THE FUTURE OF AGRICULTURAL TECHNOLOGIES

HORIZON SCANNING

ACOLA
AUSTRALIAN COUNCIL OF LEARNED ACADEMIES

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This project has been supported by the Australian Government through the Department of Agriculture, Water and the Environment.

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Published 2019

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NOTE FROM THE EXPERT GROUP CHAIR

It is no accident most of the findings presented in this report speak to leadership and collaboration across the government, industry and research sectors if we are to realise the transformational potential of advanced technology.

We are confident that the future of agriculture in Australia will be one in which data analytics and artificial intelligence are as at home on the farm as they are in any other high-tech industry – a future in which the use of advanced sensing, automation, the internet of things and other emerging technologies is no more remarkable than tractors and quad bikes are today.

Advanced technologies open possibilities for Australian agriculture beyond incremental gains in production and labour productivity. These include genuinely transformational approaches to managing capital, plant and livestock, natural resources, biosecurity and supply chains to better deal with climatic and market variability. They include possibilities to commercialise new products, differentiate Australian produce in the global market, verify its provenance and quality, and lift the profitability of agriculture while protecting social, cultural, health and environmental values.

There is a great deal to be optimistic about but there are risks too that should be managed. Perhaps the most obvious of these are consumer resistance to products perceived as unethical. Farm businesses must always play the balancing act between rates of return on capital and investment into new technology and this is particularly difficult for less profitable industries.

Of more concern to the Expert Working Group is the risk that change in the Australian agriculture sector will not be quick enough, or substantial enough, to deal with climate-induced shocks and intensifying global competition.

Sustained engagement is needed with urban and rural communities alike to ensure agriculture maintains its 'licence to operate' and attracts skills and investment to service advanced technology.

Professor Stewart Lockie FASSA

PROJECT AIMS

The aim of this horizon scan is to examine and understand the impacts, opportunities and challenges associated with around ten highly prospective technologies likely to impact agriculture over the next ten years and consider how Australian agriculture is positioned to meet them. This will include consideration of the role these technologies can play in helping Australian agriculture address the broader trends and pressures facing it, including:

- climate variability and resilience
- changing consumer preferences
- workforce capacity
- environmental and landscape sustainability
- biosecurity
- industry disruption
- costs of production.

Each technology will be analysed within the following framework:

- What transformative role could the technology play in the agricultural sector?
- What are the social, cultural, economic, legal and regulatory implications of the technology?
- What is the role of 'big data' in the technology? Where relevant, examine issues of data integrity and standards and security and privacy.
- What is the role for government and industry in addressing challenges and facilitating uptake of opportunities, presented by the technology?

EXECUTIVE SUMMARY

Australian agriculture is world-renowned for leadership in harvesting practices, water-efficient agronomy, crop and livestock breeding, conservation tillage and development of fit-for-purpose farm machinery. While Australia exports two-thirds of its produce, it is a relatively small exporter when compared to countries like the United States and the Netherlands (Howden & Zammit, 2019). Nonetheless, our primary producers (or farmers) are among the most efficient in the world, with a long history of productivity improvement and adaptation to external challenges, including environmental extremes, price fluctuations, variations in international trade conditions and changes in government policy. Farmers have embraced innovation and shown willingness to adopt technologies that lead to improvements in farm practices. Governments, research providers and a range of other stakeholders have been critical to ensuring that the appropriate resources, policies and institutional arrangements are in place to support research, development and extension.

However, new and transformational approaches will be needed for the agriculture sector to remain productive and competitive in a changing natural, social and economic environment. The development of advanced technologies is critical to this transformation, but it is not by itself sufficient. Ensuring the suitability and adoption of advanced technologies requires consideration of the broader economic, social and environmental context for technology use.

This Horizon Scanning report examines impacts, opportunities and challenges associated with nine technologies: sensors, internet of things (IoT), robotics, machine learning, large scale optimisation and data fusion, biotechnology, nanotechnology, and distributed ledger technology.

These technologies present opportunities to improve the efficiency and profitability of agricultural production, to develop novel agricultural industries and markets, and to contribute to a range of social and environmental values. Transformational change of this nature will most likely occur when multiple technologies are applied together, and their integration is underwritten by the power of big data and skilful analysis.

Methodology

A rigorous review process was conducted to explore key factors that could inform the adoption of future technologies, including the contextual and historical background of the Australian agriculture sector and the broader trends and pressures that the industry is facing. As a result of this review process, technologies were identified and examined against their potential to address broader trends and pressures over the next decade. Finally, the factors likely to determine and enable the uptake of agricultural technologies were investigated, including social, legal, regulatory and economic considerations. The outcomes of these investigations are summarised below.

Broader trends and pressures

The current prevailing drought across much of Australia highlights the importance of technological innovation as one of a range of strategies for coping with climatic and market variability. Over the coming decade, the pace and direction of innovation are likely to be influenced by:

- increasing prevalence and intensity of extreme weather events including droughts, floods, hail and frost as a consequence of climate change

- intensifying global competition as the adoption of new technologies in other countries increases the relative productivity and quality of their agricultural sectors
- biosecurity risks including exotic diseases and pests increasing as a consequence of climate change, global travel and trade
- demands from domestic and international buyers for assurance concerning the quality and safety of agricultural products, and the social and environmental impacts of agricultural products
- perceptions of risk associated with non-traditional methods of food production, which will influence consumer preferences.

Responding to these trends while ensuring a profitable and sustainable agricultural sector will demand step-changes in the productivity of Australia's agricultural systems along with new business models and the development of new food and fibre industries.

Technology opportunities

The identified technologies may result in novel products: including new traits in existing crops and animals; new forms of nutrient-rich products; and the use of microbes to produce high-value plant metabolites for food and medical purposes. The deployment of advanced biotechnology solutions and digital technologies and devices will provide opportunities to increase profitability and production, global competitiveness, environmental quality, economic growth, and community wellbeing.

The deployment of advanced technologies, such as robotics, coupled with artificial intelligence (AI) and IoT, has the potential to generate vast amounts of data that will be transformational for farming practices, complex decision making and environmental monitoring. Advanced capabilities such as data fusion and machine learning will benefit farming practices and create new markets for on-farm capital – for example, through better forecasting of weather and natural resource strategies. On-farm sensors, devices, robotics and automation will allow agricultural workers to devote more time to complex tasks rather than to activities requiring low levels of skill.

Data, AI and IoT, if properly harnessed, will underpin many future farming capabilities, including asset automation and optimisation, supply chain optimisation, rapid testing of localised crops, and robotics. This will be enabled and driven by a reduction in cost and the increasing capability of computational hardware, memory and communications, coupled with increasing investment and capacity in software and algorithm development.

Sensors and blockchain technologies employed by primary producers, processors and retailers will enable quality assurance programs to verify and communicate the quality and ethical attributes of products. This will lead to improved transparency of the environmental impacts, animal welfare and treatment of workers for consumers.

Biotechnologies have the potential to improve the resilience of crops and livestock to climate variability, pests and diseases. Gene editing provides opportunities to cultivate new and improved products in agriculture.

Creating an enabling environment for transformational change

There will be a role for primary producers, government and industry to work together in establishing the environment that enables the development, uptake and success of new technologies.

The adoption of advanced agricultural technologies has the potential to provide the sector with new opportunities and to contribute to the economic wellbeing of regional and rural Australia. At the same time, the potential for negative impacts on, for example, rural labour markets, should be mitigated through provision of education and training opportunities.

Attitudes to technology and its adoption by primary producers are complex and multifactorial. Australian primary producers need a clear value proposition in order to be willing to adopt the new technologies. In addition, new and emerging technologies need to be viewed as fit for purpose in the Australian context, which will involve partnerships between technology developers, researchers, farmers and the broader community.

Consumer and broader community expectations and concerns are increasingly influencing the agricultural sector. These must be understood, especially for gene technologies. There is a need for greater transparency and consultation between primary producers, governments, industry and consumers to understand and raise awareness of new technologies.

Creating a national approach to the use of agricultural data will be a key enabler underpinning many technologies. Relevant considerations include privacy, surveillance and ownership of data between technology users and providers. Farmers should be active participants in all discussions and decisions in this domain.

Telecommunications is a key enabler for many prospective technologies. While regional and rural telecommunication infrastructure has improved over the last decade with new technologies being developed, there remain significant areas where connectivity is unreliable or suboptimal for the needs of future technologies.

Farmers already use a diverse range of skills and expertise to manage their complex businesses, equipment and current technology solutions. However, additional skills will be needed to maximise the value of new technologies and ensure their reliability. For example, up skilling in data literacy and knowledge to maintain or repair sensors will be essential to ensure the reliability and value from on farm data streams.

The future of Australia's agriculture sector

New and emerging technologies have the potential to assist the agriculture sector to overcome a number of challenges, generate new products and market opportunities, increase rural and regional population, as well as offer rural and regional communities economic and community benefits, including for Aboriginal and Torres Strait Islander businesses.

No single emerging technology will solve the challenges facing Australian agriculture. Supporting transformational change in agriculture requires both the creative combination of multiple technologies and provision of institutional, regulatory and communications infrastructure to enable collaboration and innovation. National leadership must:

- provide a platform for cross-sectoral and cross-disciplinary collaboration in research, development and innovation
- resolve regulatory and policy issues including the use of agricultural data
- prioritise construction of critical enabling infrastructure
- ensure sustained focus across the agricultural innovation system on long-term challenges and opportunities.

There is a role for all stakeholders, including the community, in the future prosperity of Australia's agricultural sector. Governments, academia and industry all have roles in assessing and responding to consumer and public perceptions and attitudes; engagement with communities about their views and values relating to emerging technologies at all stages of the planning implementation cycle will be necessary.

Technology opens opportunities to explore new products and markets along with new or modified production systems. This is particularly important where agricultural businesses struggle with low profitability and return on investment.

Given the extent of landholdings now under Aboriginal and Torres Strait Islander control it is equally important that Indigenous landholders participate in technology development and adoption. Additional work involving, and preferably led by, Indigenous landholders, researchers and innovators will be critical to understanding this opportunity and its implications for the broader agricultural sector.

This report builds on two previous ACOLA reports on artificial intelligence and synthetic biology. The key findings identify cross-cutting themes, activities and actions to be considered in the development and application of new agricultural technologies, which address key challenges and opportunities, while mitigating risks. This will contribute to a thriving agriculture sector that meets domestic and international requirements over the coming decades and ensures profitability while considering and addressing social and environmental needs.

KEY FINDINGS

1

Addressing the opportunities and challenges facing Australian agriculture requires transformative application of emerging technologies.

- Step-changes in productivity are required if Australian agriculture is to remain profitable and sustainable. Reviving productivity growth, which has slowed over the last two decades, will necessitate adoption of new technologies and practices along with the development of new products and business models.
- Agriculture industries must work together as a cohesive sector to determine how best to capture and integrate provenance, production and environmental information to enhance product value and enable diversification, taking into account trends in consumer values and preferences.
- Efforts are needed to increase the capacity to adopt and adapt advanced technologies. Increased adoption could help to ensure our agriculture sector can respond to particular nation specific challenges with more drought resilient crops, improved resource management, better understanding and prediction of climate variability, new and enhanced products, and improved on-farm decision-making.

2

Australia's agricultural technology and innovation ecosystem needs revitalisation to provide more opportunity for stakeholder involvement and to break down sectoral and disciplinary silos.

- Future investment should more effectively leverage Australia's existing expertise in research and development, continuing a substantial legacy of innovation in agriculture. While more investment is always welcomed, the effectiveness of investment will be substantially enhanced by building more synergistic relationships across traditional sectoral boundaries and through multidisciplinary approaches to national issues.
- The inclusion of primary producers and other community members in the innovation ecosystem is critical to enable timely identification and respond to the needs and aspirations of end-users.

3

The strength and resilience of Australia's agricultural sector will be enhanced by supporting adoption of agricultural technology by Indigenous landholders.

- The size of Indigenous estate suggests there is significant potential to realise more economic value through the adoption of advanced technology by Indigenous landholders.
- Technology enabled enterprise diversification, improvement in land and water management, and supply chain development in rural and remote Australia will benefit both Indigenous and non-Indigenous businesses.

4

Technology development and adoption across Australian agriculture should include explicit consideration of buyer preferences and expectations.

- Advanced technologies offer new opportunities to address buyer concerns about the acceptability of some agricultural practices and to provide assurance, more broadly, that buyer expectations can be met in a robust and transparent manner.
- Opportunity also exists to foresee and avoid the perception of risk associated with technology itself by engaging with the public about new technologies at an early stage (i.e. as these technologies are being considered and integrated into agricultural practice) and address their concerns openly.

5

Appropriate policy settings are needed to enable technological implementation to move beyond incrementalism and support transformational change.

- Transformational change will require investment by government, industry and farmers into enabling infrastructure. This includes both physical (e.g. farm connectivity and regional data hubs) and soft infrastructure (e.g. machine learning and artificial intelligence).
- Future regulation of advanced technologies will need to be more transparent, outcome focused, accessible, and sufficiently flexible to accommodate the development of further technologies and meet the needs and concerns of affected communities.

6

Data are a powerful asset but will require appropriate national leadership and regulation to ensure their potential value to agriculture is realised.

- The collection of large amounts of farm-related data from sensors on equipment and robotics should be harnessed for better on-farm decision making and the creation of new products. National leadership is needed to ensure the equitable balance of privacy, surveillance and fair ownership of data between technology users and providers.
- The development of codes of practice and access to open source software, open data, and agricultural data codes of practice could assist in making many technological solutions more equitable and acceptable for Australian primary producers.
- Farmers should be active participants in all discussions and decisions in this domain.

7

Empowering Australia's regions through investment in local solutions and capacity will facilitate transformational change through agricultural technologies and will provide complementary social and economic benefits.

- There are roles for all levels of government in facilitating the development of innovation ecosystems servicing agriculture and other regional industries. These will be characterised by virtuous cycles of education, locally-relevant research and development, industry application, and the establishment of technical service businesses.
- Place-based approaches are needed to ensure innovation is sensitive to the full range of economic, social, cultural and environmental values relevant to agriculture, and maximises opportunities for regional employment, business development and traditional owner engagement.

8

Farmers and other agricultural workers need support to familiarise themselves with emerging technologies and to obtain the specialist skills required to maximise their use.

- Providing the skills for farmers to use new technologies on farm is important, as is developing the broader rural workforce to work in support and service roles. Upskilling could be provided through accredited training, micro-credentialing and other professional development programs.
- Higher education, TAFE and other VET providers will be important in workforce development. Potential models could include innovation precincts anchored by regional universities or other research and development providers.

INTRODUCTION

Overview of Australia's farming sector

Agriculture is a vital component of Australia's economy and agricultural businesses occupy 51 percent of Australia's land area. In 2018-19, the gross value of Australian agriculture was A$58 billion (ABARES, 2019). Agriculture provides 93 percent of Australia's domestic food supply, and two-thirds of Australian food and fibre is exported (National Farmers' Federation, 2019).

In May 2019, Australian agriculture, forestry and fishing industries employed 334,300 people, equating to 2.6 percent of people employed in Australia (Australian Bureau of Statistics, 2019). This represented a decline of about a quarter between 2000 and 2018; and is predicted to keep falling until 2023 (Australian Industry and Skills Committee, 2018). Population growth, increasing urbanisation and technology-driven increases in production efficiency are contributing factors (Hazell & Wood, 2008).

The total factor productivity of agriculture (that is, the ratio of farm outputs to farm inputs) has been growing since the mid-1950s, stimulated partly by increased adoption of technology, investment in innovation, and industry deregulation. Since the mid-1990s the rate of productivity growth has slowed and become more variable (Grafton, Mullen, & Williams, 2015; Khan, Salim, & Bloch, 2015; Sheng, Mullen, & Zhao, 2011). This has been attributed to gaps in research, low profitability, limited capital, market volatility, international competition, adverse weather events, variation in the productivity and efficiency of primary producers, and variable levels of adoption of new technology and practices. However, there is evidence despite variation that broadacre cropping in Australia is closing on the productivity frontier of existing technologies. These factors are described in greater detail in ACOLA's 2015 report *Australia's Agricultural Future* (Daly et al., 2015).

As mentioned previously, the current drought across much of Australia highlights the importance of continuing technological innovation as one of a range of strategies for coping with climatic and market variability. Over the coming decade, it is likely that the pace and direction of innovation will be influenced by:

- increasing prevalence and intensity of extreme weather as a consequence of climate change
- intensifying global competition
- biosecurity risks
- demands from domestic and international buyers for assurance relating to the quality, safety, and the social and environmental impacts of agricultural products
- perceptions of risk associated with non-traditional methods of food production influencing consumer preferences.

Technology alone cannot solve these complex challenges. However, technological solutions, especially when they are combined, enable aspects of these challenges to be addressed. This can help create a dynamic sector that contributes to economic improvements and enhanced social, cultural, environmental, and health outcomes.

Historical context of technology and innovation in agriculture

Technological innovation has been central to developing the agriculture sector into a key component of Australia's economy. The agriculture sector itself has expanded and farmers are increasingly engaged in other activities such as carbon farming.

Technology and innovation have supported productivity increases throughout Australia's agricultural history. For example, crop production more than doubled while using only 11 percent more land between the early 1960s and mid-2000s (Langridge, Cordell, & D'Occhio, 2014). This growth was partly due to the adoption of technologies such as precision agriculture, no-till cropping systems, new varieties and automation. Science and technology have contributed to the development of new wood processing, forest management and conservation practices within the forestry sector (Essence Communications, 2015), and more sustainable fisheries management.

Researchers and technology developers will continue to help meet the needs of users, lift the productivity, efficiency and sustainability of primary industries and improve the health, safety and wellbeing of consumers. However, the emergence of innovative technologies can be met with uncertainty or concern. Multidisciplinary research will be important to understand what drives acceptance or rejection of primary industry technologies and how to engage the broader community.

Community and industry attitudes to emerging technologies will need to be considered early to identify and resolve conflicts and concerns (da Costa, Deliza, Rosenthal, Hedderley, & Frewer, 2000; Mireaux, Cox, Cotton, & Evans, 2007; Siegrist, 2008).

About this report

The opportunities advanced technologies offer to address agricultural challenges in novel ways is well-documented. This report aims to build on existing work, including recent government-funded Horizon Scans (AgriFutures Australia, 2018b, 2018a).

A previous ACOLA report, Australia's Agricultural Future, highlighted the importance of Australia's agriculture sector and emphasised the importance of technology adoption to meet increased demand while managing risks associated with climate change and climate variability, and the need to address community environmental and food quality concerns (Daly et al., 2015).

The National Farmers' Federation 2030 Roadmap outlined a vision to make agriculture Australia's next A$100 billion industry and acknowledged that unlocking innovation is a key to achieving this goal (National Farmers' Federation, 2018). Supporting this vision, the Australian Government has committed to developing a national plan to help Australian agriculture reach A$100 billion in gross value of production by 2030.

Building on this, AgriFutures Australia has set a goal of identifying and supporting the emergence of agricultural industries that can reach or exceed A$10 million per annum over the coming five years (AgriFutures Australia, 2019).

A report by Ernst & Young (2019), commissioned by the former Australian Government Department of Agriculture, noted that policy communities and the agriculture sector have an appetite for increased innovation and technology.

These reports are all valuable inputs into the considerations by stakeholders in potential measures and initiatives to meet the target.

This report examines nine technologies that are grouped into the following four areas:

- sensors and the internet of things
- automation management technologies (robotics, machine learning, large-scale optimisation and data fusion)
- biotechnology and nanotechnology
- transaction technology (distributed ledger technology).

It considers the technical capabilities to address future challenges as well as the factors that can determine and enable an environment for transformational change.

Structure of the report

The report is guided by terms of reference provided by the project sponsor, the Department of Agriculture, Water and the Environment (see Appendix 2). Appendix 1 presents the full methodology for technology selection.

Chapter 1 provides a contextual and historical background of the Australian agriculture sector and outlines the broader trends and pressures faced by the sector.

Chapter 2 considers the opportunities and impacts that technology in the four technological areas could have in addressing broader trends and pressures during the next decade.

Chapter 3 considers the factors determining and enabling the uptake of technology in agriculture. The focus is on key determinants and enablers of technology adoption and the legal, regulatory and economic considerations.

CHAPTER 1
AUSTRALIAN AGRICULTURE: CHALLENGES AND OPPORTUNITIES

This chapter outlines the broad social, cultural, and economic context and challenges for the agriculture sector.

1.1 Broader socio-politico context of the agriculture sector

Key points:

- Understanding the historical, cultural, and environmental context of the agricultural sector and engaging with communities is critical in understanding the potential impacts of technologies.
- Farms are susceptible to the vagaries of world markets.
- Over recent decades, farm rationalisation and technological changes have affected rural communities and labour markets.

Australian primary producers are among the most efficient in the world with a long history of productivity improvement and adaptation to often difficult conditions (Australian Productivity Commission, 2005). From an inauspicious start, European-style agriculture in Australia has grown from providing the subsistence needs of early penal colonies to an important source of export income and national wealth. While the economy no longer 'rides the sheep's back', agriculture contributes about 14 percent of Australia's total goods and services export income (Department of Foreign Affairs and Trade, 2016).

Farming has an important social and cultural role. In the mid-nineteenth century, governments began promoting family farming as the preferred mode of agricultural development. It has been argued that this was driven, in part, by the ideal of 'civilising' the bush by bringing women and children into rural areas. Family farming was further promoted through soldier settlement schemes that followed both world wars and which contributed to enduring public attachment to the idea of family farming as a noble way of life (Berry, Botterill, Cockfield, & Ding, 2016; Botterill, 2016). Today the sector remains dominated by family farms with fewer than 10 percent of farm businesses structured as companies – the majority being operated by individuals, partnerships or trusts – and

farmers remain trusted members of the food supply chain (Broad, 2014; Gilmore, 2017).

Since the 1970s, agriculture has undergone considerable deregulation. The removal of statutory marketing schemes, bounties and subsidies, and other forms of protection and support, have resulted in Australian primary producers being among the least supported in the world (Australian Productivity Commission, 2005; Organization for Economic Cooperation and Development, 2017). The sector is very dependent on global trade with around two-thirds of production exported. Consequently, farmers are highly exposed to the vagaries of world markets and to changing consumer preferences.

Over recent decades, farming businesses have undergone extensive consolidation with the number of commercial farms (defined as those with an estimate value of agricultural operations greater than A$50,000 using 2006 values) declining 51 percent between 1981 and 2011 and average farm area increasing 23 percent 1981 to 2001 (Australian Productivity Commission, 2005; Barr, 2014). Despite consolidation, Barr (2014) estimates that as many as 75 percent of farm businesses do not generate enough receipts to provide a median Australian family disposable income and fund the business growth needed to sustain that income. This is consistent with Australian Productivity Commission (2005) findings that return on investment varies from negative three percent for the smallest one third of farms to just under three percent for the largest third.

The consolidation of farms, improvements to transport and technological changes have at times negatively impacted on rural communities, with some small towns losing businesses and services to larger regional centres. Notwithstanding these pressures, the food and agribusiness sectors continue to play a key economic and social role in many regional areas not only in terms of economic output, but also in direct and indirect employment which is essential to the ongoing prosperity of regional Australia.

1.2 Agriculture and the Indigenous estate

Key points:

- Indigenous peoples and communities are significant landholders and have considerable interests in the development of Australian agriculture.
- There has been little work exploring the potential for adoption of agricultural technology and innovation by Indigenous landholders.

