Horizon Scanning
Opportunities for New Technologies and Industries

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Foreword

Emerging technologies and new industries have the potential to transform Australian agriculture and will be a key contributor in growing the sector towards becoming Australia’s next $100 billion industry. AgriFutures Australia plays an important role in identifying these opportunities early and developing an ecosystem for technology development and adoption as well as supporting emerging industries to prosper and grow.

This report is the culmination of two years’ work by the Queensland University of Technology, uncovering 39 unique emerging technologies with potential for game-changing impact on Australia’s rural industries. Many of the emerging technologies showcased have been identified by industry experts as having significant commercial impact and transferability from overseas or non-agricultural domains for use on Australian farms or within the agricultural value chain. AgriFutures Australia is pleased to demonstrate, through this report, the diverse and significant opportunities for developing and integrating emerging technologies into the agriculture sector.

Capitalising on the insights developed for emerging technologies, the report also summarises 24 new agriculture industries that have the potential to develop due to the influence of emerging technologies. In the agriculture sector particularly, we know that emerging technologies have a range of possible impacts on the emergence of new industries. In some cases, the role is to enhance the viability of existing industries, such as through improving productivity and efficiency. In others, technology assumes a transformational role, developing entirely new ways of doing things and facilitating new products to address both growing and emerging markets. In either case, it will be essential to identify how technology can continue to build innovative agricultural industries and ensure the long-term prosperity of the sector.

This work underscores the opportunity to think differently and look in new places for how the sector can continue to innovate and grow. The findings are particularly relevant to new and existing producers seeking to diversify their business either through the adoption of new technology or to expand their enterprise mix with novel industries. Equally, this work presents longer-term trends for what the future of agricultural innovation looks like and gives us a window into the possibilities, stretching our perspectives beyond what we currently know to the opportunities that exist into the future.

Some of the technologies identified through the five Horizon Scans have already been adopted, such as LoRaWAN and personal analytics, while others may be more futuristic. The addition of the analysis covering new and emerging industries is a useful addition when evaluating the multitude of opportunities for the future of the sector.

This report is an addition to AgriFutures Australia’s diverse range of over 2000 research publications and it forms part of our Emerging Industries arena, which aims to support new and emerging rural industries. A series of five horizon scans have been published through this project and are available, along with most of AgriFutures Australia’s publications, for free downloading or purchasing online at: www.agrifutures.com.au.

John Harvey
Managing Director
AgriFutures Australia
Acknowledgments

The research provider Queensland University of Technology acknowledges the financial assistance of AgriFutures Australia in order to undertake this project.

The contributions of members of the Australian rural industries, who gave their time to participate in surveys as part of this research, are also acknowledged.
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Executive Summary

This report is the final report of the Horizon Scanning: Opportunities for New Technologies and Industries Project. The objectives of this project were to expand on the watchlist of emerging technologies established during the Detecting Opportunities and Challenges for Australian Rural Industries project, and to identify potential new agriculture industries that could emerge due to the influence of emerging technologies. These objectives align with AgriFutures Australia’s strategic vision to ensure the long-term prosperity of Australian rural industries through the anticipation of technologies that present potential opportunities and challenges now and in the future. Consideration of emerging technology as a catalyst to industry growth is highly relevant in today’s context, where technology driven disruption is expected to increase in the coming decades. The anticipation of relevant technologies has the potential to improve the existing capabilities of the Australian rural industries, as well as create new opportunities from which to deliver value to the sector and to the Australian economy.

Meeting the objectives of the project, Two Horizon Scans were conducted that expanded the watchlist of emerging technologies to thirty-nine in total. This number and variety of technologies demonstrates the openness to technology innovation and technology transferability within the rural industries. It also highlights significant opportunities for technology innovation within the agriculture sector, which has subsequently been built upon with the identification of twenty-four emerging industries that have the potential to develop in the agriculture sector. This report provides a summary of both the expanded watchlist of emerging technologies the emerging industries identified.

Methodology

This project involved three primary activities:

i. Two iterative Horizon Scans designed to identify emerging technologies that present potential opportunities and challenges to Australian rural industries.

ii. Two new industry scans designed to identify emerging industries in the Australian agriculture sector facilitated by emerging technologies.

iii. Iterative surveys conducted with technology domain experts to evaluate the potential commercial impact, transferability and timeline of select emerging technologies identified during Horizon Scans.

Summary of Watchlist

Thirty-nine emerging technologies were identified during the Horizon Scans conducted during the Detecting Opportunities and Challenges for Australian Rural Industries and the Horizon Scanning – Opportunities for New Technologies and Industries projects. These technologies have origins in a diverse number of domains and are summarised in Table 1.
Table 1. Summary of emerging technology categories

<table>
<thead>
<tr>
<th>Data Technologies</th>
<th>Smart Dust</th>
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<tr>
<td></td>
<td>Augmented Reality</td>
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<td>Digital Twin</td>
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<td>Labour Tracking</td>
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<td>LoRaWAN</td>
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<td>Smart Contact Lenses</td>
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<td>Extended Reality</td>
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<td>Quantum Computing</td>
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<td>5G</td>
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<td>High Altitude Wireless Delivery</td>
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<td>Edge Computing</td>
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<td>Biotechnology and Genomics Technologies</td>
<td>Plant Genome Sequencing</td>
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<td>CRISPR</td>
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<td></td>
<td>Microbiome</td>
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<td>Cellular Agriculture</td>
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<td>Acellular Agriculture</td>
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<td>Robotics and Artificial Intelligence Technologies</td>
<td>Collaborative Robots</td>
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<td>Brain-Computer Interface</td>
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<td>Human Augmentation</td>
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<td></td>
<td>Context-Aware Computing</td>
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<td>Human-Machine Interfaces</td>
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<td>Computer Vision</td>
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<td>Human-In-The-Loop Machine Learning</td>
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<td>Natural Language Interfaces</td>
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<td>Business Model Technologies</td>
<td>Blockchain</td>
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<td>Distributed Production</td>
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<td>Metal 3D Printing</td>
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<td>Drone Delivery</td>
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<td>Customer Journey Analytics</td>
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<td>Emotional Analytics</td>
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<td></td>
<td>Smart City</td>
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<td>Renewable Energy Technologies</td>
<td>Perovskite Solar Cells</td>
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<td>Sodium-Ion Batteries</td>
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<td>Solar Retransmission</td>
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<td>Moisture Harvesting</td>
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<td></td>
<td>Artificial Photosynthesis</td>
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<td>Advanced Materials Technologies</td>
<td>Programmable Materials</td>
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<td>Metamaterials</td>
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<td>Graphene</td>
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Emerging Agriculture Industries

The identification of emerging agriculture industries was assisted by the development of a framework outlining Australian agriculture’s strengths weaknesses, opportunities and threats. From this framework, fourteen contextual factors were specified which present critical challenges and opportunities for Australian agriculture:

- Increased Food Demand
- Less Diversified Farming
- Natural Resource Limitations
- Technology Innovation
- