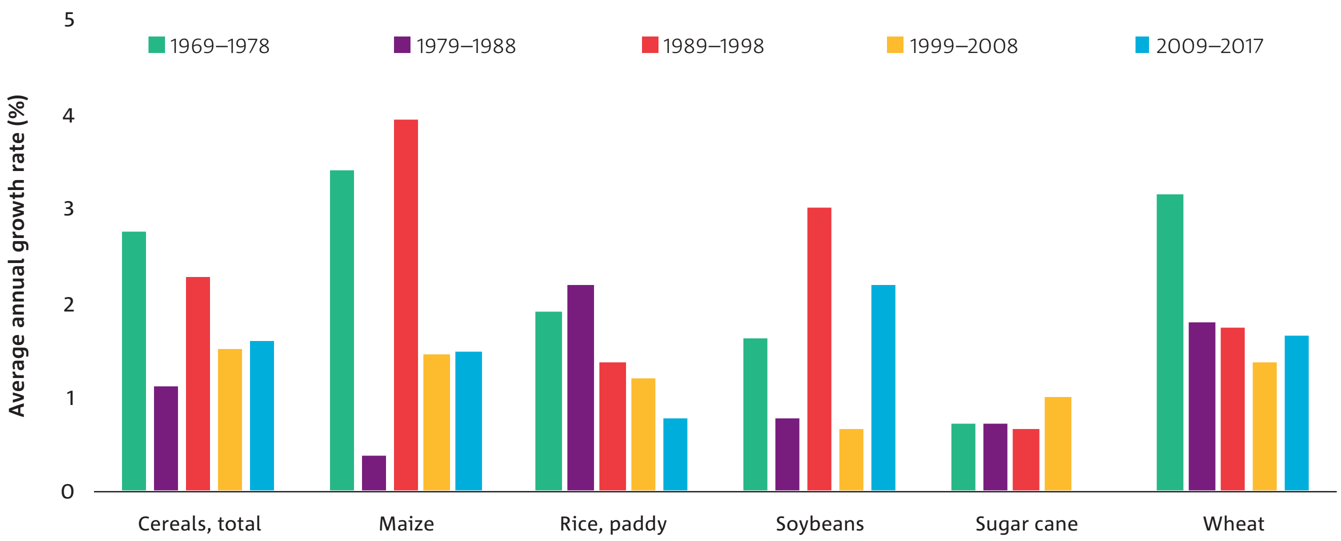



**Figure 33. Average annual global growth rates for selected crop yields**

Data source: United Nations Food and Agriculture Organization[305]

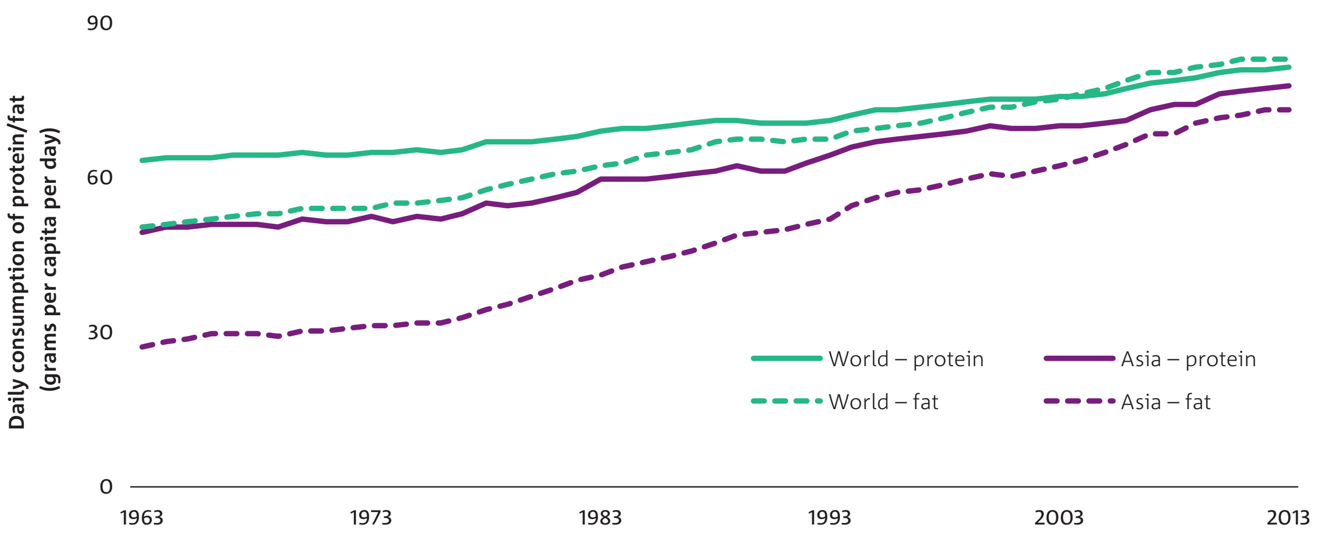



**Figure 34. Daily protein and fat consumption in Asia and worldwide**

Data source: United Nations Food and Agriculture Organization[305]

**Concerns around food safety are driving demand for provenance assurance.** There have been numerous high-profile food safety scandals in China[317] and growing demand for affordable food has led to an overreliance on hormones, pesticides and antibiotics.[318] As such, assurance around the quality and provenance of food and nutritional products has become increasingly important to Asian consumers.[318] Distributed ledger technologies (commonly referred to as blockchain) are being used to provide transparency and assurance around agricultural and pharmaceutical supply chains.[319–321] For example, QUT's Future Farming group and BeefLedger Limited are using blockchain in the Australian beef supply chain. There are opportunities to expand upon this, using digital traceability technologies and biological readings to promote intangible attributes of Queensland's food and pharmaceutical exports.[286]

**Future biosecurity threats are motivating efforts to preserve Queensland's clean and green reputation.** Australia has a strong legal framework and low levels of food-borne illnesses, which has earnt it an international reputation for being clean and green.[286] But the size of Queensland's land mass and coastline and proximity to other countries makes it is vulnerable to biosecurity risks[9] and factors such as rising urbanisation and movement of people and goods, online retailing and biodiversity loss could present new infectious diseases and pests in the future.[322] The Queensland Government committed $145 million for biosecurity in 2018–19[323] and developed the Queensland Biosecurity Strategy 2018–23 to preserve its clean and green reputation.[324] This aligns with other national efforts to improve Australia's traceability systems, such as the National Traceability Framework.

**Traditional knowledge provides unique advanced agriculture offerings.** Indigenous communities hold deep environmental knowledge that could inform current scientific enquiries and present commercial opportunities. For example, the Kakadu plum, used by Indigenous people for generations, has been recognised as a 'superfood' with antioxidant, anti-inflammatory and antimicrobial properties[325] and is now sold as a unique form of bush tucker by Indigenous communities.[326] Researchers at UQ have collaborated with the Indjalandji-Dhidhanu people in Central Australia to identify and harvest a particular kind of spinifex for materials science research.[327] Griffith University has partnered with the Jarlmadangah Burru community in the Kimberley region in a joint patent application for a painkiller based on the bark of the Marjala plant.[328] Use of traditional knowledge provides opportunities to engage and mobilise Indigenous communities[326] and provide novel insights into scientific enquiries.[329]

## OPPORTUNITIES FOR GROWING ADVANCED AGRICULTURE

### Research

Stakeholders consulted as part of this research highlighted that the agriculture and food science research sector collaborates well internationally, but these collaborations tend to be between researchers rather than institutions. There is the risk that these collaborations could cease when a researcher changes institution. The translation of research in the agriculture sector also continues to be a challenge, meaning there is limited adoption of R&D outputs.[9] Involvement of industry partners in the design and, where possible, the implementation of research projects could help ensure R&D efforts are solving real-world industry problems and are commercially practicable.[9] Greater collaboration between R&D institutions and investors could strengthen the commercialisation process too.[9]

Queensland's agriculture and food science research could expand into new areas that help the advanced agriculture sector respond to growing environmental pressures and consumer preferences. For example, Meat and Livestock Australia have announced that the Australian red meat industry could be carbon neutral by 2030.[330] Understanding the industry practices, policy mechanisms and financial incentives needed to achieve this goal will require further research efforts,[331] presenting new avenues for future scientific enquiries. Stakeholders also identified vertical agriculture as another research capability that Queensland could look to grow, exploring ways to produce food in highly dense areas with fewer resources.

### Infrastructure

Patchy telecommunications connectivity across rural and regional areas in Queensland is a major factor hindering adoption of digital tools in agriculture and many farmers do not have the download, upload and backhaul speeds needed to run AgTech innovations. Indeed, the Australian agriculture sector has the lowest share of businesses engaged in any type of innovative activity.[332] These digital infrastructure gaps are evident in international rankings on fixed broadband speeds[159] and the regional–city digital inclusion gap – a divide that grew in Queensland from 2017–18 despite shrinking in many other Australia states.[160] Addressing connectivity gaps will be a key enabler of digital adoption in the advanced agriculture sector.

