# NEW
# SMARTS

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

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Queensland
Government

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# INTRODUCTION

Knowledge is an increasingly important driver of Queensland's economy and will support the state in growing and diversifying its industries in the future. The science sector contributes to the knowledge-intensification of existing industries and emergence of entirely new industries in numerous ways (e.g. through the provision of skilled labour or research into new discoveries), but these connections can be complex and are not always clear cut.

This report identifies eight emerging 'knowledge-intensive industries', defined as those that do, or are predicted to, draw heavily on technology and/or human capital inputs. These industries fall at the intersection of Queensland's enabling technologies and research excellence, areas of comparative advantage and shifts in local, regional and global markets. This report illustrates the options available for Queensland whilst acknowledging current barriers that could impact future growth.

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 the Queensland Government and Data61. Q-Foresight provides state government agencies with improved information for decision making about future trends, risks and scenarios.

This report is divided into four sections:

- Section one defines the distinct phases of industry emergence, from the initial phase to maturity, showing how new industries form and the factors that can help or hinder growth.
- Section two presents four case studies of knowledge clusters that have emerged internationally and in Queensland, illustrating the different pathways through which nascent industries can grow.
- Section three presents eight emerging knowledge-intensive industries for Queensland, their supporting sources of supply and demand and the current barriers that require attention.
- Section four looks at the implications for future strategic and policy decisions concerning science in Queensland, exploring how the sector could support these emerging industries in the future.

Using a strategic foresight approach, this report provides a long-term view for Queensland's knowledge economy over the coming decade and the opportunities and challenges on the horizon. It identifies areas where the science sector can support existing or previously dormant industries in diversifying into new markets, products or services, and others where shifts in demand could spur new avenues for research and industry development.

To harness these industry opportunities, current shortcomings in Queensland's research collaboration and translation efforts, access to infrastructure and skilled labour, and education and training will need to be addressed. These challenges – some of which are common across emerging industries – will require joint involvement from government, industry and research stakeholders.

This report serves as a discussion starter for Queensland Government and its stakeholders around the role of science and research in Queensland and how the sector can contribute to future industry growth and diversification. It is designed to inform long-term strategies, policies and plans that will support the state in realising the full potential of its growing and evolving knowledge economy in coming decades.
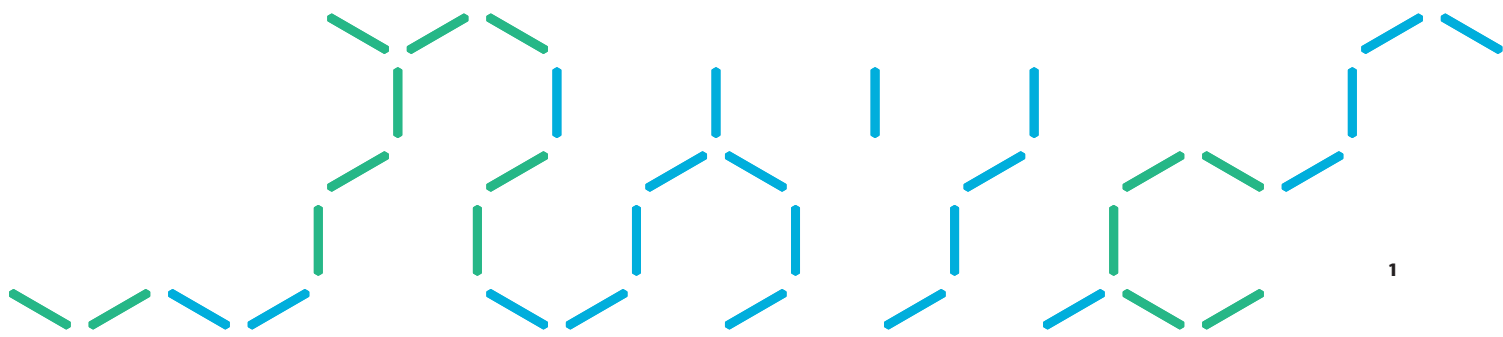
# DEFINING INDUSTRY
# EMERGENCE

Internal and external forces are reshaping existing industries and giving rise to new ones. Emerging industries reflect the earliest phases of development, where the boundaries between markets, technologies and industries are yet to crystallise.[1,2] They may be a sub-sector or technology-driven niche market of an existing industry,[3] or an entirely new industry born from a new discovery or innovation[4] or the convergence of multiple technologies.[5]
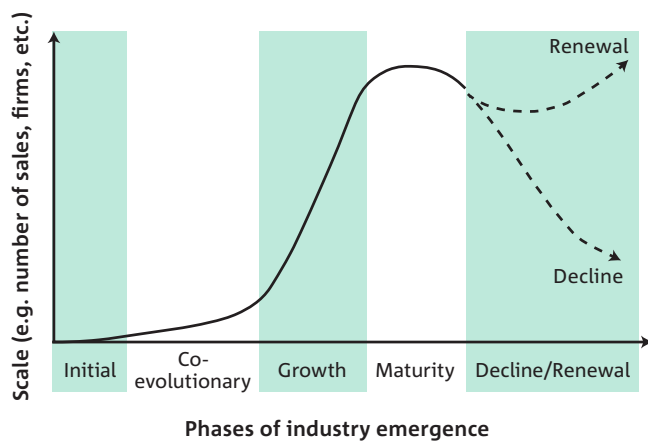


**Figure 1. Key phases of industry emergence**

Source: Adapted from Phaal et al.[2]

Industries emerge over three phases: initial, co-evolutionary and growth (see Figure 1).

1. **Initial phase:** In this phase, industry, market or technological conditions start to shift, but the new industry structure or identity is not yet clear.[6] While there are high levels of entrepreneurial activity and opportunities for new entrants and first-movers in this phase,[6] firms often lack sufficient resources, practices and skills.[7]

2. **Co-evolutionary phase:** Here the number of firms in the industry grows[8] and there is rapid imitation of organisational, technical, product and service innovations across firms.[6,9] The industry identity becomes clearer,[10] supported by networks of enterprises, universities, venture capitalists, government agencies and professional associations.[11]

3. **Growth phase:** Firm growth reaches its peak and begins to plateau in this phase,[8] coinciding with strong and rapid growth in industry sales.[6] The establishment of a dominant design and common industry standards helps cement the new industry,[10] but this also generates increased competition between existing firms and new entrants.[12]

In later phases of industry formation, industry applications, production processes and business models reach maturity.[2] Each phase of industry emergence is impacted by the broader socio-economic landscape too. For example, limited access to MP3s and broadband internet hindered Saehan's MPMan – the first digital audio player – from gaining an early foothold in the market prior to Apple's iPod.[13] For the purposes of this report, emerging knowledge-intensive industries were defined as those corresponding to the co-evolutionary phase of industry formation.

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

# KNOWLEDGE
## CLUSTERS

New knowledge clusters can emerge via a variety of factors. This section highlights four case studies of knowledge clusters that have emerged domestically and internationally, exploring the distinct roles that local governments, universities, research institutes and private companies played in supporting their emergence. These case studies demonstrate that there are multiple pathways through which an industry can emerge, but strong scientific and technological capabilities are core elements.

## Silicon Valley

Silicon Valley in the San Francisco Bay Area is a successful technology and knowledge-intensive cluster that accounts for a significant share of employment in the area (26.1 per cent in 2018)[14] and generates more patent registrations than the rest of California (636 versus 106 per 100,000 people, respectively).[15] The success of Silicon Valley was supported by infrastructure, expertise and industry–research–government collaborations that were developed with the aid of government support.

The Bay Area had a strong US Navy presence and business community[16] and major government defence-related contracts acted like an incubator for high-tech firms in the early phases of development.[16] Further enabling factors included collaborations with local universities (e.g. Stanford University)[16] and significant regulatory changes (e.g. universities were permitted to commercialise intellectual property [IP] from federally funded research[17] and citizens were allowed to invest their pensions in venture captial[18]).

## Silicon Fen

Silicon Fen refers to the cluster of technology, bioscience and medicine companies that rapidly emerged in Cambridge, United Kingdom (i.e. the 'Cambridge Phenomenon'). This knowledge cluster has founded about 5,000 firms since 1960[19] and accounted for 29 per cent of employment in Cambridge in 2015–16.[20] The University of Cambridge was a key facilitator and this knowledge cluster emerged without government engineering.

First, Cambridge University relaxed its university IP restrictions for staff, enabling them to pursue commercial and business opportunities.[21] Second, it had a good supply of in-demand skilled workers in areas such as information technology and could respond promptly to industry demand for these skills.[21] Access to land[22] and the lifestyle benefits of the region[21] were also natural advantages for infrastructure development and talent attraction.