The Australian Government's Agricultural Competitiveness Green Paper states that native title groups, traditional owners, Indigenous landowners, and Indigenous communities will be essential partners in the development of agriculture (Australian Government, 2014a). This is especially true in Northern Australia where Indigenous people hold rights and interests over large tracts of land and where technology offers new opportunities for enterprise diversification, improved land and water management, and supply chain development (Australian Government, 2014b) (see also Box 2).

Data on the full extent of land managed for agricultural purposes by Indigenous Australians are not available. However, as of October 2019, approximately 38 percent of Australia was covered by native title, including 13 percent as exclusive possession.[1] Additional land within the Indigenous estate has either been purchased by Indigenous organisations or granted under other legal instruments. For example, in 2014 Western Australia had an estimated 37 million hectares under Indigenous control; 5.5 million hectares supported approximately 70 agricultural properties ranging from small scale agriculture to large pastoral leaseholds (Western Australian Department of Agriculture and Food, 2014).

The concentration of Aboriginal land in rangelands presents challenges for agricultural business development (McClelland Rural Services, 2014) but also creates opportunities for the integration of agriculture with other land uses (Altman & Jackson, 2014). Advanced technology offers Indigenous landholders opportunities to develop and expand agricultural businesses in regional and remote locations. Beyond social and environmental benefits associated with the participation of Aboriginal and Torres Strait Islander communities in agriculture, the size of the Indigenous estate suggests considerable potential to realise more economic value through agricultural technology use and innovation.

Developing more agricultural enterprises and output in remote localities will create opportunities for both Indigenous and non-Indigenous businesses (Australian Government, 2014a). Better use of Indigenous knowledge – for example, through commercialisation of native plant and animal species – will also benefit Indigenous and non-Indigenous businesses (see Box 6).

1 Data available at http://www.nntt.gov.au/

1.3 Broader trends and pressures facing Australian agriculture

While the Australian agriculture sector has been adept at addressing past and present challenges such as climate variability, drought, biosecurity threats and global competition, the sector will face increasing and new challenges in the coming decade.

1.3.1 Climate variability and environmental and landscape sustainability

Key points:

- Australian climate is characterised by significant variability. Managing this variability is key to the financial viability of farms and to the minimisation of land and water degradation.
- Existing adaptive strategies will be tested as climate change increases the speed and magnitude of variability.
- There is potential to improve the effectiveness of existing adaptation strategies, and to develop new strategies, through the application of advanced agricultural technologies.
- Our environment is finite. Maintaining or increasing sustainability as demand increases will continue to be a key challenge.

1.3.1.1 Climate variability and resilience

Australian primary producers have always faced a high degree of climate variability. El Niño conditions in eastern Australia often causes low rainfall. The Indian Ocean Dipole influences weather in the west. These phenomena will be exacerbated by climate change, with predictions that extreme weather events including drought, intense rain events, frost and hail will be more frequent and severe (Intergovernmental Panel on Climate Change, 2018).

Adaptation to these extremes requires a range of strategies, many of which Australian farmers are already implementing (see Table 1). Most used are strategies that support incremental adaptation to short-term or seasonal climate variability (George et al., 2019). These include risk management tools such as seasonal weather forecasting and selection of plant and animal varieties for drought tolerance, changes in the timing of operations and water use efficiency measures. In 2017-18, Australian farming businesses used 10.5 million megalitres of water, with pastures and cropping accounting for 93 percent. Strategies that require more transformational change in the farm business (for example, changing land use or developing new enterprises) are less widely adopted but, modelling suggests, will be critical as climate change becomes more severe (Rickards & Howden, 2012a; Taylor, Cullen, D'Occhio, Rickards, & Eckard, 2018).

Technology development and adoption will improve the efficacy of both incremental and transformational adaptation. There is scope to embrace many of the technologies outlined in Chapter 2 to improve forecasting and monitoring and to support farmers in their risk management strategies through the provision of sophisticated decision support tools. Investment by government in drought monitoring, such as that associated with the US national drought monitor, could greatly help farm managers respond to and plan for drought. The national drought map (available at map.drought.gov.au) is a good start.

Effective adaptation will require a sympathetic policy environment that encourages longer-term planning and risk management. The Australian Government's recently released Drought Response, Resilience and Preparedness Plan and seeks to balance emergency relief for farmers and communities affected by drought with assistance to build resilience and preparedness.

Image: Sundrop Farms

Box 1: Farms adapting to climate variability

Sundrop Farms is a world-leading commercial-scale greenhouse facility in an arid zone. The highly productive facility generates 15,000 tonnes of truss tomatoes annually. Solar technology supplies electricity, heat and desalinated seawater. Tomatoes are grown within a controlled environment to minimise the use of pesticides.

Sundrop Farms has made long-term investments and received state government support. Following closure of a coal-fired power station in Port Augusta, South Australia, the tomato farm has brought new economic opportunities to the town, by providing high-tech and environmentally friendly jobs to the community. The farm also supports local and regional communities with training and research and development opportunities.

1.3.1.2 Environment and landscape sustainability

Australian farmers rely on natural resources for production and undertake management practices such as regenerative farming. Australian farmers will continue to play an important role as environmental stewards. Groups such as Landcare are important for supporting farmers and on-farm practices. The Australian environment and soils have a finite resilience and maintaining soil health will be important in prolonging our natural resources.

Demand for commodities, food ingredients, feedstock, and building materials is growing with the world's population and increasing affluence, adding pressure to achieve higher productivity accompanied by sustainable production.

Given climate challenges, industries are looking to reduce emissions and improve environmental outcomes. On-farm technologies could provide both direct and indirect opportunities to address these outcomes. Chapter 2 describes some of these technologies, however, techniques such as carbon sequestration are outside the scope of this report.

Table 1: Existing adaptive responses to climate variability in Australian agriculture.

Adaptive response		Existing and emerging strategies
Incremental	Optimisation	Soil moisture monitoring
		Use of seasonal forecasts
		Match stocking rates to pasture condition / destocking / agistment
		Adjust timing of operations (sowing, harvest, watering etc.)
		Water use efficiency measures (e.g. drip irrigation)
		Reduced tillage, stubble retention
		Water and soil conservation works
	Substitution	Selection for drought tolerance
		Introduction of drought tolerant varieties
		Diversify farm enterprise mix
	Conversion	Change land use (e.g. cropping to forestry)
		Relocation to more climatically favourable regions
	Incubation	New industries (e.g. macroalgae aquaculture)
Transformative		Production of ecosystem services (biodiversity offsets, carbon credits)

1.3.2 Industry and global disruptions and changing consumer preferences

Key points:

- The public are increasingly interested in information about agricultural products and practices. This is likely to continue to influence the agriculture sector.
- The uptake and adoption of emerging technologies has potential to disrupt some agricultural industries.

1.3.2.1 Changing consumer and community preferences

Consumers are increasingly interested in healthier, value-added and premium products, as well as information on production methods and practices. The community demands more information about, and involvement in, decision-making on resource use (e.g. soil and water) and the health, animal welfare and environmental impacts associated with food and fibre production. Consumers are increasingly expecting to receive benefits (Moffat, Lacey, Zhang, & Leipold, 2016) while also requiring assurances that regulation is adequate (Prno, 2013) and that risk to them is minimised, while being provided with food and fibre that is good value for money.

There are emerging technologies aptly suited to enabling and providing this type of information. However, technology may itself be perceived as a source of risk. Exploration of consumer and community attitudes towards agricultural technologies is dominated by new, novel and emerging food technologies, including genetic modification, food irradiation and nanotechnology. Food is an integral part of life and holds meanings that are often socially and culturally constructed and embedded. These influence consumers' and producers' responses and acceptance of new foods and food technologies.

Consumer uncertainty, particularly about food safety, often accompanies emergence of novel food technologies (Bearth & Siegrist, 2016; Frewer et al., 2011; MacFie, 2007). Simply informing people about the benefits of technologies is unlikely to improve community acceptance (Figure 1). Concern about new technologies is often closely related to conflicts in values as well as differential perceptions of risk and benefit.

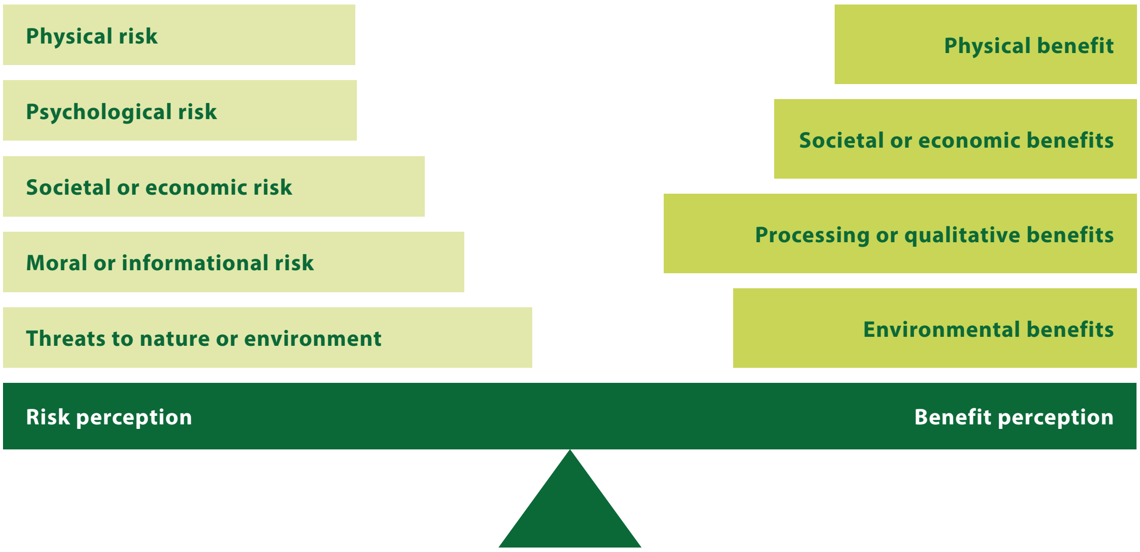

Figure 1: The risk and benefit perception categories that influence acceptance or rejection of novel food technologies.

Adapted from Bearth & Siegrist, 2016.

Many concerns associated with technology are based on perceptions of what is 'natural', on safety, on environmental and animal welfare issues, and on moral and ethical considerations (Henchion et al., 2013). Traditional farming practices and food processing techniques are generally perceived positively by consumers. However, some people distrust innovation and the use of new technologies in food production (Dietrich, 2016). People are often sceptical about, or reject, technologies with unclear benefits, or which they see as presenting risks or inadequately trialled (Bray & Ankeny, 2017).

Research on attitudes is primarily focused on land-based farming, rather than fisheries. Aquaculture, for example, depends heavily on new technologies but there is only limited research on community attitudes and understanding of this industry and its technologies.

1.3.2.2 Industry and global disruption

Industry disruption or disruptive innovation is defined as an innovation that creates a new market and value network, eventually disrupting an existing market and value network including firms, products and alliances. Industry disruption has occurred in other sectors (for example, the taxi industry). New agricultural technologies have the potential to not only change domestic production systems and market structures but also the type and nature of agricultural products globally.

1.3.3 Biosecurity and food safety

Key points:

- Globalisation of trade and travel and climate change increases biosecurity risks.
- Biosecurity contributes to the profitability and stability – in some cases the very existence – of agricultural businesses, landscape and ecosystem health, the welfare of livestock, occupational health and safety, and the safety of consumers.
- Coordinated action by government and landholders, often enabled by technology, has been critical to the effectiveness of biosecurity in the past and will be in the future.

1.3.3.1 Biosecurity

Biosecurity is the implementation of controls and measures to manage the risk of incursions and the spread of pests and diseases. Australia's biosecurity system has been integral to preventing and minimising pests, weeds and diseases in crops, livestock and humans and to maintaining our reputation as a producer of high quality, safe, goods in export markets. Globalisation of trade and travel, and climate change increase biosecurity risks.

As several emerging infectious diseases of humans are considered zoonotic in origin (i.e. can be transferred from animals to humans), understanding the nature and mechanisms of these diseases in livestock is important. Additionally, many of these diseases affect Australian industries and market access. Antibiotic resistance could further exacerbate these risks. The agriculture sector has a role to play in the prevention and control of antibiotic resistance on-farm in both animals and humans (World Health Organisation, 2018). Data sharing and analysis from a One Health perspective and improved policy structure and funding are essential for detecting and responding to diseases and antibiotic resistance (World Health Organisation, 2017).

Table 2: Management responses to biosecurity threats in Australian agriculture.

Adaptive response		Existing and emerging strategies
Incremental	Optimisation	Quarantine Monitoring/surveillance Vehicle washdown Variable rate pesticide/herbicide application Integrated Pest Management
	Substitution	Selection for pest and/or disease tolerance Introduction of pest and/or disease tolerant varieties Diversify farm enterprise mix
	Conversion	Change land use (e.g. cropping to forestry) Relocation to more climatically favourable regions
Transformative	Incubation	New industries (e.g. macroalgae)

Innovative 'defensive' technologies could help Australia develop effective responses to biosecurity threats and risks throughout the supply chain.

New and emerging technologies could be used to manage pests and help reduce plant and animal disease with surveillance and crop protection strategies (see Table 2). Examples of technology include:

- surveillance – monitoring animal behaviour, movement patterns and changes in body weight, using drones or mobile surveillance cameras for early detection of disease (Fernández-Carrión et al., 2017)
- crop protection strategies – use of transgenic technology and RNA interference technology (RNAi) to improve host defence against pests and pathogens to produce virus-resistant crops.

1.3.3.2 Food safety

Applications employing biotechnology and nanotechnology can be used to monitor the authenticity, quality and safety of food products. These attributes are likely to become increasingly important with mounting consumer interest in products that are natural, 'organic certified (or equivalent)' or locally grown, or both.

Deliverables include improved traceability through the supply chain, more accurate shelf-life predictions, real-time detection of microbial or chemical contamination, or allergens, and product quality assessment.

1.3.4 Cost of production

Key point:

- Costs associated with early adoption of new technologies may be difficult to gauge.

Technologies that lower production costs are likely to be valuable – contributing to improved profitability and reduced business risk. However, the value of technological innovation to the farm business relates to the impact on productivity and the relationship between income and expenditure over time.

Productivity is an important strategic issue for Australian agriculture. From 1946 to 2018, the prices farmers were paying for their inputs generally increased at a faster rate than the prices received for their outputs — thereby affecting profitability. By improving productivity and producing 'more with less', farmers have sought to remain profitable despite falling terms of trade (Boult & Chancellor, 2018). As is the case in a number of industries, the development and adoption of new technology has the potential to enhance productivity and profitability by influencing the ability of farms to convert inputs to outputs (productivity), improve receipts (output price multiplied by output quantity), and/or reduce costs (input price multiplied by input quantity).

A challenge with early adoption of advanced technology, as in all sectors, is difficulty gauging the real value. Complicating this further is the challenge accessing warranty support, technical advice and repairs in regional and remote locations.

1.4 Turning agriculture's challenges into opportunities

Key points:

- The development of advanced technologies will be an important aspect for the transformation of Australian agriculture, but it is not sufficient to ensure it.
- Advanced technologies can improve the efficiency, profitability, and resilience of production systems.
- Agricultural technologies should not be looked at in isolation from rural labour markets, education and training, workplace health and safety, and environmental and biosecurity outcomes. These will be critical to the acceptance and adoption of technologies among farmers and consumers.
- Farmers operate within a range of social, climatic and agro-ecological circumstances and with a broad array of experience, skills and aspirations. A one-size-fits-all technology package will not suit all farm types or farmers.

Australia's varied agro-ecological systems produce a diverse range of food and fibre, which has contributed to the nation's comparative advantage and dynamic capabilities (Withers, Gupta, Curtis, & Larkins, 2015). This diverse sector will continue to face many opportunities and challenges, such as increasing globalisation of supply chains, competition from overseas suppliers, severe droughts and weather events and in the digital economy (Australian Government, 2014b; Glover et al., 2008).

Agricultural stakeholders will need to consider how they can maintain adaptive capacity. Such capacity will in large part be aided by the adoption of scientific and technological solutions. Digitisation and wider technology uptake in other sectors – such as in finance, media, and information telecommunications – are both disruptive and beneficial to society and the economy (Converge, 2015; Deloitte, 2014). While these sectors are very different from agriculture, increased technology uptake in agriculture could similarly be both transformational and beneficial to society and the economy. For example, full adoption of digital agriculture has been predicted to yield A$20.3 billion by 2050 (National Farmers' Federation, 2018).

Dominant drivers for new agricultural technology include reduced reliance on unskilled labour, less labour demand on owners and farm managers, increased productivity, a shift towards higher-value outputs, and improved sustainability.

The future of Australian agriculture and its technologies and practices requires engagement with the broader community and understanding the attitudes of urban and rural communities that may affect agriculture's 'licence to operate' and its ability to attract the skills and investment needed to sustain viable farming enterprises.

While Australian farmers have been innovative and resilient since the start of European settlement, increasingly variable environmental conditions (including rainfall), global competition and biosecurity concerns highlight the need to ensure that primary producers have the knowledge, tools, technologies and enabling labour force to continually improve their production resilience and adaptive capacities (Barbuto, Lopolito, & Santeramo, 2019).

CHAPTER 2
ADVANCED TECHNOLOGIES AND AUSTRALIAN AGRICULTURE

A wide range of technologies could be deployed and integrated to address the pressures facing Australian agriculture. Mechanical, computational and biological technologies provide opportunities to increase production, competitiveness, environmental health, economic growth and, potentially, community wellbeing. Component technologies already identified within the food and fibre sector are being developed and applied to production systems in response to shifts in climate, markets, community values, and consumer demands. These include technologies addressing increasing consumer expectations for more information about the provenance of food and fibre products and the practices associated with their production.

The increasing use of sensors and data are laying the foundations for machine learning, artificial intelligence (AI), robotics and automation, including for commercial transactions (e.g. blockchain trading). Tying these together will be complementary advances in miniaturisation, nanotechnology, cloud computing and information communication technology (ICT). For many of these applications, agriculture can adopt or adapt technologies from other industries. However, farmers and technologists highlight the inadequacy of current communications infrastructure in some regional areas, which greatly limits the potential for uptake.

Complementing the digitisation of tools and systems are sweeping changes to the biology of food production that are enhancing farming ecosystems (e.g. soil biology, nutrition, crop water-use-efficiency) and farm (including aquaculture) productivity. Food crops could become more climate-resilient as new varieties benefit from advanced gene technologies. Veterinary, husbandry, breeding and diagnostics technologies are improving livestock welfare and biosecurity. Over the past decade, genetics has become a key enabling technology in agricultural industries. Biotechnology techniques such as genomics, coupled with AI-directed analysis

of genomic sequences, enabling accelerated plant and animal breeding, gene editing and gene silencing, herald a step-change in the capability of science.

The new fields of synthetic biology and production of novel foods (e.g. plant-based high-protein 'meat') are predicted to gain momentum over the coming decade, posing both challenges and opportunities for food industries. Such developments will amplify the need for agricultural industries to engage openly with supply chain stakeholders as well as the broader community more effectively, and to devise methods for communicating and engaging with the broader community.

As Table 3 illustrates, many applications of advanced technology focus on optimising existing production systems. In doing so, they are likely to help agricultural businesses adapt to changing market and environmental circumstances without the disruptive impacts experienced by other sectors. However, the key question is whether incremental adaptation will be sufficient in the longer-term to meet the challenges set out in Chapter 1.

Table 3: Existing and potential applications of advanced technology in Australian agriculture.

	Adaptive response		Production	Business		Market	
Incremental	Optimisation	Monitoring	Sensors/IoT			Traceability	Block chain
		Forecasting	Seasonal forecasting/ enterprise analytics/ AI				
		Efficiency	Precision agriculture/ automation/ telecommunications	Flexible ownership	Sharing platforms	Consumer targeting	Consumer behavioural analytics
	Substitution	New genetics	Gene editing			Alternative markets	Personalised markets
		New/ enhanced inputs	Nanotechnology				
	Conversion	Enterprise change				New markets	Personalised products, experiences, nutrition
Transformative	Incubation	Novel food and fibre industries	Acellular meat				

This chapter describes technologies and some applications to address the broader trends and pressures facing Australian agriculture. Table 4 identifies the major intersections between the identified technology areas and trends and pressures.

Table 4: Major intersections between the identified technology areas and trends and pressures.

Trends & pressures	Technology areas			
	Sensors & IoT	Automation management	Biotechnology & nanotechnology	Transactional technology
Climate variability & resilience	✔	✔	✔	
Changing consumer preferences	✔	✔	✔	✔
Biosecurity & food safety	✔	✔	✔	✔
Cost of production	✔	✔	✔	✔

2.1 Sensors and the Internet of Things

Key points:

- Sensor technologies can play a fundamental role in improving on-farm input management in order to achieve higher productivity, quality, and system sustainability.
- The cost of detection and control of biosecurity and food safety risks can be reduced through use of sensors and Internet of Things (IoT).
- The IoT can facilitate use of real-time information to enable more timely and efficient use of inputs including water and crop treatments.
- Sensors and IoT deployed along the supply and value chains will improve logistics, product traceability and food safety.

There is a spectrum of advances, including: farmers and advisors using digital tools to communicate more efficiently or gather new types of information; robots replacing roles traditionally performed by humans (e.g. milking); sensors and integrated decision support tools removing the need for a human advisor (e.g. soil and water monitors); and blockchain technologies recording and monitoring the progress of a product across the supply chain and potentially replacing some work traditionally performed by financial brokers, auditors and quality assurance services.

Alone or in concert, these technologies can be used to reduce production costs, enhance decision-making and communicate more effectively (Carolan, 2019; Wolfert, Ge, Verdouw, & Bogaardt, 2017).

2.1.1 Sensors

A sensor is a device, module, or subsystem that detects events or changes in the surrounding environment and converts this information into a mechanical or electronic signal. The different categories of sensors and how they can apply to agriculture are illustrated in Figure 2. Information gained from these sensors can be intelligently combined to improve knowledge of an application, environment or system. This can occur at two levels: sensor level fusion and data level fusion.

Sensor level fusion creates a combined sensor output that has less uncertainty, greater accuracy, and greater dependability, than would have been derived from any single sensor. For example, cattle can be located on farm with the fusion of sensor outputs from GPS and radio frequency tags on the animals. Estimation of a specific plant property (such as water stress) can be obtained by combining on-plant sensors with proximal sensors measuring the same property.

Data fusion involves combining different data outputs and qualities from two or more sensors or information sources (such as text and audio) to extract more functional information. An example is combining high-resolution camera imaging (which can determine colour and texture) with imaging from lower resolution radar (that is able to penetrate leaves and measure size) to deliver information on crop yield or fruit size.

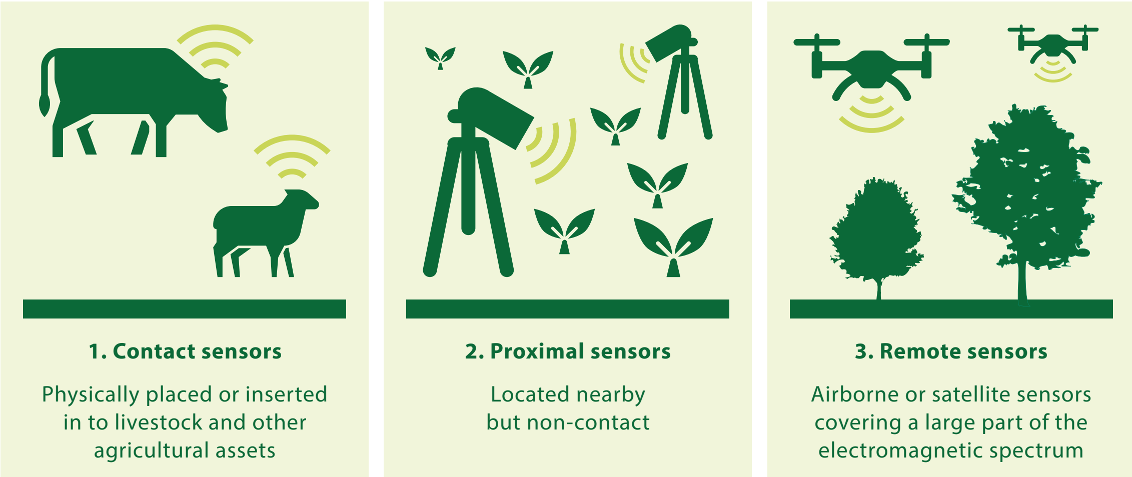

Figure 2: Categories of sensors in the context of agriculture.