## Education and the workforce

The agriculture sector faces persistent challenges in attracting and sustaining its workforce. Higher degree enrolments in agriculture, environmental and related studies have been declining or stagnant in recent decades, varying between about 3,100 and 3,700 per year between 2007–17.[27] As with other traditionally strong Queensland industries, stakeholders consulted as part of this project mentioned that the agriculture sector has suffered from the public perception that careers in this sector are labour-intensive. Given that the regional basis of many agribusinesses can act as a disincentive for younger workers too, the agriculture sector also suffers from an ageing workforce[286] and relies strongly on seasonal labour in some sub-sectors.

As the agriculture sector transitions to advanced agriculture, the capabilities required in the workforce will become less labour-intensive and more knowledge-intensive. Previous industry analyses have identified the need for skills in business, leadership, market research and data analytics in the future workforce.[286] While it may be possible to fill this skills gap with workers from other technology backgrounds, these graduates are in short supply in Queensland too,[27] and Queensland's existing STEM-qualified workforce is relatively small.[31] Enhancing industry engagement and courses in data analytics as part of tertiary education programs and embedding staff who are experienced in commercialisation could address skills gaps in the sector and improve research translation outcomes.[286]

| QUEENSLAND'S ADVANCED AGRICULTURE INDUSTRY IN A GLANCE | |
|---|---|
| **Supply drivers** | • Natural advantages in access to viable agricultural land, diverse climatic zones, easy access to natural resources and close proximity to Asian export markets<br>• World-leading and deep food science and agriculture technology expertise across universities, research institutes and existing firms and start-ups<br>• Research capabilities in synthetic biology driving opportunities to create new high-value food manufacturing processes and products<br>• Opportunities to use traditional knowledge around the environment and agricultural products in scientific enquiries and commercial applications |
| **Demand drivers** | • Growing pressures from climate-related changes, creating challenges around water shortages, pesticide resistance and declining yields<br>• Demand for high-value nutrition food and agriculture products from Asian consumers in response to growing wealth and health concerns<br>• Concerns around food safety and sustainability driving demand for greater transparency and assurance around agricultural and pharmaceutical supply chains<br>• Emerging potential for new infectious diseases and pests driving demand for strong biosecurity frameworks and systems |
| **Research opportunities** | • Including industry in the design and implementation of research projects to improve the relevance and commercial viability of research outputs<br>• Building research capabilities that will support the sector in responding to environmental and consumer pressures<br>• Expanding capabilities in vertical agriculture as an alternative method of improving resource efficiency |
| **Infrastructure opportunities** | • Addressing digital connectivity gaps, particularly in regional Queensland, to facilitate adoption of enabling technologies |
| **Education and the workforce opportunities** | • Attracting talent despite outdated public perceptions of the industry, the location of work and an ageing workforce<br>• Enhancing industry engagement in education and training to address changing requirements (e.g. skills in business, market research and data analytics) |

## Circular commodities

The circular commodities industry is focused on generating value from reducing, recycling and repurposing by-products or waste products arising from agriculture and other industrial processes. It is motivated by global challenges around sustainability, environmental impacts (e.g. greenhouse gas emissions produced from traditional manufacturing of goods for society's needs[333]) and resource scarcity, creating demand for clean and green products. This sector creates a range of bioproducts including sustainable chemicals, fuels, synthetic rubber, cosmetics, detergents and textiles,[13] and develops new methods for reducing resource use. It is comprised of start-ups developing new cutting-edge recycling technologies and industrial biotechnologies, waste management and recycling operators and large-scale biorefineries.

Queensland has the largest share of agricultural land in Australia, a subtropical-tropical climate that is well-suited for growing feedstock for bioproducts and a mature and evolving agriculture industry – factors which position the state well to grow the biofutures sub-sector of this emerging industry. While Queensland's existing biorefineries are focused on the production of biofuels (i.e. ethanol and bio-based diesel), as the circular commodities industry matures and as new technological processes become more affordable, this industry will likely expand into other bio-based products.[13] This industry is supported by Queensland's deep R&D expertise in industrial biotechnology and growing number of industry–research partnerships.

The current firm and employment trajectories associated with this industry are shown in Figure 35 (see Appendix B for industry categories associated with this industry definition). Based on the most recent data available for this calculation, it is estimated that approximately 49.9 per cent of the circular commodities workforce in 2016 were knowledge workers.

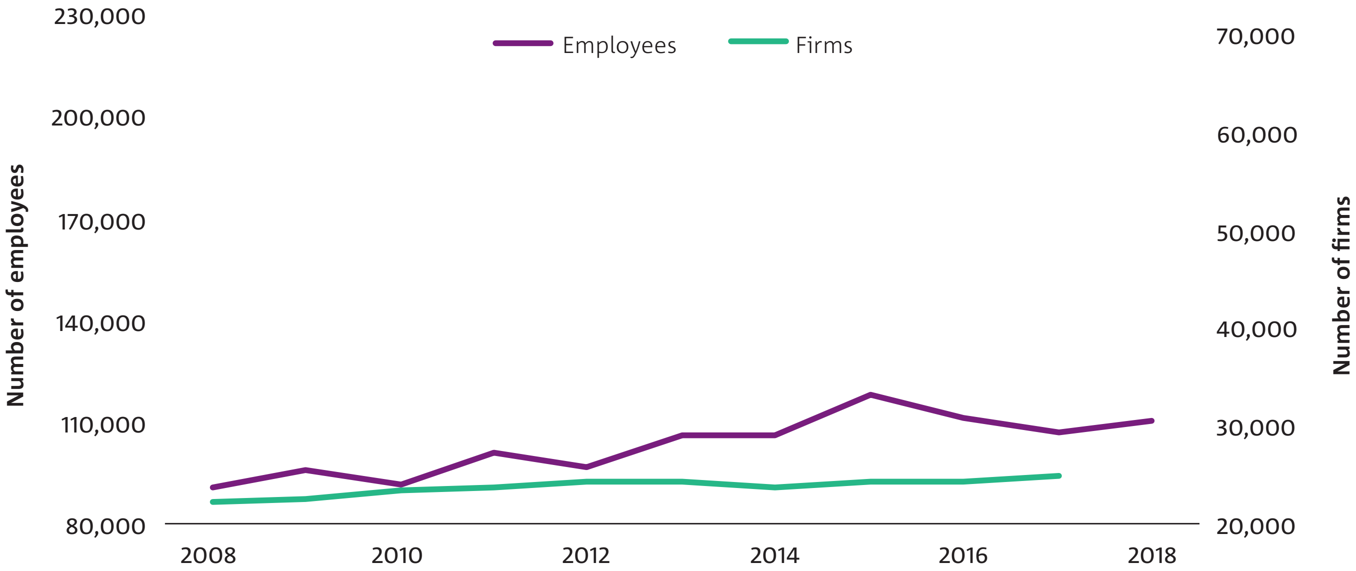



**Figure 35. Number of employees (left axis) and firms (right axis) in the circular commodities sector in Queensland**

Data source: Australian Bureau of Statistics[86,87]

*Note: Employment and firm estimates are based on historical data aggregated across a subset of ANZSIC industry categorises that are assumed to correspond to this industry (see Appendix B for more details). These ANZSIC codes cover the emerging niche industry as well as the broader industry structure. Employment estimates covers both knowledge and non-knowledge workers, reflecting the predicted size of the entire workforce of the emerging industry and its associated industry sub-sectors.*

## WHY QUEENSLAND?

**Declining commodity prices signals the need for secondary product markets**. Prices associated with some of Queensland's key commodity exports have been stagnant or declining in recent years (see Figure 36). For instance, the world sugar price reached a 10-year low in late 2018, resulting in a $500 million loss for the Australian sugar industry.[334] Given Queensland's food and agriculture sector only accounts for a small share of global production, its producers are vulnerable to global market prices.[316] To build resilience in the agriculture sector, there is value in diversifying into other secondary, higher-value markets. Non-food crops can be used as feedstocks in bioproducts, including sugarcane green waste and bagasse, and sweet sorghum and sorghum stover.[13] These secondary markets also present opportunities for Queensland's agriculture sector to do more with less and use available resources more efficiently.

**Queensland could reduce its landfill waste while creating jobs for the economy.** Queensland's waste is growing faster than its population (7.1 per cent versus 1.3 per cent from 2014–15 to 2016–17).[335] The latest state-by-state analysis found Queensland generates the greatest amount of waste per capita and has poor rates of recycling (see Figure 37). Addressing Queensland's waste challenges could provide both economic and environmental benefits for the state. Indeed, the Queensland Government's planned waste disposal levy aims to divert more waste from landfill and into biorefineries and other recycling processes, and boost employment opportunities in the resource recovery and recycling industry.[336] Queensland Treasury estimates that investment in resource recovery infrastructure could create 3,000 direct jobs.[336]

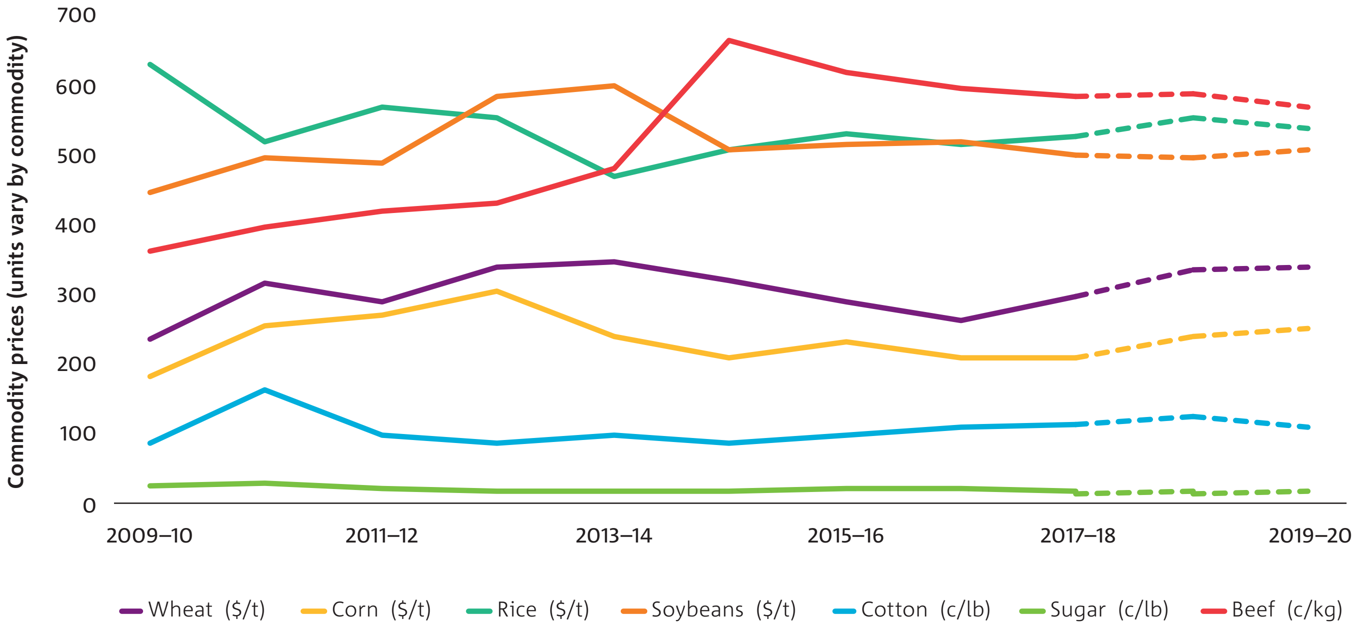



**Figure 36. Commodity prices for selected commodities worldwide**

Data source: Australian Bureau of Agriculture and Resource Economics and Sciences[343,344]

*Note: 2018 and 2019 values are estimated values and units vary across commodities.*

**Queensland's strengths in biotechnology are attracting a growing number of industry partnerships.** Queensland universities with a strong basis in biotechnology have attracted a number of industry collaborations: UQ's AIBN partnered with Amyris, using sugarcane as feedstock for biofuels;[337] JCU partnered with Pacific Biotechnologies to develop bioproducts from algae;[338] QUT collaborated with US company Mercurius Biorefining to convert biomass into jet and diesel fuels[339] and Syngenta to establish the Syngenta Centre for Sugar Cane Biofuel Development;[340] and Griffith University partnered with Utilitas to create energy from organic waste.[341] Mercurius attributed Queensland's world-class universities, favourable business climate and agricultural industry to its decision to base its biorefinery in Queensland.[342]

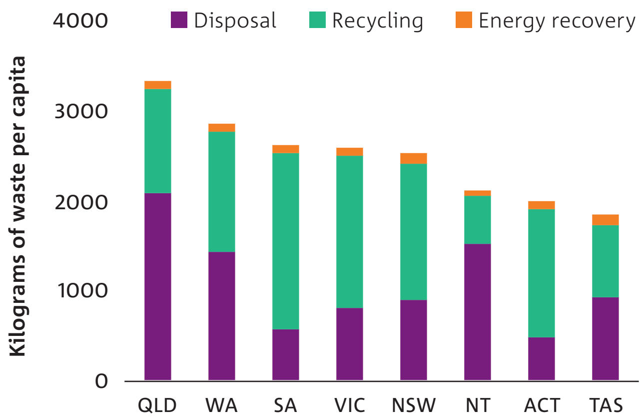



**Figure 37. Kilograms of waste per capita in Australia by processing stream and state and territory, 2014–15**

Data source: Department of the Environment and Energy[345]

**Queensland is home to existing biorefineries and biogas plants.** Pressures to reduce greenhouse gas emissions are driving demand for renewable energy sources, such as biofuel and biogas. There are three commercial biorefineries in Queensland: Wilmar BioEthanol in Sarina (molasses-based ethanol), Dalby Biorefinery (grain-based ethanol) and Ecotech Biodiesel (bio-based diesel from cooking oil and tallow).[13] A number of pilots are also running, including the Mackay Renewable Biocommodities Pilot Plant[13] and the Northern Oil Advanced Biofuels Pilot Plant,[346] with other potential biorefineries in the pipeline.[347] Deloitte estimates that seven new biorefineries would generate $1.8 billion for the Queensland economy and 6,640 full-time equivalent jobs by 2035.[348] The Local Government Association of Queensland also plans to develop five to eight biogas rendering plants that will use waste products for energy[349] and the Queensland-based AJ Bush & Sons rendering plant is already using biogas to run its boilers, which has halved its coal consumption.[350]

**There is strong regional and global demand for bioproducts**. The global market for bioproducts was worth around $487 billion in 2014 and this is expected to reach $1,578 billion by 2022.[13] While biofuels are currently generating the most revenue, bioplastics are anticipated to show stronger growth out to 2021.[351] The Asia-Pacific region is driving this demand, particularly for biochemicals.[351] Given the lack of commercial biorefineries in the Asia-Pacific region,[352] there are opportunities for Queensland to supply this emerging demand and expand its current base in biofuel technologies, acknowledging that there are current barriers that could hinder future growth (e.g. access to funding, approval processes, collaborations across sectors and access to feedstocks).[13] The biofutures industry roadmap developed by the Queensland Government is designed to support the industry in addressing these challenges.[13]

**International approaches could guide future efforts to grow Queensland's biofutures.** Countries with maturing bioproduct markets have adopted strong mandates and committed funding for research and investment in industrial biotechnology.[13] Brazil passed a national biofuels policy which introduces annual carbon intensity reduction targets for fuel distributors, an efficiency certification for biofuels and decarbonisation credits.[353] The United States has also established policies around mandates, tax credits and import tariffs to develop its nascent biofuels industry.[354] China is investing in biofuel infrastructure[355] and has implemented processor subsidies and import restrictions.[356] Finally, the European Union (EU) has committed to biofuels making up 10 per cent of transport fuel in every EU member state by 2020[357] and all EU countries have biofuel action plans.[13] Queensland could use similar mechanisms to develop its biofutures sub-sector.

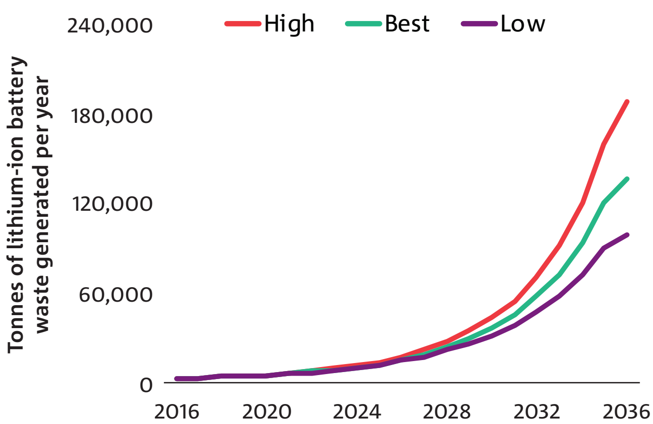



**Figure 38. Projected waste generated annually from lithium-ion batteries in Australia (in tonnes), by projection method**

Data source: Randell Environmental Consulting[358]

**Growing demand for batteries signals the imperative to recycle.** Battery markets for consumer products, transportation and grid storage are expected to grow out to 2021[359] and a natural consequence of this is rising battery waste. In 2016, Australia produced 3,300 tonnes of lithium-ion battery waste and this is projected to reach at least 100,073 tonnes annually by 2036 (see Figure 38). Most of this battery waste ends up in landfill, with 2 per cent processed through offshore recycling in 2016.[360] CSIRO estimates that Australia could miss out on between $813 million and $3 billion by 2036 without a strong domestic battery recycling industry.[360] Given the rising demand for low-carbon technologies that use batteries and the environmental and health risks associated with disposal of batteries in landfill,[360] there are significant drivers for Queensland to take the lead in developing an Australian battery recycling industry.

