Advanced Manufacturing

Implications and opportunities for Queensland

Office of the Queensland Chief Scientist
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1. Executive Summary

The manufacturing industry in Queensland is important, contributing over $19 billion directly to the State’s economy in 2013-14, and employing over 150,000 people in full-time jobs in the September quarter of 2015.

The manufacturing sector is a critical component of advanced economies as it creates well-paid jobs and maintains technical prowess; a shrinking sector is viewed as evidence of decline. Manufacturing stands on the threshold of a major transformation. A host of new design, production, and business capabilities are opening the way to new types of manufacturing-referred to, collectively, as ‘advanced manufacturing’.

This paper identifies four factors which will shape Queensland’s ‘new’ manufacturing future: the technologically-advanced products, goods, and services demanded by future generations; the disruptive technologies, practices, and processes required to produce them; the advanced materials used to make these products; and the principles, platforms, and systems by which Queensland businesses need to operate to compete in the global marketplace.

**Products**

Queensland has a highly diverse manufacturing industry supplying to growth sectors including aviation, defence, medical technologies and pharmaceuticals, and processed foods. Innovative pharmaceuticals such as biologics (biological products), medical devices, and assistive technologies are viewed as strong prospects for manufacturing in Queensland, and continued growth of these products is expected, particularly as the population ages and Asia’s middle class grows.

Queensland’s traditional strengths in manufacturing lie in the resource and agricultural sectors - the future products demanded will reflect the greater sophistication required for these 21st Century industries. The resources industry will require specialised advanced manufacturing inputs in the mining equipment and technology services (METS) sector using autonomous vehicles, big data analytics, and remote monitoring of sensor networks. Agriculture, as it moves along the value chain, will require advanced manufacturing solutions for the food industry of the future – high-tech, healthy foods, and nutraceuticals, as well as automation, robotics, and telemetry devices needed to operate remote farming enterprises.

Queensland’s R&D capacity in nano-materials (including Nano-Patch and nano-diagnostics) and graphene augur well future products made from these materials. As the suite of products made by Queensland’s advanced manufacturers becomes more defined, a commensurate demand for servicing will become more important.

**Methodologies**

New production practices and processes are providing massive opportunities for Queensland’s advanced manufacturers. Additive manufacturing (3D printing), digitisation, automation, robotics, flow chemistry are becoming integral to production processes and provide greater cost competitiveness for Queensland manufacturers in an increasingly
globalised marketplace. Queensland’s R&D capability in ‘methodologies’ is strong, and has been enhanced by locating the ‘Automated and Assistive Technologies’ theme of the newly established Innovative Manufacturing CRC in the State.

**Materials**
The design of new and revolutionary materials with superior qualities and parameters is an important driver to better make products or to develop new ones. Such materials include flexible electronics, biomaterials, graphene, and nanomaterials. Queensland has particularly strong R&D capability in advanced materials R&D with developed programs in nanomaterials and graphene. Building on this capability via a ‘Cambridge cluster’ model around critical research infrastructure, such as the AIBN, would promote collaboration and form stronger links between research and industry.

**Principles**
The guiding principles of Queensland’s ‘new’ advanced manufacturing future are premised on new paradigms for competing in a global market. Customisation, business model innovation, collaborative R&D, design-led thinking, value-adding along the supply chain, adopting a systems approach, capability alignment, and accessing global value chains are vital principles in strengthening the international competitiveness of advanced manufacturers.

The effective adoption, application, and incorporation of these activities requires a highly skilled workforce. Having skills in science, technology, engineering, and mathematics (STEM) and business management are essential for the future of Queensland’s advanced manufacturing sector, with an increasing reliance on information technologies.

**Opportunities**
Although Australia has limited ability to compete against low wage countries undertaking large scale standardised manufacturing, we do have a competitive advantage in three important areas:

- **Niche products** - smaller batches of high-value products that require rapid prototyping, agile manufacturing processes, responsive to multiple supply chains
- **Quality and standards** – excellent quality assurance protocols and a reputation for delivering a high standard of product, attributes which are highly exportable
- **Services** – the growing role and value-add of embodied services in advanced manufacturing, particularly requiring a high level of technical skills.

**Recommendations**
Success of the Queensland advanced manufacturing centre is premised on increased innovation, productivity, competiveness, and long-term sustainability. Advanced manufacturing requires new and technologically advanced skill sets, so educational institutions need to be attuned to the needs of industry to ensure a suitably trained workforce of the future.
Critical to a vibrant advanced manufacturing sector in Queensland is a strong research base working collaboratively in close proximity with industry. There is a lack of a closely co-located innovative businesses around facilities undertaking research in advanced manufacturing.

There are a number of potential sites which may allow such physical and governance co-location to occur for advanced manufacturing, but also across a range of disciplines:

- Griffith University Southport campus – on the greenfield site at the health and knowledge precinct to explore advance manufacturing in the health and pharmaceutical area
- University of Queensland - zoning of land near the AIBN and Engineering facilities or at the health and commercial precinct adjoining the Royal Brisbane and Womens Hospital (RBWH) at Herston.

In addition to close physical co-location, critical to success is stewardship by experienced industry leaders, joint appointments from successful companies, student industry placement, startup formation, and an environment that encourages the flow of staff between the manufacturing industries and academic roles.

Importantly, such effort must be strategic and start early, as long lead times are required to yield tangible outcomes. Since the future of Queensland manufacturing lies in areas in which we have a competitive advantage, especially niche products, quality assurance, and services, a focussed effort in these disciplines, both in resource allocation by business and in R&D conducted by research providers, must be a high priority.
Examples of advanced manufacturing products, methodologies, materials, and principles critical to shaping Queensland's 'new' manufacturing future.

<table>
<thead>
<tr>
<th>Products</th>
<th>Methodologies</th>
<th>Principles</th>
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<tr>
<td>Medical implants, medical devices</td>
<td>Cyber-physical interface</td>
<td>Customisation, services</td>
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<tr>
<td>Biological products (biologics)</td>
<td>Integrating simulation</td>
<td>Globalisation, global value chains</td>
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<tr>
<td>Therapeutic goods</td>
<td>Mammalian cell culture, flow-chemistry</td>
<td>Business model innovation, agility, lean start-ups</td>
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<td>Diagnostic tools</td>
<td>Good manufacturing practice</td>
<td>Design-led thinking, STEM, tailored skill-sets</td>
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<tr>
<td>Orthopaedic implants</td>
<td>Big data analytics</td>
<td>Collaborative R&amp;D, international linkages</td>
</tr>
<tr>
<td>Nano-devices</td>
<td>Additive manufacturing/ 3-D printing</td>
<td>Knowledge/ technology diffusion</td>
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<tr>
<td>Precision components for industries</td>
<td>Micro/ nanoelectronics, nanotechnology</td>
<td>Modelling, algorithms, big data, cybersecurity</td>
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<tr>
<td>including aerospace, defence, mining</td>
<td>Assistive technologies, augmented reality</td>
<td>Megatrends, augmented reality</td>
</tr>
<tr>
<td>equipment, automotive, ICT, energy</td>
<td>Information management, mobile devices</td>
<td>Internet-of-things, consumer devices</td>
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<tr>
<td>Services</td>
<td>Monitoring, automation, robotics</td>
<td>Cloud-based solutions, cloud services</td>
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<td></td>
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<td>Vertical and horizontal system integration</td>
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<tr>
<td></td>
<td></td>
<td>Human-machine interactions</td>
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</tbody>
</table>

- Biomaterials
- Fibre composites
- Graphene
- Advanced materials
- Titanium
- Polymers
- Semiconductors
- Implantable materials
- Flexible electronics
- Nanomaterials
2. Introduction

The manufacturing industry in Queensland is estimated to contribute over $19 billion directly to the State’s economy, being the fourth largest sector behind construction, mining, and health care and social assistance.\(^1\) Manufacturing accounted for over 33.8 per cent of the total value for Queensland’s international merchandise exports in 2014-2015 and employed 165,600 people in the September quarter of 2015 (7.1 per cent of total employed persons in the State). More than 87 per cent of manufacturing jobs in Queensland are full-time.

Over the past decade, Queensland manufacturing has increased its share of national industry gross value-added from 15.8 per cent in 2003/04 to 18.8 per cent in 2013/14, outperforming the two largest manufacturing states of New South Wales and Victoria for that measure.\(^2\)

Because manufacturing demonstrates a huge potential to generate wealth and to create high-quality and highly skilled jobs,\(^3\) it is regarded as an essential and uniquely powerful economic force across nations and political systems. In advanced economies, a strong manufacturing sector is celebrated for creating well-paid employment and maintaining technical prowess; a shrinking manufacturing sector is seen as evidence of decline.\(^4\)

Manufacturing stands on the threshold of a major transformation. A host of new design, production, and business capabilities are opening the way to new types of manufacturing—referred to, collectively, as ‘advanced manufacturing’.\(^5\)

Advanced manufacturing entails more than making high-tech products, and includes the use of new, often leading-edge machines and processes to make products that are unique, better, or cheaper. Advanced manufacturing also facilitates rapid integration of process improvements, readily permits changes in design, such as new part features or substitute materials, and accommodates customisation and cost-effective low-volume production. It is these ‘family of activities’ that depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences that the United States President’s Council of Advisors on Science and Technology defines as ‘advanced manufacturing’.\(^6\)

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2 Ibid
6 President’s Council of Advisors on Science and Technology (2011) Report to the President on ensuring American leadership in advanced manufacturing. Executive Office of the President. June 2011 p ii  
https://www.whitehouse.gov/administration/eop/ostp/pcast/docsreports
This next generation of additive, automated, and assistive technologies are deemed as critical to enabling Australia’s innovative manufacturing sector to compete internationally.\(^7\) Australia is not alone in recognising the importance of innovation in manufacturing to drive economic growth, jobs, and prosperity.\(^8, 9\)

This paper explores the main drivers influencing Queensland firms to produce an advanced manufactured product, or to apply advanced manufacturing practices, processes, technologies and systems to their business. These elements are described in terms of the products, methodologies, materials, and principles guiding and shaping the future of manufacturing.

Consideration is given to the past, present, and future of manufacturing in Queensland, and how best the sector might grow by embracing advanced manufacturing. Developing the right skills, research capability, and fostering collaboration between the research sector and industry are viewed as critical elements to this growth.

\(^7\) Scott, M. (2014) Innovative Manufacturing CRC. Application to Cooperative Research Centres Program
3. Background and context

3.1. Competitiveness of the manufacturing sector

Boston Consulting Group (2014) ranked Australia last out of 25 countries in terms of manufacturing cost competitiveness in 2014 (Figure 1), with expenses some 30 per cent higher than those in the United States. Moreover, Australia fell seven places to 22nd of 144 countries on the World Economic Forum competitiveness index in the five years to 2014.

![Manufacturing Cost Index, 2014 (US=100; Australia=130) for the world’s top 25 exporting countries (Boston Consulting Group 2014)](image)

Although currency appreciation of the Australian dollar at the time of these comparisons provides some answers, a significant proportion of the overall domestic cost structure resides in the relatively high cost of unskilled labour which predominates traditional manufacturing methodologies. However, as Australia trends towards more advanced manufacturing, our cost competitiveness is expected to improve. This improvement is because advanced manufacturing requires a highly skilled labour force, which has a

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relatively smaller wage disparity between Australia and the rest of the world than has unskilled labour.\textsuperscript{12}

The competitiveness of Australian manufacturing is also compromised by its geographical isolation. However, proximity to South East Asia is also a major advantage, and it is no coincidence that that region is our biggest trading partner.\textsuperscript{13}

Although Australia has limited ability to compete against low wage countries undertaking large scale standardised manufacturing, it does have a competitive advantage in three important areas:

- **Niche products** - smaller batches of high-value products that require rapid prototyping, agile manufacturing processes, with a responsiveness to multiple supply chains\textsuperscript{14}
- **Quality and standards** – excellent quality assurance protocols and a reputation for delivering a high standard of manufactured product, attributes which are highly exportable\textsuperscript{15}
- **Services** – the growing role and value-add of embodied services in advanced manufacturing, particularly requiring a high level of technical skills.\textsuperscript{16}

### 3.2. Queensland advanced manufacturers

The Queensland manufacturing industry comprises a diverse range of sectors and is geographically spread, with 46 per cent of total manufacturing employment occurring outside the Greater Brisbane area.\textsuperscript{17} Over the last twenty years to June 2015, both processed foods and machinery and equipment sectors have increased their shares of total manufacturing employment. Increases have also occurred in chemicals and polymer products.

There is an encouraging number of firms in Queensland producing an advanced manufactured product, or applying advanced manufacturing practices, processes, technologies and systems to their businesses, some of which have a global presence.\textsuperscript{18} These businesses manufacture a range of products for a number of industry sectors, including:

- aerospace, defence, military
- automotive, marine, hydraulics, machinery and equipment
- processed meat and food products, food service equipment, food packaging
- building, construction, earthmoving

\textsuperscript{12} Iacopi, F. (2015) Personal communication, Griffith University. 19 December 2015
\textsuperscript{14} ACOLA (2015) #1 Australia’s comparative advantage. Securing Australia’s future. Australian Council of Learned Academies
\textsuperscript{16} Ibid
\textsuperscript{18} Personal communication, G. Christian, QMI Solutions, December 2015
• medical technologies and pharmaceuticals, health care
• METS
• ICT, electronics
• bio-manufacturing, fibre composites, renewable energy.

Examples of advanced manufacturing firms in Queensland have been listed previously, and some case studies are presented in Appendix 1.

3.3. Research capability and focus

Queensland has access to a range of R&D capability in advanced manufacturing (Appendix 2). For example, the Australian National Fabrication Facility (ANFF) was established under the National Collaborative Research Infrastructure Strategy (NCRIS) to provide researchers and industry with access to state-of-the-art fabrication capabilities through a network of eight nodes including 21 institutions throughout Australia, with nodes at the University of Queensland and Griffith University. Each node provides their facilities on an open access basis enabling researchers to engage in interdisciplinary research across micro and nano electronics; microelectromechanical systems (MEMS) and microfluidics; bio-nano applications; advanced materials; sensors and medical devices; and photonics.

The ANFF received $12.2M in funding in 2015-16 for a further two years in the Federal Budget, as one of a total of 27 NCRIS facilities. The Queensland node, ANFF-Q, is the bio-nano node specialising in microfluidics, organic electronics, biomaterials and novel semiconductor materials. The Centre for Advanced Materials Processing and Manufacturing (AMPAM) provides a focus for UQ’s materials engineering and manufacturing activities.

R&D capacity in the aerospace industry with application to advanced manufacturing is available at the Australian Research Centre for Aerospace Automation (ARCAA) at QUT.

The Australian Institute for Bioengineering and Nanotechnology (AIBN) at The University of Queensland (UQ) brings together the skills of world-class researchers in the areas of bioengineering and nanotechnology in an integrated multi-disciplinary research institute. AIBN uses nanotechnology for energy and environmental applications and is home to 18 research groups working at the interface of the biological, chemical, and physical sciences to alleviate current problems in human health and environmental issues.

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Housed at the AIBN, the Queensland facility of the National Biologics Facility (NBF) focuses on the synthesis of biological products (biologics), especially high-quality recombinant proteins, using mammalian cell expression technology. The $13 million facility was established in 2007 with funding provided by the Queensland Government and the Australian Government through the National Collaborative Research Infrastructure Strategy. The NBF has a staff of scientists and bioprocess engineers with world-class expertise in molecular biology, antibody engineering, mammalian cell culture, biopharmaceutical development and associated current Good Manufacturing Practices (cGMP). An important role for the facility is assisting Australian biotechnology companies and researchers to bridge the gap between the laboratory and pilot scale trials by producing pre-clinical or clinical quantities of recombinant proteins.

Although based in Melbourne, Queensland researchers can access to the Innovative Manufacturing CRC (IMCRC), which is focussed on supporting ‘manufacturing innovation’, and to help accelerate Australia’s transition to high-value, knowledge-based manufacturing. The IMCRC will actively support research into and adoption of enabling technologies such as additive manufacturing, automated and assistive technologies and accelerated high value product development, and will support innovative business processes and models for industry transformation (Appendix 2). The leader for Theme 2 of the IMCRC, ‘Automated & Assistive Technologies’ will be based in Queensland.

The initiatives of the IMCRC are consistent with the view that robotics, mobile devices, consumer devices, and cloud services are important information and communication technologies (ICT) needed to underpin more customised manufacturing.

The IMCRC will make a significant contribution to the Federal target of ‘Boosting the commercial returns from research’ and underpins the Advanced Manufacturing Growth Centre, which seeks to develop an internationally competitive, dynamic and thriving Australian advanced manufacturing sector. The Advanced Manufacturing Growth Centre is part of the $225 million Industry Growth Centres Initiative and will use six programmes (Connections; Hubs, Future jobs, Commercialisation, Reforms, Compete) to drive the competitiveness and productivity of the advanced manufacturing sector.

Furthermore, Queensland manufacturing firms can also access the expertise of the CSIRO Future Manufacturing Flagship, designed to help transition Australian manufacturing for sustainable global competitiveness and economic growth through research in the fields of sustainable materials; flexible electronics; advanced engineered components; and advanced fibrous materials.

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25 Mak, S. (2014) Key enabling technologies, Advanced manufacturing: beyond the production line. CEDA, Melbourne
The Centre for Railway Engineering at CQU is an essential partner in the Rail Manufacturing CRC that develops products, technologies and supply chain networks to increase the capability and globally competitive position of the rail industry.

A diagrammatic summary of Queensland’s R&D capability in advanced manufacturing reveals a strong focus on methodologies and materials for a range of sectors (Table 1). Industry-specific entities, as well as the cross-sectoral IMCRC, also address the principles behind the changing face of manufacturing and the need for innovative solutions.

More than half the number of research entities operating in Queensland that are focussed on advanced manufacturing specialise in materials research (Table 1). This emphasis has resulted in a range of developments (Appendix 1), especially in nanomaterials. For example, the ‘Nanopatch’ work at AIBN/UQ by Professor Mark Kendall has the potential for needle-free-vaccination, and Queensland-based company Vaxxas Pty Ltd is continuing to expand the development of the technology in partnership with leading global pharmaceutical companies.

The AIBN is also exploring the use of materials chemistry with molecular biology to create an affordable and widely-available device which can test blood faster for the presence of infectious diseases such as dengue fever and malaria. Other materials research is being conducted at Griffith University using graphene as a potential component in low-cost micro-sensors with world-wide application.

There appears to be a dearth of research capacity or research partnerships focussed on products or product development in advanced manufacturing (Table 1). This result is not unexpected, since it is logical that the majority of R&D invested on products and product development would be conducted by companies directly. Indeed, of the $19.69 billion in R&D expenditure claimed by companies (and eligible entities) under the R&D Tax Incentive programme in 2013-14, an estimated three per cent in dollar terms was contracted out to universities and research organisations where approximately 70 per cent of the nation’s researchers are based.

The point is that for innovation in advanced manufacturing to occur, collaboration and co-location between R&D entities and firms needs to feature prominently in the innovation landscape. The Cambridge cluster is famously recognised as an exemplar for collaborative models, with around 57,000 people employed by more than 1,500 technology-based firms around the university, which have a combined annual revenue of over £13 billion. Much of

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the success of the cluster is attributed to the foundation of the Cambridge Science Park by Trinity College in 1970.

Therefore, a long lead time (over 40 years for the Cambridge cluster) and close proximity to significant R&D infrastructure are critical factors in developing collaborative models focussed on innovative product development. The Brisbane Technology Park at Eight Mile Plains is an example of this model which established as a business cluster to provide the opportunity for controlled serendipity between innovative companies (Appendix 2). However, to encourage greater collaboration between R&D providers and innovative advanced manufacturing companies in Queensland, close proximity is essential. Queensland’s strengths in biomedical devices (Appendix 2) can be greatly enhanced by interaction of biologists, chemists, engineers, and medical researchers.

Converse to the considerable quantum of R&D expenditure claimed under the R&D Tax Incentive programme, many small manufacturing companies in Queensland have limited capacity to undertake their own R&D.\(^{31}\) The opportunity is for collaboration with external researchers to help with parts design, materials, reliability testing, and other facets of product development to greatly enhance future competitiveness.

A competitive advantage for domestic manufacturing on three fronts (niche products, quality and standards, and services) would suggest a focussed R&D effort on high-end manufacturing in these disciplines.

\(^{31}\) Iacopi, F. (2015) Personal communication, Griffith University. 19 December 2015
Table 1. Diagrammatic representation of Queensland’s R&D capacity in advanced manufacturing

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<thead>
<tr>
<th>Principles</th>
<th>Methodologies</th>
<th>Materials</th>
<th>Products</th>
<th>Sector</th>
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<td>National Biologics Facility (AIBN)</td>
<td>Biologics</td>
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<td>ARC for Aerospace Automation (ARCAA)</td>
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<td>Aerospace</td>
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<td>QLD Centre for Advanced Technologies (QCAT)</td>
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<td>Mining/ METS</td>
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<td>CRC for Rail Manufacturing</td>
<td>Siemens, Def Sci &amp; Tech QUT</td>
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<td>Rail</td>
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<td>AutoCRC</td>
<td>AMPAM</td>
<td>CRC for Polymers</td>
<td>CSIRO Future Manuf F’ship</td>
<td>Cross-sectoral</td>
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<td>Aust Inst for Bioengineering and Nanotechnology (AIBN)</td>
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<td>Advanced Manufacturing Growth Centre</td>
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3.4. Rationale for investment

Manufacturing has been in decline in some developed countries for many years. Reduced cost competitiveness, growing competition from abroad, globalisation, and a range of other issues have been attributed to this divestment. However, with the advent of new technologies and materials, a trend towards customisation of low volume/high value products, and embracing the principles driving new production methodologies, there is a growing awareness of the importance of manufacturing at both the micro and macro parts of the economy.

3.4.1. By firms (micro)

From a business metrics perspective, companies involved in emerging advanced manufacturing technologies are often viewed as high risk for mainstream capital markets – reasons included by the President’s Council of Advisors on Science and Technology include technology risk, market adoption risk, long lead times to profitability, and significant capital requirements.32

In Australia, concern is often raised about the limited capacity, scale, and resources of manufacturing companies, leading to limited ability to engage enabling technologies and to liaise with leading researchers. Furthermore, Australian SMEs are viewed as facing impediments to the adoption and diffusion of new technologies and new business models.33

However, contrary to the myriad of concerns about the merit of investing in advanced manufacturing, one of largest ever deals conducted by Warren Buffet’s Berkshire Hathaway Inc. occurred in August 2015 when the company agreed to buy an advanced manufacturer of components for jet engines, power plants, and pipes. The company that was purchased for US$32.3 billion, Precision Castparts Corp, has customers including General Electric Co., Boeing Co., and Airbus.

The deal by Mr Buffett was described as a major bet on aerospace and advanced

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32 President’s Council of Advisors on Science and Technology (2014) Report to the President accelerating U.S. advanced manufacturing. Executive Office of the President October 2014 p.41
33 Scott, M. (2014) Innovative Manufacturing CRC. Application to Cooperative Research Centres Program
manufacturing in the United States, as well as providing a positive global outlook for the sector. Previous investments in advanced manufacturing by Mr Buffett include battery maker Duracell, chemical maker Lubrizol, and components maker Marmon Group.

The advanced manufacturing companies featured in the case studies at Appendix 1 are clear evidence of Queensland’s participation and potential in the advanced manufacturing sector. Many of these companies display similar traits – low volume production of highly customised goods and services which are complex and high-value. Because they are agile, innovative, and entrepreneurial, scale and cost-based mass production are not critical to the business models of these firms for success.

Such characteristics of successful advanced manufacturing businesses, including being responsive across multiple supply chains, have been identified previously.

3.4.2. By countries and jurisdictions (macro)

The thesis that manufacturing is vital for national development has been affirmed many times – attributed to raising incomes and providing the machinery, tools, and materials to build modern infrastructure and housing. Manufacturing makes outsized contributions to trade, R&D, and productivity, with the sector generating 70 per cent of exports in major manufacturing economies and up to 90 per cent of business R&D spending. Driven by global competition in many subsectors, the share of manufacturing to total productivity growth is twice its share of employment in the EU-15 nations and three times its share of US employment.

The value from investing in advanced manufacturing is becoming widely recognised in the international context. For example, the Singaporean government announced that it is heavily investing in advanced manufacturing technologies - over the next five years, $500 million will be injected into advanced manufacturing techniques in order to remain competitive with its South East Asian neighbours. This investment forms part of their $19 billion Research, Innovation, and Enterprise Plan (REI2020 plan) under which advanced manufacturing and engineering is one of four technology domains – to build the foundations of Singapore’s progress for the next 50 years.


38 Scott, M. (2014) Innovative Manufacturing CRC. Application to Cooperative Research Centres Program

As many economies invest in education, skill up, and move up the value chain, they are producing more advanced goods and services.\textsuperscript{40} In 2000, China produced around 6 per cent of the world’s communication equipment; by 2010 this production had increased to 26 per cent.\textsuperscript{41} Emerging Asia has increased its share of global manufacturing output from around 6 per cent in 1982 to 29 per cent in 2012 and its share of services exports has grown from 6 per cent in 2003 to 11 per cent in 2013.\textsuperscript{42, 43}

The United Kingdom too is ramping it up its investment in ‘high value manufacturing’, having identified it as a strategic priority, with the formation of the High Value Manufacturing (HVM) Catapult, comprising seven centres.\textsuperscript{44} The HVM Catapult offers access to world-class equipment, expertise and collaborative opportunities and is viewed as the catalyst for the growth and success of UK advanced manufacturing. The HVM Catapult works with manufacturing businesses of all sizes and from all sectors to help turn ideas into commercial applications by addressing the gap between technology concept and commercialisation.

Furthermore, the UK government established the Knowledge Transfer Partnerships (KTP) programme that links up businesses and the UK’s knowledge base to improve industry competitiveness, productivity, and performance.\textsuperscript{45} The KTP has achieved remarkable success since its inception in 2003 – for every £1m of government spend, the average benefits to the company amounted to an £4.25m annual increase in profit before tax, £3.25m investment in plant and machinery with 112 new jobs created, and 214 company staff trained as a direct result of the project. From the perspective of the higher education institution, each KTP project produces 3.6 new research projects, two research papers, and 60 per cent of graduates are offered and accept a post in their host company on completion.

Germany continues to invest heavily in advanced manufacturing – it’s ‘Industry 4.0’ policy is transforming manufacturing by embracing new technologies that embody new ‘man–machine’ interactions.\textsuperscript{46} The 66 Fraunhofer Institutes and research facilities at different locations in Germany have an annual budget of more than 2 billion euros (2015) with approximately 24,000 staff, conducting applied research for both private and public enterprises, as well as for the general benefit of the public.\textsuperscript{47} The Fraunhofer institutes are

\textsuperscript{41} National Science Board. (2012). Science and Engineering Indicators 2012. Arlington: National Science Foundation
\textsuperscript{44} High Value Manufacturing Catapult (2015) HVM Catapult. Innovate UK https://hvm.catapult.org.uk/
\textsuperscript{45} Innovate UK (2015) Knowledge Transfer Partnerships https://connect.innovateuk.org/web/ktp
heavily funded by the German government, with one-third direct government grants, one-third government contracts for applied research, and one-third contracts from the private sector.\textsuperscript{48}

The United States is strongly committed to regaining its pre-eminent position in manufacturing. In 2012, the President launched the comprehensive blueprint for revitalising American manufacturing.\textsuperscript{49} Newly created manufacturing ‘Centers of Excellence’ and manufacturing technology test-beds were seen to complement existing Manufacturing Innovation Institutes at earlier and later technology maturation stages. The new framework was deemed to support manufacturing innovation at different stages of maturity, particularly for SMEs. Furthermore, the Advanced Manufacturing Partnership 2.0 Steering Committee (AMP2.0) put forth a set of recommendations around three pillars: enabling innovation; securing the talent pipeline; and improving the business climate.\textsuperscript{50} Three emerging advanced manufacturing technologies of national importance have been piloted and recommended for a model for a broader effort to develop a full national manufacturing technology strategy - (1) advanced sensing, control, and platforms for manufacturing; (2) visualisation, informatics and digital manufacturing technologies; and (3) advanced materials manufacturing.\textsuperscript{51}

The proposed National Network for Manufacturing Innovation (NNMI) in the United States, modelled after Germany’s Fraunhofer Institutes, will establish up to 45 innovation hubs (each with a unique research focus) that will work towards developing and commercialising manufacturing technologies through public-private partnerships between industry, universities, and federal government agencies. These arrangements are expected to have minimal budget impact, but be highly effective as everyone has skin in the game.\textsuperscript{52}

The commitment by governments to the advancement of manufacturing is a major reason for resistance to the movement of innovative capacity and production processes offshore. For example, the President’s Council of Advisors on Science and Technology stated that when “manufacturing migrates offshore so do the knowledge and capabilities that help spur innovative new technologies and allow a country to compete in new industries.”\textsuperscript{53}

\textsuperscript{50} President’s Council of Advisors on Science and Technology (2014) Report to the President accelerating U.S. advanced manufacturing. Executive Office of the President October 2014 p.15 https://www.whitehouse.gov/administration/eop/ostp/pcast/docsreports
\textsuperscript{51} President’s Council of Advisors on Science and Technology (2011) Report to the President on ensuring American leadership in advanced manufacturing. Executive Office of the President. October 2014 p. 3 https://www.whitehouse.gov/administration/eop/ostp/pcast
\textsuperscript{53} President’s Council of Advisors on Science and Technology (2011) Report to the President on ensuring American leadership in advanced manufacturing. Executive Office of the President. June 2011 p. 11 https://www.whitehouse.gov/administration/eop/ostp/pcast/docsreports
Manufacturing is therefore viewed as an indispensable part of Australia's future as a ‘knowledge economy’, with advanced manufacturing set to drive productivity, ‘economic complexity’, prosperity, and future growth.\(^{54}\) It is clear that the next generation of additive, automated, and assistive technologies are critical to enabling Australia's innovative manufacturing sector to compete internationally.\(^{55}\)

Therefore, the scene is set for Australia, and for Queensland, to invest in a future where advanced manufacturing is a significant component, to increase the value of economic output and to improve our standard of living.

3.5. Support by government

3.5.1. Queensland

The Queensland Science and Research Priorities identifies advanced manufacturing as an important enabler to delivering productivity growth and jobs for the State.\(^{56}\) The Office of the Queensland Chief Scientist identifies advanced manufacturing as one of the State’s science challenges, particularly the need to support transformative technologies - such as nanotechnology – to develop new industries.\(^{57}\)

Queensland already has mechanisms in place for supporting the development of advanced manufacturing. For example, the Industry and Manufacturing Advisory Group (IMAG) has been established to support the Queensland manufacturing industry and will help position the State’s businesses to maximise domestic and international opportunities.\(^{58}\) Chaired by the Minister for State Development and including leading stakeholders from the Queensland manufacturing industry, the group assists industry growth by concentrating on changing demand and emerging opportunities, productivity and competitiveness, innovation and technology, and local content, business costs and regulation.

The Queensland Government also provides ongoing support for the adoption of advanced manufacturing technologies through the provision of funding for programs undertaken by QMI Solutions Limited and by Innovate Queensland (Appendix 2). The Industry Capability Network (ICN), a division of QMI Solutions, contributes to business and employment growth and fosters innovation by identifying procurement opportunities for local industry.\(^{59}\)

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\(^{55}\) Scott, M. (2014) Innovative Manufacturing CRC. Application to Cooperative Research Centres Program


To help young firms gain access to early stage investment capital, the Queensland Government has established the Business Development Fund under its Advance Queensland initiative.60 This $40 million co-investment fund will enable Queensland startups (including those in advanced manufacturing) at the forefront of commercialising cutting edge research or innovative ideas, products or services to access capital to help unlock their innovative potential.

Collaboration is a central tenet of the Advance Queensland initiative, which, has at its core, programs that require the co-location of university graduates within businesses. A good example is the Knowledge Transfer Partnerships program,61 which offers up to $50,000 per submission to enable a business to partner with universities, with graduates working on a specific project within a business, potentially an advanced manufacturing enterprise.

3.5.2. Federal

In 2015-16, the Commonwealth Government’s investment in R&D will reach around $9.7 billion.62 In total, approximately 56 per cent of this investment will be allocated to universities, publically funded R&D agencies, and two research councils. An additional 30 per cent is to be allocated to business through the R&D Tax Incentive which can be accessed by advanced manufacturing firms as an entitlement to undertake R&D. An estimated $440 million of the $2.65 billion supporting national priorities in 2015-16 is allocated directly to the advanced manufacturing priority area (Figure 2).63

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3.6. Trends in manufacturing innovation

‘New’ manufacturing is becoming defined by shorter runs, high value/complexity/variability, global value chain accessibility, nimble and flexible production methods, and is rich in new technologies and materials.\textsuperscript{64} Supply and distribution arrangements are also changing as manufacturing businesses increase their participation in complex global value chains and establish coalitions (collaborations) with a range of contractors and business partners. These new arrangements include innovation providers, such as software companies, professional specialists, universities and research organisations. The capacity to collaborate is recognised as a major source of competitive advantage.\textsuperscript{65}

The convergence of skills from widely varying disciplines is a continuing trend, as manufacturing becomes more reliant on the application and coordination of information, automation, computation, software, sensing, and networking, and/or making use of cutting


edge materials and emerging capabilities enabled by the physical and biological sciences. 66

A ‘manufacturer’ may now be classified as an entrepreneur, a ‘brand manager’, or an ‘integrator’ that does not actually own any physical capital.

The success of Queensland manufacturing will depend on how well it embraces innovations in products, their design and production processes, new materials, and the principles driving new business models, customer needs, and expectations.

**Materials**

The need for new capabilities and higher performance in materials, the need for greater customisation, and a greater focus on long-term cost and resource sustainability are all driving innovations in materials. 67 These advances – in nanotechnology, biologics, and lightweight composites – affect manufacturing industries as diverse as aerospace and food.

Advanced materials include graphene and carbon nanotubes have nano-scale crystalline structures that could serve markets for data storage, energy, optoelectronics, avionics, defence and packaging. Potential products include highly attuned chemical and biological sensors, fuel cells, touch screens, lightweight body armour, and airframes.68:

**Products**

The ultimate products or services which help shape our manufacturing future will be underpinned by advanced processes and systems. These advanced methodologies have a critical role in making new products and enabling technologies competitive, affordable, and accessible so as to multiply their societal and economic benefits.69 Trends such as demand for greener products and service-led personalised products will be major determinants of future demand. The European Commission identified a wide range of products for the future based on the European Union’s grand societal challenges, including sustainable mobility, improved recycling, better home care for the elderly, and sustainable energy sources.70 Indeed, innovative pharmaceuticales, medical devices, and assistive technologies are viewed as strong prospects for manufacturing in Queensland, and continued growth of these products is expected, particularly as the population ages and Asia’s middle class grows.

The driving forces for new products are still driven by traditional influences such as personalised products, consumer electronics, connectivity, telecommunications, mobility,

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68 President’s Council of Advisors on Science and Technology (2011) Report to the President on ensuring American leadership in advanced manufacturing. Executive Office of the President. June 2011 p 19 [https://www.whitehouse.gov/administration/eop/ostp/pcast/docsreports](https://www.whitehouse.gov/administration/eop/ostp/pcast/docsreports)
and big data intelligence. Some examples of advanced manufacturing technologies and associated products include:  

- **Flexible electronics**: Technology that allows electronic circuits to be printed on thin, flexible substrates that can be shaped without damage. It has the potential to improve a range of existing products including displays and photovoltaic panels and to form the basis of new products, such as bandages that sense the presence of infection and alert medical staff, foldable solar panels, clothing that monitors and displays physiological signs, and ultra-efficient lighting.

- **Nanotechnology Enabled Medical Diagnostic Devices and Therapeutics**: Advances in nanomedicine have the potential to revolutionize the pharmaceutical industry, by dramatically improving prevention, diagnosis and treatment. Potential developments include ultrasensitive assays for identifying and treating diseases at earlier stages than conventional diagnostic tools, new ways of delivering powerful therapeutics to the point of disease within the body without unintended side effects, and the development of entire new classes of pharmaceuticals.

**Methodologies**
The efficiency and sustainability of manufacturing is very much determined by the processes that shape and assemble the components of final products. Future production processes and methodologies are likely to require a shift in the manufacturing paradigm by introducing new methodologies that require greater productivity, cost efficiency, and product quality.

Four trends in production methodologies were identified by the McKinsey Global Institute as important in coming years: digital modelling, simulation, and visualisation; advances in robotics; additive manufacturing; and green manufacturing.  

The CSIRO has identified robotics, mobile devices, consumer devices, and cloud services as being the most important enablers for advanced manufacturing in the future.

Additive manufacturing (3-D printing) is reportedly the fastest growing sector of manufacturing globally, growing at some 16 per cent annually and was estimated to reach US$3.5 billion in 2015.  

It is projected that the global market for additive manufactured products alone will be US$130-$250 billion by 2025.

Manufacturing will benefit from information-driven intelligence arising from advanced analytics, big data, social technologies, greater connectivity through the ‘internet of things’, and the use of smart devices which monitor production machinery, supply chains, and products.

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71 President’s Council of Advisors on Science and Technology (2011) Report to the President on ensuring American leadership in advanced manufacturing. Executive Office of the President. June 2011 p 19  
https://www.whitehouse.gov/administration/eop/ostp/pcast/docsreports


The internet of things is expected to change the way manufacturers do business, market their products and services, shape their factories, and train their staff. Specifically, wireless networking, machine-to-machine connection protocols, device and sensor connectivity platforms, robotics, 3D printers, and smart building systems will underpin major shifts in manufacturing processes.\textsuperscript{75} 

Furthermore, augmented reality is predicted to become a significant enhancement to manufacturing operations through enhancing skilled workers in their day-to-day operations, including training, pre-visualisation, manufacturing, construction, inspection, and maintenance.\textsuperscript{76} 

**Principles**

Advanced manufacturers in Australia will ultimately embrace the suite of new business principles necessary for competing in a global market place. Customisation, agile business models, innovation, collaborative R&D, design-led thinking, value-adding along the supply chain, and accessing global value chains are vital principles in strengthening the international competitiveness of advanced manufacturers. 

The effective adoption, application and incorporation of these principles will require Queensland manufacturers to specialise in areas along the value chain in which they have a competitive advantage, while outsourcing or off-shoring the rest. This comparative advantage lies in low-volume, high value products, with a strong focus on the pre- and post-production activities such as design, R&D, innovation, and communications.\textsuperscript{77} Such an approach means that Australian manufacturers would take advantage of the ‘servification’ trend in order to add value to the sector.

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4. Towards Queensland’s ‘new’ manufacturing future

Priority opportunities to develop advanced manufacturing depend on circumstance. In the United States, the focus is on: advanced sensing, control, and platforms for manufacturing; visualisation, informatics and digital manufacturing technologies; and advanced materials manufacturing.\(^{78}\)

Given the unique tapestry of industry and research strengths for advanced manufacturing in Queensland, there are several approaches that can be used to guide and shape the State’s ‘new’ manufacturing future.

4.1. Picking winners, building on our strengths

Queensland manufacturing has traditionally supported the resources and agricultural sectors through activities such as minerals, meat, and sugarcane processing, soil tilling, and crop harvesting. Accordingly, the three largest manufacturing segments in Queensland are processed foods and beverages, metal products and machinery, and equipment manufacturing.\(^{79}\)

Continuing in this supportive role makes sense, but the kinds of manufacturing will need to reflect the greater sophistication required for these 21\(^{st}\) Century industries. The resources industry requires specialised advanced manufacturing inputs into the mining equipment, technology and services (METS) sector. Agriculture, as it moves to higher value products along the value chain, requires advanced manufacturing solutions for the food industry of the future – high-tech, healthy foods, and nutraceuticals, as well as automation, robotics, and telemetry devices need to operate farming enterprises remotely on large and isolated tracts of land.

In recent years the manufacturing sector has diversified and expanded into higher value-added and high technology industries. Queensland can build on its strengths in:

- **Innovative pharmaceuticals, biotechnology, and medical devices** – this sector is identified has having one of the strongest prospects in manufacturing in Australia.\(^{80}\)

  Nationally, exports of pharmaceuticals and medical devices alone are worth around $4 billion per annum.\(^{81}\) Continued growth is expected, particularly as populations age and Asia’s middle class grows. Research and development expenditure by this sector is substantial, supported by a strong intellectual property environment and educated

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\(^{78}\) President’s Council of Advisors on Science and Technology (2014) Report to the President accelerating U.S. advanced manufacturing. Executive Office of the President October 2014 p.15
https://www.whitehouse.gov/administration/eop/ostp/pcast/docsreports


workforce.\textsuperscript{82} Cook Medical Australia (Appendix 1), a Brisbane-based medical manufacturer and leader in research and development of endovascular stents and IVF technologies, is a great example of Queensland’s strengths in medical devices. As is the work being conducted at the University of Queensland nano-diagnostics that is using thousands of microscopic projections on a small polymer wafer to quickly detect biomarkers for infectious diseases such as dengue fever and malaria (Appendix 1). The State also has a well-established expertise in biological products of complex molecules (biologics), with Patheon Biologics (based at the Translational Research Institute employing approximately 100 staff, Appendix 1) manufacturing these products, noting that seven of the eight best-selling drugs in 2013 were biologics.\textsuperscript{83} There is also a growing cluster of related companies active in the clinical trials design and running associated activities, many with strong links with the National Biologics Facility (NBF) located at the AIBN (Appendix 2).

- **Advanced materials** – Australia has a competitive advantage in advanced and composite materials research to improve product design and fabrication,\textsuperscript{84} and this strength is particularly relevant to Queensland in terms of the number of entities involved in advanced materials R&D (Table 1). Queensland has particular strengths in advanced materials, with complex graphene research being conducted at Griffith University and work on molecular nanosystems for a range of applications (Appendix 1).

A competitive advantage for domestic manufacturing in the areas of niche products, quality and standards, and services suggests the need for focussed effort on high-end manufacturing in these disciplines.

**4.2. New business models, shifting paradigms, changing markets**

There is worldwide recognition that advanced manufacturing is evolving towards smaller batches, customised high-value products, rapid prototyping, agile manufacturing processes, and responsiveness to multiple supply chains. In this context, Australian manufacturers must develop appropriate business models and prepare for increasingly innovative and competitive offerings in terms of price and flexibility in their domestic and international market niches.\textsuperscript{85}

Additionally, as manufactured products become more sophisticated and complex, business models are changing to reflect the extra technical skills required to service the equipment. The traditional value proposition of selling manufactured items is being usurped by the need for associated service and maintenance. Hardware manufacturing is acting as a platform for selling technical services and new value-added features. This transition towards service-focussed business models is embraced by some German manufacturers, for whom a


negative profit margin from the sale of hardware is offset by the sale of services. This trend is likely to become more profound as Queensland manufacturers transition towards more advanced processes and production methodologies.

Changes in technology and international supply chains (exhibiting increasing complexity and international disaggregation), together with new innovative business organisation, have opened up opportunities for competitive new manufacturing. These changes mean that often, being small is not a disadvantage, with such manufacturing typically based on short runs, low volume, high variability and complexity, rapidity to market, and highly customised goods and services. Participating companies position themselves along these complex supply chains, known as global value chains. A leading example of a successful Australian participant in a global value chain is Boeing Australia, which has worked with its parent company in the United States to provide flight control components for the Boeing 787 Dreamliner (Figure 3).

Some Queensland examples of advanced manufacturers providing components in global value chains are shown in Appendix 1, and include:

- **PWR Holdings Limited** - designs and produces customised cooling solutions for motorsports and the automotive industry for the teams such as F1, NASCAR, V8 Supercars, Deutsche Tourenwagen Masters and World Rally Championship
- **Ferra** - designs, manufactures, assembles, and tests aerospace structures and sub-systems for customers including Lockheed Martin, Airbus, Boeing, BAE Systems, GE Aviation, and Thales.

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87 Scott, M. (2014) Innovative Manufacturing CRC. Application to Cooperative Research Centres Program
4.3. Embracing innovation for cost reduction

Although Australia ranked last out of 25 countries in terms of manufacturing cost competitiveness in 2014, Germany, the world’s second largest exporter of manufactured goods, also ranked poorly - at seventh last (cost index values of 130 and 121, respectively, Figure 1). Indeed, the high labour costs for manufacturing in Western Europe prompted the CEO of Festo (a large German industrial control and automation company) to state that “the more expensive you are, the better and smarter you have to be.”

So despite these costs, advances in production processes (such as robotics, 3D printing, flow chemistry), supplying to global value chains, and specialising have the capacity to greatly reduce costs, and allows Queensland manufacturers of advanced products to become more competitive.

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90 ATSE (2013). Dreamliner is real collaboration. Focus 180, p.8 October 2013 Australian Academy of Technological Sciences and Engineering


4.4. Skilling the workforce of the future

The more innovative manufacturing becomes, the more skilled labour is an important input. For example, the economic growth of the German state of Baden-Württemburg - where the manufacturing hub of Stuttgart is located (headquarters for Mercedes-Benz and Porsche) - is becoming severely constrained by a dearth of skilled labour in its manufacturing industries.93 Unemployment rates typically hover around three to four per cent.

Indeed, 75 per cent of manufacturers surveyed in the United States are reportedly impacted negatively by skills shortages, mainly as a result of technological developments that have outpaced workforce skills and demographic shifts.94 Australia fares little better - 42.5 per cent of the manufacturing workforce having no post-school qualifications, and many of the post-school qualifications in trade areas with little relevance to future technological adoption.95

With the demise and closure of many manufacturing industries in Australia over past decades,96 the skills challenge may also be compounded by public misconceptions about future job prospects. Therefore, developing a pipeline of talented and committed workers in advanced manufacturing is a potential issue for Queensland, as the economy broadens.

To address the need for an innovative and skilled workforce in advanced manufacturing, ACOLA recommended greater investment in STEM.97 Of particular relevance is an increasing reliance on information technologies, with workers requiring expertise in not only eSkills (general computer/internet abilities) but also iSkills (understanding data, connectedness, the internet-of-things).98

To encourage greater participation in STEM subjects, there is merit in teaching to become more engaging, with practical sessions and placement with companies. There is also scope for incorporating design and business skills into the STEM curricula (design-led thinking, communication, project management, understanding business plans, intellectual property, and basic legal skills) without compromising a solid STEM basis.99


94 President’s Council of Advisors on Science and Technology (2014) Report to the President accelerating U.S. advanced manufacturing. Executive Office of the President October 2014 p.7 https://www.whitehouse.gov/administration/eop/ostp/pcast/docsreports


99 Iacopi, F. (2015) Personal communication, Griffith University. 19 December 2015
The potential for advanced manufacturing to create knowledge-intensive jobs is widely reported. Industry and academia need to work together in responding to skill requirements in technological innovation, which is otherwise too expensive for individual businesses to accommodate. However, not all skills development will be accredited and delivered through registered training organisations or higher learning institutions, as each individual employer will have a unique suite of requirements.

4.5. Communication, collaboration, and co-location

The level of collaboration between Australian businesses and research organisations is low by international standards, despite significant improvement over the last decade. Across almost all industry sectors and firm sizes, the proportion of innovating Australian businesses engaged in research collaborations with universities and other higher education institutions has increased from only 1.6 per cent in 2006-07 to 9.7 per cent in 2012-13. Even so, Australia remains at the bottom of the Organisation for Economic Co-operation and Development on this measure, ranking 33rd of 33 OECD countries. Accordingly, CEDA notes that strengthening the links between industry and research groups would overcome cultural barriers to undertaking applied research and drive development of improved capabilities.

Futurists often assume far less centralised economies in the years ahead with the increasing prominence of enabling technologies which support geographic dispersion – for example, cloud technologies, the mobile internet, data sharing, digitisation, robotics, and 3D-printing. Paradoxically, as telecommunications and travel have grown steadily cheaper, people are now living closer together, rather than further apart.

As urbanisation continues unabated, productivity of knowledge workers rises exponentially when they are in close proximity. Their interaction stimulates creativity and innovation – new and different ideas – which in turn drives productivity in the knowledge economy. Therefore, the success of collaborative models for research and business through cohesive and strategic co-location looks set to persist and develop.

Indeed, strategic alignment of research is an important finding of the recent review of the CRC program that recommended that CRCs work more closely with the goals of the Industry 100 President’s Council of Advisors on Science and Technology (2011) Report to the President on ensuring American leadership in advanced manufacturing. Executive Office of the President. June 2011 p. 10 https://www.whitehouse.gov/administration/eop/ostp/pcast/docsreports


Growth Centres. Consistent with this recommendation, the Innovative Manufacturing CRC (IMCRC) has signed a memorandum of understanding with the Advanced Manufacturing Growth Centre to ensure synergy of effort - a step that was necessary for the IMCRC to receive $40 million of federal funding pledged in the May 2015 budget as part of a $731 million budget funding package for CRCs.

The IMCRC will build on initiatives over recent years under the Federal /NCRIS/EIF/CRIS umbrellas, together with Queensland Government support, leading to the Australian National Fabrication Facility (ANFF) seven years ago. The establishment of leading-edge nanofabrication facilities for academia and industry in Queensland through the ANFF-Queensland node at the University of Queensland and Griffith University (Appendix 2) have, together with other national groups, been supporting world-class innovation and service to local industry.

One of the most successful collaborative models in high-tech manufacturing is the Fraunhofer Society, a network of government-backed research institutes based in Germany. Managed mostly by engineering professors with years of experience, many of the 22,000 employees move onto roles in prominent companies, such as Porsche or Audi. Others start their own companies, and employees are encouraged to found start-ups to sell the technology the institutes develop – an important draw for talent.

A similar collaborative model, a National Network for Manufacturing Innovation (NNMI) is under consideration in the United States, which is looking to set up innovation hubs where people from both industry and academia can collaborate on specific areas such as 3D printing or advanced materials.

Critical to the success of such public-private arrangements is stewardship by experienced industry leaders, joint appointments from successful companies, physical colocation of students, start-up formation, and an environment that encourages the flow of staff between industry and academic roles.

The importance of collaboration in advanced manufacturing in Queensland can be illustrated by the recent production by the National Biologics Facility (NBF) of batches of a monoclonal antibody that may be a potential therapeutic for Hendra virus infection in humans. The NBF was contracted to produce this biologic in collaboration with Queensland Health, CSIRO’s Australian Animal Health Laboratory and the Henry M Jackson Foundation.

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The paucity of research capacity or research partnerships focussed on products or product development in advanced manufacturing (Table 1) was discussed previously, and attributed, in part, to the lack of suitably co-located facilities of R&D entities and innovative companies, similar to the Cambridge cluster.

Historically, some clusters in Queensland have been established in locations often unsupportive of cross-pollinating ideas between research and industry. The original premise was one akin to the quote made famous from the 1980’s movie ‘Field of Dreams’; viz. “Build it and they will come”. Several decades on however, with OECD data revealing poor metrics in Australia for collaboration between research bodies and innovation active firms, there is a realisation that the old model should be revisited and overlain with a new emphasis on strategic collocation and collaboration between relevant research capacity and innovative businesses and industry.

The Cambridge Cluster, Europe’s largest technology cluster and one of the exemplars for technology transfer between research and industry in the world, had its genesis over 50 years ago and was spurned on with the establishment of Cambridge Science Park by Trinity College in 1970.

Potential sites in Queensland which may allow close proximity between research and industry engaging in advanced manufacturing, but also across a range of disciplines may include:

- Griffith University Southport campus – on the greenfield site at the health and knowledge precinct to explore advanced manufacturing in the health and pharmaceutical area. This approach would be consistent with an impetus towards shifting major investment and high-profile by the university to this campus
- University of Queensland – favourable zoning of land near the AIBN and Engineering facilities or at the health and commercial precinct adjoining the Royal Brisbane and Women’s Hospital (RBWH) at Herston.

Queensland’s capability in biomedical devices and biologics would be significantly enhanced by such a co-location model that fosters the interaction of biologists, chemists, engineers, and medical researchers, supporting the development of new and innovative products. A cluster of research and business infrastructure in close proximity is an important strategy to realising this outcome.

There are a range of facilitation groups and activities in Queensland that assist in the collaboration of research groups with industry (Appendix 2):

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• **QMI Solutions** – specific to advanced manufacturing, QMI provides a research partnerships fund with the University of Queensland, mainly through the Centre for Advanced Materials Processing and Manufacturing (AMPAM). The fund supports collaboration on specific projects with industry partners, up to approximately $100,000 per year. In 2015, three projects were funded:
  - Boeing - incremental sheet forming\(^{113}\)
  - White Industries – application of 3D printing technology in developing complicated sand moulds and cores\(^{114}\)
  - Volvo Group Governmental Sales Oceania – safety HALO design for emergency service vehicles.\(^{115}\)

• **Impact Innovation Group** - more generally through the Innovate Queensland program funded by the Queensland Government, Impact Innovation Group conducts IQ Link activities (online and hosted events) designed to bring people together to generate ideas and solve industry-specific problems.\(^{116}\)

These facilitators of information exchange and trusted intermediaries are essential in brokering collaborative partnerships between researchers and industry. Their effectiveness may be greatly enhanced by location in close proximity with R&D providers and businesses, augmented by a distributed model of information exchange.

In the context of peer-to-peer collaboration, the Industry Capability (ICN), a division of QMI Solutions Limited and supported by the Queensland Government, links local industry with procurement opportunities throughout Australia, New Zealand, and around the world using an online communication platform.\(^{117}\) It is estimated that the ICN assisted local suppliers to find $30 billion of contracts since its inception in 1984. The ICN Queensland has developed a Major Project Supplier Program (MPSP) to help suppliers improve their capability and competitiveness when bidding for tenders on major projects.\(^{118}\) The MPSP supported an estimated 10 per cent of the total number of manufacturers in Queensland.

Collaboration is a central tenet of the Advance Queensland initiative, which, has at its core, programs that require the co-location collaboration of university researchers within businesses. A good example is the Knowledge Transfer Partnerships program,\(^{119}\) which offers up to $50,000 per submission to enable a business to partner with universities, with


graduates working on a specific project within a business, potentially an advanced manufacturing enterprise. Another is the Innovation Partnerships Program,\(^\text{120}\) which supports collaborative research in priority areas, including advanced manufacturing - grants of up to $1.5 million are available to research groups to undertake R&D in collaboration with an industry partner.

4.6. Accessing capital and programs

Emerging advanced manufacturing technology companies often are not compelling investments for capital markets due to technology risk, market adoption risk, long lead times to significant revenue, and significant capital requirements.\(^\text{121}\) To address some of these concerns, the Advance Queensland initiative has programs that can help. For example, the Business Development Fund\(^\text{122}\) is a $40 million co-investment fund that will enable Queensland startups (including those in advanced manufacturing) at the forefront of commercialising cutting edge research or innovative ideas, products or services to access capital to help unlock their innovative potential. When announced, there might also be options through the Startup Queensland package.

Furthermore, the Commonwealth Government’s R&D Tax Incentive program can be accessed by advanced manufacturing firms as an entitlement to undertake R&D.

4.7. R&D investment, skin in the game, leveraging funding

Australian manufacturers are highly innovative and are second only to service industries in terms of expenditure on R&D.\(^\text{123}\) In Queensland, manufacturing is a major contributor to R&D (in 2013-2014, manufacturing accounted for over 19.7 per cent of total business expenditure on R&D) and the sector was one of the most innovative in the State over the three year period to December 2013, being the second most likely to engage in R&D.\(^\text{124}\)

However, it is also true that the Queensland manufacturing sector is dominated by SMEs with a relatively low spend on R&D. This lack of investment places the State’s manufacturing industry at considerable economic risk, particularly from global competition. The spectrum of manufacturing R&D is skewed towards traditional disciplines facing high competition from the south-east Asian region, with over 60 per cent of the R&D spend on ‘Machinery and Equipment Manufacturing’ and ‘Food Product Manufacturing’.


\(^{121}\) President’s Council of Advisors on Science and Technology (2014) Report to the President accelerating U.S. advanced manufacturing. Executive Office of the President October 2014 p.41 https://www.whitehouse.gov/administration/eop/ostp/pcast/docsreports


\(^{123}\) Department of Industry, R&D tax incentive data.

Leveraging the contribution of the industry and Queensland Government will be a prerequisite to build scale and scope. There is opportunity is to leverage funding from the federal government’s Industry Innovation and Competitiveness Agenda.
5. Conclusions

There is a bright future for manufacturing firms in Queensland which embrace change, have adaptive business models, supply to niche markets or to global value chains, and are innovative. Such businesses are not disadvantaged by being small, and will typically supply niche markets seeking high value, complex, highly customised goods and services.

Focusing resources on technologies in defined disciplines, particularly around Queensland’s strengths in medical technologies and devices, and servicing our traditional industries such as agriculture and mining, is an important step in accelerating innovation in manufacturing technology. Building on these traditional links would provide a virtuous cycle of innovation and investment.

This paper identifies four factors that will shape Queensland’s ‘new’ manufacturing future: the technologically-advanced products, goods, and services demanded by future generations; the disruptive technologies, practices, and processes required to produce them; the advanced materials used to make these products; and the principles, platforms, and systems by which business needs to operate to compete in the global marketplace.

**Products**

Queensland has a highly diverse manufacturing industry supplying to growth sectors including aviation, defence, medical technologies and pharmaceuticals, mining equipment and technology services, and processed foods. However, its traditional strengths lie in the resource and agricultural sectors, with the three largest employing segments (processed foods and beverages, metal products and machinery, and equipment manufacturing) accounting for 65 per cent of total manufacturing jobs.125

Building on these strengths, the future products demanded will reflect the greater sophistication required for these 21st Century industries. The resources industry requires specialised advanced manufacturing inputs in the METS sector using autonomous vehicles, big data analytics, and remote monitoring of sensor networks. Agriculture, as it moves along the value chain, requires advanced manufacturing solutions for the food industry of the future – high-tech, healthy foods, and nutraceuticals, as well as automation, robotics, and telemetry devices needed to operate farming enterprises remotely on large and isolated tracts of land.

Innovative pharmaceuticals and medical devices are products with one of the strongest prospects for manufacturing in Australia126, with national exports of pharmaceuticals and

medical devices alone are worth around $4 billion per annum.\textsuperscript{127} Continued growth in these products, along with those utilising assistive technologies, is expected, particularly as the population ages and Asia’s middle class grows.

Queensland’s R&D capacity in nano-materials (including Nano-Patch and nano-diagnostics) and graphene augur well future products made from these materials. As the suite of products becomes more tailored and complex, a commensurate demand for servicing becomes more important to the advanced manufacturing sector.

Methodologies
New production practices and processes are providing massive opportunities for Queensland’s manufacturing industries. For example, additive manufacturing (3D printing), digitisation, automation, robotics, and flow chemistry are becoming integral to production processes and provide opportunities to not only reduce costs and become more competitive in an increasingly globalised marketplace, but to also move along the value chain.

Queensland’s R&D capability in methodologies is strong, and has been enhanced by locating the ‘Automated and Assistive Technologies’ theme of the newly established Innovative Manufacturing CRC in the State.

Materials
The design of new and revolutionary materials with superior qualities and parameters is an important driver to better make products or to develop new ones. Such materials include flexible electronics, biomaterials, graphene, and nanomaterials.

Queensland has particularly strong R&D capability in advanced materials R&D with developed programs in nanomaterials and graphene. Building on this capability via a ‘Cambridge cluster’ model around critical research infrastructure, such as the AIBN, would promote collaboration and form stronger links between research and industry.

Principles
The guiding principles of Queensland’s ‘new’ advanced manufacturing future are premised on new paradigms for competing in a global market. Customisation, agile business models, innovation, collaborative R&D, design-led thinking, value-adding along the supply chain, capability alignment, and accessing global value chains are vital principles in strengthening the international competitiveness of advanced manufacturers.

The effective adoption, application and incorporation of these activities requires a highly skilled workforce. Having STEM and business management is essential for the future of Queensland’s advanced manufacturing sector, and of particular relevance is an increasing reliance on information technologies, with workers requiring expertise in not only eSkills

(general computer/ internet abilities) but also iSkills (understanding data, connectedness, the internet-of-things). The Queensland Government through the Office of the Queensland Chief Scientist has prepared a paper that will inform future policy setting in this important area.\textsuperscript{128}

### 6. Recommendations

The success of Queensland in becoming an advanced manufacturing centre is premised on increased innovation, productivity, competitiveness, and long-term sustainability. Although Australia has limited ability to compete against low-wage countries undertaking large scale standardised manufacturing, there is a significant advantages in firms focussing on three areas:

- Producing small batches of high-value niche products requiring rapid prototyping and agile manufacturing processes
- Capitalising on excellent quality assurance protocols and standards that have underpinned a reputation for delivering a high quality manufactured product
- Embracing a more service orientated culture to take advantage of the growing trend towards services in advanced manufacturing.

Advanced manufacturing requires new and technologically advanced skill sets, so educational institutions need to be attuned to the needs of industry to ensure a suitably trained workforce of the future.

Critical to a successful manufacturing industry is a vibrant research base working collaboratively and in close proximity with industry. There is a dearth of such facilities and arrangements in Queensland. Potential sites which may allow such physical co-location to occur in advanced manufacturing, and therefore provide the opportunity for cross-pollination of ideas between research and business include:

- Griffith University Southport campus – on the greenfield site at the health and knowledge precinct to explore advance manufacturing in the health and pharmaceutical area. This approach would be consistent with an impetus towards shifting major investment and high-profile by the university to this campus
- University of Queensland - zoning of land near the AIBN and Engineering facilities or at the health and commercial precinct adjoining the Royal Brisbane and Women’s Hospital (RBWH) at Herston.

Such effort must be strategic and start early, as long lead times are required to yield tangible outcomes. In addition to these university/ industry centres, government research providers such CSIRO and Defence Science and Technology (DST) Group would contribute synergistically through relocation close to the relevant cluster.

Additionally, the joint appointment of leading business representatives within the academic framework is highly desirable to build collaborative relationships. Trusted intermediaries and brokers of information exchange such as existing providers are valuable catalysts supporting a collaborative environment.

7. A final word

Creating the right environment to support a dynamic advanced manufacturing sector in Queensland is paramount – a skilled workforce and talent pipeline, a collaborative and relevant R&D capability, an innovative and progressive business sector, an availability of capital, and a willingness for continuous improvement.

In a review paper such as this one, there is often the temptation to make recommendations which are overly prescriptive. A mixture of prescience and critical analysis is required, but ultimately, serendipity and market forces determine how resources are best allocated. A simple strategy for embracing the future by the Queensland manufacturing industry may well be the most incisive; “choose what we make, then make the best”.\(^{129}\)

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Appendix 1. Case studies

Case Study 1: Patheon

Patheon, with a facility located at the Translational Research Institute, has become one of the world’s leading contract development and manufacturing organisations through organic growth and recent acquisition.\textsuperscript{130} The Brisbane operation is an important part of Patheon’s four sites manufacturing biological products (biologics) distributed over three continents.

Patheon currently employs approximately 100 staff at the Brisbane facility and has become a major driver of the emerging biologics sector of the local pharmaceutical industry. The biologics that are being manufactured by Patheon are important components of the world drug market, with seven of the top eight best-selling drugs in 2013 comprising biologics.\textsuperscript{131}

Building on the success of Patheon is a growing cluster of related companies active in the clinical trials design and running of associated activities, with strong links with the National Collaborative Research Infrastructure Strategy (NCRIS) capabilities in the Australian Institute for Bioengineering and Nanotechnology (AIBN) in the National Biologics Facility (NBF).

Patheon offers services across the value chain, combining the corporate strength of a large multi-national corporation with the focus and flexibility needed in successful partnerships with biopharmaceutical customers.\textsuperscript{132}


Case Study 2: Ferra

Ferra is a Brisbane-based company producing a niche input to be part of global supply chains. The company specialises in the design, manufacture, assembly, and testing of aerospace structures and sub-systems. Its customers include Lockheed Martin, Airbus, Boeing, BAE Systems, GE Aviation and Thales.

Ferra has recently signed a number of long-term agreements to supply JDAM ER Wing Kits, P-8, CH-47, F-18, 767 and 747-series components, as well as contracts to produce Weapon Pylons and Mission Kits for the MH-60R Romeo helicopter and weapon adapters for the F-35 Joint Strike Fighter project.

The company has also diversified into medical devices and the renewable energy sector, and successfully worked its way into global supply chains.

Case Study 3: PWR

PWR Performance Products, which has its headquarters at Ormeau in south-east Queensland, derives about 60 per cent of its revenue from supplying professional motorsports teams, including competitors in the NASCAR and IndyCar series in the United States.

Elite motor sport is the main income earner for the company, but it is exploring other opportunities in the emerging sector of home battery storage technology, where pioneers such as Tesla’s chief executive Elon Musk, are making strong inroads.

PWR listed on the Australian Stock Exchange on 18 November 2015 and its share price increased by as much as 93 per cent on the day. The forecast revenue for the company in 2015-16 is $47 million, with a net profit after tax estimated at $10.5 million.

PWR chairman, Bob Thorn said that “we supply cooling systems for battery technology and this is a big growth area for the future”. The company’s manufacturing processes “were used
at the elite end of world motor sports, where a tiny equipment malfunction could have a huge impact on the outcome of races.

The PWR founder and chief executive, Mr Kees Weel, is a former V8 Supercars driver who once finished in third place in the Clipsal 500 event in Adelaide. He was the principal of the PWR Racing V8 Supercars team from 1998 to 2007 where he competed against top drivers. Mr Weel started the business in 1996, but has a manufacturing history dating back to 1987.

PWR CEO Kees Weel has experienced a big first day on the ASX. Photo: Bradley Kanaris

Case Study 4: Research Directions Pty Ltd

Research Directions is a Brisbane-based SME specialising in the advanced manufacture of organic compounds and chemistry consulting. Recently, the company has embraced innovative flow chemistry to produce high-value chemicals for international markets. Australia does not have significant manufacturing capability for organic compounds.

CEO, Dr Stephanie Smith, said that the recent advent of flow chemistry techniques will enable the company to take on international competitors which have lower wage costs than in Australia. Additionally, the new processes enable the large scale manufacture and

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synthesis of chemicals in much smaller production facilities than required by traditional manufacturing.

Staff employed at Research Directions are highly qualified, with 80 per cent possessing a PhD in organic chemistry. The company is collaborating with several other Australian SMEs and is a member of the Innovative Manufacturing CRC.

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**Case Study 5: Anatomics**

In world-first surgery, a Spanish cancer patient has received a 3D printed titanium sternum and rib cage, designed and manufactured Australia.136

Because the chest is notoriously difficult to recreate with prosthetics due to complex geometry and design for each patient, the patient's surgical team at Salamanca University Hospital determined that a fully customisable 3D printed sternum and rib cage was the best option.

Medical device company Anatomics designed and manufactured the implant using CSIRO’s $1.3 million Arcam printer to build up the implant layer-by-layer with its electron beam, producing the implant which was promptly couriered to Spain.

Anatomics was originally collocated at the QMI Solutions’ facility at Brisbane Technology Park where 3D printing – stereolithography – was first successfully introduced to Australia.137 Through a technology diffusion program supported by the Queensland Government, QMI Solution helped Anatomics to establish a medical prosthetic business that used stereolithography to make implants for cranio-maxillofacial surgery, orthopaedic implants, and other medical prosthetics.

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A major advantage of 3D printing is its rapid prototyping. Stereolithography has been used in the past to create heel bones and 3D printed mouth-guards for sleep apnoea suffers. Twelve days after surgery, the recipient of the 3D printed sternum and ribs cage was discharged from hospital and recovered well.

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**Case Study 6: Cook Medical Australia**

A record year for exporting has further secured a Brisbane-based medical manufacturer’s standing on the world stage.

Cook Medical Australia is a leader in R&D of endovascular stents and IVF technologies, and in 2014, manufactured more than 10,000 stent grafts – used for the treatment of aortic aneurysms – along with more than 3000 custom-made medical devices and 750,000 needles to assist in the treatment of reproductive health. All up, 92 per cent of its locally manufactured products were exported last year, totalling $119.3 million.

Managing director Barry Thomas says Australia has carved out a significant global position in medical devices, with companies such as Cook Medical, ResMed and Cochlear among those leading the charge.

He says the three companies contribute almost 20 per cent of total inventions filed in the medical devices field for Australia, citing the latest Australian Medical Devices Patent Analytics Report.

Cook Medical Australia, established in 1974, serves as the Asia Pacific headquarters for Cook Inc., the largest privately owned medical device company in the world. Its locally developed medical technology is exported to more than 135 countries.

But despite the bulk of its customers living thousands of kilometres away, Mr Thomas says the company is committed to supporting and promoting local manufacturing, particularly because its aortic stent grafts were developed and commercialised from Australia.

“We believe in keeping R&D and manufacturing together because there are so many advantages that we can take by keeping both under the same roof,” says Mr Thomas. “I am dedicated to continue leading one of the few remaining and highly successful Australian advanced technology medical device manufacturing companies and retain local manufacturing and local research and development.”

“We are always looking in the pipeline for new ideas,” he says. “We have been working with and will continue to work with physicians, innovators research centres, universities and anyone else who is willing to back themselves with an idea that fits within our company mould. If it doesn’t, we will try and help find someone that can.”
“Medicine and medical devices can be a complex field, but if the correct manufacturing and research environment can be created, Australia has the opportunity to become the world leader in this field and the home to a new wave of innovative and progressive companies.”

In the meantime, Cook Medical takes a straightforward approach to fostering innovation. “You back the people you work with. Pretty simple but you cannot be afraid to take a risk,” says Mr Thomas. “Innovation means that a risk was taken and it paid off.”

**Case Study 7: Molecular nanosystems**

Using the latest developments in chemistry and biotechnology, exciting new classes of nanoparticles are being developed with applications in agriculture, health, and environmental fields.

- **Professor Michael Yu (AIBN, UQ)** and collaborators at QAAFI have developed a series of nanoparticles with controlled nanostructures and morphology which are being applied for the controlled release and delivery of bioactive molecules for agricultural and veterinary applications in association with the companies Elanco and Zoetis.
- **A/Professor Stephen Mahler (AIBN, UQ)** has developed novel bi-functional monoclonal antibodies which are being used by Engenic Pty Ltd for the targeted delivery to cancer cells of particles loaded with a cytotoxic agent.
- **Dr. Kris Thurecht (AIBN, UQ)** is receiving Queensland Government support to work with colleagues researching prostate cancer to develop new imaging agents and new theranostics, nanoparticles which combine diagnosis with therapy. Such theranostic nanoparticle lead into the growing area of ‘personalised nanomedicine’ where the therapy is custom designed for a specific individual and often take advantage of genetic sequence data determined for the individual.

Another class of molecular nanosystems is the ‘virus like particles’ (VLPs) being developed to be able to rapidly respond to emerging diseases and pandemics. The human papilloma virus vaccine ‘Gardasil’ developed in Queensland is a VLP vaccine.

There are some excellent research initiatives underway which are receiving Queensland Government funding and the support of groups like WHO and Gates and commercial support on developing the next generation of VLP’s and employing the new technologies to allow their rapid deployment in response to pandemics as well as addressing chronic intractable disease reservoirs.
Case Study 8: Nano-diagnostics

The exciting work on needle free vaccination from AIBN/UQ using Professor Mark Kendall’s ‘Nanopatch’ is developing well with the Queensland based company Vaxxas Pty Ltd continuing to expand their development of the technology in partnership with leading global pharma companies, and the WHO as a potential method for delivering polio vaccine.

In addition, Dr Simon Corrie from Professor Kendall’s lab has received Queensland government support to combine materials chemistry with molecular biology to create an affordable and widely-available device which can test blood faster, without a need for needles and syringes.

Dr Corrie aims to prove that thousands of microscopic projections on a small polymer wafer can be used to quickly detect biomarkers which point to the presence of infectious diseases such as dengue fever and malaria.

The device will be designed to sit on the skin, draw in fluids to react with antibodies and reporter probes and turn a particular colour, similar to a litmus test, if biomarkers are present.

Case Study 9: Graphene for biosensing

A/Professor Francesca Iacopi is using world-first technology at Griffith University to harness the remarkable properties of graphene with the potential to launch the next generation of mass produced, low-cost micro-sensors. Graphene is one of the thinnest, lightest and strongest materials known to humankind. A supreme conductor of electricity and heat, much has been written about its mechanical, electrical, thermal and optical properties and the anticipated technological advances that its use would bring.

The novel process enables production-scale manufacturing of a superior and versatile material with countless applications. One example is the commercial production of sensor devices that are biocompatible, chemically resistant, and highly sensitive.

This fabrication platform has received international academic and industrial recognition with a Global Innovation Award at the TechConnect conference in Washington DC, May 2014. The US Air Force is already providing funding to support the work, and a large US-based multinational producing semiconductor equipment (Applied Materials) has expressed intention of partnership.
## Appendix 2. Entities/programs/partnerships supporting advanced manufacturing