2.1.1.1 Sensor-enabled monitoring to improve farm management strategies

Sensor technologies can contribute to higher productivity, quality and system sustainability across cropping, livestock, horticulture, forestry and aquaculture. These technologies could also allow for innovative land use to change the notion of a 'farm', especially on widespread Indigenous lands. Box 2 outlines an innovative use of sensors to monitor the location and health of animals, often considered pests, on non-farming lands. This could open new markets for distinctly Australia products, with secondary benefits of biosecurity management and economic development for remote and Indigenous communities.

Box 2: Advanced management of cattle and buffalo in the northern Indigenous estate

Collaboration is bringing advanced sensing, satellite tracking and data-driven planning tools to the management of wild cattle and buffalo in Northern Australia. The North Australian Indigenous Land and Sea Management Alliance, Mimal Land Management Aboriginal Corporation, Aak Puul Ngantam Ltd and South Cape York Catchments Inc. are collaborating with CSIRO, James Cook University, Charles Darwin University and IoT company Kinéis. Funded under the National Landcare Program's Smart Farming Partnerships, the project aims at enabling real time monitoring of herd location and health, the optimisation of management operations and multi-scale planning. These activities will contribute to improved environmental management, biosecurity, and profitability.

Existing and emerging strategies

The most common types of sensors used in agriculture are vehicle mounted. These include GPS devices to measure the location and velocity of a tractor, with the most recent activity being GPS-guided tractors for controlled traffic farming, and sensors used for asset management, such as measuring the performance of a tractor (Halpin, Cameron, & Russo, 2012). Virtual fencing is another example of an existing application of sensors, wireless connectivity and GPS enabled livestock management. Virtual fencing allows the farmer to create a boundary to control the location of livestock. When livestock the boundary or virtual fences they are given audio and sensory cues to shepherd them back into their grazing areas (Campbell et al., 2017).

Other common sensors devices are fixed-in-ground soil sensors that can measure nutritional and water properties (Department of Primary Industries and Regional Development, 2019). More of these sensing technologies have been combined to deliver precision agriculture techniques such as spraying and fertiliser distribution – otherwise known as precision agriculture variable rate technology (Grains Research & Development Corporation, 2007).

Sensor miniaturisation will have a major impact in agriculture. Producing cheap low energy sensors will mean further in field distribution and wider temporal-spatial data collection.

Sensors can provide insight into insect behaviour and travel, and hence biosecurity risks. For example, CSIRO has used advances in miniaturisation to deploy micro-sensing technology on thousands of honeybees in Tasmania, monitoring both their movement and the environment. Such information is important given that bees are integral to pollination of crops and food production.

Hyperspectral imaging is another type of sensor that can detect light wavelengths in the ultraviolet, visible and near infrared parts of the electromagnetic spectrum. Changes in the physiology and health of crops can change its reflective properties. Hyperspectral imaging can detect these small changes, identifying conditions such as plant stress arising from a range of factors including disease, nutrient deficiency and water stress (see Figure 3). Hyperspectral imaging can be applied on farm to support crop management and disease and pest detection (Lee et al., 2010; Moshou et al., 2011; Oerke, Mahlein, & Steiner, 2014; Vermeulen et al., 2017).

There are two challenges with hyperspectral imaging. The first is the expense. However, the cost of hardware is gradually reducing and there are cheaper options including the push-broom scanner (a device for obtaining images with spectroscopic sensors) (Jaud et al., 2018). Second, hyperspectral imaging is effective for remote sensing, however when used as a proximal sensor there is considerable uncertainty (Lee et al., 2010). These spatial resolution limitations can result in difficulties detecting early outbreaks of disease.

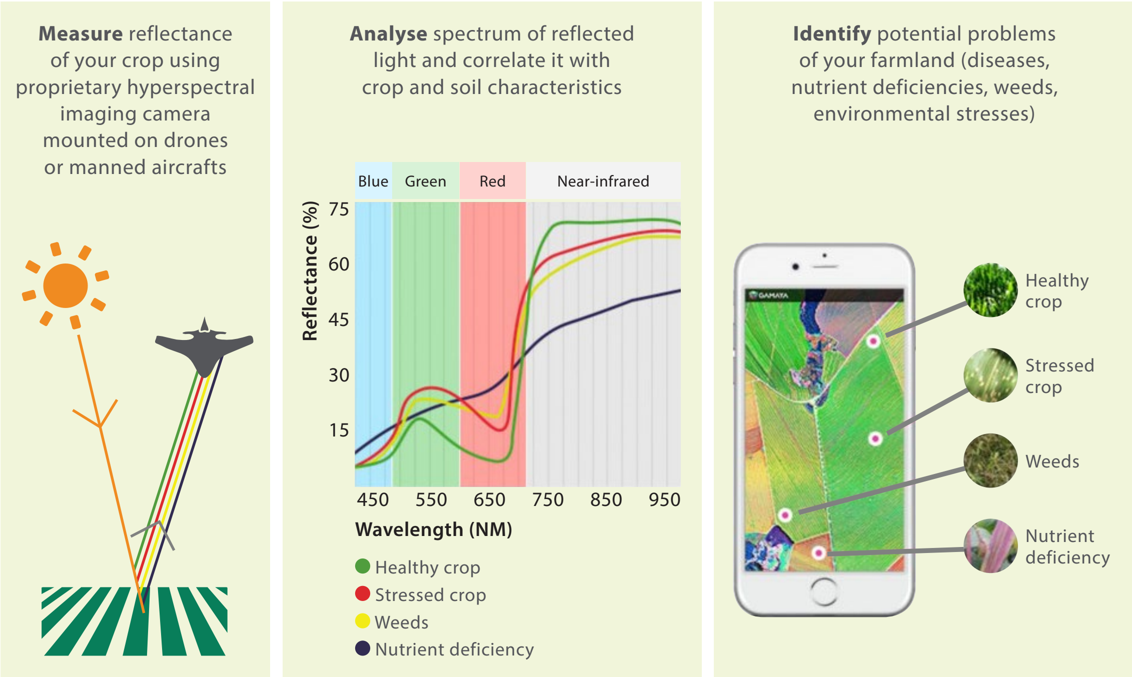

Figure 3: Hyperspectral image sensing of crop health.

Adapted from GAMAYA, 2016.

Emerging strategies that incorporate a combination of sensing technology, machine learning and other AI techniques have been used to efficiently and rapidly extract crop and animal management information (Rumpf et al., 2010).

Box 3 provides another example of how sensors can monitor environmental conditions and improve aquaculture outputs.

Box 3: Sensors in aquaculture

One of the challenges facing the oyster industry is understanding how environmental variables, including temperature and salinity, affect oyster growth and health. Small sensors can be attached to oysters to record and detect both biological (e.g. oyster heart activity and shell gape) and environmental (e.g. water temperature and pressure) variables in real-time (Rutkin, 2014). Linking these variables through IoT can provide insights into environmental and aquaculture management practices and allow oyster farmers to become more competitive and sustainable.

All of these technologies, alone or in concert, aim to reduce production costs and enhance decision-making; two factors that are the cornerstones for securing the long-term economic and environmental sustainability of Australia's food and fibre value chains. Sensor technology can lower costs through increased monitoring and input saving and improve global competitiveness of primary producers (Carolan, 2019). Similarly, informed and rapid decision-making will be enhanced through access to, and use of, real-time data (Wolfert et al., 2017).

2.1.2 Internet of Things

IoT is a collection of technologies built around networks and sensors including wireless sensor network technology, micro-sensors, radio frequency identification, intelligent embedded technologies, the internet and its technologies, and integrated intelligent processing technology and nanosensors (Chen & Jin, 2012). Figure 4 illustrates IoT's defining aspects, nodes, wireless connectivity and processing capabilities.

Embedded IoT capabilities can facilitate the use of real-time information collected from sensors as well as from other digital devices. This can include managing soil moisture to better distribute water and using climate monitoring to determine the need or timing for insecticides or fungicides.

Another important feature of IoT is the ability to communicate. While machine-to-machine communication is not unique to the IoT, it is advantageous as it implies that the IoT can facilitate the communication between multiple devices, not only sensors.

2.1.2.1 Facilitating monitoring to improve management from farm to plate

The gathering of sensor data and remotely controlling equipment is only one part of the IoT ecosystem. The fusion of the IoT and associated devices can yield significant improvements in efficiency across the supply chain. The analysis and delivery of results and insight to the primary producer is equally important as it adds another dimension of the opportunities in IoT. However, for sensors and IoT systems to be able to provide information to a computer, tablet or smart phone to help in decision making, connectivity between devices may need to be improved across agricultural areas. Implementation of the IoT has the potential to manage farming inputs more efficiently to improve produce quality, yield and profitability, as well as delivering positive environmental impacts (e.g. reduced use of herbicides and pesticides).

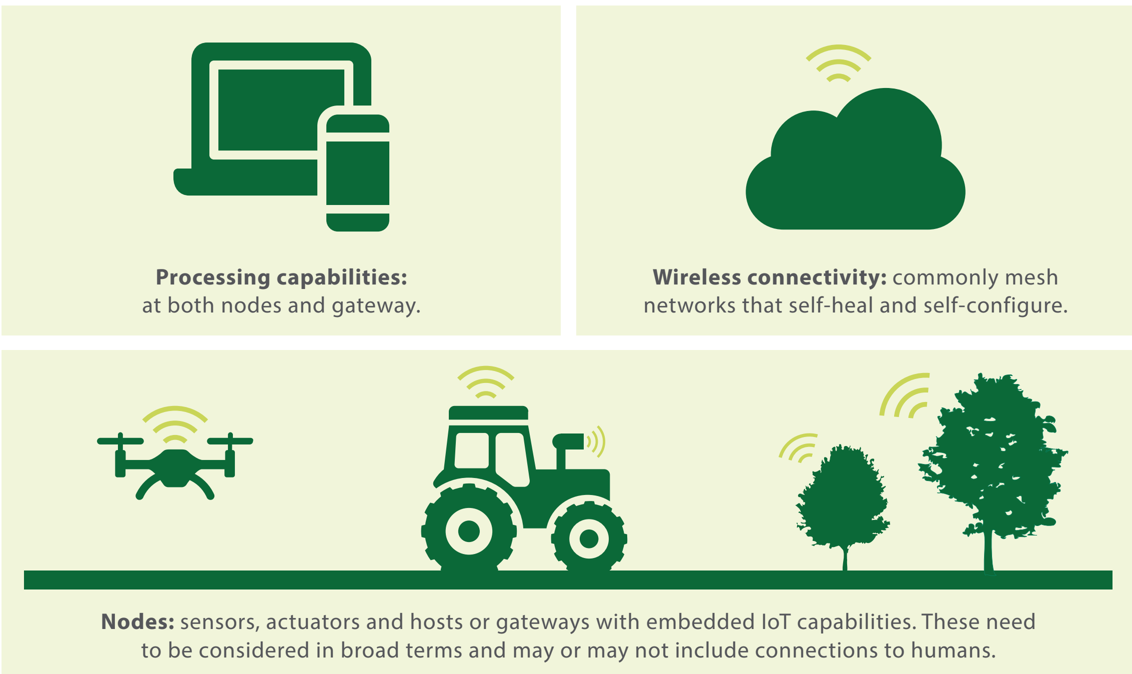

Figure 4: Defining aspects of the IoT.

Existing and emerging strategies

In IoT, sensors can also be combined with machine-to-machine communication which can facilitate monitoring to improve farm management strategies.

The use of IoT connectivity can create more precise livestock management through virtual fencing, stock health monitoring and traceability requirements (Banhazi et al., 2012; Kwan, 2019; Moro, Byrne, Kennedy, Campbell, & Tizard, 2018).

Monitoring the environmental impact of primary production can guide actions to minimise the environmental footprint and ensure sustainable practices (Borgia, 2014; López Riquelme et al., 2009). See Box 4.

IoT can help traceability of primary products through innovations such as DNA barcodes (species identification using a short section of DNA). A barcode could be embedded into timber, for example, facilitating traceability from harvest to finished boards. Similar applications could track fruit and other produce to strengthen food safety and biosecurity, as well as increase provenance of foods along the value chain.

Sensors and IoT are also being deployed along the supply and value chains, from produce packhouses, early-processing stages such as meatworks, and in transport to point of sale. Examples include QR codes for digital logistics, provenance and point-of-origin identification; temperature sensors that validate the frozen or cool state of produce; and multiple sensors used in food-processing lines.

IoT applications that require connected devices need a capable telecommunication network. The variable state of this communication infrastructure in rural and regional areas is cited frequently to be a source of frustration of primary producers and is perceived as an impediment for many primary producers who contemplate adopting these technologies (Lamb, 2017; Mark, Griffin, & Whitacre, 2016; Thomas et al., 2018). Connectivity is explored further in Chapter 3.

Box 4: IoT and orchard management

IoT combined with sensors on an apple and pear orchard can help conserve water through automated drip irrigation systems.

The system allows a farmer to access real time soil moisture readings from sensors, permitting more efficient water use. The incorporation of IoT and sensors into the irrigation system can also highlight problems such as blockages or leaks. The system can be controlled by a smartphone app, allowing farmers more flexibility and greater responsiveness to conditions in their orchard (Agriculture Victoria, 2019).

2.2 Automation management technologies

Key points:

- The agricultural community recognises the need for greater precision in farming to reduce the use of chemicals, for economic and environmental reasons, and to optimise yield.
- Robotic systems offer the potential to reduce costs and increase efficiencies by enhancing or extending human efforts.
- Artificial intelligence, machine learning, data fusion and large-scale optimisation have the potential to allow robots to perform tasks that would normally require human intelligence, complementing farmers' existing knowledge of their land through improved weather and climate modelling and prediction of crop yields.
- On-farm automation focuses on the application of robotics and machine learning (ML). These technologies have the potential to reduce input costs and maximise yield through persistent and precise actions.

Robotics and ML have been used extensively in industries such as mining, infrastructure and logistics. Recently, as the costs of these technologies have reduced and their capabilities increased, there have been developments of on-farm autonomous systems, adopting many of the lessons learnt in other industries.

2.2.1 Robotics

A robot is a programmable machine able to carry out actions autonomously or operated remotely. It is a machine, or system, that perceives the world around it, makes a decision based on this perception and then acts according to the decision. The term 'robotics' encompasses the system components, the perception, cognition and actuation – the combination of which allows robots to perform tasks automatically or make decisions intelligently.

Figure 5 illustrates the technologies used within robotic systems in agriculture.

Figure 5: Technologies used within robotic systems in agriculture.

2.2.1.1 Increasing productivity and precision and reducing the cost of production

Robotic systems can reduce costs and increase efficiencies by replacing mechanical methods or human labour with autonomous systems. Robotics also offers the potential for 24/7 autonomous farming with minimal human intervention. While some applications and enabling technologies are advancing rapidly, the widespread adoption of robotics in agriculture requires additional technological breakthroughs, such as the ability to work reliably in unstructured and unpredictable environments (Bac, van Henten, Hemming, & Edan, 2014; Bechar & Vigneault, 2016).

Existing and emerging strategies

Robotic technology can increase productivity through sensing and ML, the pairing of which can deliver more precise information on the state of the farm, resulting in better decision making. The sensing and reasoning capability of robotics enables the handling of complex tasks and processing and then applying objectivity to information gathered. Thus, robots can have pre-emptive and reactive capabilities; necessary requirements when operating autonomously in dynamic environments such as farms.

Robotics promise greater precision in farming by reducing the use of chemicals (for economic and environmental reasons) and optimising yield potential. Robots can monitor phenomena around the farm repeatedly and with greater accuracy than a human. As well as automating many farming practices, robotics can also improve processes at other stages along a production chain.

Beyond precision farming, sophisticated automation can reduce value chain waste (e.g. food processing, packaging and handling) and add value to fibre production through automated objective measurement (Nayak & Padhye, 2018; Saggiomo, Wischnowski, Simonis, & Gries, 2018).

The first wave of agricultural robotics is likely to feature tools that fit into current farming practices. Robotic functionalities such as mechanical weeding, precision spraying, automated harvesting, and the provision of crop intelligence are evolving quickly and becoming more accessible. Examples include monitoring crops for their nutrient status, pest and disease burden, readiness for picking or harvest, assessment of weeds and appropriate weeding techniques, and tracking and monitoring animals and their health (see Box 5).

Emerging strategies associated with improved sensing technology could further increase robot capabilities. Red-green-blue camera sensors can quickly assess plant colour, texture and shape. Hyperspectral scanners (see 2.1.1) can acquire detailed information about a crop, and thermal cameras can help assess its water status providing a robotic system with the capability of tracking the environment and monitoring important locations on-farm.

Combining these technologies could deliver high-resolution information about crops and livestock and enable reliable autonomous decision-making, providing robotic systems with the capability of acting autonomously on-farm to herd animals, and undertake spraying, weeding and harvesting. This could help farmers produce more yield per unit area using fewer agricultural inputs and facilitate consistently higher quality products.

Box 5: On-farm robotics

The introduction of a robotic agricultural solution can alleviate some of the biggest on-farm pain points such as manual weeding, prevention of pests and diseases and the monitoring of crop health.

Grech Farms Camden is owned and operated by one of Greater Sydney's most successful vegetable farmers, Paul Grech. The business, which has been operating for over 30 years, incorporates three NSW properties at Theresa Park (140 acres), Ellis Lane (60 acres) and Cooma (140 acres). These properties predominantly focus on growing cabbages and potatoes that are supplied to the Sydney Markets and large processors, as well as providing baby leaf spinach and lettuce to other distributors.

As with many other farms, Grech farms is continuously facing increases in input costs such as manual labour and chemicals, in parallel with downward price pressure from cheaper imports and increasingly stringent quality parameters from buyers. To overcome some of these issues, the farm is trialling robotic solutions to mechanise and automate farming operations in order to rely less on manual labour and to make the business more efficient and profitable. By adopting such robotic solutions Grech farms can alleviate some of the pressure from price squeeze, as well as variability in crop quality.

Image not representative of the case study farm, however provides an example of on-farm robotic technology.

2.2.2 Machine learning

AI is the science and implementation of computing systems that allow robots to perform tasks that would normally require some level of human intelligence. ML is a branch of AI that studies algorithmic approaches that use data and pattern recognition to give robots the capability of acting without being explicitly programmed to do so. With ML, computers solve problems by detecting patterns. ML can then supply these patterns, along with other computer methods and techniques, to help develop AI that could go on to mimic human cognitive learning (Walsh et al., 2019).

2.2.2.1 Providing new insights to help address future challenges

The high-performance and low-cost agricultural problem-solving that ML provides can augment farmer knowledge and support complex management decisions, as well as drive the uptake of robotic systems such as automatic cattle (grazing) rotations or automated crop spraying regimes.

Existing and emerging strategies

Large agricultural data sets offer the potential to encode agronomy data into models driven by sensor data. The collection of large data sets can help to build localised models, giving primary producers a management tool customised for their farm or district.

More effective water management can be accomplished with ML. ML-based applications can make irrigation systems more efficient by estimating daily, weekly, or monthly evapotranspiration from meteorological station temperature data (Liakos, Busato, Moshou, Pearson, & Bochtis, 2018). Prediction of daily dew point temperature can help to estimate evapotranspiration, evaporation and likely weather phenomena (Mohammadi et al., 2015).

ML can also be used to better understand and improve animal welfare. There is increasing public pressure to ensure that livestock are treated ethically. Data collected from drone images or mobile surveillance cameras can be used to monitor animal behaviour for signs of stress or other issues. Movement patterns, including standing, moving and grazing, can predict the onset of disease, or changes (intended and unintended) in body weight (Fernández-Carrión et al., 2017). Data on an individual animal can dictate whether or not it should be culled. Prediction systems can estimate the weight of cattle as far as 150 days before the slaughter date, enabling farmers to modify diets and conditions (Alonso, Rodríguez Castañón, & Bahamonde, 2013).

2.2.2.2 Monitoring and adapting to changes in consumer preferences

Personalisation is the use of technology and customer information to tailor digital interactions between a supplier and its customers. Personalisation technologies are emerging from the convergence of social networks and digital devices with data analytics, ML and AI. Such technologies may help to strengthen links between consumer preferences and production systems, with implications for agricultural value chains and business models.

Existing and emerging strategies

The digital era has provided consumers with ready access to information about food, fibre and other products, and many people are making more informed choices about what they buy. Consumers also frequently want the opportunity to customise or shape products and services. The rise in digital devices has led to growth in online shopping, with online data providing businesses with greater insights into customers' purchasing patterns, history and interests.

Product personalisation may pose challenges for agricultural businesses, the majority of which operate by providing high-volume products or services through mass production and distribution. The shift from mass distribution to mass personalisation is a challenge for many businesses as it requires balancing the number of options required to create an individualised product or service for consumers, while remaining profitable.

Personalisation analytics are already being used in the agricultural supply chain. For example, one of Australia's large supermarkets deployed a platform that collects information about how customers are interacting with the organisation across multiple points of contact to improve customer experience. Agricultural retailers are increasingly investing in digital and data capabilities to improve business operations and customer experience. Businesses now have the capability to measure exactly what each customer wants and can adapt their processes and supply chain accordingly.

2.2.3 Large-scale optimisation and data fusion

Data fusion is the process of integrating multiple data sources with the objective of producing more consistent, accurate, and useful information than that provided by any individual data source. Large-scale optimisation is a set of mathematical techniques that are designed to solve optimisation problems that are too large (typically because of high dimensionality) to be solved using standard optimisation methods.

These are generic technologies and each has a wide variety of potential applications to agriculture. In general, however, data fusion techniques address the need to monitor the state of land, plants or animals as a basis for decision-making. Optimisation techniques have two main kinds of application to agriculture. First, they can be used directly to identify the best decision in a given context, typically in situations where a scarce resource such as irrigation water or fertilizer must be allocated across land and seasonal periods. Second, optimisation can be used to help infer quantities of inputs of outputs to a farm manager from noisy or uncertain data (Houska, Kraus, Kiese, & Breuer, 2017; Huang et al., 2018; Iizumi, Yokozawa, & Nishimori, 2009; Wang, Li, Lu, & Fang, 2013). In particular, large-scale optimisation techniques commonly form part of the process of deriving predictive functions using ML and AI techniques.

2.2.3.1 Assisting decision making and farm management with data driven methods

Data fusion and large-scale optimisation analytics can help to analyse agricultural systems and the relationships between complex agricultural events (e.g. meteorological occurrences, pest and disease) (see Carbonell, 2016; Kamilaris, Kartakoullis, & Prenafeta-Boldú, 2017). These analytics underpin data-driven forms of agriculture, such as smart or precision farming, where the objective is predicting events to enable better planning and management of resources.

This data fusion and large-scale optimisation can provide insight into challenges such as climate variability and environmental and landscape sustainability by delivering data-driven and thus informed decision-making processes for primary producers. Further, when these data analytic techniques are combined with ML and AI the computing outputs can improve weather and microclimate modelling as well as better predict crop yields (Australian Government, 2019b; Chlingaryan, Sukkarieh, & Whelan, 2018).

Existing and emerging strategies

Large-scale data fusion techniques are already practised in agriculture, though they are not typically labelled as such. They assist with managing seasonal conditions, and improving farm business management, and agricultural research – all of which underpin future sector performance.

The fusion of large-scale spatial data sources such as satellite data with different spatial and temporal resolutions can create information-rich maps. For example, interpolated grids of near-real-time historical weather data, or digital soil maps can be generated. These data fusion applications typically rely on public sector data sets from the Australian Bureau of Meteorology or Geoscience Australia.

Fusion of the environmental data from networks of in-glasshouse or in-field sensors is starting to be used in operational systems for farm monitoring and control, especially in controlled-environment agriculture (Giovino, Argento, & Aiello, 2017; Wang, Yang, Wheaton, Cooley, & Moran, 2010). In addition to producing more robust and precise information, large-scale data fusion may also help regulatory bodies better quantify resources reserved for the environment, and resources allocated to farmers.

Dynamic land use planning in arable farming is an area where there are substantial economic gains to be made from improved on-farm decision making; Perrett et al. (2017) estimate a potential A$1.75 billion p.a. gain from decision agriculture that improves "crop rotations" in the grains industry alone. Lawes and Renton (2015) showed a small-scale optimisation model for rotations in single paddocks, was capable of identifying crop sequences that were more profitable than those recommended by local agronomists. Using this small-scale model and applying large-scale optimisation approaches could extend this model to multi-paddocks as well as incorporate other variables such as climatic and price, however such strategies are only emerging.

Optimisation of harvest and processing in more-complex value chains – particularly meat, but also horticultural produce – is also emerging and becoming more technically feasible as more famers begin to routinely monitor land and animals. Co-ordinating supply and demand between multiple suppliers (farmers) and processing facilities has the potential to provide a more-reliable supply of a more-consistent agricultural product, so enhancing an industry's position in export markets.

2.3 Biotechnology (omics and synthetic biology) and nanotechnology

Key points:

- Advances in genomics and more affordable DNA sequencing technologies will continue to enable the genetic modification of crops and animals to increase resilience to climate variability, pests, and diseases and reduce the use of herbicides and pesticides.
- Changes to regulation of some gene editing techniques and the lifting of moratoria in some states could provide new opportunities to the sector
- Nanotechnologies could have wide application on-farm; however, these technologies are still in early developmental stages for use in the agriculture sector.
- Biotechnology provides opportunities for creating new, improved and cheaper products, a trend that has been fast-emerging due to the interest of consumers and their changing preferences.
- Enhanced resilience through genetic modification and gene editing can improve animal welfare and biosecurity.

While the term 'biotechnology' is relatively recent, the techniques and methods it describes have long been in use in agriculture but have become more ubiquitous over recent decades.

Newer technologies in genetics and biochemistry, as well as the recently developed interdisciplinary field of synthetic biology, have yielded valuable information about organisms and biological processes. This has partly been driven by more affordable DNA sequencing technologies, which have led to sequencing and analyses of the genomes of many plants and animals.

These technological advances together with greater knowledge about biological systems have enabled the development of techniques such as RNA-interference to silence genes, as well as gene-editing (such as CRISPR-Cas9) whereby only one or a few nucleotides of the DNA sequence are altered to breed organisms with more desirable traits.

Synthetic biology involves the design and construction of artificial biological pathways, organisms, networks, or devices, or the redesign of biological systems (Gray et al., 2018). Many scientists view the approach as a natural progression from biology and genomics, involving the use of techniques and approaches from biology and molecular engineering. In 2018, ACOLA published a Horizon Scanning Report on synthetic biology that explored opportunities in Australian agriculture and food, environment and biocontrol. It also outlined community concerns raised by the technology, highlighting the importance of an adaptable and responsive regulatory system to guide responsible advancement.

Nanotechnology has been recognised as one of six 'Key Enabling Technologies' by the European Commission (European Commission, 2012). A nanomaterial has one of its three dimensions in the range of 1 to 100 nanometres. A nanometre (nm) is one-billionth of a metre. For comparison, the width of human hair is 50,000 to 100,000 nm.

Nanotechnology involves applications of nanomaterials that possess unique physico-chemical properties, such as catalytic reactivity, large surface area, high solubility, or specific size and shape. Fuelled by multi-disciplinary research, nanotechnology has a variety of potential applications across industries (Bhagat et al., 2015). However, nanotechnology is still emerging and often considered to be an 'immature' technology.

Significant advances in biotechnology have outpaced the legislation regulating genetically modified (GM) organisms. Australia's Gene Technology Regulations 2001 have been amended to provide certainty and legal clarity to researchers, industry and government. Particularly significant are changes to the regulation of some gene editing techniques, such as CRISPR. While most gene editing techniques are regulated under legislation site-directed nuclease-1 (SDN-1), is exempt as it presents no different risk to an organism carrying natural genetic changes (Australian Government, 2019a). Many other countries have also reviewed or are proposing to review their regulatory frameworks for this gene editing technology.

Biotechnology and nanotechnology have great potential to address broader trends and pressures (see Figure 6), but their introduction will require due consideration of community perceptions regarding risk, safety and benefit.

Technology capabilities	Potential outcomes	Impacts on broader trends and pressures
Biotechnology can help develop new plant varieties and new products	Creation of new markets and new commodities	Industry disruption
Gene edited animals can improve animal welfare	Higher value products	Changes in consumer preferences
Gene sequencing technologies that can detect plant and animal disease	Rapid identification of pathogens to minimise the spread of disease and produce loss	Biosecurity and food safety
Nono-formulated fertilisers and pesticide can improve crop yield	Targeted and reduced use of fertilisers and pesticides	Environmental and landscape sustainability and cost of production

Figure 6: Applications of biotechnology and nanotechnology and their outcomes for agriculture.

2.3.1 Breeding and modifying crops for resilience

As mentioned previously, advances in genomics and more affordable DNA sequencing have led to widespread sequencing and analyses of plant and animal genomes. These advances have enabled genes responsible for particular traits, such as increased resilience to climate variability, pests and diseases, to be mapped and identified. Such traits can then be incorporated into conventional breeding programs, often using molecular genetic markers. Benefits include reduced use of herbicides and pesticides, decreasing the time it takes to breed improved varieties and narrowing the time between research and the delivery of benefits to farmers and consumers.

Crop plants are being bred with genetic traits that allow profitable grain production on soils affected by salinity or acidity, allowing production in some marginal agricultural regions.

In crops where a desired trait is not available from within that particular species or from crossing with related species, genes from unrelated species have been introduced successfully. Incorporation of traits in this way, via genetic modification (GM), is faster and more precise than by conventional breeding, which typically involves many generations of backcrossing and selection, sometimes over decades. Advancements in gene technologies used to modify or edit an organism's genome, such as CRISPR-Cas9, are making the process cheaper, faster, and more reliable.

Existing and emerging strategies

Although several GM crops are grown worldwide, in Australia only three are approved for commercial production: cotton, canola and safflower.

Sowing transgenic cotton (Bt cotton) with insecticide resistance gene(s) of bacterial origin has enabled cotton growers to decrease insecticide use by 93 percent since 1997. Since 2010, the increased income for Australian cotton farmers from using this technology is A$395 million, an average of about A$180 per hectare.

Australian cropping typically involves minimum or no tillage to preserve topsoil. This requires herbicides to remove weeds before crops are sown. GM-canola tolerant to the herbicides glyphosate (Roundup) and glufosinate has been created by the insertion of specific bacterial genes allowing the crops to be grown concurrently with herbicide treatment. Increasing acreage over the past decade has provided income stability for growers and an environmental benefit from weeds controlled chemically, rather than by tillage, thus preserving topsoil (Brookes & Barfoot, 2013). In these cases (cotton and canola), strategies are nonetheless needed to inhibit the development of resistance in the pests or plants themselves (Holtzapffel, Mewett, Wesley, & Hattersley, 2008). However, there is growing public concern – and regulatory limitations in some locations – about the safety of glyphosate, potentially inhibiting use of some of these techniques.

Box 6 illustrates a recent project that aims to engage with and use Indigenous knowledge to identify alternative grazing grasses for farmers.

Box 6: Using climate resilient Indigenous plants for sustainable farm management

A project aimed at improving and supporting sustainable agriculture practices is investigating how to unlock the potential of Kangaroo Grass (Themeda Triandra) as a viable cropping option (Australian Government, 2019c). Kangaroo Grass is a nutritious native grass that is resilient to extreme climate conditions, such as drought, and could be used to feed grazing livestock, in addition to being a grain crop. The research project will draw heavily on traditional Indigenous knowledge to assist farmers develop more understanding of how to germinate and propagate the species for commercial use.

The project, in collaboration with Dja Wurrung Clans Aboriginal Corporation, will work with researchers to develop a scientific method to select best yielding varieties for varying climates and growing conditions. Community engagement strategies such as workshops and site visits will help support the upskilling of land managers and traditional owner groups to encourage uptake of this novel approach to cereal crop production.

Innovative approaches to increasing the efficiency of plant photosynthesis by improving the efficiency of water use and of carbon capture are emerging. This can be achieved by introducing genes from plants that are efficient at carbon capture (e.g. maize) into those that are less so (e.g. rice), or by engineering plants to incorporate cellular organelles from cyanobacteria or algae to increase the fixation of atmospheric carbon and hence crop productivity (Lin et al., 2014; Mackinder, 2018). Such strategies can enable agriculturally significant plants to be more climate resilient and function better in hot, dry conditions because they affect CO_2, H_2O and O_2 concentrations inside leaves and therefore patterns of stomatal opening and closure.

Artificial photosynthesis is an alternative approach, whereby carbon dioxide is converted into hydrocarbons without using plant enzymes. Chlorophyll is replaced by high-energy hydrocarbons produced using electron-rich gold nanoparticles. The efficiency of artificial photosynthesis can be improved by nanomaterials, such as titanium dioxide nanoparticles, carbon nanotubes and small carbon nanoparticles known as carbon dots (Song et al., 2012). For example, carbon nanotubes incorporated into green plant cells increase the capture of light energy and the rate of electron transport in leaves of the plant, Arabidopsis (Giraldo et al., 2014). Further, the uptake and transport of carbon dots through plants enhances root and shoot length and increases crop yield (Li et al., 2018).

Artificial photosynthesis is still an emerging technology and unlikely to be viable by 2030. However, the benefits of its implementation at scale could be significant while, at the same time, providing a clean, self-sustaining, energy source (Yu & Jain, 2019). Artificial photosynthesis could also be engineered to mitigate greenhouse gas emissions by storing carbon dioxide in suberin, a naturally occurring, carbon-rich, substance in roots that resists decomposition. The Harnessing Plants Initiative based in the US is aiming to use suberin to help transfer atmospheric carbon into the soil using plants that grow robust and larger root systems containing suberin (Salk Institute, 2019).

Pesticides, insecticides and herbicides can be delivered to crops in nanoformulations which have increased surface areas, resulting in greater solubility, mobility and durability and reducing the chance of harmful agrochemicals being released onto non-target organisms. Another way of providing nitrogen to crops is via *Rhizobium* bacteria, which nodulate roots of legumes in a symbiotic relationship and fix atmospheric nitrogen. This demonstrates why legumes are an integral component of crop rotations with cereals and canola.

For plants unable to fix their own nitrogen (particularly cereals) research is underway to reduce their nitrogen requirements. One approach is to generate cereals capable of using *Rhizobium* enzymes such as nitrogenase. Another is to exploit other bacteria that can fix nitrogen. One such bacteria originally cultured from sugarcane roots and stems can colonise the roots of a range of crop plants including cereals, canola and potato. Coating of seeds with this bacterium can increase yield, that is likely to occur through intracellular nitrogen fixation, leading to enhanced rates of photosynthesis and additional plant growth (Dent & Cocking, 2017).

2.3.2 Breeding, modifying or editing crops to enhance value

The propagation of crops that have an increased value could provide primary producers with a niche product that is differentiated from regular bulk commodities. Such products have the potential to transform markets and methods of production as well as increase the profitability of businesses.

Existing and emerging strategies

Genes from several organisms have been used to create a biosynthetic pathway for an omega 3 fatty acid that has been incorporated into canola to enhance its nutritional value (Petrie et al., 2012). This omega 3 product is now in aquaculture feed (Aquaterra®) and in a human nutritional supplement (Nutriterra®). The latter product satisfies a particular niche as it addresses increasing consumer demand for enhanced nutritional products.

Gene technology has been used to give GM safflower a new high-value market, namely industrial oils for cosmetics, fine lubricants, and biofuels. To achieve this altered oil profile, gene technology has silenced a gene in the fatty acid synthetic pathway. Small acreages of GM safflower with high levels of oleic acid are being sown as the crop enters the commercial phase.

Another recent example of a new crop with valuable traits is hemp. In Australia, the genomes of hemp varieties have been sequenced and the genes responsible for biosynthesis of the active drug molecules have been identified. This is leading to the development of a medicinal marijuana industry.

A collaboration between CSIRO, Meat and Livestock Australia, and James Cook University has identified a red alga species native to Queensland that when added to cattle feed as a supplement reduces methane production during the digestion of feed (Box 7).

Box 7: 'Methane-busting seaweed' feed supplements

Livestock, which contribute approximately 60 percent of agricultural greenhouse emissions, are responsible for around 10 percent of Australia's overall emissions. Methane is a far more potent greenhouse gas than carbon dioxide (Wallace et al., 2019).

A red alga species that produces a molecule that inhibits an enzyme in cattle gut flora has been discovered in Queensland. Supplying this alga as a 3 percent supplement in feed has reduced methane emissions from cattle by up to 80 percent in research trials. Wider adoption is dependent on farming this alga at an industrial scale. Selection and breeding of seaweed varieties for higher bioactivity may lead to lower quantities of alga required to supplement feed. The approach has the potential to reduce greenhouse gas emissions while continuing to support global food security (Kinley, de Nys, Vucko, Machado, & Tomkins, 2016).

Gene-editing technology also holds considerable promise, though most work to date has been done overseas. An example close to commercialisation in the US is production of lucerne (alfalfa) containing reduced lignin (a plant cell wall component that is largely indigestible). Reduction of lignin makes the plants more digestible by livestock. Research is underway to reduce lignin content in fast-growing trees such as poplar, to improve their properties for use as biofuels and in paper-making pulp.

2.3.3 Adapting to consumer preferences and creating new commodities

The agriculture sector constantly responds and adapts to changes in markets, global competition and consumer preferences. These trends are expected to intensify. Biotechnology can offer new and adaptive ways of responding to challenges as well as improving environmental sustainability and profitability. However, many consumers and producers are hesitant about use of biotechnologies particularly in food. There are concerns about safety and risk, the potential environmental impacts, and questions about who derives benefits from the new approaches.

Existing and emerging strategies

'Cellular' and 'acellular' agriculture refers to high-value products produced in fermenters or in cell cultures. These technologies are already disrupting traditional markets.

In acellular agriculture, microbes, such as yeast or bacteria, are used as a 'factory' to produce fats, proteins and metabolites for medical or food purposes. Acellular agriculture has potential to create transformational change with global impacts, through the production of new commodities and increased profitability. Acellular technologies could redirect agricultural production from low quality bulk items to differentiated and higher quality boutique foods (Goold, Wright, & Hailstones, 2018). Growing a versatile feedstock generating reliable income rather than season-sensitive commodity crops is another benefit of acellular technologies.

Compounds used in various industries can be produced in microbes such as the bacterium, *Escherichia coli* and the yeast, *Saccharomyces cerevisiae*. An example relevant to agriculture is raspberry ketone, an expensive natural flavour component. General broadacre feedstock crops such as barley, sorghum, wheat and corn can be broken down into ferments for several commodities depending on market conditions. For example, if there is a glut of raspberry ketone, the broadacre crop can be repurposed and sold as a substrate for production of, for example, vanillin (a synthetic vanilla) if that price is more favourable.

These new microbial fermentation products may also drive innovations such as the generation of new biomaterials from agricultural wastes (Wierckx et al., 2015), new biological sensors capable of real-time assessment of food quality (Ravikumar, Baylon, Park, & Choi, 2017), and new ways to produce crop-based commodities (Lee, Lloyd, Pretorius, & Borneman, 2016; Paddon et al., 2013). These biotechnological advances coupled with progress in chemical engineering and biorefining could create new opportunities for biomass production and management.

Cellular agriculture has in part arisen from consumer-driven food consumption changes. There is already evidence of disruption of traditional markets. The technology uses cell cultures to produce proteins, fats and tissues, with significant environmental benefits through reduced greenhouse gas emissions, reduced water consumption and land use, and reduced antibiotic use and antimicrobial resistance (Tuomisto & Teixeira de Mattos, 2011).

Production of alternative, non-meat or fish-based proteins requires fewer natural inputs than traditional sources of protein. Between 2012 and 2016, the percentage of Australians who are vegetarian or eat predominantly vegetarian foods increased slightly from 10 to 11 percent (Roy Morgan, 2016). However, the availability and demand for such products is growing and no longer focused on vegetarian and vegan consumers. Plant-based meats are designed to replicate the taste and sensory experience of eating conventional meat (Lawrence & King, 2019) and are being developed by several companies. A product based on leghaemoglobin, an iron-carrying protein from nitrogen-fixing nodules of soybeans, which mimics the colour and texture of a beef patty, is already on the US market. In Australia, a CSIRO-backed start-up, V2food, has invested in a specialised manufacturing facility for its plant-based meat alternative, which is being trialled in restaurants.

CSIRO Futures recently published a report on growth opportunities for Australian food and agribusiness (Wynn & Sebastian, 2019). Strong demand for alternative proteins is expected to continue, driven by rising consumer preference for sustainable and ethical sourcing of foods and strong population and income growth in key export markets with large vegetarian populations such as India. CSIRO estimates that the alternative protein market in Australia could develop into a A$6.7 billion market (domestic and export) by 2030. Similarly, a report from Food Frontier estimates that plant-based protein could add A$2.98 billion to the Australian economy by 2030 with total exports of A$1.37 billion (Lawrence & King, 2019).

2.3.4 Modifying livestock for improved resilience

Most agricultural applications of genomics and synthetic biology have involved plants, due to the longer generation time, technical issues and additional ethical issues associated with animals.

Globally, biotechnology projects are aimed at improving livestock welfare or resistance to disease. These projects may provide opportunities to breed more resilient livestock as well as to cater to consumer concern for improved animal welfare.

There are no transgenic livestock commercially available in Australia, although production of several types of gene-edited animals is imminent.

Existing and emerging strategies

Gene-edited, polled dairy cows have been developed in the US. Removing horns from Holstein dairy cattle improves animal welfare related to crowding during milking and management. Genetic linkage between the horn phenotype and milk productivity phenotype means that strategies to produce 'polled' cattle using conventional breeding with hornless cattle would take decades. Mechanical dehorning has been utilised but is costly and painful for the animal. Gene editing has been used recently to produce cattle without horns as well as the first gene-edited thermotolerant Angus cattle, which are resistant to higher temperatures. The founder animals (first generation of those with the gene-edited trait) are sold to companies that then integrate the genetic background from these animals into their elite breeding lines. Box 8 illustrates another method of improving animal welfare.

There are also several examples of gene editing in swine.

- Traditionally, pigs are castrated mechanically to prevent aggressive behaviour and to improve meat flavour. By editing specific genes, progression to puberty in male swine is prevented, eliminating the need for mechanical castration.
- Pigs with 25 percent less body fat have been produced. The target gene allows pigs to regulate their body temperature better by burning fat. Ancillary benefits include reduced costs to farmers for heating and feeding, and production of leaner meat (Zheng et al., 2017).
- Pigs resistant to the viral disease, porcine reproductive and respiratory syndrome, have been produced, lowering production costs and minimising biosecurity threats (Shike, 2019).

Box 8: Preventing culling of male chicks

The practice of culling male chicks post-hatch creates an ethical dilemma. Pre-hatch sex determination of chickens negates the need to cull males, as well as providing an alternative use for pre-hatched male eggs. Advances in gene technology have enabled male and female chicks to be differentiated pre-hatch by inserting a visible marker on the chicken's sex-determining chromosome. Examining chicken eggs by fluorescence and Raman spectroscopy through the shell membrane enables the males to be identified before hatching and then removed before incubation.

The eggs can be used to culture influenza virus for vaccine production. This reduces production costs and eliminates culling male chicks.

2.3.5 Enhancing biosecurity and food safety

Australia has a strong biosecurity system that protects farms as well as the environment from pests, weeds, and diseases. However, there are occasional breaches and the risk of vector-borne diseases (particularly mosquito) arriving in Australia because of climate change is likely to challenge existing measures. Potential increase to biosecurity risks could result from increases of people travelling internationally, importation of insects (purposefully or accidentally), and population growth in northern Australia.

Existing and emerging strategies

Rapid in-field identification of plant and animal pathogens and their early treatment or removal will reduce biosecurity breaches and disease incursions. Genomic sequencing technologies have improved pathogen detection.

Portable devices have enabled the detection and subtyping of pathogens in farm animals and food and show potential for on-site pathogen identification and surveillance of foodborne disease. New 'long-read' sequencing technologies can identify and detect antibiotic resistance genes in pathogens (e.g. *Mannheimia haemolytica* associated with bovine respiratory disease) and promise improved control of resistance and reduced economic loss.

Gene editing combined with gene drives (a process that increases the chances of offspring possessing a desired trait) could be harnessed to suppress pests and diseases. Examples include genes that suppress the ability of vectors such as mosquitoes, ticks and midges transmitting diseases to humans and livestock, and genes that make weeds and pests more susceptible to pesticides.

RNA interference (RNAi) can be exploited for crop protection. This regulatory mechanism is important in host defence against pests and pathogens. The trigger molecule, dsRNA, guides degradation of pathogen RNA, but is unstable following foliar application and protection is short-lived. Protection can be extended by delivering a foliar spray containing dsRNA loaded onto non-toxic, biodegradable and biocompatible clay nanosheets (Mitter et al., 2017).

Nanoparticle-adjuvant vaccines and nano-encapsulated veterinary medications can protect animals from disease.

Beyond the farm, applications using advanced biotechnology and nanotechnology include monitoring the provenance, quality and safety of food products at each step of the production and processing pathway. The technology can also be used to improve traceability through the supply chain, predict shelf life, signal microbial or chemical contamination in real-time, and detect presence of allergens.

Incorporation of nanomaterials into packaging provides a more effective barrier to oxygen and carbon dioxide gas, improving shelf life. Improvements in food safety may result from topical application of nanomaterials such as silver, copper and zinc oxide nanoparticles, which have broad-spectrum antibacterial properties (Liu et al., 2009; Vimbela, Ngo, Fraze, Yang, & Stout, 2017).

2.4 Transactional technology

Key points:

- The use of distributed ledger technology can increase product provenance and supply chain transparency and traceability to address the interests of consumers as well as supply chain actors by streamlining a number of certification and legalisation obligations.
- The ability to implement distributed ledger technology is underpinned by sensors and digital technologies.
- Applications, such as blockchain, have significant potential to reduce food safety breaches and improve public health.
- Distributed ledger technology in agriculture can provide a powerful and trusted platform for primary producers to create product differentiation, potentially leading to high value products and increased profitability.

E-commerce provides a method to interact with many more customers, both locally and globally. Distributed ledger technology can improve the collection and reliability of data along the supply chain. For example, consumers are increasingly interested in receiving information about the location and conditions of food production.

2.4.1 Distributed ledger technology

Distributed ledger technology (DLT) refers to a digital system (technology) for recording and updating a data structure (ledger) simultaneously in multiple places (distributed).

DLT records and tracks information in a distributed and decentralised manner. This provides a network's participants with secure access to information at any time, with the ability to view information according to access privileges.

DLT is still an early-stage experimental technology. There are different types including blockchain, Hash Graph, Directed Acyclic Graphs and Holochain (Anwar, 2018). In this report only blockchain will be discussed as it is the most developed application (The World Bank, 2018). A blockchain is an arrangement of technology components including public key cryptography, peer-to-peer networking, databases, game theory, and consensus algorithms. The system records and tracks information in a shared, distributed and decentralised manner. Blockchains can facilitate peer-to-peer transactions and value transfer.

DLT has significant limitations in relation to scaling, interoperability, user experience, market development and regulatory environment (Data61, 2017). The main regulatory challenge is to create a common digital standard trade infrastructure protocol.

Increased cases of product fraud, interest in more information about production, increased awareness of food-related health hazards and concerns about use of biotechnologies and genetically modified organisms are driving trends in consumer preferences (Opara, 2003). DLT unalterable ledger can improve the way data are recorded and secured, therefore ensuring credibility. The extensive and credible information can increase transparency of a product to a growing number of discerning consumers as well as help primary producers manage their businesses and meet industry requirements and regulations.

2.4.1.1 Transparency, provenance and traceability

DLT can facilitate transparency of the supply chain, provide information on provenance about food and fibre and enable better and quicker traceability of products.

DLT, with other complementary technologies, can capture more or new information about agricultural practices or provable quality of products. Provable quality of farm products refers to characteristics such as specific batch conditions, compliance with standards, safety information, consistency, purity, or measures of provenance and authenticity. Increasing the amount of provable quality and their attributes, all potentially impact the price of farm commodities. For example, when looking at organic foods, missing information on the certification can cause a product to trade at a discount to its full information price, as can uncertainty about the quality of information.

Creating trust or proving reliability of the data can be expensive. DLT, such as blockchain, promise to reduce administrative and monitoring costs associated with transactional data and could have far reaching effects on costs associated with supply chain and trade. Additionally, if that same technology facilitates adding further trusted information, then that information may increase the value of that commodity. By both lowering cost and increasing value, DLT, such as blockchain technology, are likely to increase the profitability of agricultural produce along the value chain.

Figure 7 illustrates how blockchain can facilitate and secure the flow of information from farm to plate. In Figure 7, the physical flow of goods is tracked digitally, with the internet serving as the connecting

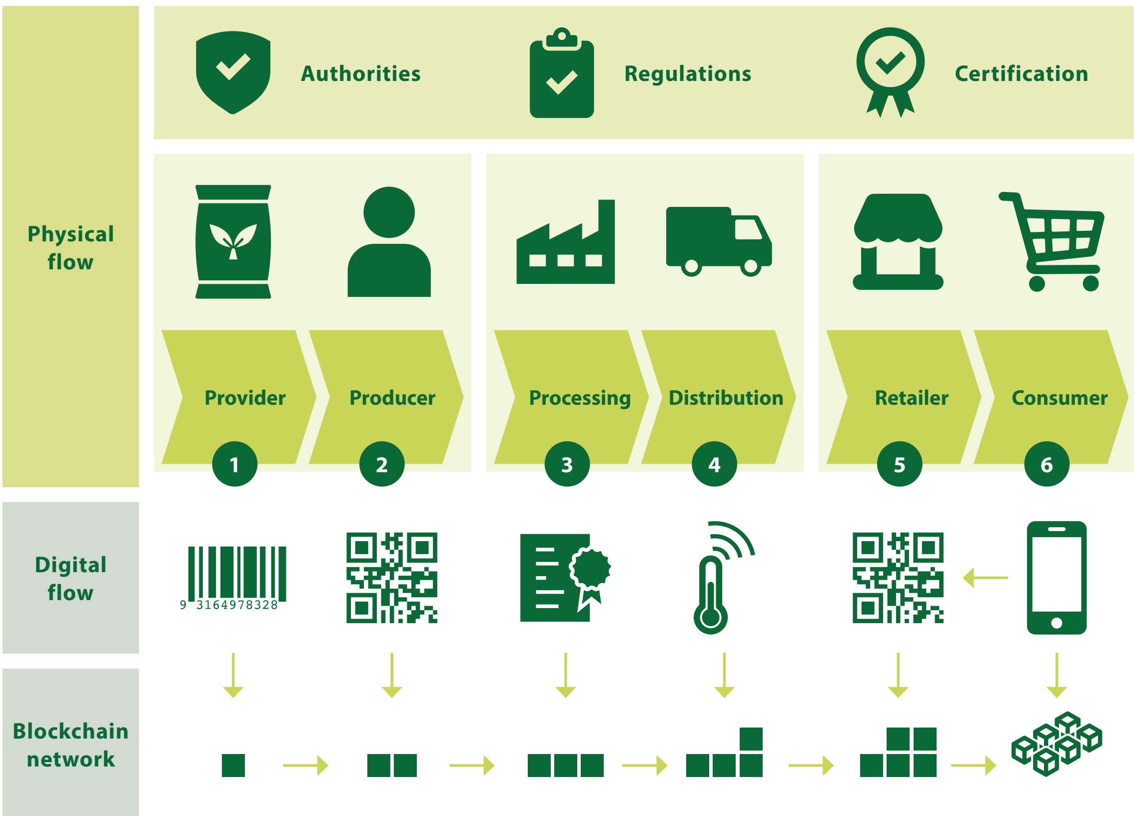

Figure 7: Digitisation of the food supply chain, supported by blockchain technology.

Adapted from Kamilaris, Fonts, & Prenafeta Boldú, 2019.

infrastructure. Every action performed along the supply chain is recorded to the blockchain, which serves as an unalterable information store. Figure 7 outlines a six step process: 1) inputs used by the farmer can be tracked via barcodes from the provider; 2) producers use QR codes to inform the supply chain about the farming practices they use; 3) processing plants convey their certifications in a secured and legitimate manner; 4) distributors record their compliance with code of practice and logistical requirements, such as cold chain standards; 5) retailers collate relevant supply chain information and communicate it to their consumers through QR codes; 6) consumers use their digital devices to access certified and transparent information about their product (Kamilaris, Fonts, & Prenafeta Boldú, 2019).

Existing and emerging strategies

In a global comparative study, Australian traceability systems for agricultural commodities ranked 'average', along with Canada, Japan, Brazil, New Zealand and the United States – all of which were out-performed by the European Union (Charlebois, Sterling, Haratifar, & Naing, 2014). Australia was deemed to have high-quality traceability systems for livestock, but the overall rank was negatively affected by inadequate systems for other commodities.

To improve Australia's traceability ranking across all agricultural commodities, businesses will need to invest in both virtual and physical technologies in order to provide consumers with additional information, including product origin, production processes and inputs, suppliers, processing materials, transport conditions, distribution mechanisms, nutrient profile, genetic makeup, sustainability and environmental impacts (CSIRO Futures, 2017). The production of an information-rich diversified product can be enabled through other technologies such as digital tracking or biological analyses. Box 9 illustrates an application in the beef export industry.

Blockchain has significant potential to reduce food safety breaches and improve public health. Indeed, this is the major value proposition being advanced by technology companies such as IBM's FoodTrust platform, or by AgriFood giants such as US-based Cargill through their blockchain turkey program. Blockchain integration into supply chains enables traceability and targeted rapid recall of contaminated product, without expensive blanket recalls that can take weeks to implement.

Blockchain-based applications for agriculture facilitate integration with other digital technologies and automation. Automated sensing technologies such as IoT can provide the hardware that uploads information to blockchain-enabled supply chains. AI and ML technologies embedded into machinery can enable automated technologies such as irrigation systems, plant and harvesting equipment, and transport vehicles to engage in smart contracting and payments (e.g. automating payment upon delivery). These same sensing and contracting capabilities facilitate blockchain-enabled management across the supply chain and associated markets.

Integrating these technologies with DLT can provide a powerful and trusted platform for primary producers to differentiate their domestic and export products, potentially leading to premium products and increased profitability. The implementation of traceability and provenance systems could provide the sector with a platform to demonstrate its sustainable and socially responsible approaches to food and fibre production.

Box 9: Provenance and traceability of beef

In 2017 the Australian cattle industry exported about 70 percent of beef and veal (Meat and Livestock Australia, 2018).

The export beef supply chain can be a long and complex journey involving transportation, processing and regulatory regimes to reach international consumers. As the global demand grows for beef, maintaining Australia's reputation for delivering high quality and ethically produced products could be key to remaining competitive. DLT and blockchain platforms have been used to integrate provenance, security and payment processes.

2.5 Approaching the adoption of new technologies

The deployment of advanced technologies is a key to the transformation of Australian agriculture; however, it may not be sufficient to ensure it. Emerging technologies are likely to promote an environment of incremental changes such as improvements in productivity, reduction in cost of inputs, and reduction of environmental risks.

The creation of transformational change will require a holistic approach that addresses challenges and confers benefits to enhance the wellbeing of agricultural regions.

Chapter 3 discusses the factors that determine and enable the uptake and adoption of technologies within the agriculture sector.

CHAPTER 3
FACTORS SHAPING THE UPTAKE OF TECHNOLOGY IN AGRICULTURE

The Australian agriculture sector is faced with an unprecedented range of enhancing or transformational technologies with the potential to increase productivity, profitability and sustainability (economic, social and environmental). The adoption of these technologies and the realisation of their benefits will depend on the characteristics and potential of the technologies and the attitudes towards their implementation by primary producers, regulators, consumers and by society as a whole.

This sector comprises many industries and stakeholders with varying interests, highlighting that, in shaping technological pathways, engagement of agencies that service these communities will be essential (Jasanoff, 2016).

This chapter considers four inter-related issues: enablers of adoption; legal and regulatory factors affecting the uptake of agricultural technologies; economic opportunities; and roles of government and industry.

Table 5 illustrates the factors determining or enabling the uptake of technology in agriculture.

Technology areas	Factors determining or enabling the uptake of technology in agriculture				
	Community acceptance	Workforce	Connectivity	Regulatory	Empowering regional communities
Sensors & IoT		✔	✔	✔	✔
Automation Management		✔	✔	✔	✔
Biotechnology & nanotechnology	✔			✔	✔
Transaction technology	✔	✔	✔	✔	✔

Table 5: Factors determining or enabling uptake of technology in the agriculture sector.

3.1 Enablers of technology adoption

Key points:

- Public responses to novel technologies are complex and framed by perceptions of risk and benefit, purpose and responsibility.
- Ensuring regional and rural communities are equipped to adapt and thrive through the uptake and adoption of emerging technologies could become key to transformational change.
- Emerging technologies are likely to affect the nature of work and upskilling may be necessary in some roles, particularly if digital technologies are involved.
- The establishment of appropriate infrastructure, such as technical services and data centres, to create hubs will help diversify and empower regional areas.
- A capable telecommunication network will underpin opportunities from agricultural technologies.
- Continued public and private investment in research and development in agricultural technologies is needed to ensure technologies meet Australia's unique needs, with the most optimal outcomes likely when all stakeholders are involved in the development process.

The technologies identified in this report have potential to contribute and increase the profitability and sustainability of Australian agriculture. However, in order for this potential to be realised, they need to be adopted in an appropriate manner. Levels of adoption and acceptance of technology are dependent on the characteristics and attitudes of the intended technology user (farmers), as well as the attitudes and risk perceptions of the broader community and consumers (Vanclay, 2004).

While individual technologies are important, consideration of the environment within which they operate is critical. New technologies are often connected virtually or as on farm technological packages. It is therefore necessary to take a holistic view of technology.

The development of agricultural technologies will undoubtedly reshape production practices and potentially community values relating to agriculture. It is important that agricultural technology developments and future research be preceded by communication and engagement with stakeholders, including engineers and regulators, but particularly with farmers, rural communities and others in the value chains.

3.1.1 Adoption by primary producers

Behaviour in relation to the adoption of emerging technologies depends on a broad range of social and psychological factors, including motivations and norms, in addition to attributes of the technologies themselves (Pannell et al., 2006). Different sources of information, including agricultural professionals, also shape and influence the retention of attitudes to technology adoption (Wheeler, 2008). It follows that adoption or rejection of a particular technology should be interpreted in isolation as evidence of positive or negative attitudes toward that technology or to the use of emerging technologies more generally.

The choice to adopt or reject a technology depends on its perceived advantage. Considerations include economic merit, compatibility with existing practices and values, ease or complexity of use, and tangible benefits (Rogers, 2003). Gender, age, education, experience with technology, farm size and production heterogeneity have all been shown to moderate these considerations; albeit in sometimes contradictory ways (Hay and Pearce, 2014). Consistency with users' knowledge and experiences, preferred ways of learning, occupational identities and personal goals are all important (Carruthers & Vanclay, 2012; Guerin, 1999; Mankad, 2016; Pannell et al., 2006).

Attitudes toward new and emerging technologies tend to be unevenly formed and subject to change. As technologies 'mature', their advantages for users are likely to become clearer but so too must the technical, legal and training infrastructure necessary for adoption if their potential is to be realised (Skinner, 2018). Nano materials, synthetic biology and gene editing are examples of 'immature' technologies to which stakeholders' attitudes and adoption decisions may still be unformed (Lyndhurst, 2009; Ribeiro & Shapira, 2019). At the same time, distinctions between existing and emerging technologies can be blurred in the minds of potential users. Attitudes to the adoption of emerging digital and genetic technologies, for example, may be influenced by prior experience with precision agriculture devices, decision support systems, and genetic modification (Ribeiro & Shapira, 2019; Sonka, 2016).

Robertson et al. (2019) argue that a farmer-centric approach to the development and extension of innovations is needed if the value of agricultural technologies is to be realised. They identify eight imperatives for digital agricultural systems development, more specifically, with relevance to other technology domains. These imperatives include:

1. **Make it easy to collect data.** Farmers have competing priorities. Ensuring data can be collected in an easy and streamlined manner, either through automation or by pairing collection with another activity or task, can increase the likelihood farmers will collect it.
2. **Avoid overcomplicating matters.** Despite the ability of digital systems to collect and generate high volumes of data, too much information can overwhelm decision makers. Determine how much information is helpful.
3. **High frequency precise data are not always needed.** High frequency and precise information are useful to farmers if it aligns with decision timeframes. Exceeding these timeframes undermines the utility of data and is potentially confusing.
4. **Minimise the steps between data collection and useful knowledge.** Systems that convert data into knowledge useful for decision-making in a streamlined manner are more attractive to adopt.
5. **Extrapolation and forecasting are more useful than sensor measurements.** Synthesis and interpretation are needed to translate data into actionable information – extrapolation and forecasting from collected data are particularly useful in managing uncertainty.
6. **Help farmers test and improve their own knowledge, rather than replacing it.** Farmers apply deep knowledge formed through experience in the form of heuristics (rules) to decisions. Building on this is critical to adoption and to improving farm practices.
7. **Digital agriculture systems are likely to inform some aspects of a decision, but not all.** Farming can be viewed as socio-ecological systems with a complex interplay of business, psychosocial and cultural factors at play. Information from digital systems are likely to provide hard data that is combined with other sources of information to support decisions.
8. **Connectivity is important, but not for every decision.** High speed and reliable connectivity will be important for data supported tactical decisions needed on the spot. However, low powered communication systems can also provide utility for other types of decision making.

A farmer-centric approach will also require sensitivity to the heterogeneity of the agriculture sector – diversity in the aspirations, capacities and values of end-users being as important here as variation in enterprise mix, farm size, location and climate.

To conclude that innovations are adopted only when they are simple, proven and easily applied would be incorrect. For example, early adopters, farmers willing to experiment with unproven technologies or complex and novel systems, do not fit a neat demographic profile (see Box 5 for an example of an early adopter of on-farm robotics).
For instance, digital technologies are used more frequently by women than men in the grazing sector; women reporting that they find use of these technologies empowering (Hay & Pearce, 2014).

The experience of both incremental and transformational change demonstrates that adoption is enhanced by supportive social and institutional environments characterised by strong peer networks and the availability of locally relevant advisory, technical and research and development services.

3.1.2 Acceptance by consumers

There are a number of ways in which consumers may benefit from the adoption of advanced technologies: through lower prices, greater access to quality produce and through increased access to information.

Technological developments will reshape the relationship between farmers and consumers. Digital technologies and devices will allow for new forms of information sharing and new relationships between consumers, the community, and farmers, as well as various parties along the value chain. QR codes allow consumers to scan product codes for additional information regarding the provenance of products and share this on social media, which can raise the profile of both positive and negative information about the product. Advanced technology should help Australian agriculture become more consumer-centric by becoming more agile and responsive to consumer preferences.

Acceptance cannot, however, be taken for granted. Although agricultural development is often treated as a technical challenge, the most prominent barriers to the adoption of technologies relate to values, trust, equity, and governance along the supply chain.

Broader community values are central to all considerations of technology adoption. When products are perceived as 'unnatural', where industry is seen to be putting its own interests ahead of those of consumers or the community, or where there is a lack of trust in regulators, there is strong potential for conflict or resistance. Public responses to novel technologies are not straightforward; instead, they are framed by understandings of risk and benefit, purpose and responsibility, trust and accountability.

Price premiums may be available to primary producers capable of supplying distinct markets with products consumers perceive to be safe, sustainable, humane, local or traditional (Lockie, 2019). However, consumer preferences are often mediated by other supply chain actors including retailers.

Retailers already impose their own standards where they do not think industry or government standards address risks associated with safety and responsibility, or where they perceive a market niche advantage such as in ethical labelling (Lockie, 2019). Retailer standards, particularly international retailer standards, have been criticised for their focus on production practices, rather than food safety or environmental outcomes, and lack of relevance to specific production environments. The basis of these standards is largely invisible to consumers.

Further, while the Sanitary and Phytosanitary Agreement of the World Trade Organisation prevents governments from regulating products without sound scientific evidence, private standards arrangements are not so constrained. For example, GlobalGAP can require producers to refrain from using particular technologies if they wish to sell to large retailers that have signed up to this private accreditation system (Botterill & Daugbjerg, 2011).

Increasingly, the ability to demonstrate an adequate level of social and environmental responsibility is a minimal condition of market access rather than a means of securing price premiums (Lockie, 2019). Standards that increase economic value are those that are visible to consumers, align with their values and target markets for high quality differentiated products.

Private certification systems such as various organic labels can provide increased product value but include some standards in conflict with technological development. These private standards organisations act as mediators of the consumer interest and can have considerable influence over producer behaviours and production choices, including choices of technologies (Levidow & Bijman, 2002).

3.1.3 Empowering regional communities

The uptake and adoption of technology can come with both risks and benefits, ensuring potential risks (such as changes in job opportunities) are well managed in local communities is likely to be crucial to their subsistence. Regional economies may need assistance to provide a new range of services and inputs, including technical services, as the adoption of emerging technologies increases on-farm and across the supply chain. This can provide new opportunities for local workforces. Investment into place-based approaches to education, technical services, value-adding and processing hubs can help support adoption of technologies (see Box 10). The advent and coordination of service hubs will enable and empower regional communities to develop transformational options for farmers.

There is a role for all levels of government in facilitating the development of innovation ecosystems servicing agriculture, environmental management, and other regional industries. These will be characterised by virtuous cycles of education, locally relevant research and development, partnerships with Indigenous communities, industry application and technical services businesses.

Box 10: Diversifying regional areas

The Agriscience research and business park (AgriPark) based at Charles Sturt University, Wagga Wagga, has established an innovation hub with dedicated infrastructure and services to support the development agricultural research, development and extension. AgriPark is in a region that generates 18 percent of New South Wales farm-gate production and hopes to attract substantial investment that could be transformational to the region.

AgriPark aims to help create new businesses, new products and new ways of thinking to meet emerging national and global challenges.

By building appropriate infrastructure and creating a collaborative environment, AgriPark aims to:

- create an environment where an innovation ecosystem can flourish
- foster regional growth at all levels of government
- devise solutions to industry challenges
- improve productivity across the entire value chain.

Surrounded by rich agricultural land, the site provides real opportunity for growth in a regional setting.

Image credit: Charles Sturt University

3.1.3.1 Workforce and training

Impacts on the nature of work

The agriculture sector involves a complex and wide-ranging supply chain, with many in the workforce occupying roles that are unique and specific to certain industries. Other factors such as the seasonal nature of employment and the importance of working visa programs indicate the transitions the workforce experiences over time.

The widespread adoption of advanced agricultural technologies is likely to create a transformational change within the sector and affect the nature of farming and associated communities. For example, by performing the more dangerous tasks on farms and in forestry operations, digital technologies and devices (robotics) could improve workplace conditions, health and safety.

Concerns related to the impacts of advanced technologies on the agricultural workforce are likely to be overstated and understanding of the relationship between work, jobs and automation is still developing. Agricultural robots are likely only to be semi-autonomous and still require human oversight even when operating in an autonomous mode. Additionally, technology is unlikely to replace local knowledge, which includes understanding, insight, intuition, experience and contextualised information (Weinberger, 2010).

Future technological change and the intensification of agriculture may increase the requirement for a workforce with specialist skills (Dufty, Martin, & Zhao, 2019). This could lead to employment opportunities shifting away from low-skilled jobs (Srnicek & Williams, 2015). Advanced technologies could provide opportunities for agricultural workers to focus more time on tasks that require complex decision-making, such as data management, analysis and interpretation or the maintenance and repair of advanced robotics and their sensor arrays.

Technologies that permit remote oversight and sensing, as well as autonomous or semiautonomous farming, have led to speculation about the prospects for 'farmerless' farms (Lardinois, 2018). Although, even if it proves to be technically feasible across industries, it is unlikely to be socially and politically acceptable given the cultural value that Australians place on primary producers and their communities, and on the products grown by people in more traditional ways.

Upskilling the workforce

While the benefits of technologies may not be evenly distributed across all industries, many of the new and emerging technologies have the potential to provide rural and regional communities with economic opportunities and diversified career paths. The regional and rural workforce will require additional skills to work with the new technologies. Astute organisation and strategic direction in upskilling the agricultural sector will be essential if it is to realise the economic and environmental benefits of the technologies now becoming available.

Programs and initiatives such as the 'Skills package: Delivering skills for today and tomorrow' and the 'National agricultural workforce strategy' are aimed at addressing the changes in the modern workforce by providing opportunities for adult learning and development of other skills (Australian Government, 2019d).

Digital technology is likely to underpin many new and emerging technologies and the way that farmers manage their businesses will change as they adopt different approaches to on-farm data collection and analysis and production management. Therefore, digital literacy skills will be important to enable the adoption of some technologies. Identifying digital capabilities within the agricultural industry could help fill gaps and meet requirements to upskill the workforce. A recent framework developed by a group of rural research and development corporations identifies six digital capabilities and five enabling capabilities that will be required for the workforce to advance and succeed in a digital environment (KPMG and Skills Impact, 2019b). These are presented in Figure 8.