## OPPORTUNITIES FOR GROWING CIRCULAR COMMODITIES

### Research

As has been flagged in previous industry analyses[13] and stakeholder consultations as part of this project, growth in the circular commodities industry will depend on greater communication and collaboration between industry, government and academia. Otherwise, bioproduct projects might not align well with industry requirements or present a viable commercial opportunity for farmers. For instance, crop types vary from year to year and without incentives to grow specific crops, farmers are unable to supply sufficient feedstock for biorefinery processes. Government-supported hubs or precincts have been shown to promote closer industry–government–research biofutures collaborations in other countries[13] and could promote a range of collaborative initiatives around bioproducts and other circular commodities.

Stakeholders also highlighted the potential to expand research capabilities into further understanding ways to recycle and repurpose batteries and other forms of e-waste. Domestic battery recycling alone could present a multi-billion-dollar opportunity for Australia and have significant environmental and health benefits.[360] The research sector, in collaboration with industry and government, could provide insights into processing methods and applications for recycled materials. Stakeholders also noted that Queensland could learn from international best-practice approaches to reducing, recycling and repurposing resources and aligning policy mechanisms with research programs and industry needs.

### Infrastructure

While Queensland has invested heavily in biorefineries, there are limited facilities for processing and repurposing other waste streams. Victoria opened Australia's first lithium-ion battery recycling facility in 2018[361] and Western Australia will host the Future Battery Industries CRC (in which QUT is a partner),[139] which includes battery recycling as part of its portfolio.[138] Similar developments could be in the pipeline for Queensland with the current feasibility study into a lithium-ion battery manufacturing plant in Townsville.[125] This facility, along with QUT's existing lithium-ion manufacturing plant,[126] could be used for resource recovery processes. The circular commodities sector could also benefit from greater streamlining between processing facilities and supply-chain infrastructure from farms and households.

### Education and the workforce

Stakeholders acknowledged that there were gaps in the public's understanding and awareness around recycling practices and the harmful environmental and health impacts of failing to recycle. Improvements in public awareness around recycling behaviours was attributed as a key driver of the not-for-profit recycling industry in the United States.[57] Recycling education could be offered through school-based education programs (such as those run by local councils) and as a part of employee responsibilities in the workforce. Government regulation, such as the Queensland Government's ban on single-use lightweight plastic bags in 2018[362] and the EU's ban on single-use plastics by 2021[363] can also promote behavioural change. Improved awareness around reducing, recycling and repurposing waste could stimulate demand in this sector.

| QUEENSLAND'S CIRCULAR COMMODITIES INDUSTRY IN A GLANCE | |
|---|---|
| **Supply drivers** | • Strong biotechnology research sector, industry–research partnerships and a portfolio of existing and planned biorefineries and biogas plants<br>• International examples of policies, mandates and investment decisions that could help drive growth in Queensland's nascent biofutures sub-sector |
| **Demand drivers** | • Declining or stagnant commodity prices associated with agricultural exports is driving the need to expand into secondary markets<br>• Growing local, national and global waste challenges and the rising imperative to improve resource recovery rates<br>• Strong regional and global demand for bioproducts, particularly from the Asia-Pacific region<br>• Rising adoption of low-carbon technologies and batteries generating a growing problem around management and repurposing of battery waste |
| **Research opportunities** | • Using government-supported hubs to promote closer industry–government–research collaborations in biofutures<br>• Aligning industry and research needs to ensure research opportunities are commercially viable<br>• Expanding research capabilities to cover recycling methods and applications for e-waste and other materials |
| **Infrastructure opportunities** | • Investing in infrastructure to support processing of other types of waste streams outside of bioproducts<br>• Streamlining processing facilities and supply-chain infrastructure from farms and households |
| **Education and the workforce opportunities** | • Using workplace programs and government regulation to incentivise behaviours that reduce and reuse waste |

# 5 POLICY IMPLICATIONS FOR SCIENCE

The findings in this report have implications for future policy and strategy decisions concerning Queensland's science sector. As a key supply driver of Queensland's knowledge economy, the research sector and the policy decisions that affect its operating environment will weigh into the state's ability to seed and grow its emerging knowledge-intensive industry opportunities. Informed by consultations with stakeholders across a range of industry, government and academic sectors, this chapter explores future policy implications for Queensland's science sector over the coming decades and explores opportunities and challenges that are shared across Queensland's emerging knowledge-intensive industries.

## Improving collaboration between institutions, sectors and disciplines

Collaboration was highlighted as a common gap across all of Queensland's emerging knowledge-intensive industries. Australia fares poorly when it comes to industry–research collaborations, with the OECD placing Australia near the bottom of the pack for collaborations between higher education or research institutes and SMEs and large businesses (see Figure 39). Queensland universities are good at collaborating with international researchers though, with UQ placing first in Australia for international collaborations in scientific research in the Nature Index 2019.[22] Poor collaboration within institutions and between the research sector and other sectors is problematic as it can lead to duplicated efforts and infrastructure, a disconnection between research projects and industry needs, and inefficient use of funding and resources.

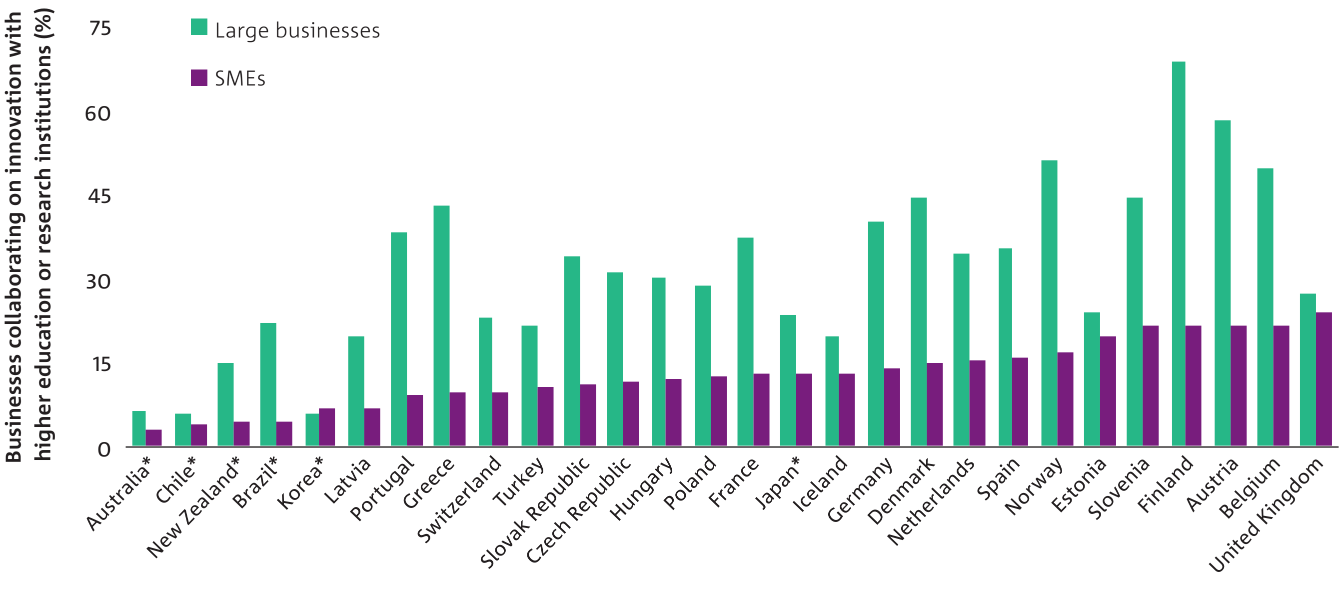



**Figure 39. Share of businesses collaborating on innovation with higher education or research institutions across OECD countries as a percentage of product and/or process-innovating businesses in each size category, 2012–14**

Data source: Organisation for Economic Co-operation and Development[364]

*Note: Data from countries denoted with an asterisk (*) corresponds to alternative years: Australia (2014–15 for SMEs, 2012–13 for large businesses), Chile (2013–14 for SMEs, 2011–12 for large businesses), New Zealand (2013–14 for both values), Brazil (2012–14 for SMEs, 2009–11 for large businesses), Korea (2013–15 for SMEs, 2011–13 for large businesses), Japan (2012–14 for SMEs, 2009–11 for large businesses).*

Stakeholders noted that collaborations between industry and universities and research institutions can also strengthen community trust and confidence through the provision of credible and independent research into industry problems. This is particularly important for the resources industry where public trust in mining companies is low.[183] Existing collaborations, such as the UQ Centre for Coal Seam Gas and the Gas Industry Social and Environmental Research Alliance were highlighted as example partnerships that have improved community trust in the oil and gas sector. Improving industry–research collaborations could help the smart mining, exploration and extraction sector expand into new areas focused on environmental and community impact and facilitate low-carbon transition research initiatives that support the sustainable energy sector.