**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. This cluster accounted for a quarter of all Israeli high-tech companies in 2018 and employed 38,091 people in 2016 (12 per cent of Israel's total workforce).[23] The success of Silicon Wadi and Israeli's broader technology industry has been attributed to several factors.

First, Israel invested heavily in high-tech industries to improve its global competitiveness and this was supported by its existing telecommunications infrastructure and highly educated workforce.[24] Second, the Israeli military provided training for high school graduates in military technologies, which could be spun off commercially.[24] Third, the Israeli Government funded various initiatives (e.g. the Technological Incubators Program[25,26]), which continue to foster innovation between the military and other sectors.[24]

## 'Silicon Sunshine'

Queensland is home to the Gold Coast Health and Knowledge Precinct, which reflects the emergence of a new knowledge cluster (coined here as '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. It has already created 9,200 jobs and will contribute 11,000 more and $1.4 billion to the Queensland economy once completed.[27]

The Queensland Government has been heavily involved in the design of this development,[27] contributing $2.4 million in the 2019–20 state budget.[28] The Precinct capitalises on its proximity to local universities, hospitals and research institutes and has connecting infrastructure to other knowledge hubs in South East Queensland.[27] The concentration of experts and world-leading institutes and facilities have been critical in building the Precinct's clinical trial capacity and reputation[29] and attracting international firms such as Materialise – a world-leading additive manufacturing company.[30]

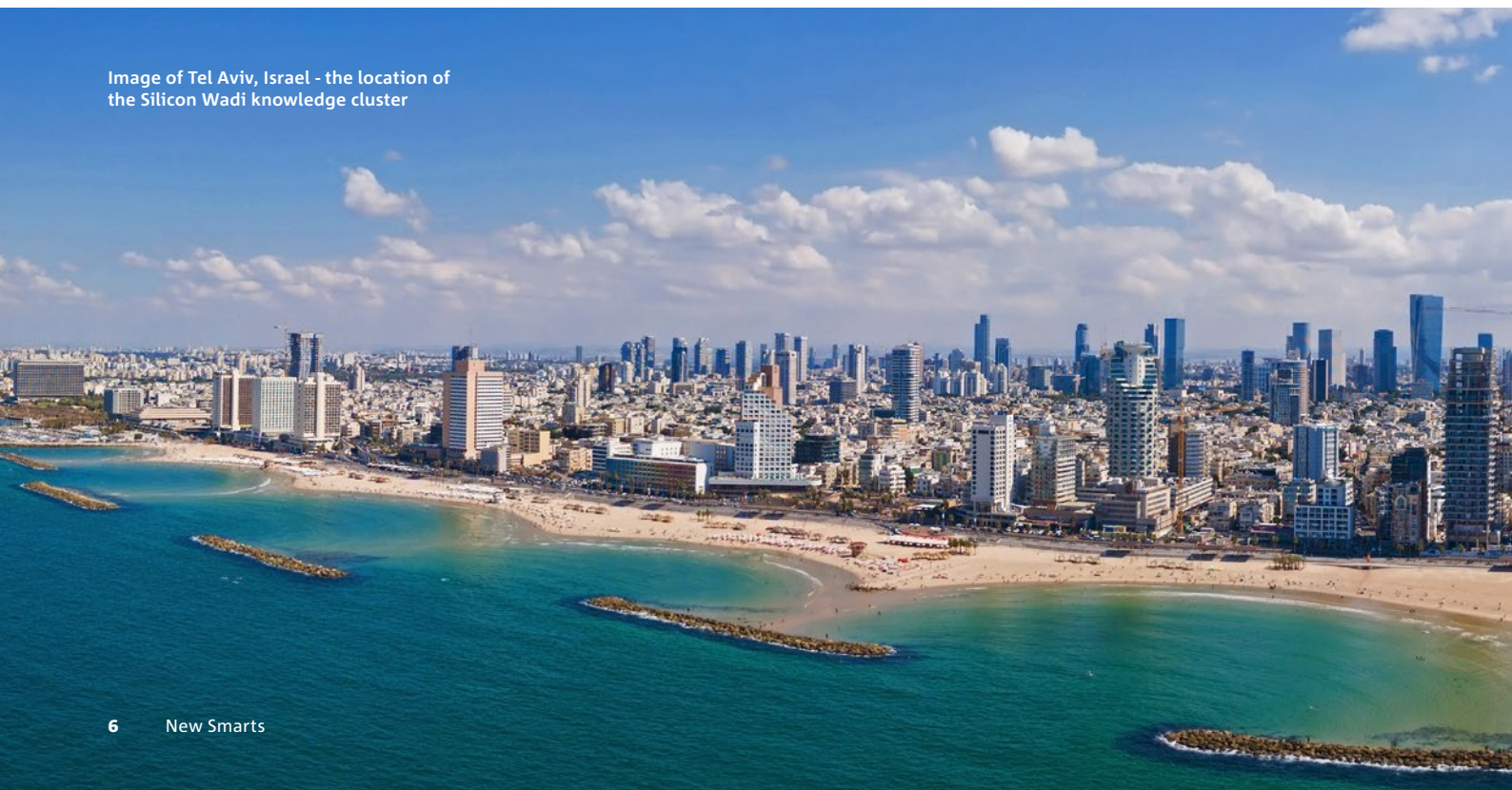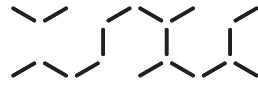**Image of Tel Aviv, Israel - the location of the Silicon Wadi knowledge cluster**

Image of the Gold Coast, Queensland, Australia - the location of the 'Silicon Sunshine' knowledge cluster

# EIGHT EMERGING
## INDUSTRIES

This report identifies eight emerging knowledge-intensive industries that fall at the intersection of multiple supply and demand trends and drivers. Here a change in supply presents opportunities to offer new products or services or provide existing ones more efficiently, and a change in demand can create new markets or customer preferences. These emerging industries could provide significant economic, social or environmental benefits for the state.

Each emerging knowledge-intensive industry is supported by enabling technologies, changes in local, national and global markets and existing expertise in various scientific domains. This section provides a summary of each industry and their supporting trends and quantifies current growth in terms of the number of firms and employees. Here firm growth is taken as a lead indicator of industry emergence. Methodology details for defining and estimating industries are provided in the full version of the research report.

## Sustainable energy

The sustainable energy industry designs, manufactures, installs and manages products that store and distribute reliable and affordable energy. Some firms offer products such as solar photovoltaic (PV) panels, wind turbines, batteries, smart grid and micro-grid technologies and household 'smart' devices, while others offer advisory services for organisations looking to switch to cheaper, more reliable and sustainable energy sources.

This industry is driven by geopolitical, environmental and consumer pressures to transition to a low-carbon economy. In support of this, the Queensland Government has committed to achieving zero net greenhouse gas emissions by 2050[31], invested $150 million in a clean energy hub in North and North-West Queensland[32] and developed a Queensland Hydrogen Industry Strategy to position the state as a future hydrogen supplier.[33]