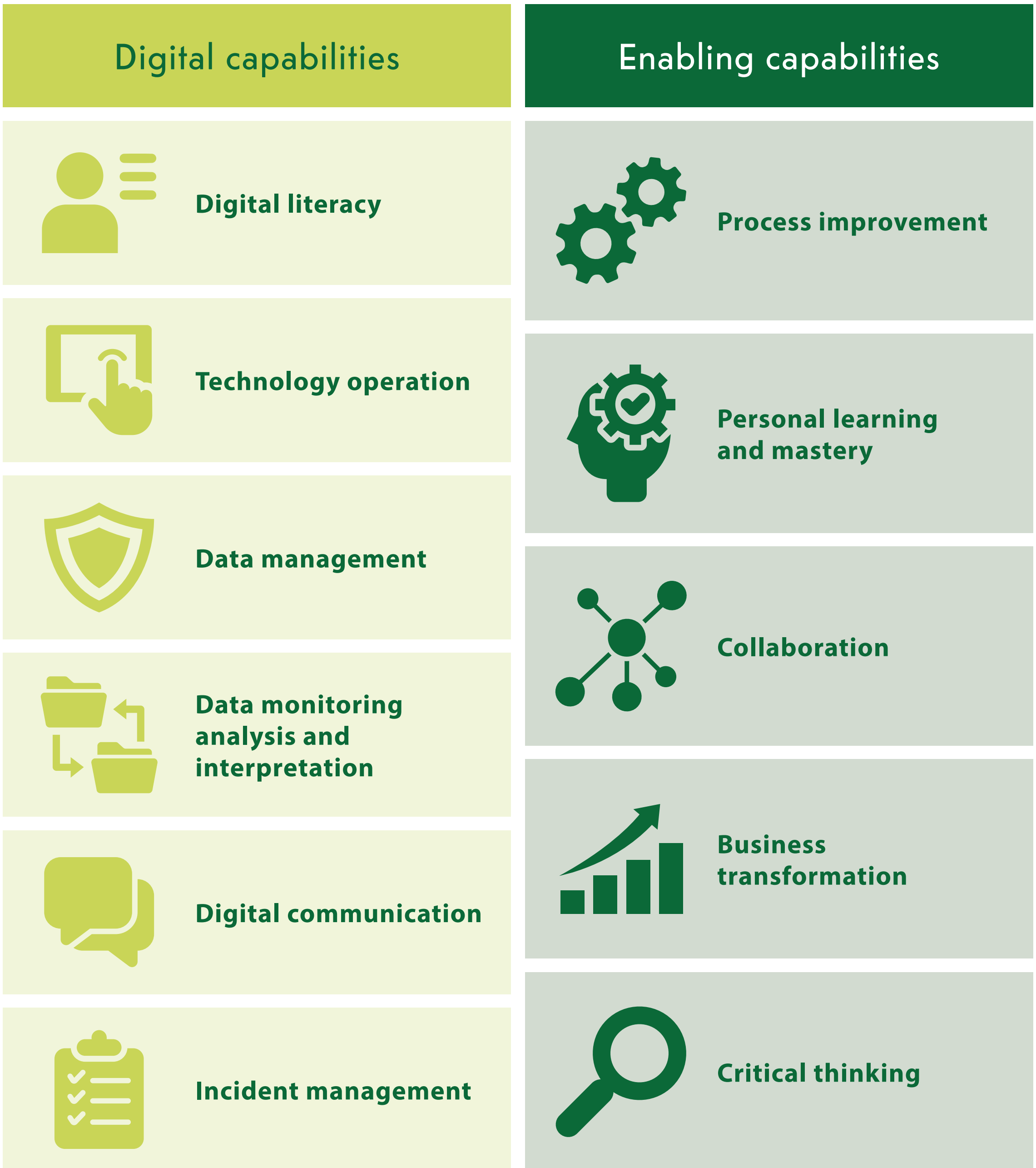

Figure 8: Digital capability framework.

Adapted from KPMG and Skills Impact, 2019b.

Maintaining and developing the future workforce will require strong education, skills and training programs. On-farm, people who are better educated, with increased competencies in relevant fields, tend to be more productive (National Committee for Agriculture Fisheries and Food, 2017). Further, education level influences the adoption of new technologies and practices (National Committee for Agriculture Fisheries and Food, 2017).

Massive open online courses (MOOCs) and short courses represent one method of introducing digital literacy skills. However, Vocational Education and Training (VET), TAFE and other accredited training services may be more appropriate for teaching more complex or involved technical elements. A training and curricula handbook designed for education and training providers outlines suggestions of the learning outcomes required to upskill the agricultural sector workforce (KPMG and Skills Impact, 2019a).

Increasing the level of participation in educational and training activities is beneficial to industry as it ensures the ongoing supply of human capital; and for individuals as it helps to maintain and foster increased workforce opportunities, social inclusion and general economic benefits in regional areas (Bureau of Rural Sciences, 2008; Kilpatrick, n.d.).

Informal learning of technologies by farmers

Farmers are business people with technical knowledge. They possess industry-specific knowledge of business structures, finance and strategic planning. While formal education is an important way to upskill workers, informal learning through the work of extension officers has been an integral way that farmers receive information and learn about emerging agricultural technologies. Extension services provide knowledge and skills to farmers to make their operations more productive and sustainable (Australian Government, 2007).

In Australia, the extension environment comprises farmer organisations, cooperatives or groups, local government, marketing boards, Research and development corporations (RDCs), Cooperative Research Centres (CRCs) and university departments. Agribusinesses also provide extension services to farmers, for example, through livestock agents or agronomists who conduct trials and provide advice to farmers, though often (but not always) linked to merchandise sales (Marsh & Pannell, 2000).

Since the 1970s, there has been a global shift away from the traditional top down model of technology transfer to participatory extension methodologies that encourage information flows, adult learning principles and stakeholder participation (Chamala & Keith, 1995; Hamilton & Hamilton, 2010; Knowles, 1984; Rölling, 1988).

Future farmers are likely to want more control over information, and hence engagement is a critical element of information provision and education. These trends may facilitate extension services that are 'demand-pulled' rather than 'science-pushed' (Anil, Tonts, & Siddique, 2015; Marsh & Pannell, 2000). The increased use of farmer groups has become one of the defining features of new 'bottom up' forms of agricultural extension.

3.1.3.2 Technical services

Repair networks in rural areas capable of handling both software and hardware components will be required to support new technologies. Personnel both on-farm and those within businesses that provide technical services to the agricultural sector will benefit from reskilling. Much of the technical training could be supplied by universities or equipment manufacturers. Equipment manufacturers could establish partnerships with regional university hubs to enact warranty services associated with their products. New facilities such as auto recharge, refill stations, communication networks to deal with blackspots, and specialised housing for the platforms, may be required to support the adoption of robotic technologies.

Development of localised technical services presents opportunities for diversification of rural and regional economies as new industries and support services are established near agricultural production and technology end-users.

3.1.3.3 Regional data centres and data management

Many emerging technologies will require data management (storage and analysis of data), infrastructure to support data acquisition, cloud storage and computing. For example, high throughput capacity for synthetic biology is enabled by big data acquisition, storage and management.

As computing becomes more powerful and cheaper, researchers have been able to explore more resource-intensive ML models and methods. This trend will continue.

Collecting data in real time and making it available to researchers and analysts would benefit large-scale environmental models in which many sources of data are integrated to model complex natural systems. If agencies that collect agricultural and environmental information were to create a national database for data fusion this would considerably increase system capability. The integration of data from geographically distributed facilities and coupling with other metadata will require sophisticated data handling infrastructure.

In some cases, infrastructure is needed to support technologies that require large amounts of data and high capacity communications to transfer data. Further, high performance computing centres will be necessary for undertaking AI and ML research on a large scale.

A major shortcoming of existing biological datasets is a frequent lack of phenotypic information – observable characteristics or traits of an individual resulting from the interaction of its genotype with the environment. Therefore, information derived from 'omics' such as the genome, transcriptome and metabolome cannot be readily linked to traits in plants and animals. This lack of phenotypic information is generally due to the high cost and time investment required to collect and curate such information. However, if existing biological datasets are to be used to their full advantage, a concerted effort to gather comprehensive phenotypic information is required.

The storage and management of data and data support teams located in regional areas may provide valuable opportunities to locals through the creation of jobs and increased maintenance options that are close to users. Such data centres are beginning to receive support; for example the NSW Government has recently invested A$100 million into regional data hubs through the regional digital connectivity program (New South Wales Government, 2019). Data centres could fill a similar role to that played by stock and station agents that offered rural and regional employment opportunities in the 20th century.

3.1.3.4 Connectivity

Economic modelling suggests the uptake of digital agriculture could increase the gross value of Australian agricultural production by A$20.3 billion (Leonard et al., 2017). Digital agriculture is underpinned by big data and encompasses the digital technologies and devices explored in this report (sensors and

IoT, automation management technologies and transactional technologies) as well as many others. Appropriate internet and data connectivity (herein connectivity) and capabilities are a key enabler for digital technologies and other emerging technologies.

Regional and rural telecommunications infrastructure has improved over the last decade and this will continue as new communication technologies are being developed. Farmers utilise the telecommunications infrastructure available and use a variety of connections to access the internet, including digital fixed line (DSL), mobile wireless, fixed wireless and satellite. However, reliable and fast connectivity across agricultural lands and regions is still a challenge for Australian primary producers (Lamb, 2017; Mark et al., 2016; Thomas et al., 2018).

In 2016-17, ABARES surveyed 2,200 farmers (broadacre, dairy and vegetable) to better understand the role of information and communication technologies (ICT) in Australian agriculture and potential barriers to its uses. The survey reported that while most Australian farmers (95 percent of farms surveyed) are connected to the internet, a third report that their access to the internet is impeding the uptake of new ICT tools. These impediments are reported more from farmers in remote areas who rely on mobile coverage (3G or 4G) and satellite internet connection, suggesting the nature of the internet connection plays a role. Indeed, farmers surveyed noted speed as a concern for ADSL connections when compared to fixed wireless connections. For farmers relying on mobile and satellite connections, speed and cost were more likely reported as impediments (Dufty & Jackson, 2018). Additionally, a 2019 report by Infrastructure Australia noted regional, rural and remote areas often experienced poor connectivity, speeds and data allowances (Infrastructure Australia, 2019). Unequal access to internet and broadband connectivity may exclude farmers in remote areas or of lower socio-economic status from benefiting from the advantages that can be obtained from, particularly digital, technologies (Park, 2017).

The rollout of the National Broadband Network (NBN) in Australia is aiming to ensure all premises, including businesses and residential properties, have adequate connectivity. To complement the NBN, the government is investing in improving mobile coverage and access to data through the mobile black spot program and regional connectivity program. These competitive grants programs are designed to attract co-investment from state governments and industry to improve connectivity in regional Australia.

An emerging connectivity solution could be low-earth orbit satellite constellations. Low-earth orbit satellite constellations could provide critical infrastructure to support digital agricultural services particularly for remote areas within the next decade.

To unlock the potential of emerging technologies, such as digital agriculture devices, the government, telecommunication companies and industry players should continuously explore and test new ways to increase connectivity at a price that is reasonable, given remoteness, but at required speeds and bandwidth.

3.1.4 Good design and explainability

Good design and explainability will be important in promoting adoption and securing the benefits of emerging technologies, particularly digital technologies.

The quality of the outputs of digital technologies and devices, particularly ML and AI, depends on the quality of the data on which they have been trained. Biases in the data may lead to unintended outcomes, such as if the collected data and associated algorithms are unrepresentative of the reality to which they are being applied. For example, Australian farmers could introduce new risk to their farm management if the AI systems they buy are trained on data drawn from crops or soil chemistry in the US (Keogh & Henry, 2016). Some risks associated with data collection and algorithm development could be mitigated through well thought-out design and planning (Rose et al., 2016). For example, bias within algorithms and data sets could be mitigated by alerting designers to risks and ensuring data used for automation management technologies is accurate and reflective.

As digital technologies and devices encroach on particular tasks in agriculture, even if they are intended only to serve as an advisor, human tendency to trust machines (so called 'automation bias') could result in farmers and others in the agriculture workforce ceasing to exercise the knowledge and skills to supervise effectively (Carr, 2015).

It will become crucial that advanced technologies (such as digital devices with ML capabilities) retain explainability to ensure farmers, the end users, can understand why the system acts in certain ways and what it may do in unexpected circumstances (Gunning, 2017; Swartout, Paris, & Moore, 1991). Explainability could help to establish responsibility and, when it is appropriate, to have confidence in such systems.

3.1.5 Research, development and extension

State and national governments provide investment in research, development and extension as well as regulatory environments that support or limit the adoption of certain technologies (Eastwood, Klerkx, & Nettle, 2017).

At least two of Australia's national science and research priorities are directly applicable to the development and adoption of agricultural technology in Australia. However, it is not clear that government-supported research infrastructure is structured optimally, or that the right incentives are in place to support a unified vision for Australian agriculture. Further, the incentive structures for university research are not conducive to interdisciplinary research and the success of technological advances is often contingent on social, environmental, and economic factors. These factors need to be considered in tandem, not as an afterthought or obstacle to be overcome.

Similarly, the structure of Commonwealth agencies that provide research and policy services for government could be examined to ensure they are supporting a consistent approach to addressing the challenges and maximising the opportunities that agricultural technology presents to the food and fibre industries.

Ongoing public and private investment in research, development and extension in agricultural technologies is crucial if advancements are to lead to improved farmer profitability and consumer outcomes (Eastwood et al., 2017). The agriculture innovation system has provided a good foundation to address industry specific issues. However, this has also created an approach that is siloed from each industry as well as from the wider innovation system. To address this, the government is currently undertaking a review of the rural research and development corporations, titled '*Modernising the research and development corporation system*'.

Future innovation strategies could benefit from a more cross-industry and cross-sectoral approach that draws on shared challenges and past experiences. A more cohesive and connected agricultural innovation system would foster both incremental and transformational change. This includes the involvement of existing extension agencies, consultants and social or professional networks that facilitate technology adoption through awareness raising, knowledge exchange, skills training and support services (Anil et al., 2015; Bramley & Trengove, 2013; Eastwood et al., 2017).

While there is a lack of comparable metrics to assess the performance of agricultural innovation internationally, there is an opportunity for Australia to advance the impact and efficiency of investment in the agricultural innovation system by observing other countries such as the Netherlands, Israel and New Zealand. For example, in the past five years, Israel has founded 190 AgTech start-ups that have raised US$281 million in funding (Ernst & Young, 2019).

3.2 Legal, regulatory and economic considerations

Key points:

- Digital agriculture will be underpinned by big data. It will be important to ensure there are appropriate considerations surrounding data ownership, data sharing and privacy.
- Ongoing review of regulatory frameworks for emerging technologies, such as gene editing and biotechnology, is necessary to ensure alignment with scientific advancements and community attitudes.
- Some emerging technologies could be used by government to monitor on-farm compliance or provide information for decision-making.
- Digital agriculture can significantly increase the gross value of agricultural production.
- Farmers' business case for investing in new technology will be influenced by a range of factors including upfront capital and operating costs, potential return on investment and potential barriers to uptake.
- While technological advances have significant opportunities for profitability, the affordability of technologies and the complexity of data arrangements present social, legal and regulatory considerations.

3.2.1 Introduction to regulatory considerations

Agricultural industries are inclined to adopt technology and knowledge aimed at rationalising human labour (to reduce effort and increase efficiency) and monitoring environments (cultivating plants, animals and landscapes in pursuit of productive growth). As more agricultural decision-making processes shift from humans to technologies, regulating and undertaking rigorous systemised error-checking of these technologies is necessary to ensure safe use.

Agriculture intersects with a broad range of legal processes including:

- property (relating to water property, land property, and intellectual property in farming practices, biological and chemical materials, and other technologies)
- contracts and licenses for equipment and formula use
- surveillance and privacy rights (related to monitoring both landscapes and people)

- risk of injury (to the environment or third parties from robotocised equipment)
- consumer protection
- animal welfare
- regulation and protection of the labour force.

Broadly speaking, mechanisation introduces potential machine-related harms, and monitoring technologies present potential surveillance and privacy risks. Innovations currently in development for agriculture, such as autonomous vehicles, or robotic delivery of pesticides, promise to cut across these areas of legal purview, and can present challenges for regulation. For example, rules relevant to robotic innovation are emerging as hybrids of public and private law, such as those protecting worker interests, property rights, data governance, investment, animal welfare, and business practices such as consumer protection and competition.

The legal pathways for dealing with new agricultural development are complex. Safely adopting new agricultural technologies such as robotic sheep-shearing, for example, requires thorough legal scrutiny to ensure these technologies respect rights, and do not cause harm. In the case of robotic sheep shearing, legal considerations include regulating the machinery, sensors, animal handling devices, responsive cutting machines, and complex informatics, as well as protecting farm workers.

There are many other agricultural processes that will require engagement with legal and regulatory frameworks. Key areas of emerging complexity are addressed in the following sections.

3.2.2 Sharing the benefits

The benefits and risks from agricultural technology developments are perceived by some commentators to be unevenly shared, with disproportionate benefit accruing to businesses upstream and downstream from the farm gate (Jakku et al., 2018).

Some technologies may unintentionally exclude some landholders due to the varying ability of farmers to access, use or apply technologies. Further, some landholders may trust different information sources or prefer to receive information in different ways (Sherwood & Bommel, 2012). Understanding the character or diversity of these preferences is likely to improve participation and uptake (Dolinska & d'Aquino, 2016).

Many agricultural technology companies are large multinational corporations. Consequently, there can be an unequal bargaining position between farmers and technology providers when digital farming technologies are adopted. This imbalance between those who contribute data and those who control, aggregate and share the data is evidenced already by the inability of farmers to negotiate the standard terms of large agribusiness' that dominate agricultural technology (Andrejevic, 2014; Carbonell, 2016; Jakku et al., 2018).

Open source software and open data could become important mitigation strategies to ensure the benefits of digital technologies and devices are widespread and balanced (Carbonell, 2016; Keogh & Henry, 2016). This may be particularly relevant to small holdings, which in turn can help distribute the benefits of smart farming more widely and equitably (see Fleming, Jakku, Lim-Camacho, Taylor, & Thorburn, 2018). Digital governance may need to co-evolve with digital technology development (Bronson & Knezevic, 2016).

3.2.3 Data ownership, sharing and privacy

Digital agriculture is both a driving force of the evolution of agricultural knowledge and innovation systems, and a potential cause of concern to farmers. Agribusinesses, like governments and researchers, rely on the willingness of farmers to trust the way in which they manage agricultural data collection and use. Indeed, as Jakku et al. (2018) note, 'issues of trust and transparency…have the potential to constrain the willingness of farmers to participate in smart farming technologies'.

The collection, aggregation and dissemination of agricultural data are regulated by data licences used by agricultural technology providers. The terms of a data license can vary; however, they generally are a contractual agreement in which the farmer pays a fee to be permitted to use a specific digital technology, such as farm machinery, sensors or digitally enhanced equipment.

While the incremental risks of making farm and agricultural data more accessible may appear to be small (noting the volume of agricultural data that are already in the public domain), the trust of farmers must be maintained (Australian Productivity Commission, 2017).

An agricultural industry survey undertaken as part of the *Accelerating precision agriculture to decision agriculture* (P2D) project confirmed that a key concern for farmers is the lack of transparency and clarity on data ownership, portability, privacy, security, trust and liability (Zhang, Baker, Jakku, & Llewellyn, 2017). These issues are central to the lack of trust that farmers experience when their farm data are collected, aggregated and shared.

With the push for open data in agriculture, there is a need for community acceptance and trust from farmers in the handling of data by agribusinesses, researchers and governments.

For farmers to 'have a sound basis for believing in the integrity and accountability of entities (public and private) handling data, they need to feel that they have some control over how their own data are used and by whom, and an inalienable ability to choose to experience some of the benefits of these uses themselves' (Australian Productivity Commission, 2017).

There is a need to balance privacy, surveillance, and ownership of data and the role for intellectual property covering farming methods. If digital agriculture and agricultural data are to transform agri-food networks, greater trust around agricultural data access and use needs to be fostered (Barnard-Wills, 2017; Box, Sanderson, & Wilson, 2017).

Engagement of farmers and other stakeholders will have the added benefit of promoting better understanding of the potential community-wide benefits of agricultural data use.

Australian privacy law distinguishes between personal and non-personal information. Personal information is data or information that can be used to identify a person such as a name, address, location data or telephone number. Non-personal data include agronomic data, machine data and weather data. The distinction between personal and non-personal information is important, as under Australia's *Privacy Act 1988*, a set of Australian privacy principles exists that applies only to 'personal information'. By contrast, 'non-personal information' is generally governed by the law of contract.

Much of the machine-collected data on farm are likely to be considered non-personal data. However, some of the data, such as GPS locations, could be considered to be or linked to personal data. Potential overlap between privacy law and other regulatory regimes may generate excessive bureaucracy that could negate benefits. The distinction between which farm data are personal and which are not requires further study and clarification.

3.2.3.1 Errors, misuse or misinterpretation of data

Data and information from AI systems can be used in a misleading or negligent manner. Data and analysis failings may lead to unreliable decisions and cause economic loss. Additionally, there have been a number of examples of the misuse of data, raising concerns that technology providers may share data with third parties.

Consequently, this could result in deception, which has the potential for liability, particularly under the Trade Practices Act or state consumer protection laws.

In the case of robotic systems, data problems could lead to the application of chemicals or the deployment of mechanical devices in the wrong place or incorrectly. Compensation for harms suffered as a result of data failures could arise under tort law, occupational health and safety law, and contract law as well as other laws.

3.2.3.2 Voluntary agricultural data codes of practice

Agricultural data codes of practice are emerging internationally to improve clarity around the terms of data licences that regulate the ownership, sharing, privacy and security of collected data.

The emergence of agricultural data codes of practice such as the American Farm Bureau's *Privacy and security principles for farm data* (American Farm Bureau Federation, 2015), New Zealand's *Farm Data Code of Practice* (Farm Data Accreditation Limited, 2016) and the European Copa-Cogeca (Copa-Cogeca, 2018) have attempted to address some of the concerns identified in the previous sections.

The development of a code of practice in Australia would be useful and could consider how best advisors and agribusinesses can ethically, fairly and transparently treat primary producers' data.

3.2.3.3 Proposed data regulation

A recent report from the Australian Productivity Commission (2017) on data availability and use examined ways to improve access to public and private sector data. The report proposed two key recommendations:

- a *Data Sharing and Release Act*, with a national data custodian to govern risks and ethical considerations in data use
- a comprehensive right for consumers to use their own data and to view, request edits or corrections and be advised of the trade of their data to third parties.

The proposals are aimed at increasing data sharing and strengthening the ability of government agents to access and use databases, while increasing consumer data rights.

However, these reform proposals do not address many of the complex big data issues in farming, particularly the ownership of the data generated by farmers' machines. Ownership rights do not arise until an 'own-able' form of property is created, such as an image or a database with limited protection of copyright, or a contract.

Further, a key challenge is that creating legislation for farmers to own their data may breach a number of international trade and legal agreements relating to intellectual property, international competition and intellectual assets (World Trade Organisation, 1994).

An alternative to legislated protection of farmer interests in data may be present in sections of Australian competition law that cover misuse of market power or other breaches of Trade Practices law. The use of a binding industry code or standards could be a substitute for legislated ownership rights.

Many suppliers of farm equipment or information services have contract terms, or standards, that respect farmer desires for an interest in data. Thus, a binding industry code under the federal *Competition and Consumer Act 2010* may be another viable option.

To enable the adoption and uptake of digital technologies on farms, it is important to address the lack of trust that digital technologies appear to generate. Relevant literature suggests that the development of an agricultural data governance framework could facilitate transparency and equity in the way that agricultural data, collected from sensors, IoT and computing technologies on-farm, are managed and shared (Wiseman, Sanderson, & Robb, 2018; Wiseman, Sanderson, Zhang, & Jakku, 2019). Data governance, adapted to the agricultural sector and taking into account the breadth of digital technologies on farms, will be important to supporting the use of digital technology and data in the future. Importantly, governance is not synonymous with government regulation (e.g. legislation) but includes industry and voluntary initiatives as well as co-operatives and other collaborative initiatives.