<table>
<thead>
<tr>
<th>Name</th>
<th>Purpose</th>
<th>Period</th>
<th>Funding ($m)</th>
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<tbody>
<tr>
<td><strong>R&amp;D</strong></td>
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<tr>
<td>Australian Research Centre for Aerospace Automation (ARCAA)</td>
<td>To conduct research into all aspects of aviation automation, with a specific focus on autonomous technologies which support more efficient and safer utilisation of airspace and the development of autonomous aircraft and on-board sensor systems for a wide range of commercial applications. The ARCAA is led by QUT and based in Brisbane</td>
<td>2008-</td>
<td>6</td>
</tr>
<tr>
<td>Queensland Centre for Advanced Technologies (QCAT)</td>
<td>To provide the highest standard science, engineering and innovation to the Australian mining, exploration, minerals processing, and manufacturing industries, with particular focus on those resources and industries located in Queensland. QCAT is Australia’s largest integrated R&amp;D precinct for the resources and associated advanced technology industries. QCAT is a collaboration between the CSIRO, the Queensland Government, cooperative research centres and R&amp;D industries</td>
<td>1992-</td>
<td></td>
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<tr>
<td>Centre for Advanced Materials Processing and Manufacturing (AMPAM)</td>
<td>To provide a focus for materials engineering and manufacturing activities for the University of Queensland, and for those of its partners in major successful national collaborative ventures. The AMPAM aims to capitalise on emerging trends in manufacturing research where innovations in material developments are driving new combinations of metals, polymers, ceramics, and composites that have not before been economically possible</td>
<td></td>
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<tr>
<td>CRC for Rail Manufacturing (including the CQU Centre for Railway Engineering)</td>
<td>To develop products, technologies and supply chain networks to increase the capability and globally competitive position of the rail industry. An essential partner of the CRC for Rail Manufacturing is the Centre for Railway Engineering (CRE). The CRE is an industry focused research centre hosted by the School of Engineering and Technology (SET) at Central Queensland University located in Rockhampton.</td>
<td>1/07/2014 to 30/06/2020</td>
<td>31.0</td>
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<th>Name</th>
<th>Purpose</th>
<th>Period</th>
<th>Funding ($m)</th>
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<tr>
<td>Australian Institute for Bioengineering and Nanotechnology (AIBN)</td>
<td>To bring together the skills of world-class researchers in the areas of bioengineering and nanotechnology in an integrated multi-disciplinary research institute. Uses nanotechnology for energy and environmental applications. Based at the University of Queensland St Lucia, the AIBN is home to 18 research groups working at the interface of the biological, chemical and physical science to alleviate current problems in human health and environmental issues</td>
<td>Ongoing</td>
<td>75.0</td>
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<tr>
<td>National Biologics Facility (NBF)</td>
<td>Housed at the AIBN, the Queensland facility of the National Biologics Facility (NBF) focuses on the synthesis of biological products (biologics), especially high-quality recombinant proteins, using mammalian cell expression technology. The $13 million facility was established in 2007 with funding provided by the Queensland Government and the Australian Government through the National Collaborative Research Infrastructure Strategy. The NBF has a staff of scientists and bioprocess engineers with world-class expertise in molecular biology, antibody engineering, mammalian cell culture, biopharmaceutical development and associated current Good Manufacturing Practices (cGMP). An important role for the facility is assisting Australian biotechnology companies and researchers to bridge the gap between the laboratory and pilot scale trials by producing pre-clinical or clinical quantities of recombinant proteins</td>
<td>2007 to present</td>
<td>13</td>
</tr>
<tr>
<td>Australian National Fabrication Facility (ANFF)</td>
<td>Investment in advanced manufacturing by the Queensland Government is centred on the Australian National Fabrication Facility (ANFF) that was established under the National Collaborative Research Infrastructure Strategy (NCRIS). The ANFF provides researchers and industry with access to state-of-the-art fabrication capabilities through a network of 8 nodes including 21 institutions throughout Australia, with nodes at the University of Queensland and Griffith University. Each node provides their facilities on an open access basis enabling researchers to engage in interdisciplinary research. The Queensland node, ANFF-Q, is the Bio-nano node specialising in microfluidics, organic electronics, biomaterials and novel semiconductor materials</td>
<td>2007-2017</td>
<td>12.2 (2015-16)</td>
</tr>
<tr>
<td>Innovative Manufacturing CRC (IMCRC)</td>
<td>To assist Australian manufacturers to transition to high-value internationally competitive manufacturing. It will develop knowledge-intensive competitive industries in areas of global growth, including additive manufacturing, lightweight robotics and medical devices. It will develop, adapt and utilise emerging enabling technology platforms and build innovative business organisations active in global value chains by bringing together the best and brightest</td>
<td>1/07/2015 to 30/06/2022</td>
<td>40.0 ($210m in matching funds from industry,</td>
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<th>Name</th>
<th>Purpose</th>
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<th>Funding ($m)</th>
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<tr>
<td>Advanced Manufacturing Growth Centre (Cth Dept Industry, Innovation and Science)</td>
<td>Will assist Australian manufacturers to transition from traditional manufacturing to knowledge-intensive, internationally-competitive activities</td>
<td>1/07/2015 to 30/06/2019</td>
<td>Research institutions and state governments</td>
</tr>
<tr>
<td>CRC for Polymers</td>
<td>To establish Australian manufacturing as a leading provider and exporter of products that meets emerging global needs in three areas: health therapies and delivery; water and food security; and low-cost solar energy, using enabling and sustainable advanced polymer technology</td>
<td>1/07/2012 to 30/06/2017</td>
<td>14.5</td>
</tr>
<tr>
<td>The Australian Synchrotron (ARC Special Research initiative in Synchrotron Science). The QLD node of Synchrotron contributors (DSITI, QU, QUT, JCU, CQU, USC, USQ)</td>
<td>To support access of Queensland research agencies to the Australian Synchrotron national science facility with applications in material science, bio-medical research, the manufacturing industry and other areas. The facility consists of a three Ge V synchrotron particle accelerator located near Monash Uni in Melbourne, VIC. The Queensland Government provided $1M over four years (2012-16)</td>
<td>2012-2016</td>
<td>1</td>
</tr>
<tr>
<td>Partnership between Siemens, Defence Science and Technology Group, and QUT</td>
<td>To advance the use of high temperature superconducting (HTS) technologies in Australia which have the potential to save energy and increase capabilities of Naval Fleets, and have broader applications that could add significant productivity to Australian industries. 143</td>
<td>2015-2020</td>
<td>2.5</td>
</tr>
<tr>
<td>CSIRO Future Manufacturing Flagship</td>
<td>To help transition Australian manufacturing for sustainable global competitiveness and economic growth through researching: Sustainable Materials; Flexible Electronics; Advanced Engineered Components and Advanced Fibrous Materials</td>
<td>2010-</td>
<td></td>
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<tr>
<td>Automotive Australia 2020 CRC</td>
<td>To tackle the complex problems that currently impede the uptake of low emission vehicles worldwide, such as the technological and social barriers to the uptake of gaseous fuels in cars and trucks, and producing greener vehicles and components more competitively. QUT is a research partner</td>
<td>1/07/2012 to 30/06/2017</td>
<td>26.0</td>
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<th>Name</th>
<th>Purpose</th>
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<tbody>
<tr>
<td><strong>Industry/ business support</strong></td>
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| Brisbane Technology Park  
(Queensland Government) | Created to support new and existing technology and research companies to progress, become world leaders in innovation and to encourage growth. The park has developed to accommodate more than 150 national and multi-national companies working in industries including biotech, health and medical, mining, communications, electronics, and software development | 2015- |  |
| Innovate Queensland  
(Delivered by Impact Innovation Group) | Helps SMEs to grow their business by implementing practical innovation and technology commercialisation solutions:  
- The free *Pathways Program* workshops focus on innovation, technology commercialisation, and innovation planning and R&D design  
- The *GRID Program*, an online innovation implementation forum connects participants from Pathways Program workshops or other events to innovation and technology commercialisation practitioners  
- The *IQLink program*, offers online and face-to-face opportunities for participants to collaborate creatively and solve industry-specific challenges | 2015- |  |
| QMI Solutions | A not-for-profit organisation that assists industry achieve world best practice in manufacturing and sustainability, recognising the importance of providing companies with the necessary skills and tools to introduce and improve cost-focused innovation. The primary objective is to help local manufacturers meet the identified challenges ahead to develop new products and new markets. QMI Solutions better equips SMEs with the knowledge and expertise they need to be more competitive and grow using technology, systems, skills, opportunities and collaboration.  
QMI Solutions was the first to successfully introduce 3D printing to Australia and was a leader in the introduction of Lean Manufacturing, whole-of-industry benchmarking, and design-led innovation. The group has been a trusted deliverer of Queensland Government programs for 23 years.  
QMI has also established a research partnerships fund with the University of Queensland, mainly through the Centre for Advanced Materials Processing and Manufacturing (AMPAM), to encourage collaboration on specific projects with industry partners. Projects usually span approximately three months and QMI provides the funds $100K for AMPAM to do the research and work with the industry partner. | 1993 - present | Variable |
<p>| Trade and Investment Queensland - Regional Trade Advisor Network | Helps Queensland firms to access overseas markets. A network of trade advisers to support regional and rural businesses on their export journey | Ongoing |  |
| R&amp;D Tax Incentive | Entitlement program to encourage more businesses to do R&amp;D and innovate. Open to companies of all sizes in all sectors who are conducting eligible R&amp;D. R&amp;D Activity eligibility | Ongoing |  |</p>
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<th>Name</th>
<th>Purpose</th>
<th>Period</th>
<th>Funding ($m)</th>
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<tr>
<td>(Cth Dept Industry and Science)</td>
<td>assessed by AusIndustry and the Australian Taxation Office assesses eligible business structure, notional deductions and provides the disbursement of the offset.</td>
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<tr>
<td>Austrade</td>
<td>Helps Australian businesses of all sizes, across all sectors, to succeed in international trade and investment</td>
<td>Ongoing</td>
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<tr>
<td>Export Market Development Grant (EMDG)</td>
<td>EMDG provides a re-imbursement of eligible promotional expenses up to a maximum grant of $150,000. The EMDG program is aimed at assisting applicants enter new markets and increase export of products and services globally. Applicants are limited to making eight EMDG applications over the life of the business. The EMDG reimburses up to 50% of eligible export promotion expenses above $5,000 provided that the total expenses are at least $15,000.</td>
<td></td>
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<tr>
<td>Australian Trade Commission</td>
<td></td>
<td>Ongoing</td>
<td>137.9</td>
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<tr>
<td>business.gov.au</td>
<td>business.gov.au is an online government resource for the Australian business community. business.gov.au offers simple and convenient access to government information, forms and services, including Grant Finder which locates the grants and assistance programs available for businesses from the Australian, state and territory governments.</td>
<td>Ongoing</td>
<td></td>
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<tr>
<td>Manufacturing Transition Programme</td>
<td>The Commonwealth Government programme provides grants to help manufacturing businesses become more competitive and sustainable. The Programme supports capital investment projects that help businesses: * move or expand into higher value or niche manufacturing activities * build skills in higher value and knowledge intensive activities in new or growing markets. Up to 25% of eligible costs can be funded for projects with a minimum investment of $4 million.</td>
<td>Currently closed for applications</td>
<td>50</td>
</tr>
<tr>
<td>Victorian Manufacturing Productivity Networks Program</td>
<td>Designed to assist networks undertake activities and projects that will improve the productivity and competitiveness of Victorian manufacturing businesses</td>
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<tr>
<td>Victorian Veski Innovation Fellowships</td>
<td>Brings outstanding international scientists and researchers to Victoria. Focuses on following sectors: biotechnology, biomedical, advanced manufacturing including food science and bioengineering, environmental and energy technologies, and the enabling sciences</td>
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<tr>
<td>Next Generation Manufacturing Investment Programme (VIC &amp; SA)</td>
<td>A competitive grants programme for South Australian and Victorian businesses that provides capital to establish or expand high value manufacturing operations, build scale and capability.</td>
<td>2015 - 2018</td>
<td>60</td>
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### Name | Purpose | Period | Funding ($m)
---|---|---|---
| | and compete in new and growing markets. Grants are available for up to 50% of eligible costs for projects with a minimum investment of $1m. Delivered by AusIndustry | | ($12m each from SA & VIC)
| South Australia Innovation Voucher Program | Aims to stimulate innovation in SMEs through collaboration with public and private research providers to develop new manufactured products or processes and drive productivity and business profitability | | |