Emerging knowledge-intensive industries often fall at the intersection of multiple research disciplines too. For example, the cyber-physical security sector draws upon research capabilities in cybersecurity, robotics, autonomous systems, defence and behavioural sciences, with influences from other industry and customer segments that will utilise the sector's outputs (e.g. healthcare, agriculture and mining). Growing Queensland's knowledge-intensive industries and developing the supporting research capabilities will therefore rely upon cross-disciplinary research collaborations. Out-of-the-box collaborations could be particularly fruitful, such as the UAP Project which combined QUT's and industry capabilities in robotics and the creative arts to develop an innovative stream of advanced manufacturing for public art pieces.[259]

Barriers to collaboration are complex and are unlikely to have a single solution. Stakeholders consulted as part of this research suggested that government grants (e.g. the ARC Linkage Projects) could be one mechanism to incentivise greater collaboration across institutes and sectors, along with CRCs, government-funded precincts and hubs and other open-innovation approaches. CSIRO's Data61 has also developed Expert Connect– a platform that automatically gathers researcher profiles from a range of sources to help industry find relevant research collaborators.[365] Future collaborative efforts could strategically focus on common industry research gaps (e.g. capabilities in composite materials are needed in advanced materials and precision engineering and next generation aerospace and space technologies industries).

Limited sharing of physical and digital research infrastructure was highlighted as both a symptom and a contributing factor of siloing in the research sector. For example, stakeholders noted that there is significant variability in data management systems across Queensland universities and research institutes (e.g. for medical data) and firms (e.g. between mining companies and agribusinesses). While access to reliable and affordable digital infrastructure is a challenge for industries becoming more technology-intensive, insufficient or absent legislative frameworks around the use of industry and research data can also limit data use. Addressing barriers around access to shared infrastructure could further contribute to improved collaboration, particularly for collaborations involving start-ups and SMEs.

## Supporting research across the entire pipeline

The amount of research funding awarded by the ARC has fluctuated over the past couple of decades and has plateaued for Queensland following its peak in 2014 (see Figure 40). Research with demonstrated application has attracted the majority of research funding in Australia, with applied research accounting for the largest share of R&D expenditure in government/private not-for-profit organisations (55.8 per cent in 2017)[366] and the higher-education sector (48.5 per cent in 2016),[24] while experimental development makes up the majority of business expenditure on R&D (65.2 per cent in 2016).[367] Most basic research is conducted in the higher-education sector.[24]

Basic research is typically theoretical or experimental and is designed to advance knowledge without necessarily having a specific practical application, whereas applied research draws upon existing knowledge to develop new products or solutions. As such, basic and applied research are often falsely viewed as a dichotomy instead of a continuum. Because applied research tends to have a shorter-term focus and more tangible outputs, it tends to be valued more than basic research. Evaluating research in economic terms alone can be misleading, however, as it fails to consider other social, environmental and cultural benefits of research.[368] These can deliver financial dividends indirectly (e.g. by mitigating risk) or provide value in other ways (e.g. by increasing knowledge and understanding of a given issue or improving wellbeing).[368] New knowledge generated through basic research is a necessary precursor to applied research projects and significant scientific discoveries and innovations.[369]

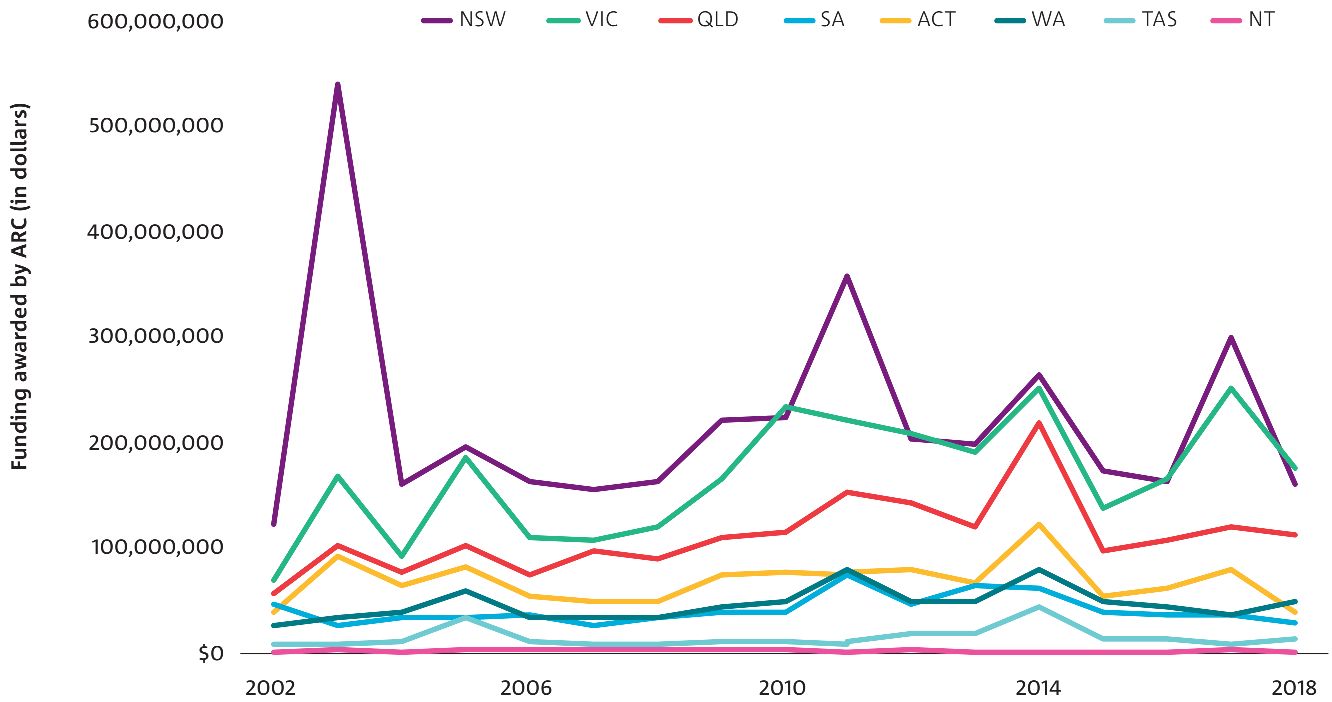



**Figure 40. Amount of funding awarded by the Australian Research Council (ARC, in dollars), by state and territory**

Data source: Australian Research Council[370]

Stakeholders acknowledged the need to strike the right balance between funding for basic and applied research. The amount of R&D funding spent on basic research varies across countries, where OECD countries allocate an average of 17 per cent of funding to basic research, with some countries spending significantly more (35 per cent in Korea) or less (4 per cent in China).[371] Basic research will be necessary in developing the new knowledge base needed for applied projects and a short-term focus on applied research funding could have longer-term consequences for growing Queensland's knowledge economy. Indeed, the International Council for Science noted that economies lacking the capacity for basic research can put themselves at a disadvantage in influencing international science and innovation directions.[369]

## Attracting, training and retaining a skilled and diverse workforce

Each emerging knowledge-intensive industry will require a highly skilled workforce and will likely demand a range of different technical skills. However, STEM fields accounted for a small proportion of completed higher education degrees in Queensland in 2017[27] and fewer STEM-qualified people reside in Queensland (20 per cent of Australia's STEM-qualified workers) than New South Wales (33 per cent) or Victoria (25 per cent).[372] Consequentially, Queensland's emerging knowledge-intensive industries could experience future skills shortages. Stakeholders noted that early participation in STEM could leverage children's natural interest in science – a sentiment that aligns with the Queensland Government's Strategy for STEM in Queensland State Schools.[373]

Workers in emerging knowledge-intensive industries will also require soft skills. For example, the sustainable energy sector will require workers with ICT and data security skills as well as capabilities in customer service.[140] These skills or skill combinations might be novel for traditional sectors and differ from what is offered in current programs and courses. Queensland's education system will need to respond to these new requirements, particularly for courses in existing industries that are becoming more knowledge-intensive (e.g. mining, manufacturing and agriculture). School-based programs (e.g. the Gateway to Industry Schools program run by the Queensland Government[374]) and organisational programs (e.g. Rio Tinto's Pioneer Lab in Brisbane[375]) could also expose prospective students and workers to the new career options available in knowledge-intensive industries, helping to shift current outdated career perceptions.

Some of the in-demand skills and capabilities in emerging knowledge-intensive industries will likely overlap. For example, the technical skills needed to manage, analyse and protect data collected through platforms and sensors in the smart mining, exploration and extraction industry will likely overlap with the skills needed for similar processes in the personalised and preventative healthcare sector. While it will be important to incorporate these new capabilities into industry-specific courses, there could be value in developing generic courses that are designed for workers from a variety of different industries. These programs could be tailored to individuals who are currently engaged in the workforce and seeking further education and training to adapt to their changing role requirements or to transition into a new role.

Diversity is a key consideration for the future workforce, both in the research sector and across emerging industries. Indeed, stakeholders highlighted a lack of diversity as a current challenge facing the cyber-physical security workforce. Improving diversity is not only key to avoiding bias in data,[163] but also for ensuring that scientific research questions are representative of the broader community.[376] Outreach programs such as UQ's Women in Engineering Research[377] help promote diversity in male-dominated careers and are conducted in close collaboration with industry. Additional initiatives include the 'FindHer' service of Data61's Expert Connect platform, in which users can specifically search for female researchers with certain capabilities or expertise to improve female representation in male-dominated research domains.[365]

## Broadening the role of government as a customer, enabler or innovator

There are a number of different roles that government can play in supporting the growth of emerging knowledge-intensive industries. For instance, government can be an early customer or adopter of the products and services developed by an emerging industry, sending a positive signal to the market. Indeed, government contracts were integral to the development of Silicon Valley, as they afforded resources to high-tech firms during early phases of development.[63] Moreover, the success of Silicon Wadi was in part due to the Israeli Government's investment in technological innovations for the defence sector that later translated into civil applications. Research has also found that start-up firms which are government suppliers tend to perform better than those receiving grants and subsidies.[378]

Government can be an innovator too. For example, the US Defence Advanced Research Projects Agency was responsible for the world's first weather satellite, the first mobile robot capable of navigating its way through a room and the technology that underpinned the modern internet.[379] Moreover, Australia's DSTG has launched a $730 million Next Generation Technologies Fund to support research projects focused on key defence challenges and improve participation of small businesses in federal research and development that has the potential for commercialisation.[380] In Queensland, the Queensland Government's Business Development Fund provides early-stage co-investment funding in partnership with venture capital investors.[381] These initiatives position government in local and national innovation ecosystems.

Funding and procurement are not the only mechanisms through which government can support new knowledge-intensive industries. Indeed, Silicon Fen in Cambridge emerged without any formal government support. Government can facilitate industry growth instead by incentivising international start-ups, researchers and firms to come to Queensland, particularly in areas where current industry and research gaps exist. Government programs such as Hot DesQ[382] and Startup Onramp[383] are designed for this purpose, but stakeholders noted that regular showcase events which highlight Queensland's research excellence to domestic and international collaborators and investors could be useful too.

Government can also facilitate collaboration between sectors and with the community. From an industry–research collaboration perspective, government could facilitate better translation of research by providing the policy and funding settings that enable industry to take up these opportunities.

Moreover, government can facilitate greater community awareness and engagement in science. For instance, New York City's Genspace is a community lab where experts teach hands-on biology courses and anyone is able to access the laboratory facilities, equipment and basic lab training to conduct their own projects.[384] Finally, siloed data management systems and poor data governance can limit data use and sharing for industry or research purposes. There could be a role for government in developing and managing common data platforms that can be used by different institutions or sectors.

Stakeholders consulted as part of this research also noted the importance of linking Queensland's R&D activity to economic, social and environmental state priorities. For example, the South Australian Government has established the Premier's Research and Industry Fund Research Consortia Program which aims to promote cross-sector research collaborations that focus on the state's critical challenges or align with its economic priority areas.[385] There could be a role for government in linking state funding initiatives for the research sector with broader strategic objectives for the state and the economic, social and environmental opportunities provided by its emerging knowledge-intensive industries. Stakeholders noted that this gap currently exists in R&D activities associated with industries such as the resources sector.

## Positioning universities in supporting the advanced knowledge economy

Universities and research institutes play a critical role in driving knowledge creation, innovation and research application across emerging knowledge-intensive industries. For instance, the University of Cambridge helped facilitate the emergence of Silicon Fen, enabling staff to participate in commercial and business activities outside of the university without strict IP constraints.[72] Many Queensland universities and research institutes have developed their own commercialisation entities (e.g. UQ's UniQuest, QUT's Bluebox and USC's Innovation Centre) that aim to commercialise their IP through spin-out companies and improve the translation of research and technology outputs.

These commercialisation initiatives focus on transferring IP out of universities and research institutes for broader use, but the research sector also has a role to play in developing new IP in collaboration with industry, government and community partners. Graduate student–industry programs could help close current collaborative gaps that exist in all emerging knowledge-intensive industries. These include the Graduate Research Industry Partnerships run by Monash University – which connect businesses with graduate researchers to solve real-world industry problems and provide applied research experience[386] – and the Industry and PhD Research Engagement Program (iPREP) – an innovative collaboration between five universities in Western Australia that links PhD candidates with industry for short-term research projects.[387]

Future education and workforce requirements were a consideration for all emerging knowledge-intensive industries. While there is a role for all levels of the education sector to respond to changing requirements, universities will need to ensure their curriculums are responsive to emerging knowledge-intensive industry needs. Some industries identified in this report (e.g. the smart mining, exploration and extraction and advanced materials and precision engineering sectors) may struggle to grow their workforces as they are associated with traditional industries that are labour-intensive or declining. Universities, in partnership with government and industry, could support talent attraction in these industries through public campaigns that promote new education offerings and career pathways and include industry placements as part of degrees.

Universities will need to consider broadening their methods for delivering education too, acknowledging that prospective students may be seeking further education in response to changing job or industry requirements. Research by Alphabeta estimates that Australians will complete 41 per cent of their lifetime education and training after the age of 21 by 2040, compared to 19 per cent currently.[388] This increase in lifelong learning will likely be reflected in on-the-job and formal training over traditional university degrees.[388] Some universities are already responding to this change in demand, such as the University of New England's bespoke courses which allow students to choose up to four courses across the same or different degrees rather than completing a full degree.[389]

Finally, universities and research institutes will need to be mindful of emerging trends in early-career researchers. A recent survey found that 51 per cent of Australian PhD students intend to work in business or the public sector following graduation.[390] However, PhD programs largely prepare students for an academic career and they struggle to communicate the transferability of their skills for non-academic domains.[390] Employers do not send a clear demand signal either: 80 per cent of online job advertisements that are looking for candidates with advanced research skills do not list a PhD as a desired qualification.[391] Initiatives such as the iPREP program in Western Australia,[387] Advance Queensland's Industry Research Fellowships[392] and the Australian Postgraduate Research Intern program[393] will become increasingly important in preparing PhD graduates for non-academic careers in Queensland's knowledge economy.

# 6 CONCLUSION

This report presents a set of emerging knowledge-intensive industries that provide new opportunities for Queensland to grow and diversify its economy over the coming decades. These industries were defined by clusters of supply and demand trends and drivers, where changes in supply indicate opportunities to offer new products or services or deliver existing business processes more efficiently, and a change in demand opens up a new market. The discoveries, innovations and skilled workers provided by Queensland's science sector serve are key inputs into these emerging knowledge-intensive industries, helping existing or previously dormant industries become more knowledge-intensive or seeding entirely new industries.

The eight emerging knowledge-intensive industries identified in this report highlight major geopolitical, environmental, social, economic and technological shifts impacting Queensland's economy. These include pressures on natural resources, climate change, growing cybersecurity vulnerabilities, volatility in export markets and consumer preferences for personalised and higher value goods. But what will the path to emergence look like for each industry? While nascent local, national and international shifts in supply and demand present new opportunities for Queensland's knowledge economy, there are potential barriers that will need to be addressed in supporting future growth.

The sustainable energy industry represents the next evolution of energy generation and distribution and reflects growing demand for more reliable, sustainable and affordable energy. While Queensland has strong research capabilities in renewable energy, the pathway from discovery to commercialisation is typically slow and the current grid structure could limit adoption of new decentralised energy options. The cyber-physical security sector is responsive to rising uptake of technology and concerns around cybersecurity, drawing upon Queensland's research strengths in defence and robotics and autonomous systems. There are opportunities to broaden existing research capabilities into new technology domains, but growth in this sector rests upon efforts to improve to digital infrastructure and ICT skill shortages.

The smart mining, exploration and extraction industry draws on data platforms, sensors and advanced automation to increase knowledge intensity across the entire mining value chain. Queensland has a mature mining sector and strong capabilities in METS research, but current industry–research collaborations are fragmented, and public perceptions of mining careers make it difficult to attract in-demand skills. The personalised and preventative healthcare industry supports the delivery of customised and proactive healthcare services and leverages Queensland's world-class biomedical infrastructure and research institutes. Future efforts will need to address current gaps in the use of medical data and the commercialisation of biomedical research to help grow this sector.