Sustainable energy

Cyber-physical security

Smart mining, exploration and extraction

Personalised and preventative healthcare

Advanced materials and precision engineering

Next generation aerospace and space technologies

Advanced agriculture

Circular commodities
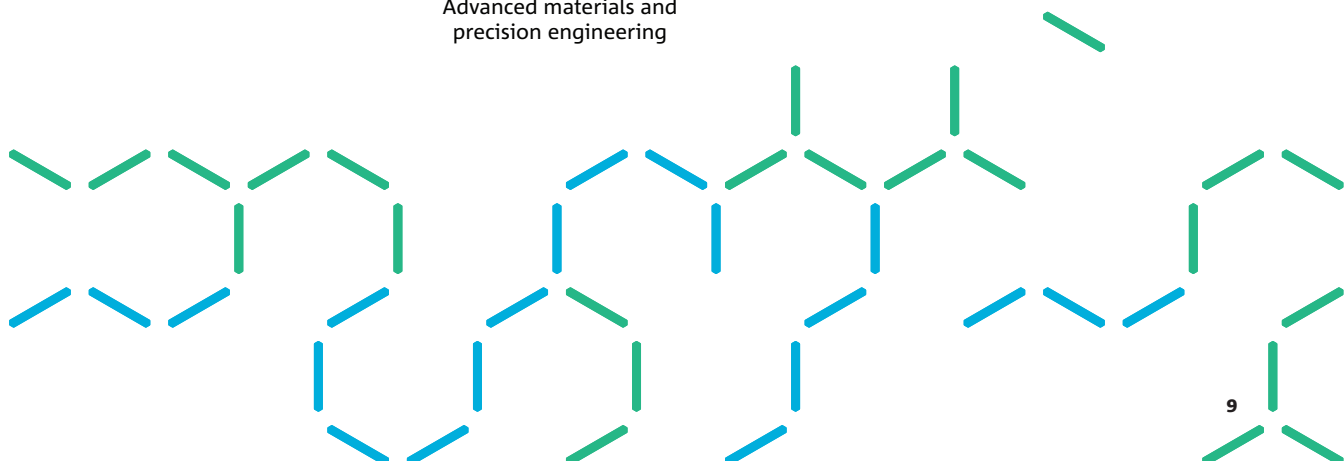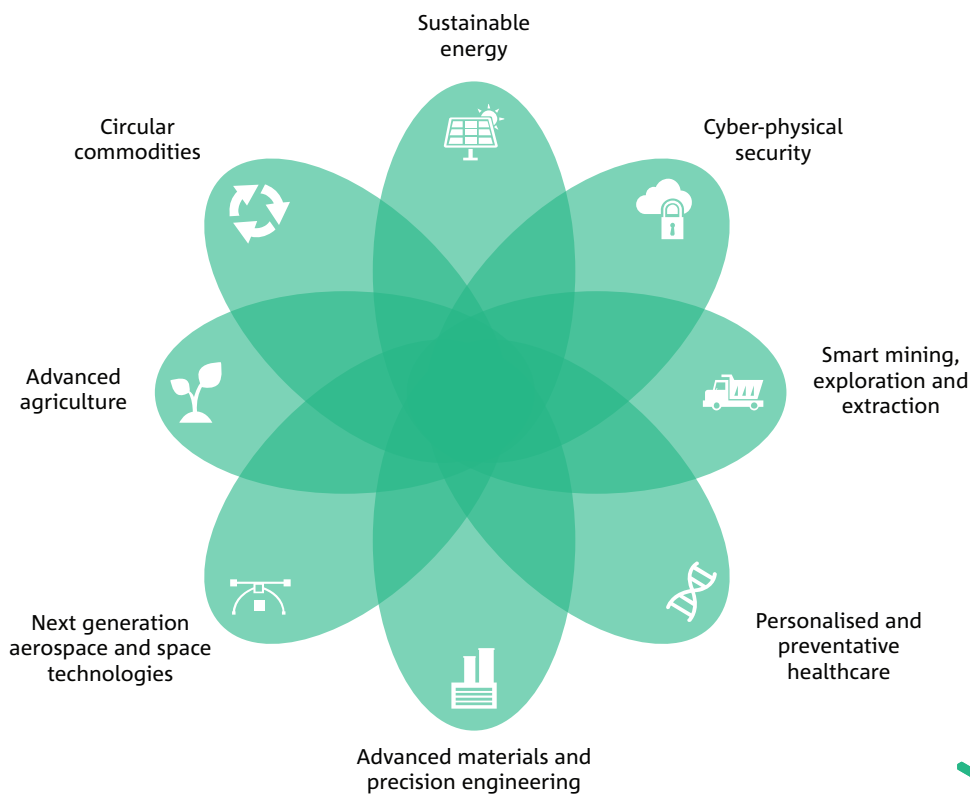
**Figure 2. Cost of lithium-ion batteries worldwide (in dollars per kWh)**

Data source: Bloomberg New Energy Finance[34]

Queensland has natural strengths (e.g. 8.2 hours of sunshine per day in Brisbane versus 7.1 in Sydney[35]) and has the largest share of rooftop PV systems[36] and generates the most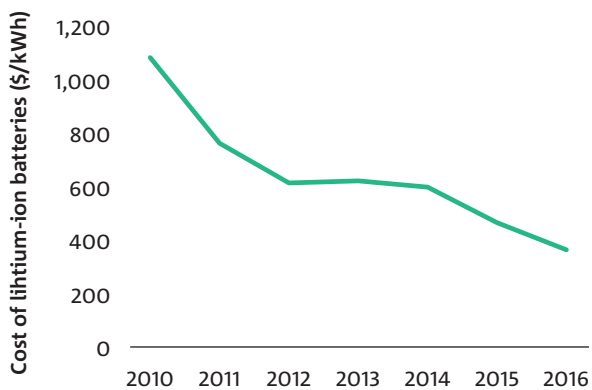 amount of solar electricity in Australia[37]. Renewable sources of energy are also becoming more economically viable, with wholesale electricity prices up 57 per cent from 2015–16 to 2016–17[38] and the cost of lithium-ion batteries on the decline (see Figure 2).

Queensland has strong research and development (R&D) capabilities in renewable energy, advanced manufacturing and environmental sustainability. For example, the Australian Institute for Bioengineering and Nanotechnology and Dow Centre for Sustainable Engineering and Innovation have developed flexible, ultra-thin batteries[39] and the Centre for Clean Environment and Energy at Griffith University conducts research into a range of sustainability domains, including energy storage devices.[40]

| OPPORTUNITIES FOR GROWING SUSTAINABLE ENERGY | |
| --- | --- |
| **Research** | • 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** | • 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** | • 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 for cyber-physical systems (i.e. those that consist of both software and physical components). Firms offer security solutions for specific devices, platforms or systems, or advisory services to help organisations adopt more cyber-secure practices. This industry will be responsive to the cybersecurity needs of other emerging digital industries in Queensland that require these outputs.

Global demand for cybersecurity remains strong, particularly from the Indo-Pacific region, with AustCyber estimating that global expenditure on cybersecurity will increase from $170 billion in 2017 to $347 billion by 2026.[41] Australia has a competitive advantage in software, services that protect organisational networks, applications and endpoints and services that increase awareness of cybersecurity risks in organisations.[41]

Queensland has existing research strengths in robotics, aerospace and autonomous systems, such as the Robotics and Autonomous Systems group at Queensland University of Technology (QUT), CSIRO's Data61 Robotics and Autonomous Systems Group and the Brisbane-based Australian Centre for Robotic Vision. The Queensland Government also plans to establish an AI Hub in Brisbane to attract world-leaders in artificial intelligence.[42]

Queensland is plugged into national initiatives in robotics, autonomous systems and cybersecurity too, such as the Sixth Wave Alliance[43] and the Cybersecurity Collaborative Research Centre (CRC), which is jointly funded by federal and state government, industry, university and research partners.[44] Finally, Queensland has a strong defence industry and is home to the headquarters for the first Defence CRC for Trusted Autonomous Systems,[45] which will support the development of robotics and autonomous systems for defence and other cyber-physical industries.

| OPPORTUNITIES FOR GROWING CYBER-PHYSICAL SECURITY | |
|---|---|
| **Research** | • Focusing future research efforts on cyber-physical security solutions that are relevant for Queensland's industries |
| | • Balancing research focus on specialised technical domains with the need for research into cyber-secure behaviours and ethics of data and technology use |
| | • Importance of cross-sector collaborations in R&D in developing exportable cyber-physical security solutions |
| **Infrastructure** | • Addressing digital connectivity gaps, particularly in regional Queensland, to remain globally competitive |
| | • Drawing upon innovations from other emerging industries (e.g. the space sector) to address infrastructure gaps |
| **Education and the workforce** | • Addressing existing shortages in skilled professionals for Australia's growing cybersecurity workforce |
| | • Sourcing labour supply from other disciplines like law, communications and psychology |
| | • Ensuring the industry responds to broader population needs by encouraging workforce diversity |

# Smart mining, exploration and extraction

The smart mining, exploration and extraction industry uses sensor, drone and platform technologies and advanced automation to improve mining efficiency, safety and sustainability. Firms offer solutions for the entire mining value chain from exploration to remediation.[46] This industry is closely connected to other emerging industries (e.g. the space and cyber-physical security sectors), drawing upon their outputs for remote operations.

Queensland has a strong base in resources and METS (mining equipment, technology and services). The mining sector accounted for 11.8 per cent of gross state product and employed 61,000 people in 2017–18[47,48] and there are over 800 METS firms in Queensland.[49] Declining ore grade quality[50] and volatility in commodity prices,[51] however, have created an imperative for the resources sector to innovate, diversify and become more resilient.