Collaboration between Australian agricultural industries and government could be beneficial to determining the overall process and aim of collecting, aggregating and interpreting large amounts of agricultural data. Best practice in data management could be an important first step. Indeed, 'buy in' is vital to the success of data management principles and policies and is one of the main challenges for voluntary schemes such as codes of conduct and data certification and accreditation.

Should an agricultural data governance framework be implemented, dynamic data standards and licensing arrangements should be established that align with the specific contexts and needs of primary producers. Key areas of concern include obtaining prior and informed consent when collecting and using data; being transparent about the reasons for collecting data; making sure data are secure; allowing producers to access their own data; not sharing data with third parties without prior informed consent; and notification of data breaches.

Current and proposed legislative amendments concerning data and data sharing should engage and consider the needs of the Australian agriculture sector and the broader social good that it may produce.

An essential part of the adoption of a data governance process is the development of a broad education and capacity building program. Such programs for primary producers, agri-businesses, rural industries and their industry stakeholders would increase knowledge and understanding of best practice in agricultural data management and data licensing and explain the potential risks from data misuse. Cross-industry engagement could occur at all levels of the agricultural supply chain to assist in the development of data skills, capabilities and digital and legal literacy.

3.2.4 Commercialisation and intellectual property

Innovations that form part of remote or autonomous devices and machines may be protected under intellectual property (IP) law, mainly as patents or registered designs, under copyright, or as trade secrets using contracts and confidentiality rules.

IP ownership is often interwoven with contractual arrangements, notably user licenses or technology transfer agreements.

IP issues and commercialisation can also be affected by evolving international negotiations on protection and trade in intellectual property and by the legal approaches used in different countries (World Trade Organisation, 1994).

3.2.4.1 Plant breeders' rights

Plant breeders' rights are existing exclusive commercial rights for a registered variety of plant. Hence one of the main forms of intellectual property involving biotechnology will be patents for inventions under the *Patents Act 1990* (Cth) and plant breeders' rights under the *Plant Breeders' Rights Act 1994* (Cth) (Australian Government, 2019e).

Both patents and plant breeders' rights are property and can be licensed and assigned (ss 13 and 14 and 20(1) respectively). For several grain crops there is alternative IP protection in Australia – the end point royalty system. This unique system shifts the payment of royalties from seed purchase to payment on tonnage produced. This strategy shares the risk of return between the breeder and the grower.

3.2.4.2 Nanomaterials

In 2016, IP Australia reported on the patenting landscape for agricultural nanomaterials. The report concluded that although there was a wide range of nanomaterial-based inventions with agricultural uses, Australians were not inventing in this area (Intellectual Property Australia, 2016). This finding might suggest that more could be done to encourage IP protection (specifically patents) for nanotechnology-based products.

3.2.5 Ownership and leasing rights for farm equipment

Traditionally, acquisition of farming equipment has been through sale and purchase, involving few conditions. However, new equipment with digital capabilities can have complexities related to data and the data licenses that tie the equipment purchase with servicing by the supplier.

This situation could certainly arise in the robotic equipment industry. The use of trade practices law could help to mitigate potential problems between purchasers and the robotic equipment industry. Some states in the US have passed legislation to ensure purchasers of electronics, including farm equipment, are allowed access to parts, tools and service information they require to make repairs without returning to the manufacturer.

3.2.6 Changes to regulatory frameworks and risk assessments

New products or novel technologies generally undergo some form of risk assessment and registration before they are commercialised. Because machines operate differently, chemical registrations and use instructions may have to be adjusted for each delivery system – until technologies become standardised. Labelling and other safeguards may therefore also need to be adapted. If assessment indicates changes to the risk, then restrictions may need to be imposed, which may include training and certification requirements for workers (Kookana et al., 2014). Remote and autonomous systems could trigger changes to the registration of chemicals, biologicals and pesticides; alter user licenses and training; and the registration parameters for vehicles and aircraft.

Legal issues may become relevant to contemporary concepts of autonomous and remote farming equipment; for example, drone regulation, autonomous farm equipment or trucks on public roads.

Public perceptions of GM food products can present barriers to adoption as many primary producers are constrained by the demands of international and domestic markets (Anderson & Jackson, 2005). The limitation of GM production to cotton, canola and safflower, as well as continued moratoria in some states (such as South Australia and Tasmania) have been key barriers of adoption to date.

The Office of the Gene Technology Regulator (OGTR) is Australia's regulating body for genetic modification and possesses compliance and enforcement capabilities. The OGTR performs regular reviews on its legal framework to ensure the regulatory system and risk assessment is aligned with new scientific and technological discovery and their potential impacts and risks.

A technical review of the Gene Technology Regulations 2001 released in April 2019 has produced several amendments to keep up with rapid changes and discoveries in biotechnology. One important change from this review excludes organisms generated by site directed nucleases (SDN-1) genome editing technologies including some CRISPR techniques.

In addition to the OGTR, other bodies such as Food Standards Australia New Zealand, Therapeutic Goods Administration and Australian Pesticides and Veterinary Medicines Authority have responsibility for specific applications of biotechnology and genetic modification. The key focus of all of these bodies are the impacts of GM on human health, safety and the environment. However, they do not consider economic or social impacts of GM technologies (Australian Academy of Science, 2019). Recently, Food Standards Australia New Zealand performed a review on food derived using new breeding techniques. The review involved extensive consultation with stakeholders and the community and concluded that many of the definitions were no longer fit for purpose and lacked clarity. This conclusion has led the organisation to amend current definitions and to look at reviewing current regulations (Food Standards Australia New Zealand, 2019).

3.2.7 Autonomous monitoring and reporting for government

Automation management technologies when combined with other technologies such as sensors could be used by government to monitor on-farm compliance or provide information for decision-making.

Large amounts of data from different sources increasingly inform government decisions about policy, regulation and monitoring and enforcement (Azzone, 2018). For example, data collected from satellites and drones can monitor and gather evidence for the prosecution of illegal land-clearing (Queensland Department of Environment and Science, 2018).

3.2.8 Economic opportunities

While most of the technologies being adopted in agriculture are not unique to the sector, the rapid growth of the AgTech sector globally is emerging as a driver for development and adoption of emerging technologies. This growth is also partly driven by the convergence between the agriculture, technology and finance sectors and global trends such as demand for food, increasing productivity and changes in consumer preferences (De Clercq, Vats, & Biel, 2018; Finistere Ventures, 2018).

The Australian agriculture sector has an opportunity to capitalise on the growing global demand for food and fibre. For example, the adoption of digital agriculture alone has the potential to lead to significant increases in the gross value of agriculture production in Australia (25 percent increase in the gross value of production) (Perrett et al., 2017).

Emerging technologies may also result in significant structural shifts and industry disruption (De Clercq et al., 2018) including:

- new production techniques – especially of novel food such as plant-based protein
- proximity of production to consumers – use of new technologies to bring food production to consumers, thus increasing efficiencies in the food chain
- incorporation of cross-industry technologies and applications – precision agriculture techniques may significantly change the underlying economics of production costs in the global supply chain for food and the competitive positions of primary producers globally.

3.2.8.1 Business case for farmers

The business case for investment in technology will be influenced by a range of factors including the upfront capital and ongoing operating costs, potential ROI (return on investment) and other barriers to uptake, such as level of complexity.

While there is only limited information on financial benefits from the application of emerging technologies, some recent insight into the current use of digital technologies and the economic opportunities related to adoption of technologies in Australia have been published (Perrett et al., 2017; Vogt, 2017). For example, upfront capital cost is one of the determining factors in the uptake of digital technologies in the agriculture sector. Larger operations benefit from up-front capital investment in hardware and software as the cost per hectare is lower (Vogt, 2017).

Future business case

The 'immaturity' of some emerging technologies suggests that currently there is a weak value proposition associated with adoption (Nolet, 2018). However, emerging technologies are constantly evolving and developing (outlined in Chapter 2) and so will the business case for adopting them.

The development and application of digital technologies across the economy will continue to drive improvements and reduce costs. As outlined, an appropriately skilled workforce and technical services will be critical to support these developments, especially in regional locations.

Market trends and the future competitive environment for the Australian agriculture sector are likely to drive a need for innovation and adoption of technology to take advantage of new opportunities and maintain current market access and market share (including traceability across the supply chain).

3.3 Roles and responsibilities of governments and industry

Key points:

- Government has an important role in establishing an appropriate regulatory framework, supporting an environment for R&D to thrive, ensuring connectivity and to support training and workforce development in regional and remote areas.
- Industry will have a critical role in being a bridge between technology developers and primary producers to provide meaningful feedback about the useability of particular technologies and the types of support that primary producers need.

The adoption of emerging agricultural technologies should enhance the profitability of Australian farm businesses while delivering better environmental outcomes and responding to consumer demand for high quality and ethical food and fibre products which align with their values. The trends identified in this report indicate a bright future for Australian agriculture but will require action by all stakeholders to address challenges and mitigate risks.

3.3.1 The role of governments

Commonwealth, state, territory and local governments all have a role to play in establishing an environment that enables the uptake of technologies to benefit the whole community , and in managing any potential adverse impacts of those technologies.

The primary role for governments is to establish a regulatory framework that does not impose excessive costs on the agricultural technology industry or farmers but ensures that the risks arising from technologies are managed, and that the adoption of technology is efficient and likely to be beneficial.

The Commonwealth has a responsibility to protect public health and safety and biosecurity. This is done through agencies such as the Office of the Gene Technology Regulator, Food Standards Australia New Zealand, Plant Health Australia, Animal Health Australia, and the Australian Pesticides and Veterinary Medicines Authority. The scope and focus of these agencies will need to be kept under review to avoid gaps and duplication as new technologies, and new applications of existing technologies, emerge. The role includes ensuring that Australia meets its international obligations including environmental protection and to the trading rules of the World Trade Organization.

Governments have a role in addressing market failures that impede the uptake of technology and competition issues that can arise from industry concentration and any imbalance in market power between buyers and sellers of technology. This includes ensuring that competition law and intellectual property frameworks, including plant breeders' rights, are effective in relation to the uptake of new and emerging agricultural technologies.

Governments also have a role in providing essential infrastructure unlikely to be developed by the private sector. An example identified in this report is internet connectivity in rural and remote areas. The potential of many of the technologies discussed are unlikely to be met without improved internet services in rural and remote areas.

Continued support certification and quality assurance services are needed, with attention to issues arising from emerging technologies. While some of these responsibilities are shared with the private sector, others are required by international agreements, such as in the area of biosecurity and quarantine.

Support for agricultural research, education and training will be critical to realising the potential of many agricultural technologies. Providing technology skills for farmers and the rural workforce is important as is helping the broader rural workforce to work in a support and service role. Beyond seeing agricultural technologies from an end-user perspective, there are opportunities for Australia to develop an agricultural technology industry of its own which would develop technological solutions both for the unique challenges facing Australian agriculture and as a potentially significant export industry. This will require investment in tertiary education in the relevant technological skills as well as investment in blue sky research.

Continued support by governments for research platforms such as the National Collaborative Research Infrastructure Strategy, as well as the encouragement of commercialisation of research is crucial for the uptake and adoption of technologies, particularly biotechnology and nanotechnology, in the agriculture sector.

3.3.2 The role of industry

Ultimately, the successful adoption of agricultural technology rests with the business choices made by individual farm managers. Their judgments about the likely financial impact of adopting particular technological solutions will vary by industry, size of the operation, and the life stage of the farm operator. Early adopters can act as champions of particular technologies, working through grower groups to develop peer-to-peer extension services to share experiences.

Industry groups can communicate with developers of agricultural technologies to provide information about the success or otherwise of particular technologies and the support that primary producers need to maximise the benefits.

3.3.3 Shared responsibilities

The public and private sectors both have a role in research and development in agricultural technology. Governments can create the enabling environment for research through tax incentives for private investment as well as investing through publicly funded institutions such as universities and CSIRO. Several of the Commonwealth government's national science and research priorities are directly applicable to agricultural technology.

Continued engagement with consumers and the community will be essential for considering any uses of emerging technology in agriculture and its potential impacts on farmers' livelihoods, rural communities, consumer choices, animal and human health, and the environment, among other considerations.

CONCLUSION

This report has identified a number of challenges that demand both incremental and transformational change over the coming decades. Variable environmental conditions, such as drought and biosecurity concerns highlight the need to improve the resilience and adaptive capacity of agriculture (Barbuto et al., 2019). The ability to transform and better adapt through the development of new industries, new business models, and step changes in the productivity of existing industries will be vital.

Emerging technologies provide opportunities to address many future challenges. Biotechnology offers a host of tools to improve the fitness and resilience of crops and livestock for increased productivity and profitability. Advances in genomics can enhance the detection of disease and bolster responses to biosecurity threats. The use of digital technologies to collect data, both on-farm and along the supply chain, can inform farming practices and decision making. Data fusion and machine learning can use and analyse disparate data to provide even richer information. Data sets are a powerful asset in agriculture that will require appropriate leadership to build trust in its use and ensure their value is realised.

Researchers and developers of technological innovations will continue to contribute to meeting the needs of users; to the productivity, efficiency and sustainability of primary industries; and to the health, safety and wellbeing of consumers. Technology can provide opportunities to grow and develop Indigenous agricultural businesses. Partnerships are needed with Indigenous landholders and communities to understand aspirations and needs.

Australian primary producers are enthusiastic technology adopters and have been successful in achieving consistent improvement in productivity and natural resource management. Transformational change in the face of new challenges, however, will not be easy to achieve and emerging technologies alone will be insufficient to generate such change. Supporting transformational change in agriculture requires the empowering of people within Australia's regions to use of a mix of technologies coupled with investment by the public and private sectors in an enabling environment.

There is a role for all stakeholders, including the community, in supporting incremental and transformational change in Australian agriculture. New technology, thoughtfully implemented, will be critical to helping the sector meet the many challenges of the coming decade.

APPENDIX 1
TECHNOLOGY SELECTION METHODOLOGY

ACOLA conducted extensive desktop research and considered both international and national research to outline the scope of the project. This desktop research included reviews of both academic and grey literature to produce a scoping document that shortlisted emerging technologies that were identified as most likely to have an impact on agriculture in the next decade.

The EWG reviewed and synthesised the initial list of technologies to determine which technologies would be included in the project. The discussions were guided by the following questions:

1. Which technologies are poised to present opportunities and have transformative impact on Australian agriculture and society by 2020-2030?
2. Does the technology have applications across different agricultural sectors or zones?
3. Would adoption and uptake of the technology address an issue, either currently or predicted to impact Australia? What social, ethical and legal considerations will need to be considered for technology uptake?
4. What adoption opportunities exist for different sized agriculture ventures? Is the technology accessible?

The technologies were then grouped into four initial clusters to provide a broader thematic understanding and approach to the emerging areas of technology. The technology groups were:

1. Sensors and Data
2. Automation Technologies
3. Biotechnology
4. Transactional Technology

Subsequent discussions with the EWG highlighted the need for further desktop research on emerging technologies and technology trends that may have an impact on the agriculture sector to refine the technology shortlist.

Based on this research, the shortlist of agricultural technologies was further refined and the EWG reviewed the technologies to identify gaps and opportunities.

The EWG ensured that the technologies assessed were truly technologies as opposed to high level capabilities or applications of a technology. For example, vertical farming, the practice of growing crops in vertically stacked layers, particularly in controlled-environments, uses several different technologies, such as robotics and sensors, to achieve an innovative form of cultivation.

Based on desktop research, the technologies were initially assessed using an impact graph according to the technology's potential impact to address broader trends and pressures (identified in the project Terms of Reference) and the likely impact on Australian agriculture sector over the next decade. The EWG members then identified approximately nine technologies on the graph according to their understanding of the technology's potential and likely impact. Figure 9 outlines a schematic of the impact graph used in this process.

Following this review process, the technologies that were identified as high impact and high potential to address the broader trends and pressures were selected for further examination. Subsequent work focused on further defining these technologies, undertaking a gap analysis, and screening the technologies based on the project Terms of Reference.

The EWG responses were collated and according to the desktop research and expertise from the EWG members, the top nine technologies were identified as:

- Sensors, communication and computing
  - Sensors
  - Internet of things
- Automation management technologies
  - Robotics
  - Machine learning and Artificial Intelligence
  - Large-scale optimisation and data fusion
- Biotechnology
  - Omic technologies
  - Synthetic biology
- Nanotechnology
- Transactional Technology
  - Distributed ledger technology

Personalisation technology was an emerging area identified by the Expert Working Group which is explored in the context of Machine Learning and monitoring and adapting to changes in consumer preferences (section 2.2.2.2).

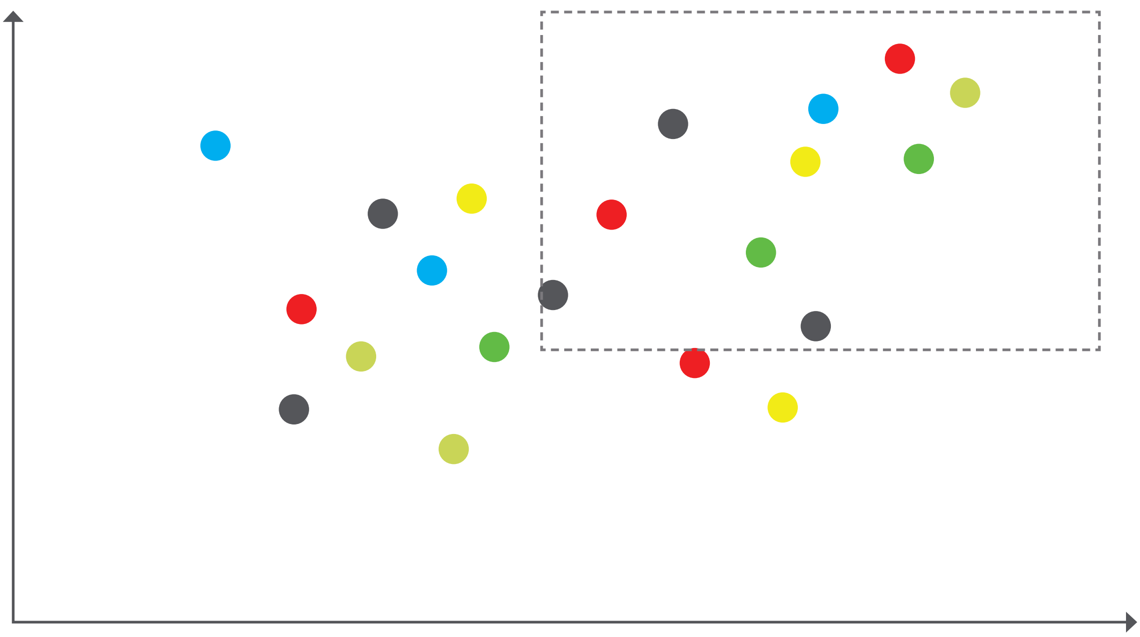

Figure 9: Schematic of the impact graph used in the ACOLA process.

Note: coloured dots represent different technologies.

APPENDIX 2
TERMS OF REFERENCE

The Australian Government Department of Agriculture, Water and the Environment supplied the following terms of reference for this report.

The future of agricultural technology

Agricultural technology presents both challenges and opportunities for agricultural industries which have been highlighted in a number of recent reports:

- ABARES (2013) – Using enabling technologies to meet demands for food security and sustainability
- Australian Council of Learned Academies (2015) – *Australia's Agricultural Future*
- AgriFutures Australia, CSIRO (2015) – Rural Industry Futures: Megatrends impacting Australian agriculture over the coming twenty years
- House of Representatives Standing Committee on Agriculture and Industry (2016) – Smart Farming: Inquiry into Agricultural Innovation
- KPMG (2016) – Powering Growth: Realising the Potential of AgTech for Australia
- Australian Farm Institute (2016) – The implications of digital agriculture and Big Data for Australian agriculture
- Productivity Commission (2017) – Regulation of Australia Agriculture
- Cotton Research and Development Corporation (2017) – Accelerating precision agriculture to decision agriculture

Aim

The aim of this horizon scan is to examine and understand the impacts, opportunities and challenges associated with around ten highly prospective technologies likely to impact agriculture over the next ten years and consider how Australian agriculture is positioned to meet them. This will include consideration of the role these technologies can play in helping Australian agriculture address the broader trends and pressures facing it, including:

- climate variability and resilience
- changing consumer preferences
- workplace, health and safety
- biosecurity
- industry disruption
- costs of production.

Each technology will be analysed within the following framework:

- What transformative role could the technology play in the agricultural sector?
- What are the social, cultural, economic, legal and regulatory implications of the technology?

- What is the role of 'Big Data' in the technology? Where relevant, examine issues of data integrity and standards and security and privacy.
- What is the role for government and industry in addressing challenges and facilitating uptake of opportunities, presented by the technology?

Outcomes

The final report will include findings about technologies relevant to each of the focus areas mentioned above. The report will also provide an overview of relevant broader government policies. The study's overarching key findings will be presented to inform government decisions and policy making over coming decades.

Scope

- The horizon scan should focus on the 'uptake and adoption' side of agricultural technology, as opposed to the 'investment and supply' side.
- The horizon scan should make use of previous research to inform the report.
- The horizon scan should consider the agriculture, fisheries and forestry industries, as well as their broader supply chains.
- The horizon scan should also take into account the experiences of other industries in making use of technology and data and note whether there are any learnings for the agriculture, fisheries and forestry industries. This should consideration include findings from other horizon scans.
- The project will focus particularly on 2020 to 2030, noting the industry's goal to reach A$100 billion by the end of that period (see the National Farmers' Federation *Budget roadmap charts course for $100 billion in farm production by 2030* media release).

APPENDIX 3
FARM NUMBERS AND SIZE

As noted in the Productivity Commission report 'Trends in Australian agriculture', between 1982 and 2003, there was a significant decline in the number of Australian farms. Over this period, the number of farms fell by around one quarter, from approximately 178,000 to 132,000 (see Figure 10). In 2016, there were 85,681 agricultural businesses (Australian Bureau of Statistics, 2016).

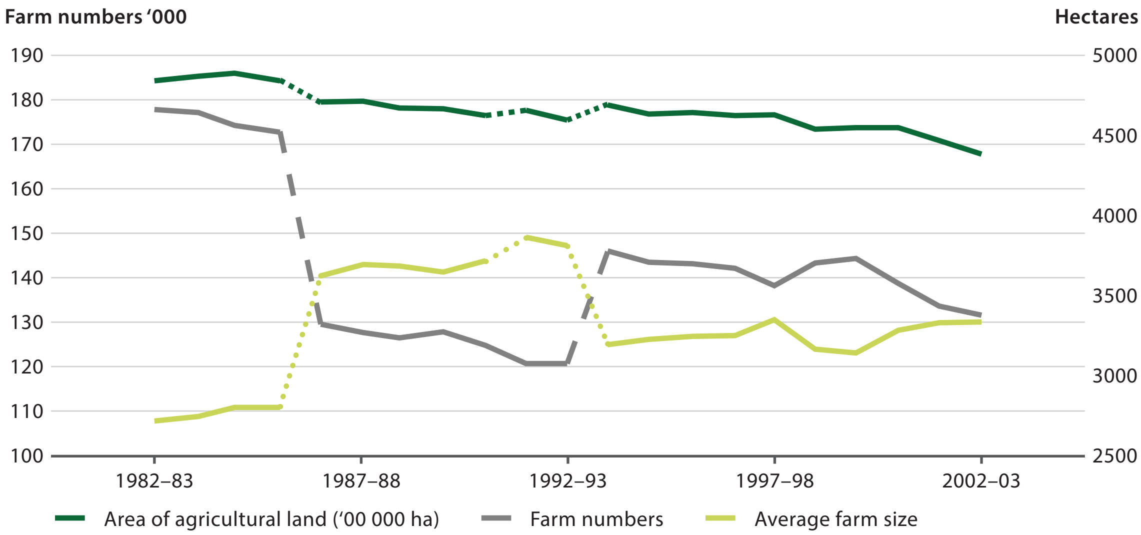

Figure 10: Farm numbers, farm size and area of agricultural land between 1982-83 and 2002-03.

a Farm numbers refer to business establishments engaged in productive agricultural activities, typically at one physical location. **b** Breaks in the series reflect periodic revisions to the minimum threshold for inclusion of establishments, based on the estimated value of agricultural operations (EVAO). Until 1985–86, farm numbers included agricultural establishments with an EVAO of $2500 or more. In 1986–87, the EVAO threshold was raised to $20 000, and from 1991–92 it was raised to $22 500. From 1993–94, the EVAO was reduced to include establishments with an EVAO of $5000 or more. Estimates of the number of establishments and average farm size are, therefore, not strictly comparable between periods with differing EVAO thresholds.

Data source: ABS (Cat no. 7121.0)

ABBREVIATIONS

ABARES	Australian Bureau of Agricultural and Resource Economics
ABS	Australia Bureau of Statistics
ACOLA	Australian Council of Learned Academies
AI	Artificial intelligence
AR	Augmented reality
ATP	Adenosine triphosphate
CRC	Cooperative Research Centre
CRISPR	Clustered regularly interspaced palindromic repeats
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DLT	Distributed ledger technology
DNA	Deoxyribonucleic acid
dsRNA	Double-stranded ribonucleic acid
EWG	Expert working group
FSANZ	Food Standards Australia New Zealand
GDP	Gross domestic product
GM	Genetically modified
GPS	Global positioning system
IoT	Internet of things
IP	Intellectual property
ML	Machine learning
NFF	National Farmers' Federation
NGO	Non-governmental organisations
R&D	Research and development
RDC	Research and development corporation
RNA	Ribonucleic acid
ABARES	Australian Bureau of Agricultural and Resource Economics
ABS	Australia Bureau of Statistics
ACOLA	Australian Council of Learned Academies
AI	Artificial intelligence
AR	Augmented reality
ATP	Adenosine triphosphate

GLOSSARY

Acellular agriculture	Microbes, such as yeast or bacteria, are used as a 'factory' to produce fats, proteins or metabolites for medical or food purposes
Agistment	The movement of livestock from a property where there is insufficient feed or water to another property where there are adequate supplies in exchange for payment. This arrangement may be more cost-effective then hand-feeding
AgTech	Agricultural technology
Agronomy	The study of crops and the soils in which they grow
Algorithm	A set of mathematical processes used by machines to perform calculations, processing and decision making
Artificial intelligence	The ability of a computer or computer-controlled robot to perform tasks commonly associated with human intelligence
Artificial photosynthesis	A chemical process that biomimics the natural process of photosynthesis to convert sunlight, water, and carbon dioxide into carbohydrates and oxygen
Automation bias	The propensity for humans to favour suggestions from automated decision-making systems and to ignore contradictory information made without automation, even if it is correct
Big data	Very large data sets that are unable to be stored, processed or used via traditional methods
Biomass	The total quantity or weight of organism in a given area or volume
Biotechnology	Any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use
Blockchain	A public ledger of information collected through a network
Buyer	This is inclusive of consumers, retailers and processors. In most cases, farmers are dealing with the intermediary buyers
Cellular agriculture	The use of cell cultures to produce proteins, fats and tissues that would otherwise come from traditional agriculture
Data fusion	The process of integrating multiple data sources with the objective of producing more consistent, accurate and useful information than that provided by any individual data source
Digital agriculture	Use of digital technology to integrate agricultural production from the farm to the consumer, offering the agricultural industry tools and information to make more informed decisions and improve productivity
Distributed ledger technology	Digital system for recording and updating a data structure simultaneously in multiple places
Explainability	Ensuring that the actions, outputs, and decision-making processes of an AI system are transparent and easily understood by humans
Gene-editing	A molecular tool for making small and precise changes to an organism's DNA
Genomics	The study of genes and their interrelationships

Hyperspectral imaging	The process by which images are taken and numerical values assigned to each pixel, using a range of wavelengths across the electromagnetic spectrum, including visible and infrared
Information and communication technology	Technologies that provide access to information through telecommunications
Internet of Things	A network of technologies that can facilitate the interconnection of all things anywhere, anytime with complete awareness, reliable transmission, accurate control, intelligent processing and other characteristics
Interoperability	The capacity of systems to connect, share and exchange data, and use exchanged information
Machine learning	The ability of computers to execute tasks through processes of 'learning' that derive inspiration from (but are not reducible to) human intelligence and decision-making. It involves the capacity of machines to process and adapt rapidly and independently to large quantities of data, without being explicitly programmed to do so
Nanomaterials	Material with one of its three dimensions in the range of 1 to 100 nanometres
Nanotechnology	Using properties of nanoscale materials, that differ from the properties of individual atoms, molecules, and bulk matter, to create improved materials, devices and systems that exploit these new properties
Nitrogen fixation	A process by which molecular nitrogen in the air is converted into ammonia or related nitrogenous compounds and taken up by leguminous plants
Open source software	Software with source code that anyone can inspect, modify and enhance
Primary industries	Industries that obtains or provides natural raw materials for conversion into commodities and products for the consumer
Provenance	The place of origin or earliest known history of something
Quick response (QR) code	A matrix barcode that contains information about the item to which it is attached
RNA-interference	Biological process in which RNA molecules inhibit gene expression or translation, by neutralising targeted mRNA molecules
Semi-autonomous	Denoting or performed by a device that is capable to some extent of operation without human control
Sensors	A device, module, or subsystem that detects events or changes in the surrounding environment and converts this information into a mechanical or electronic signal
Social license	The ongoing acceptance of a company or industry's standard business practice and operating procedures by its employees, stakeholder and the public
Synthetic biology	The design and construction of artificial biological pathways, organisms, networks, or devices, or the redesign of existing natural biological systems
Virtuous cycle	Virtuous cycle is a recurring cycle of events, the result of each one being to increase the beneficial effect of the next.

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EXPERT WORKING GROUP

Professor Stewart Lockie FASSA

(Chair, September – December 2019)

Professor Stewart Lockie is a Distinguished Professor of Sociology and Director of the Cairns Institute at James Cook University. Professor Lockie is an environmental sociologist whose research addresses environmental governance and risk in a variety of contexts including climate change, biodiversity conservation, agriculture and food security, the greening of consumption practices, and the social impacts of resource development. Professor Lockie is committed to lifting research capacity and impact among the social sciences and humanities in the South Pacific and across the broader tropical region.

Professor Lockie is the current President of the International Sociological Association's Research Committee on Environment and Society and a member of the International Council for Science's Committee for Scientific Planning and Review. He is Foundation Editor of the journal Environmental Sociology and a Fellow of the Academy of the Social Sciences in Australia. He is a member of the Great Barrier Reef Restoration and Adaptation Program's social, economic and institutional feasibility sub-project.

Dr Kate Fairley-Grenot FAICD FTSE

(Chair, December 2018 – September 2019)

Kate Grenot has a 25-year professional services background that spans business, societal and technical dimensions. Originally a biophysicist at Sydney and Harvard Universities, Kate's third degree is from Sussex University and specific to science and technology policy. Management consulting projects and directorships have been accompanied by life-long learning, including micro-credentials in applied finance from the Australian Securities Institute and data science from UC Berkeley. Kate is a former director of Wirra Wirra Vineyards, the Grape and Wine Research and Development Corporation, and AgriFutures Australia. Former roles also include Chair of Australia's Rural Research Development Council and Member of the Prime Minister's Science Engineering and Innovation Council Expert Working Group on Carbon-Energy-Water Intersections. Early-career research conducted by Kate at bench-level focused on nanobiology in agriculturally-significant plants, while some projects and Audit Committee roles have required analyses of risks associated with research outputs. For the past decade, all work has been associated with Agtech.

Professor Rachel Ankeny

Rachel A. Ankeny is Professor of History and Philosophy and Deputy Dean Research in the Faculty of Arts at the University of Adelaide, and Honorary Visiting Professor in the College of Social Science and International Studies (Philosophy) at the University of Exeter. She leads the Food Values Research Group and the Public Engagement in Science and Technology Adelaide research cluster. Her research crosses several fields including food and agricultural studies, science policy and public understanding of science, history and philosophy of the biological/biomedical sciences, and bioethics. Her scholarship focuses on excavating the underlying values associated with agricultural and food-related practices, hence redirecting focus away from purchasing preferences and onto community understandings of decisions about agriculture including research prioritisation and regulations, and is recognised as integrating diverse methods from humanities and social sciences to examine and articulate the complexities associated with food decisions in relation to ethical issues including environment and economic considerations. She has served on several agriculture related projects and committees, including the ACOLA Expert Working Group on Securing Australia's Future (Agriculture) and co-author of the resulting major report (2014–15); a working group to prepare a question-and-answer document on genetically-modified organisms (2017–18) and the Expert Working Group on gene drives (2016), both for the Australian Academy of Science; the GM Crop Advisory Committee for the Government of South Australia (2010–present); and the Gene Technology Ethics and Community Consultative Committee (formerly Ethics Committee) of the Office of the Gene Technology Regulator, Commonwealth of Australia (2005–13).

Professor Linda Botterill FASSA

Linda Botterill, FASSA is Professor in Australian Politics and Head of the Canberra School of Politics, Economics & Society at the University of Canberra. She is a political scientist working in the areas of Australian politics, and public policy theory. The main focus of her work is the role of values in politics and policy, and she has particular expertise in Australian rural policy. She has published nearly 70 scholarly articles and book chapters, four co-edited books, and 2 monographs. Key publications include *Interrogating Public Policy Theory: A Political Values Perspective* (2019, Edward Elgar – with Alan Fenna); *Wheat Marketing in Transition: The Transformation of the Australian Wheat Board* (2012, Springer); *The National Party: Prospects for the Great Survivors* (2009, Allen & Unwin – edited with Geoff Cockfield); and articles in a range of Australian and international journals covering public policy and political science.

Prior to commencing her academic career, Professor Botterill worked as a policy practitioner – including over a decade in the APS, as an adviser to two Ministers for Primary Industries and Energy in the Keating government, and as senior policy adviser in two industry associations. She was elected as a Fellow of the Academy of the Social Sciences in Australia in 2015.

Professor Barbara Howlett FAA

Barbara Howlett is an Honorary Professor in the School of BioSciences at the University of Melbourne. She has worked in research areas including influenza, bacterial memory, pollen allergy, nitrogen fixation and plant disease.

Her major interest is blackleg, a fungal disease that limits canola production worldwide. She has developed molecular genetic tools and genomic resources necessary to determine how virulence of the blackleg fungus evolves, which genes are involved in disease and how farmers can avoid devastating yield losses.

This multidisciplinary 'genome to paddock' approach has had a significant economic impact on the Australian canola industry: for instance, in 2012 in the Eyre Peninsula, SA, canola yield losses of up to A$18 million were averted.

Prof Howlett was brought up on a farm and has a keen interest in agriculture. She has been a panel member of the Grains Research and Development Corporation and she currently chairs the National Committee for Agriculture, Fisheries and Food for the Australian Academy of Science, of which she is a Fellow. Prof Howlett is also Fellow of the Australasian Plant Pathology Society, the American Academy of Microbiology and the American Mycological Society. She is a member of the National Science and Technology Council, which advises the federal government on scientific and technological issues.

Professor Alex McBratney FAA

Alex McBratney is a world-renowned soil scientist. He is Director of the Sydney Institute of Agriculture and Professor of Digital Agriculture and Soil Science. He holds BSc, PhD and DSc degrees in soil science from the University of Aberdeen in Scotland, and the DScAgr degree from the University of Sydney for research in precision agriculture. He has made major contributions to soil science and agriculture through the development of the concepts of Pedometrics, Digital Soil Mapping, Precision & Digital Agriculture, and Soil Security.

His innovative, pioneering and forward-thinking work in precision agriculture and soil science has been eagerly adopted by research groups and practitioners worldwide, as well as by hundreds of Australian farmers. Alex. is currently pursuing new integrative concepts, including Soil Security, which recognises the interacting biophysical, economic, social and policy dimensions to secure soil for global sustainability; and Digital Decommoditisation which aspires to build a new profitable, resilient and consumer-connected post-industrial agriculture.

Professor Elspeth Probyn FAHA FASSA

Elspeth Probyn FAHA FASSA is Professor of Gender & Cultural Studies at the University of Sydney. She has published several ground-breaking monographs including *Sexing the Self* (Routledge, 1993), *Outside Belongings* (Routledge, 1996), *Carnal Appetites* (Routledge, 2000), *Blush: Faces of Shame* (Minnesota, 2006), *Eating the Ocean* (Duke, 2016), and over 200 articles. Her current research focuses on fishing as extraction, fish markets as gendered spaces of labour, and anthropocentric oceanic change. She is the co-editor of a new collection, *Sustaining Seas: Oceanic Space and the Politics of Care* (Rowman & Littlefield, 2020).

Professor Tania Sorrell AM FAHMS

Professor Tania Sorrell AM FAHMS, is Professor of Clinical Infectious Diseases and Director of the Marie Bashir Institute for Infectious Diseases and Biosecurity, University of Sydney; Group Leader, the Centre for Infectious Diseases and Microbiology, Westmead Institute for Medical Research, Westmead, NSW; and Service Director, Infectious Diseases and Sexual Health, Western Sydney

Local Health District. Over several years, she has been an international leader in mycology research – on the pathogenesis of fungal (cryptococcal) infections, emerging fungal diseases, new antifungal drug development, new diagnostics and clinical trials of antifungal diagnostic and treatment strategies. More recently she has extended her research and capacity building work to One Health and emerging infectious diseases. Professor Sorrell is a past President of the Australasian Society for Infectious diseases. She has served on state and national advisory committees in Infectious Diseases and therapeutics, the Research and Human Ethics Committees of NHMRC and chaired a World Health Organisation Advisory Group of Independent Experts on WHO's Smallpox Research Program (2010, 2013). She is currently a member of the Expert Technical Advisory Group, Indo-Pacific Centre for Health Security, Australian Government Department of Foreign Affairs and Trade and of the Genomics Health Futures Mission Expert Advisory Committee (Medical Research Future Fund).

Professor Salah Sukkarieh FTSE

Salah Sukkarieh is the Professor of Robotics and Intelligent Systems at the University of Sydney, and is the CEO of Agerris, a new Agtech startup company from the ACFR developing autonomous robotic solutions to improve agricultural productivity and environmental sustainability. He was the Director Research and Innovation at the Australian Centre for Field Robotics from 2007-2018, where he led the strategic research and industry engagement program in the world's largest field robotics institute. He is an international expert in the research, development and commercialisation of field robotic systems and has led a number of robotics and intelligent systems R&D projects in logistics, commercial aviation, aerospace, education, environment monitoring, agriculture and mining.

Salah was awarded the NSW Science and Engineering Award for Excellence in Engineering and Information and Communications Technologies in 2014, the 2017 CSIRO Eureka Prize for Leadership in Innovation and Science, and the 2019 NSW Australian of the Year nominee. Salah is a Fellow of Australian Academy of Technological Sciences and Engineering (ATSE), and has over 500 academic and industry publications in robotics and intelligent systems.

Professor Ian Woodhead

Professor Ian Woodhead is Lincoln Agritech's Chief Scientist and Group Manager of the Lincoln Technology Group. With almost 40 years' experience in sensor development, his main research interests are measuring the broadband dielectric properties of composite materials including water content, physical measurements using microwave and mm waves, and high speed electronics.

Professor Woodhead has created a number of globally-marketed sensors, including devices to evaluate the performance of electric fences, the Aquaflex electronic soil moisture sensor, and the Bluelab Pulse meter for water content and conductivity in hydroponics.

Professor Woodhead was awarded the Royal Society Te Aparangi's Scott Medal in 2017; the engineering science and technology award was presented in recognition of the wide range of sensors he has developed for the agricultural and environmental sectors.

PEER REVIEW PANEL

This report has been reviewed by an independent panel of experts. Members of this review panel were not asked to endorse the Report's conclusions and findings. The Review Panel members acted in a personal, not organisational, capacity and were asked to declare any conflicts of interest. ACOLA gratefully acknowledges their contribution.

Dr Peter Dodds FAA

Dr Peter Dodds is a Chief Scientist at CSIRO Agriculture&Food where he leads a team developing genetic tools to improve the control of important rust diseases of wheat. Dr Dodds received a Bsc(hons) in 1991 and a PhD degree in 1996 from the University of Melbourne, Australia. After a postdoctoral stint at the USDA/UC Berkeley Plant Gene Expression Center in Albany, California he returned to Australia as an ARC Postdoctoral Fellow at CSIRO analysing disease resistance gene evolution and specificity in the flax rust disease system. His current research involves the identification of virulence factors from rust fungi, understanding their role in disease as well as exploiting the immune responses of the host plants for protecting wheat crops from disease though improved disease resistance breeding. He was elected as a fellow of the Australian Academy of Science in 2012.

Dr Tony Fischer AM FTSE

Tony Fischer was a wheat researcher in NSW Agriculture, the International Maize and Wheat Improvement Center (CIMMYT) in Mexico, and CSIRO, at the same time remaining involved in farming in S NSW. He directed the CIMMYT Wheat Program from 1988 to 1995, managed the Crops Program at the Australian Centre for International Research (ACIAR), then returned as an honorary Research Fellow to CSIRO Food and Agriculture in Canberra. He has served on the Boards of the International Center for Research in Dry Area Areas (ICARDA), the International Rice Research Institute (IRRI) and the Grains Research and Development Centre (GRDC). Thus he has very extensive experience in cropping both in Australia and globally. As a Research Fellow he has pursued strategies in breeding and agronomy to improve crop yields, as well as keeping a close watch on world food security and related development, environment and sustainability issues. His jointly-authored book (Fischer et al 2014) on crop yield gain and global food security (https://aciar.gov.au/publication/mn158) has over 500 citations (Google Scholar), while 140+ scientific publications across many aspects of crops have been cited 8400 times, leading to an H index of 50 (Web of Science). He has been ACT Coordinator for the Crawford Fund for the last decade.

Professor John Freebairn FASSA

John Freebairn holds the Ritchie chair in economics at the University of Melbourne. He has degrees from the University of New England and the University of California, Davis. Prior to joining Melbourne in 1996, his preceding career includes university appointments at the ANU, LaTrobe and Monash, and periods with the NSW Department of Agriculture and the Business Council of Australia. John is an applied microeconomist and economic policy analyst with current interests in taxation reform and environmental economics.

Professor Libby Robin FAHA

Libby Robin is emeritus professor at the Fenner School of Environment and Society, Australian National University, and was elected Fellow of the Australian Academy of Humanities in 2013. Her work spans the history of science, especially ecology, global systems science and climate science; environmental history in Australia and globally; and the history of environmental activism. She has also worked extensively in museums and was a founding member of the ecological humanities group in Australia in 2001. Her current work includes a book-in-progress on presenting the Anthropocene concept in museums. Her books have won prizes in history, zoology and literature. Her most recent books are Collecting the Future: Museums, Communities and Climate Change (edited with Jennifer Newell and Kirsten Wehner, Abingdon, 2017) and The Environment: A History of the Idea (co-authored with Paul Warde and Sverker Sörlin, Baltimore 2018).

EVIDENCE GATHERING

Workshops and meetings were held across Australia during this project. Many people have contributed their time and expertise to the project through written submissions, meetings with members of the Expert Working Group and participating in the workshops.

The views expressed in this report do not necessarily reflect the opinions of the people and organisations listed in the following sections.

Workshops

- **Initial scoping workshop:** held in Sydney on 29 November 2018 to discuss the scope of the horizon scan with the Expert Working Group and key stakeholders
- **Second scoping workshop:** held in Sydney on 4 March 2019 to discuss the scope of the horizon scan with the Expert Working Group and key stakeholders
- **Expert Working Group workshop:** held in Melbourne 17 June 2019 with the Expert Working Group and project sponsors to synthesise the submissions received
- **Expert Working Group workshop:** held in Sydney 30 September 2019 with the Expert Working Group to synthesise the submissions received
- **Synthesis workshop:** held in Sydney 22 October 2019 with the Expert Working Group and project sponsors to synthesise the submissions received and develop key findings

Government stakeholders consulted

We thank the following stakeholders for their time and participation in the ACOLA Future of Agricultural Technologies project:

Lisa Kerr

Dr Penny Leggett

Dr Alan Finkel

Rebecca Coward

Joann Wilkie

Michael Ryan

Martin Worthy

Nick Blong

Department of Infrastructure, Transport, Regional Development and Communications

Department of Education, Skills and Employment

Written submissions

As part of the evidence-gathering to support the development of the report, a call for input was sent to experts in the field. The development of the report has been made possible through their generous contributions. ACOLA and the Expert Working Group would like to sincerely thank the following people.

People and New and Emerging Technologies in the Australian Primary Industries
Rebecca Paxton and Dr Emily Buddle

Internet of Things
Frank Zeichner and Geof Heydon

Sensors and Internet of Things
Professor Ian Woodhead

Robotics, Machine Learning, Artificial Intelligence, Large Scale Optimisation and Data Fusion
Professor Salah Sukkarieh

Autonomous Tractors
Professor Craig Baille

Large Scale Optimisation and Data Fusion
Dr Andrew Moore

Machine Learning and Artificial Intelligence
Associate Professor Richi Nayak

Synthetic Biology
Dr Hugh Goold

Omic Technologies
Professor Mohan Singh

Microbial and microbiome technologies for the agriculture sector
Dr Jasmine Grinyer and Professor Brajesh Singh

Prospective applications of nanotechnology in agriculture
Professor Zhi Ping Xu

Economic and financial viability
David Graham, Sapere

Social and community implications of sensors, communications and computing
Simon Feilke, Dr Emma Jakku, Aysha Fleming and Bruce Taylor

Key legal and regulatory constraints of sensors, communications and computing
Professor Leanne Wiseman

Social and community considerations of automation management technologies
Professor Rob Sparrow and Dr Mark Howard

Legal and regulatory considerations of automation management technologies
Professor Paul Martin

Social and community considerations of biotechnology
Dr Christopher Mayes

Legal and regulatory considerations of biotechnology
Professor Charles Lawson

Agricultural Nanotechnologies, Public Engagement and Regulation
Associate Professor Matthew Kearnes and Declan Kuch

Legal and regulatory considerations of nanotechnology
Scott Bouvier, Mark Beaufoy, James Ellsmore and Chloe Walker of King & Wood Mallesons

Legal and regulatory considerations of nanotechnology
Eleanor Pollock, Zoe Zhang, Jacob Ward and Professor Thomas Faunce

Blockchain in Agriculture
Professor Jason Potts

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We also gratefully acknowledge the expertise and contributions from our project stakeholders. In particular, we would like to acknowledge Dr Alan Finkel, Lisa Kerr and Dr Penny Leggett from the Office of the Chief Scientist, and Rebecca Coward, Joann Wilkie, Michael Ryan, Martin Worthy, and Nick Blong from the Department of Agriculture, Water and the Environment. We also thank our peer reviewers for the time and effort they have provided in reviewing the report.

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We would like to thank Dr Kate Fairley-Grenot for her time and contributions as both an expert working group member and chair of the project from November 2018 – September 2019.

Our thanks to the EWG who put a great deal of time, effort, and insight into coordinating the report's conceptualisation and production, and also to the ACOLA team, in particular Michelle Steeper, Dr Emily Finch, Dr Lauren Palmer and Ryan Winn who made significant contributions to supporting the EWG and managing the project.


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