Queensland's long-standing manufacturing base is already becoming more knowledge-intensive, giving rise to the advanced materials and precision engineering industry. This sector is supported by enabling sensor technologies, robotics and automation, but it is limited by access to infrastructure for SMEs and challenges in recruiting its future workforce due to public views of the industry. The next generation aerospace and space technologies sector designs, develops and tests a range of flight vehicles and Queensland's geographical strengths and base of aerospace businesses and contractors put it in a competitive position to grow this industry. Space-related infrastructure developments could help attract firms and research collaborators to Queensland, but this will need to coincide with efforts to address local workforce gaps.

Advanced agriculture firms are increasing the value of food and agriculture products through enhanced processing, production and distribution methods, drawing upon Queensland's strengths in food science research. This industry is driven by demand for sustainable, secure and nutritious food, but is hindered by current limitations in the industry relevance of research projects and regional digital connectivity gaps. The circular commodities industry provides economic and environmental benefits to the state by reducing, recycling and repurposing waste products. For the sector to succeed, biotechnology applications need to be feasible and commercially viable for industry and public awareness around recycling practices could be improved.

This report raises implications for future policy and strategic decisions in Queensland's science sector. For instance, collaboration is a persistent challenge for all emerging knowledge-intensive industries, whether it be across sectors, institutions or disciplines. Given these sectors draw upon diverse capabilities that extend beyond a single entity or discipline, and international firms, investors and collaborators are attracted to capability clusters, collaboration will be an important enabler of future growth. Government and research stakeholders can support Queensland's evolving knowledge economy in a number of ways. For instance, universities can facilitate cross-sector or cross-disciplinary research and design courses and programs that are responsive to the changing education and skill requirements of these industries.

Each of the eight emerging knowledge-intensive industries will likely mature over different timespans in coming decades and current barriers to growth may be more difficult to address in some industries than others. This report is designed to present the options available for Queensland's economy – based on existing research capabilities, enabling technologies and emerging trends in local, national and international markets – and highlight potential future challenges. Moving forward, it will be important to identify a process for addressing these challenges, acknowledging the role for government, industry and research stakeholders, and potentially prioritising different opportunities. Through a coordinated effort, Queensland can realise the full potential of its growing and evolving knowledge economy.

# APPENDIX A: STRATEGIC FORESIGHT METHODOLOGY

This project employed strategic foresight approaches to identify emerging sources of knowledge-intensification across Queensland's economy over the coming decade. CSIRO's Data61 has developed its generic strategic foresight process which was adapted for the purposes of this project. This research protocol was approved by the CSIRO Social Science Human Research Ethics Committee.

The first stage consisted of a background study and scope definition. This phase involved mapping out the current state of Queensland's knowledge economy and historical conditions. The second stage corresponded to the horizon scan, where the project team conducted desktop research and investigative interviews with stakeholders across government, industry and the research sector. This stage had a broad focus and was intended to identify any potentially relevant trends, drivers and areas of competitive advantage for Queensland.

In the third stage, these trends, drivers and areas of competitive advantage were screened, validated, classified and prioritised to ensure they were supported by robust evidence and were relevant to the project's scope. Trends were collated to identify clusters which signalled emerging knowledge-intensive industries that would likely emerge as a mature industry over the next 10 years. Industries, and their broader industry structure, were quantified using current trends in firm and employment growth, ensuring each industry showed positive growth in one or both of these variables (i.e. corresponding to the 'co-evolutionary' phase of industry emergence; see Appendix B for further details).

The fourth stage served to validate the draft outputs of the project via a validation workshop with stakeholders across government, industry and the research sector. The outputs of this workshop were used to refine the definitions and supporting trends associated with each knowledge-intensive industry. In the final stage, the research findings and their implications for Queensland's science sector were refined and prepared for communication to the broader stakeholder community.

1

**UNDERSTAND CORE ISSUES, QUESTIONS & SCOPE OF PROJECT**

PROJECT INCEPTION & BACKGROUND STUDY

2

**CONDUCT HORIZON SCAN**

DESKTOP RESEARCH & INVESTIGATIVE INTERVIEWS

GEOPOLITICAL | SOCIAL | ECONOMIC | ENVIRONMENTAL | TECHNOLOGICAL

3

**IDENTIFY EMERGING KNOWLEDGE-INTENSIVE INDUSTRIES**

SCREEN, CLASSIFY, VALIDATE & PRIORITISE TRENDS
DEVELOP DRAFT EMERGING INDUSTRIES

4

**TEST & REFINE EMERGING INDUSTRIES**

STAKEHOLDER VALIDATION WORKSHOP

5

**CRAFT & COMMUNICATE FINAL REPORT**

INFORM FUTURE STRATEGIC & POLICY DECISIONS

# APPENDIX B:
# METHODOLOGY FOR QUANTIFYING EMERGING KNOWLEDGE-INTENSIVE INDUSTRIES

## Modelling approach for emerging industries

This project quantified the number of firms and employees associated with each emerging knowledge-intensive industry. For the purpose of modelling, industries were defined by a subset of 3-digit ANZSIC (Australian and New Zealand Standard Industrial Classification) categories which were assumed to form part of the new cross-sector relationships defined in each emerging industry and its broader industry structure. Employment data was sourced from the ABS Labour Force Survey (2008–18)[86] and firm data was sourced from the ABS Counts of Australian Businesses (2008–17).[87] Historical trends in employment and the number of firms were calculated using data corresponding to the ANZSIC codes identified for each industry.

ANZSIC categories were selected via two steps. First, core activities associated with each emerging industry were selected based on the qualitative definition of each industry. Second, upstream and downstream activities associated with each core activity were identified according to historical industry input-output data and expert opinions. Upstream sectors could include those that provide raw materials and other industrial inputs for core activities (e.g. design and R&D) and downstream sectors include primary purchasers and distributors. The industry categories associated with each emerging industry were benchmarked against other similar emerging industry analyses conducted in the EU and the United States.

Employment estimates included both knowledge workers (i.e. defined as workers employed as managers and administrators, professionals and associate professionals[19]) and non-knowledge workers. The proportion of employment associated with knowledge workers in each emerging industry was calculated via a two-step procedure. First, the percentage of knowledge workers for each industry at the 1-digit ANZSIC code was calculated using the Queensland Government Statistician's Office's Queensland Regional Database.[20] Second, this value was weighted for each industry based on the proportion of employment in that industry (at the 3-digit ANZSIC code level) that is accounted for in that 1-digit ANZSIC code.

## ANZSIC category definitions for emerging industries

### SUSTAINABLE ENERGY

| SECTOR | ANZSIC (3-DIGIT CODE) |
|---|---|
| **Manufacturing** | 231 Motor Vehicle and Motor Vehicle Part Manufacturing |
| | 243 Electrical Equipment Manufacturing |
| | 245 Pump, Compressor, Heating and Ventilation Equipment Manufacturing |
| **Electricity, Gas, Water and Waste Services** | 261 Electricity Generation |
| | 262 Electricity Transmission |
| | 263 Electricity Distribution |
| | 264 On Selling Electricity and Electricity Market Operation |
| **Construction** | 323 Building Installation Services |
| **Wholesale Trade** | 349 Other Machinery and Equipment Wholesaling |
| **Rental, Hiring and Real Estate Services** | 664 Non-Financial Intangible Assets (Except Copyrights) Leasing |
| **Information Media and Telecommunication** | 542 Software Publishing |
| | 592 Data Processing, Web Hosting and Electronic Information Storage Services |
| **Professional, Scientific and Technical Services** | 691 Scientific Research Services |
| | 692 Architectural, Engineering and Technical Services |
| | 696 Management and Related Consulting Services |
| | 699 Other Professional, Scientific and Technical Services |
| | 700 Computer System Design and Related Services |

## CYBER-PHYSICAL SECURITY

| SECTOR | ANZSIC (3-DIGIT) CODE |
|---|---|
| **Manufacturing** | 241 Professional and Scientific Equipment Manufacturing |
| | 242 Computer and Electronic Equipment Manufacturing |
| **Information Media and Telecommunication** | 542 Software Publishing |
| | 592 Data Processing, Web Hosting and Electronic Information Storage Services |
| **Financial and Insurance services** | 632 Health and General Insurance |
| | 642 Auxiliary Insurance Services |
| **Rental, Hiring and Real Estate Services** | 664 Non-Financial Intangible Assets (Except Copyrights) Leasing |
| **Professional, Scientific and Technical Services** | 691 Scientific Research Services |
| | 692 Architectural, Engineering and Technical Services |
| | 693 Legal and Accounting Services |
| | 696 Management and Related Consulting Services |
| | 699 Other Professional, Scientific and Technical Services |
| | 700 Computer System Design and Related Services |
| **Public Administration and Safety** | 772 Regulatory Services |
| **Other Services** | 942 Machinery and Equipment Repair and Maintenance |