Queensland's mining industry is becoming more knowledge-intensive, with the sector accounting for the largest share of business expenditure on R&D in 2015–16 (see Figure 3). Queensland also has 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).[49]

Mining innovations are focused on safety and productivity improvements. For example, Queensland-based company Emesent uses drones to collect data in dangerous underground mine sites[53] and Interlate develops systems for mining companies to derive real-time insights from operational data.[54] Low public trust in mining companies[55] is also driving demand for mine remediation and closure services.[46] Indigenous knowledge could be used to inform the design of future remediation and closure planning services.[56,57]

**Pie chart legend:**

- 1) Mining
- 2) Manufacturing
- 3) Wholesale Trade
- 4) Construction
- 5) Retail Trade
- 6) Information Media and Telecommunications
- 7) Electricity, Gas, Water and Waste Services
- 8) Health Care and Social Assistance
- 9) Education and Training
- 10) Professional, Scientific and Technical Services
- 11) Financial and Insurance Services
- 12) Administrative and Support Services
- 13) Transport, Postal and Warehousing
- 14) Agriculture, Forestry and Fishing
- 15) Rental, Hiring and Real Estate Services
- 16) Arts and Recreation Services
- 17) Other Services
- 18) Accommodation and Food Services

**Pie chart values:**

- 1) 505,034
- 2) 361,155
- 3) 83,490
- 4) 72,170
- 5) 37,676
- 6) 30,338
- 7) 26,980
- 8) 21,426
- 9) 10,757
- 10) 431,604
- 11) 119,696
- 12) 73,834
- 13) 50,371
- 14) 36,258
- 15) 28,927
- 16) 23,569
- 17) 18,702
- 18) 8,535

**Figure 3. Business expenditure on research and development in Queensland by industry (in thousand dollars), 2015–16**

Data source: Australian Bureau of Statistics[52]

| OPPORTUNITIES FOR GROWING SMART MINING, EXPLORATION AND EXTRACTION | |
|---|---|
| **Research** | • 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** | • 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** | • 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 offers efficient, customised and proactive healthcare services for patients and health professionals. It consists of firms offering wearables and in-home monitoring devices, bionics and implants, medical diagnostic platforms and services for the design, production, testing and manufacturing of high-value pharmaceuticals, vaccines and nutraceuticals.

This industry aims to mitigate the growing pressures placed on existing hospital and health services. Indeed, healthcare expenditure in Queensland has grown at a faster rate (4.8 per cent from 2004–15) than the national average (4.2 per cent).[58] Declining cost of genome sequencing (see Figure 4) and Queensland's strengths in genomics (e.g. through the Australian Translational Genomics Centre,[59] UQ,[60] and Griffith University, CSIRO and James Cook University[61]) provide opportunities for personalised medicine.
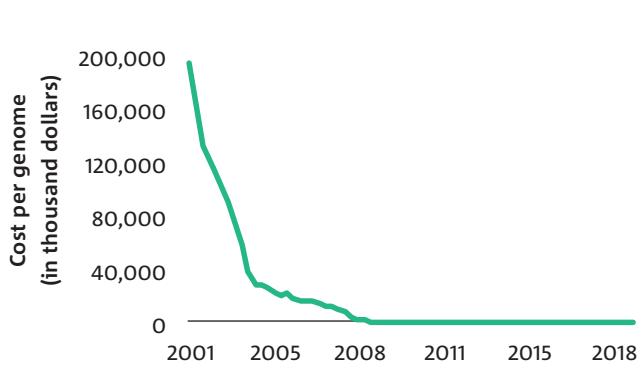
Queensland has a portfolio of biomedical knowledge clusters: the Herston Health Precinct, the Translational Research Institute and broader Princess Alexandra Health Precinct, the Gold Coast Health and Knowledge Precinct, Health City Springfield Central and the Sunshine Coast Health Precinct.[63] The state's biomedical research capabilities cover infectious and tropical diseases[64–66], cancer immunotherapy, biomarker and target discovery, human genetics, biopharmaceutical manufacturing and clinical trials[67,68].

Queensland's healthcare sector has been a strong digital adopter. Brisbane's Princess Alexandra Hospital was the first large-scale digital hospital in Australia[69] and the Wesley Hospital,[70] the Royal Brisbane and Women's Hospital[71] and the Greenslopes Private Hospital[72] have all adopted surgical robots for training purposes. Queensland is a leading adopter of telehealth services in Australia too (see Figure 5) – approaches which have been shown to save on healthcare expenditure.[73]



**Figure 4. Cost of sequencing a human-sized genome (in thousand dollars)**

Data source: National Human Genome Research Institute[62]



**Figure 5. Number of requested Medicare items for telehealth services in Australia by state and territory, 2008–18**

Data source: Department of Health[74]

| OPPORTUNITIES FOR GROWING PERSONALISED AND PREVENTATIVE HEALTHCARE | |
| --- | --- |
| **Research** | • Improving commercialisation through focused research translation and linkages between discovery and application |
| | • Strengthening connectivity between sectors and research fields, both domestically and internationally, to facilitate cross-disciplinary discoveries and innovations |
| **Infrastructure** | • Utilising existing assets better, potentially through funding incentives or a biomedical infrastructure strategy |
| | • Breaking down silos around data management and use of health data to improve patient and systems-level outcomes |
| | • Establishing a local or national ethical framework for health data to address issues around ownership and use |
| **Education and the workforce** | • Equipping the current and emerging healthcare workforce with translation and commercialisation skills |
| | • Broadening workforce capabilities to cover big data, health economics, biomedical engineering and advanced manufacturing |
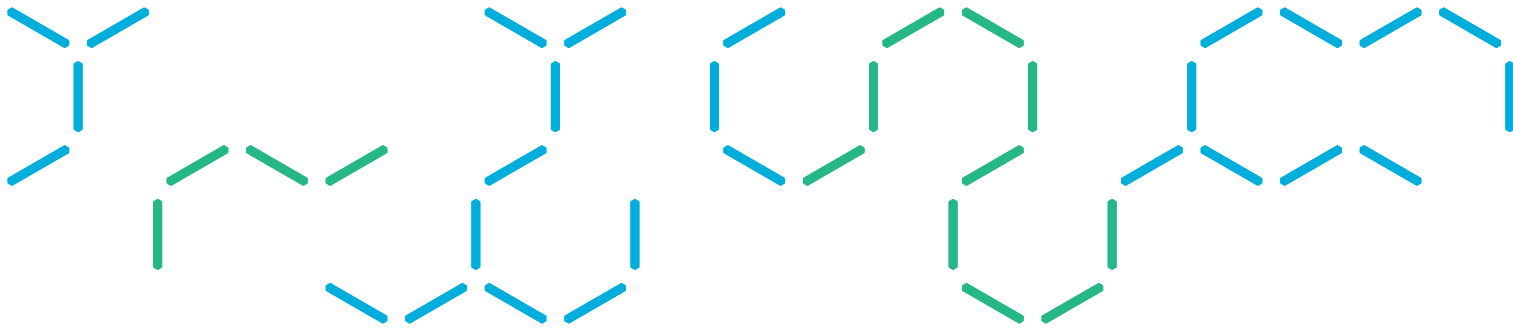
## Advanced materials and precision engineering

The advanced materials and precision engineering industry develops new materials and designs and produces precise, highly individualised machines, systems or parts for the aerospace, biomedical, energy and agriculture sectors, among others. Enabled by the convergence of sensors, 3D printing, robotics and automation,[75] firms are focused on pre- and post-production services, with production processes largely automated.

Queensland has a robust manufacturing base, consisting of 16,406 firms in 2018.[76] Global demand for customised products is growing, and the globalisation of supply chains and challenges around resource scarcity[75] are encouraging existing firms to become more knowledge-intensive. Indeed, 57.5 per cent of Queensland manufacturing firms are already halfway or more through their transition to advanced manufacturing.[77]

There are more than 70 institutes, facilities, precincts, laboratories and other organisations currently involved in advanced manufacturing research in Queensland.[78] These groups cover various domains: for example, the Australian Research Council (ARC) Research Hub for Advanced Manufacturing of Medical Devices – a collaboration between multiple Queensland universities and industry partners – develops technologies for custom medical devices.[79]

Growth in other knowledge-intensive industries will fuel future demand for advanced materials and precision engineering. For instance, the defence and aerospace sectors will require tougher, more durable and lightweight advanced materials and compact and high-powered components for flight vehicles.[80] Advanced manufacturing can be used for bespoke art pieces too, as QUT has done in collaboration with industry and research partners.[81]

## 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 drones, rockets and missiles and spacecraft.[82] It includes space-enabled services too that provide data analytics, geospatial mapping and remote communications. Niche sub-sectors are likely to emerge in areas such as drone testing, high-value and customised maintenance, repair and overhaul services and applied training programs.

Queensland is a hub for aviation and aerospace businesses, with the Australian headquarters of Boeing Training and Flight Services Australia, Airbus Helicopters, Raytheon, Sikorsky, GE Aviation and Northrop Grumman all based in Queensland. Queensland is also home to the Army Aviation Centre and three Royal Australian Air Force bases. The state's strong defence presence is attractive for international defence contracts (e.g. the LAND 400 Phase 2 contract with Rheinmetall Defence Australia[45]), providing opportunities for smaller firms to participate in global supply chains.

| OPPORTUNITIES FOR GROWING ADVANCED MATERIALS AND PRECISION ENGINEERING | |
| --- | --- |
| Research | • Broadening the focus of advanced manufacturing R&D to cover all stages of the commercialisation pathway |
| | • Drawing upon collaborative innovation centres to enable smaller firms to participate in research activities |
| | • Growing research capabilities in composite materials with superior structural or functional properties |
| Infrastructure | • Improving access to incubators and development hubs in regional and metropolitan areas to support commercialisation activities of smaller firms |
| | • 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 | • Using industry placements and targeted school programs to shift public perceptions around the industry as declining |
| | • Aligning current industry skill needs with education and training to ensure a globally competitive workforce |
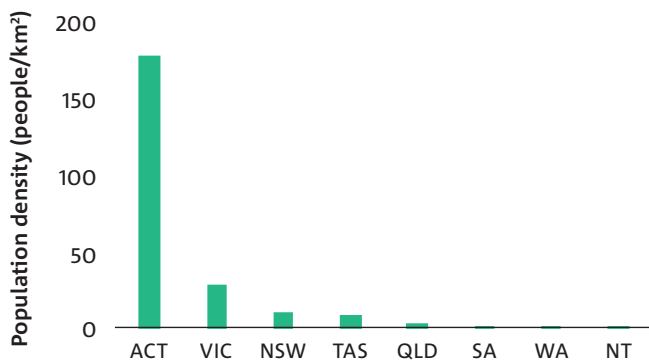
**Figure 6. Population density (people per square kilometre) in Australia by state and territory**

Data source: Australia Bureau of Statistics[83] and Geosciences Australia[84]

A number of Queensland universities and research institutes also have active aerospace-related research programs and industry collaborations. For example, UQ has the Boeing Research and Technology Australia Centre[85] and a hypersonic flight research program with multiple government and industry partners,[82] QUT has formed an Aviation Innovation Network,[82] and the University of Southern Queensland (USQ) is home to Australia's only wind tunnel facility for supersonic and hypersonic experiments.[82]

The Queensland Drones Strategy acknowledges opportunities to grow the drone industry[86] – a global market estimated to reach $140 billion by 2025.[87] Queensland's low population density (see Figure 6), access to areas free of radio interference and proximity to the equator make it an ideal site for drone testing, launch activities and ground processing.[88,89] Domestic competition for space-related research in Australia is growing and there are opportunities for Queensland to better utilise its geographical advantages.[89]

| OPPORTUNITIES FOR GROWING NEXT GENERATION AEROSPACE AND SPACE TECHNOLOGIES | |
|---|---|
| **Research** | • 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** | • Leveraging Queensland's geographical strengths and investing in infrastructure (e.g. a launch port) to attract international investors and researchers |
| **Education and the workforce** | • 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 outputs through the method of processing (e.g. crops that require fewer resources) or production (e.g. organic produce or free range livestock)[90] or other intangible attributes (e.g. assurance around provenance and safety).

Queensland has a long-standing agriculture industry, diverse climatic zones, easy access to natural resources and close proximity to Asia. The state has deep food science expertise, which could help the sector become more climate resilient and knowledge-intensive. For example, UQ has developed a pest-resistant genetic variant for sorghum,[91] QUT conducts research on a range of agriculture-related digital applications,[92] and Griffith University uses artificial intelligence to assess the quality of strawberries.[93]

More of Asia's population is crossing over to the middle-income bracket,[94] creating demand for high-value nutrition. For instance, consumption of fat and protein has grown rapidly (see Figure 7) and 93 per cent of Asian consumers are willing to pay more for foods with health attributes.[95] Food safety is a concern for Asian consumers too.[96] Blockchain could be used to provide transparency in food supply chains, as QUT and BeefLedger Limited are doing in the Australian beef supply chain.[97]

The global functional food market is expected to reach $917.6 million by 2026[99] and Queensland companies (e.g. Natural Evolution and Qponics) are already pursing these opportunities. Future growth in functional foods could be supported by research capabilities at USQ and UQ and local Indigenous knowledge[100]. High-tech foods using synthetic biology and other manufacturing processes could also meet growing demand for plant-based foods. Australia has the third-fastest growing vegan market[101] and 11.2 per cent of Australians already eat a vegetarian diet all or most of the time.[102]
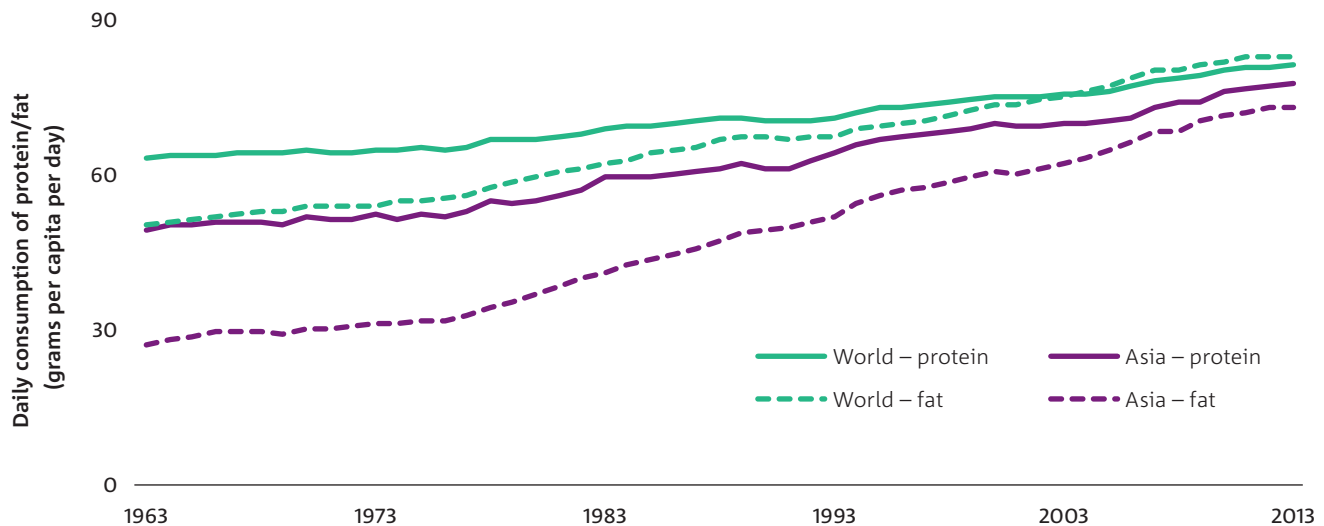
**Figure 7. Daily protein and fat consumption in Asia and worldwide**

Data source: United Nations Food and Agriculture Organization[98]

| OPPORTUNITIES FOR GROWING ADVANCED AGRICULTURE | |
|---|---|
| **Research** | • 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** | • Addressing digital connectivity gaps, particularly in regional Queensland, to facilitate adoption of enabling technologies |
| **Education and the workforce** | • 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 generates value from reducing, recycling and repurposing by-products or waste products from agriculture and other industrial processes. This sector creates a range of bioproducts including sustainable chemicals, fuels, synthetic rubber, cosmetics, detergents and textiles,[103] recycles other waste streams (e.g. e-waste) and develops new methods for reducing resource use and the amount of greenhouse gas emissions released during traditional manufacturing processes.[104]

Commodity prices associated with some of Queensland's key exports have stagnated or declined in recent years.[105,106] The sector could build resilience to global shifts by diversifying into secondary, higher-value markets (e.g. using sugarcane as feedstock for bioproducts[103]). Queensland also generates the greatest waste per capita in Australia (see Figure 8). Investment in resource recovery infrastructure could provide environmental and economic value for the state and is estimated to create 3,000 direct jobs.[107]
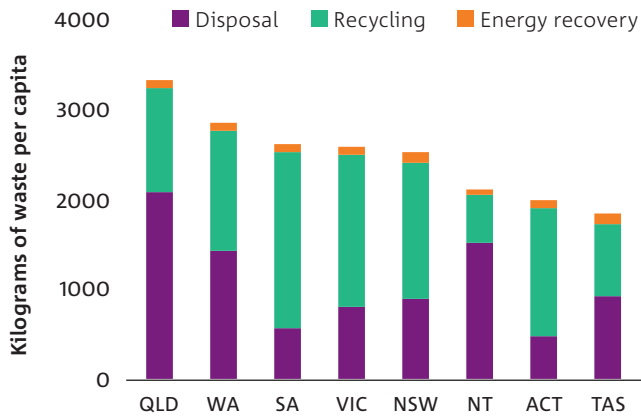
**Figure 8. Kilograms of waste per capita in Australia by processing stream and state and territory, 2014–15**

Data source: Department of the Environment and Energy[108]

Queensland has strong biotechnology capabilities, which has facilitated various industry–research partnerships. For example, the UQ-Amyris partnership is using sugarcane as feedstock for biofuels,[109] the JCU-Pacific Biotechnologies partnership is developing bioproducts from algae[110] and QUT has collaborations with Mercurius Biorefining (converting biomass into jet and diesel fuels[111]) and Syngenta (to establish the Syngenta Centre for Sugar Cane Biofuel Development[112]). Queensland also has three commercial biorefineries[103] and two biorefinery pilots,[103,113] with more in the pipeline.[114]

Battery waste is a growing problem given the widespread use of batteries for a range of technologies.[115] Australia produced 3,300 tonnes of lithium-ion battery waste in 2016 (2 per cent of which was recycled offshore) and this is projected to reach at least 100,073 tonnes annually by 2036 (see Figure 9). CSIRO estimates that Australia could miss out on between $813 million and $3 billion by 2036 without a strong domestic battery recycling industry[116] – an opportunity Queensland could take the lead in.
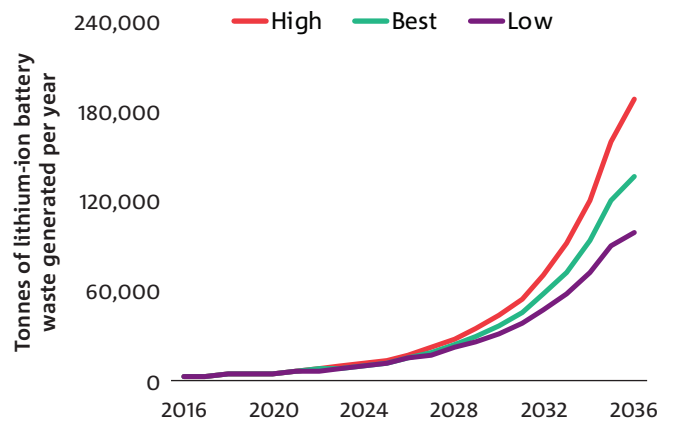


**Figure 9. Projected waste generated annually from lithium-ion batteries in Australia (in tonnes), by projection method**

Data source: Randell Environmental Consulting[117]

| OPPORTUNITIES FOR GROWING CIRCULAR COMMODITIES | |
| --- | --- |
| **Research** | • 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** | • 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** | • Using workplace programs and government regulation to incentivise behaviours that reduce and reuse waste |
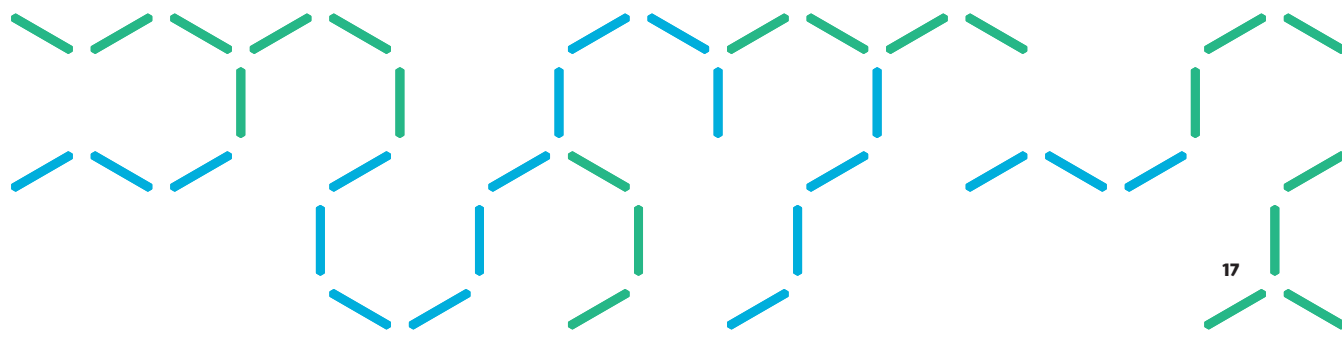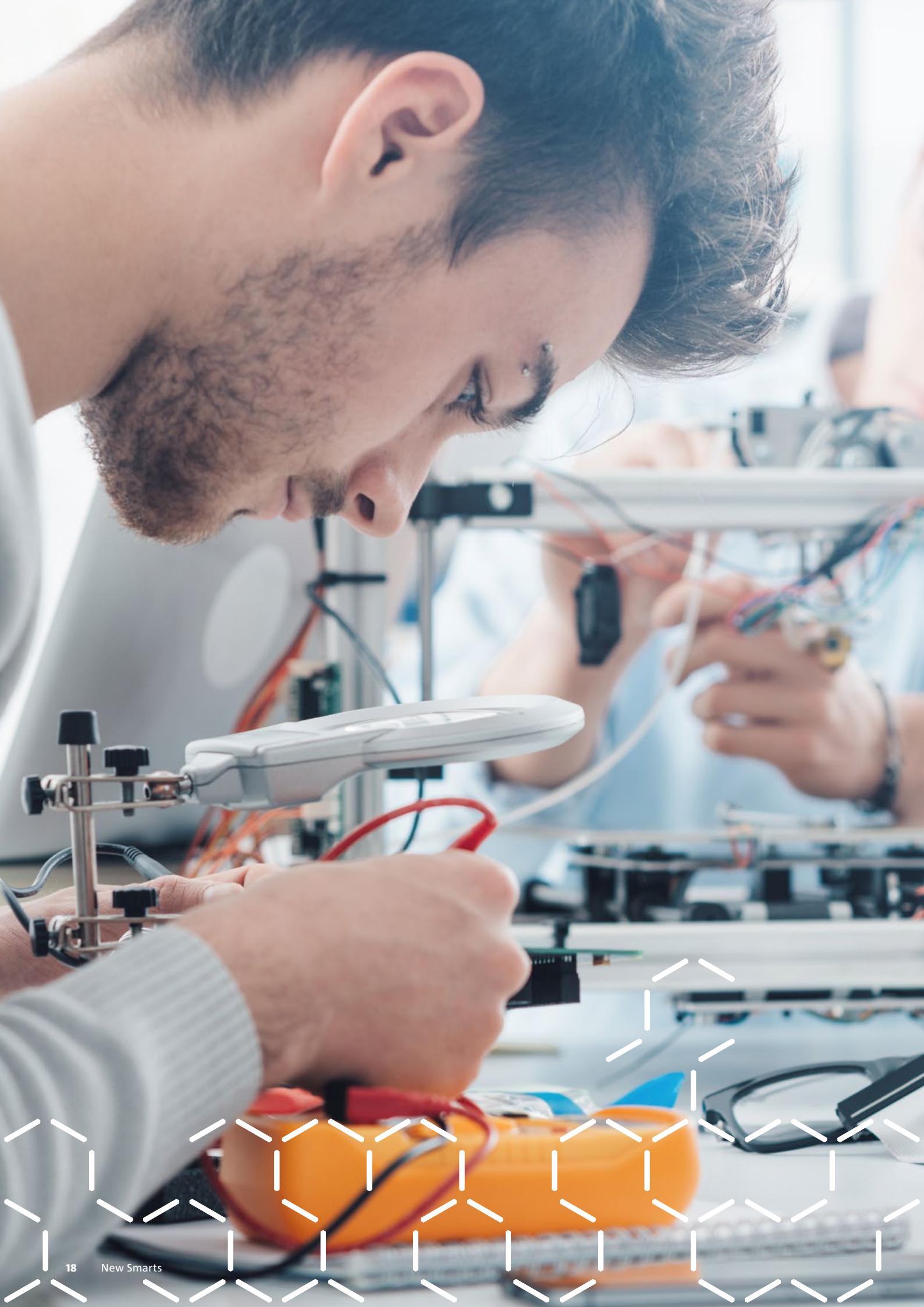
# FUTURE
## SCIENCE

The findings in this report have implications for future policy and strategy decisions concerning Queensland's science sector. This section explores the role of the research sector in driving growth in Queensland's future knowledge economy and the policy decisions that may affect its operating environment. It is informed by consultations with stakeholders across a range of industry, government and academic sectors.

## Improving collaboration between institutions, sectors and disciplines

Collaboration is a common challenge for each of Queensland's emerging knowledge-intensive industries. Australia is currently in last place out of all OECD (Organisation for Economic Co-operation and Development) countries for collaborations between higher education and research institutes and businesses.[118] A lack of collaboration 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.

There are many benefits to collaboration. For one, collaborations between industry, universities and research institutions can help to strengthen community trust and confidence in these sectors. Public trust in mining companies is currently low[55] and improving industry–research collaborations could help the smart mining, exploration and extraction sector expand into new areas focused on environmental and community impacts.

Multidisciplinary collaborations are often necessary inputs for knowledge-intensive industries given they fall at the intersection of various research domains. For example, cyber-physical security draws on capabilities in cybersecurity, robotics and autonomous systems, defence and behavioural sciences, with influences from healthcare, agriculture and mining. Out-of-the-box collaborations, such as QUT's fusion of advanced manufacturing, robotics and creative art capabilities for public art[81] could be considered.

Barriers to collaboration are unlikely to have a single solution though. Government grants (e.g. ARC Linkage Projects), CRCs, government-funded precincts and hubs and networking platforms (e.g. CSIRO's Data61 Expert Connect[119]) were offered as potential mechanisms. Future efforts could strategically focus on research gaps in emerging industries (e.g. capabilities in composite materials would support growth in advanced materials and precision engineering and next generation and space technologies).

## Supporting research across the entire pipeline

Federal research funding in Australia has fluctuated over the past two decades and has plateaued between $97–119 million for Queensland, following its peak of $218 million in 2014.[120] Applied research accounts for 55.8 per cent of R&D expenditure in government and not-for-profit organisations in Australia (2017 figure)[121] and 48.5 per cent in the higher-education sector (2016 figure),[122] and experimental development makes up 65.2 per cent of business expenditure on R&D (2016 figure).[123]

Basic and applied research are often falsely viewed as a dichotomy, where the latter has more practical applications than the former. But evaluating research in economic terms alone fails to consider other social, cultural and environmental benefits.[124] Indeed, new knowledge created through basic research is a necessary precursor to applied research and significant scientific discoveries and innovations.[125] Stakeholders noted the need to strike the right balance between funding for basic and applied research.

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

Each knowledge-intensive industry will require a skilled workforce with capabilities in a range of technical domains. There could be future skill shortages, however, given that STEM fields account for a small proportion of higher education degree competitions in Queensland[126] and only one-fifth of Australia's STEM-qualified people reside in Queensland.[127] STEM participation in early schooling could take advantage of children's natural interest in science.[128]

Soft skills will be important for future knowledge workers too. For example, the sustainable energy sector requires capabilities in information and communications technology and data security as well as customer service.[129] These skills or skill combinations might differ from existing curriculums. Queensland's education sector will need to be responsive to these changing skill requirements, potentially offering industry-specific and general courses for workers seeking training to adapt to, or transition into, new roles.
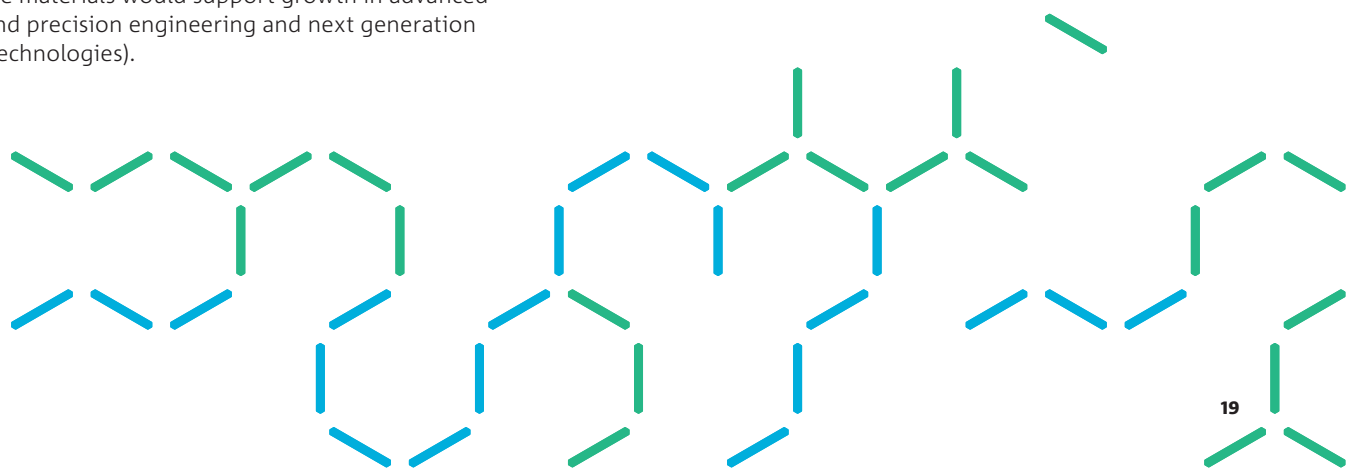
Diversity is a key consideration for the future workforce, particularly for industries like cyber-physical security which may struggle to attract a heterogenous workforce. Diversity helps prevent data biases[130] and ensures the broader community is reflected in scientific enquiries.[131] Outreach programs, such as UQ's Women in Engineering Research[132] and Data61's Expert Connect platform's 'FindHer' service[119] can help improve female representation in male-dominated careers and research domains.

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

Government can support the growth of emerging knowledge-intensive industries in a number of ways. For instance, government can be an early customer of the emerging industry, as was the case with government contracts in early stages of development in Silicon Valley[16] and Silicon Wadi.[26] Indeed, start-ups which are government suppliers tend to perform better than those receiving grants and subsidies.[133]

Government can be an innovator too. For example, the US Defence Advanced Research Projects Agency was responsible for innovations around weather satellites, robotics and artificial intelligence and the modern internet.[134] Moreover, the Australian Government has a $730 million Next Generation Technologies Fund to support defence-related applied research[135] and the Queensland Government's Business Development Fund provides early-stage co-investment funding.[136] These initiatives position government in local and national innovation ecosystems.

But Silicon Fen demonstrates that knowledge clusters can also emerge without government support. Government can instead facilitate growth by attracting international start-ups, researchers and firms to come to Queensland. Government could expand its existing programs (e.g. Hot DesQ[137] and Startup Onramp[138]) to include regular events that showcase the state's research excellence to domestic and international collaborators and investors. There could be a role for government in connecting the research sector to economic, social and environmental state priorities too.

Government can also facilitate collaboration between researchers, industry and the community. For instance, government can create the policy and funding settings that enable industry to take up opportunities to translate research outputs. It can also develop common data platforms to improve data use and sharing between different institutions or sectors. Finally, government can facilitate greater community engagement in science through community labs like New York City's Genspace.[139]

## Positioning universities in supporting the advanced knowledge economy

As illustrated in the four Silicon case studies, universities can play a critical role in the creation of new knowledge, innovation and seeding new industries. Indeed, many Queensland universities have adopted commercialisation functions (e.g. UQ's UniQuest, QUT's Bluebox and the University of the Sunshine Coast's Innovation Centre) that aim to spin-out IP and improve the translation of research and technology outputs.