## SMART MINING, EXPLORATION AND EXTRACTION

| SECTOR | ANZSIC (3-DIGIT) CODE |
|---|---|
| **Mining** | 060 Coal Mining |
| | 070 Oil and Gas Extraction |
| | 080 Metal Ore Mining |
| | 091 Construction Material Mining |
| | 099 Other Non-Metallic Mineral Mining and Quarrying |
| | 101 Exploration and Other Mining Support Services |
| | 109 Other Mining Support Services |
| **Manufacturing** | 246 Specialised Machinery and Equipment Manufacturing |
| | 249 Other Machinery and Equipment Manufacturing |
| **Construction** | 329 Other Construction Services |
| **Wholesale Trade** | 341 Specialised Industrial Machinery and Equipment Wholesaling |
| **Transport** | 502 Pipeline and Other Transport |
| | 529 Other Transport Support Services |
| **Information Media and Telecommunication** | 542 Software Publishing |
| | 592 Data Processing, Web Hosting and Electronic Information Storage Services |
| **Rental, Hiring and Real Estate Services** | 661 Motor Vehicle and Transport Equipment Rental and Hiring |
| | 663 Other Goods and Equipment Rental and Hiring |
| | 664 Non-Financial Intangible Assets (Except Copyrights) Leasing |
| **Professional, Scientific and Technical Services** | 691 Scientific Research Services |
| | 692 Architectural, Engineering and Technical Services |
| | 696 Management and Related Consulting Services |
| | 699 Other Professional, Scientific and Technical Services |
| | 700 Computer System Design and Related Services |

## PERSONALISED AND PREVENTATIVE HEALTHCARE

| SECTOR | ANZSIC (3-DIGIT CODE) |
|---|---|
| **Manufacturing** | 184 Pharmaceutical and Medicinal Product Manufacturing<br>241 Professional and Scientific Equipment Manufacturing<br>242 Computer and Electronic Equipment Manufacturing<br>249 Other Machinery and Equipment Manufacturing |
| **Wholesale Trade** | 341 Specialised Industrial Machinery and Equipment Wholesaling<br>372 Pharmaceutical and Toiletry Goods Wholesaling |
| **Retail** | 427 Pharmaceutical and Other Store-Based Retailing |
| **Information Media and Telecommunication** | 542 Software Publishing<br>592 Data Processing, Web Hosting and Electronic Information Storage Services |
| **Rental, Hiring and Real Estate Services** | 664 Non-Financial Intangible Assets (Except Copyrights) Leasing |
| **Professional, Scientific and Technical Services** | 691 Scientific Research Services<br>692 Architectural, Engineering and Technical Services<br>697 Veterinary Services<br>699 Other Professional, Scientific and Technical Services<br>700 Computer System Design and Related Services |
| **Healthcare and Social Assistance** | 840 Hospitals<br>851 Medical Services<br>852 Pathology and Diagnostic Imaging Services<br>859 Other Healthcare Services<br>860 Residential Care Services<br>879 Other Social Assistance Services |

## ADVANCED MATERIALS AND PRECISION ENGINEERING

| SECTOR | ANZSIC (3-DIGIT CODE) |
|---|---|
| **Manufacturing** | 161 Printing and Printing Support Services<br>170 Petroleum and Coal Product Manufacturing<br>181 Basic Chemical Manufacturing<br>182 Basic Polymer Manufacturing<br>189 Other Basic Chemical Product Manufacturing<br>191 Polymer Product Manufacturing<br>202 Ceramic Product Manufacturing<br>209 Other Non-Metallic Mineral Product Manufacturing<br>213 Basic Non-Ferrous Metal Manufacturing<br>214 Basic Non-Ferrous Metal Product Manufacturing<br>229 Other Fabricated Metal Product Manufacturing<br>241 Professional and Scientific Equipment Manufacturing<br>242 Computer and Electronic Equipment Manufacturing<br>243 Electrical Equipment Manufacturing<br>245 Pump, Compressor, Heating and Ventilation Equipment Manufacturing<br>246 Specialised Machinery and Equipment Manufacturing<br>249 Other Machinery and Equipment Manufacturing |
| **Wholesale Trade** | 341 Specialised Industrial Machinery and Equipment Wholesaling<br>349 Other Machinery and Equipment Wholesaling |
| **Information Media and Telecommunication** | 542 Software Publishing<br>592 Data Processing, Web Hosting and Electronic Information Storage Services |
| **Rental, Hiring and Real Estate Services** | 664 Non-Financial Intangible Assets (Except Copyrights) Leasing |
| **Professional, Scientific and Technical Services** | 691 Scientific Research Services<br>692 Architectural, Engineering and Technical Services<br>695 Market Research and Statistical Services<br>699 Other Professional, Scientific and Technical Services<br>700 Computer System Design and Related Services |
| **Other Services** | 942 Machinery and Equipment Repair and Maintenance |

## NEXT GENERATION AEROSPACE AND SPACE TECHNOLOGIES

| SECTOR | ANZSIC (3-DIGIT CODE) |
|---|---|
| **Manufacturing** | 239 Other Transport Equipment Manufacturing<br>242 Computer and Electronic Equipment Manufacturing<br>246 Specialised Machinery and Equipment Manufacturing |
| **Transport, Postal and Warehousing** | 490 Air and Space Transport<br>522 Airport Operations and Other Air Transport Support Services |
| **Information Media and Telecommunication** | 542 Software Publishing<br>561 Radio Broadcasting<br>562 Television Broadcasting<br>570 Internet Publishing and Broadcasting<br>580 Telecommunications Services<br>592 Data Processing, Web Hosting and Electronic Information Storage Services |
| **Rental, Hiring and Real Estate Services** | 664 Non-Financial Intangible Assets (Except Copyrights) Leasing |
| **Professional, Scientific and Technical Services** | 691 Scientific Research Services<br>692 Architectural, Engineering and Technical Services<br>699 Other Professional, Scientific and Technical Services<br>700 Computer System Design and Related Services |

## ADVANCED AGRICULTURE

| SECTOR | ANZSIC (3-DIGIT CODE) |
|---|---|
| **Agriculture, Forestry and Fishing** | 011 Nursery and Floriculture Production<br>012 Mushroom and Vegetable Growing<br>013 Fruit and Tree Nut Growing<br>014 Sheep, Beef Cattle and Grain Farming<br>015 Other Crop Growing<br>016 Dairy Cattle Farming<br>017 Poultry Farming<br>018 Deer Farming<br>019 Other Livestock Farming<br>020 Aquaculture<br>052 Agriculture and Fishing Support Services |
| **Manufacturing** | 111 Meat and Meat Product Manufacturing<br>112 Seafood Processing<br>113 Dairy Product Manufacturing<br>114 Fruit and Vegetable Processing<br>115 Oil and Fat Manufacturing<br>116 Grain Mill and Cereal Product Manufacturing<br>117 Bakery Product Manufacturing<br>118 Sugar and Confectionery Manufacturing<br>119 Other Food Product Manufacturing<br>183 Fertiliser and Pesticide Manufacturing<br>184 Pharmaceutical and Medicinal Product Manufacturing<br>246 Specialised Machinery and Equipment Manufacturing |
| **Wholesale Trade** | 331 Agricultural Product Wholesaling<br>360 Grocery, Liquor and Tobacco Product Wholesaling |
| **Transport, Postal and Warehousing** | 530 Warehousing and Storage Services |
| **Information Media and Telecommunication** | 542 Software Publishing<br>592 Data Processing, Web Hosting and Electronic Information Storage Services |
| **Rental, Hiring and Real Estate Services** | 664 Non-Financial Intangible Assets (Except Copyrights) Leasing |
| **Professional, Scientific and Technical Services** | 691 Scientific Research Services<br>692 Architectural, Engineering and Technical Services<br>697 Veterinary Services<br>700 Computer System Design and Related Services |

## CIRCULAR COMMODITIES

| SECTOR | ANZSIC (3-DIGIT CODE) |
|---|---|
| **Manufacturing** | 152 Converted Paper Product Manufacturing |
| | 181 Basic Chemical Manufacturing |
| | 182 Basic Polymer Manufacturing |
| | 183 Fertiliser and Pesticide Manufacturing |
| | 191 Polymer Product Manufacturing |
| **Electricity, Gas, Water and Waste Services** | 281 Water Supply, Sewerage and Drainage Services |
| | 291 Waste Collection Services |
| | 292 Waste Treatment, Disposal and Remediation Services |
| **Information Media and Telecommunication** | 542 Software Publishing |
| | 592 Data Processing, Web Hosting and Electronic Information Storage Services |
| **Rental, Hiring and Real Estate Services** | 664 Non-Financial Intangible Assets (Except Copyrights) Leasing |
| **Professional, Scientific and Technical Services** | 691 Scientific Research Services |
| | 692 Architectural, Engineering and Technical Services |
| | 700 Computer System Design and Related Services |

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