There is a broader role for universities in facilitating industry–research–government partnerships though, and graduate student–industry programs could help address current collaborative gaps. For example, Monash University's Graduate Research Industry Partnerships connect students with businesses to solve real-world industry problems[140] and the Industry and PhD Research Engagement Program (iPREP) in Western Australia provides opportunities for PhD candidates to collaborate with industry.[141]

Curriculums across the education sector, including universities, will need to reflect the capabilities in demand in emerging knowledge-intensive industries. This will ensure skill supply aligns with demand. Universities, in partnership with government and industry, could also help emerging industries attract future talent. This is particularly relevant to industries like advanced materials and precision engineering, which is currently impacted by perceptions of other declining manufacturing subsectors.[75]

The research workforce is evolving too. Fifty-one per cent of Australian PhD students want to work in business or the public sector, yet they are not equipped for non-academic careers.[142] Moreover, a PhD is not listed as a desired qualification in 80 per cent of online job postings requesting advanced research skills.[143] Industry placements (e.g. Advance Queensland's Industry Research Fellowships[144] and the Australian Postgraduate Research Intern program[145]) could equip PhD graduates for future knowledge careers.
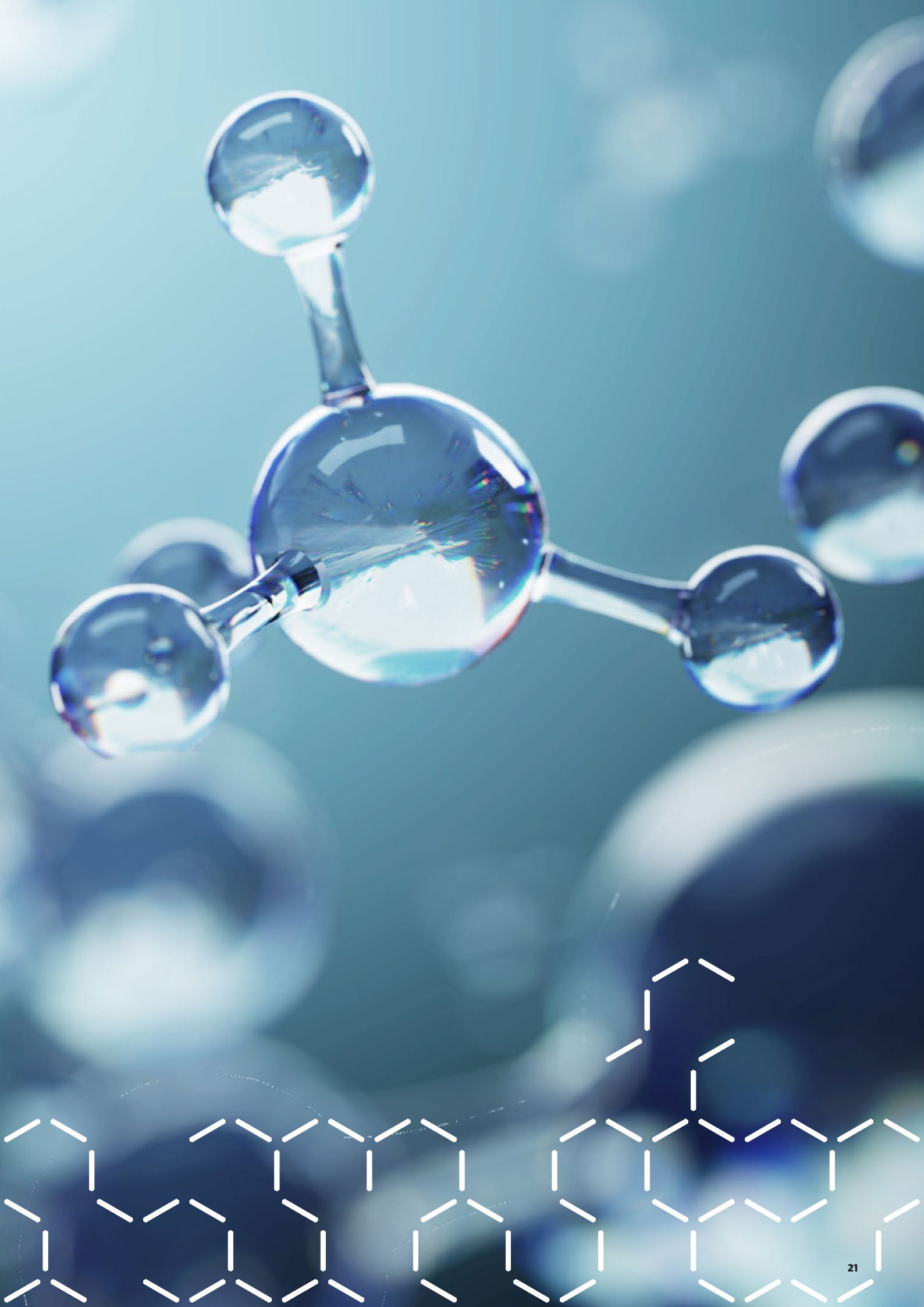
# CONCLUSION

This report presents a set of emerging knowledge-intensive industries that provide new opportunities for Queensland to grow and diversify its knowledge economy over the coming decades. It is designed to illustrate the options available for the state and the current barriers that could limit future growth, and aims to inform future policy and strategy decisions concerning science in Queensland.

This report outlines opportunities to increase the knowledge-intensification of traditional industries in Queensland, such as manufacturing, mining and agriculture. By increasing the human capital and technology inputs of industries like the advanced agriculture sector, there are opportunities to diversify exports into secondary markets, build climate resilience and respond to consumer demand for high-value nutrition and food safety.

There are also opportunities for Queensland to seed entirely new industries, drawing upon existing strengths in research and supporting industries. For example, the cyber-physical security industry is born from the convergence of existing research into robotics, autonomous systems and defence and links to industry, along with Queensland's active role in growing Australia's cybersecurity industry more broadly.

This report also raises a number of challenges that could limit future growth of these emerging knowledge-intensive industries. For instance, some industries may experience skills shortages as firms demand novel skills or skill combinations. Moreover, there is room to improve the current level of collaboration between the research sector and industry, and between institutions and disciplines. These gaps could limit future research applications and lead to duplicated efforts.

These findings aim to support the development of improved polices and strategies for Queensland's science sector, enabling it to support positive social, environmental and economic outcomes for the state. It will be important to identify a process for addressing the challenges raised in this report, acknowledging the roles of each stakeholder group and potentially prioritising opportunities. Through a coordinated effort, Queensland can realise the full potential of its growing and evolving knowledge economy.

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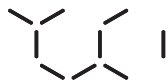
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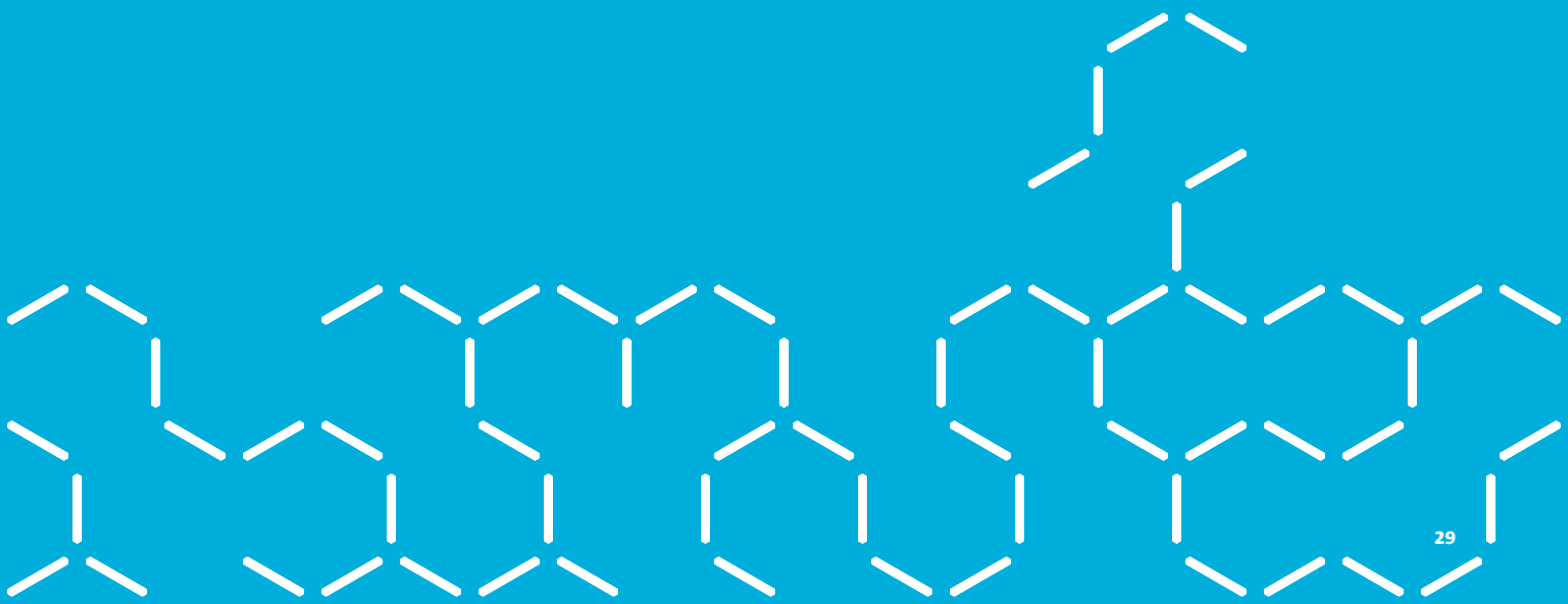
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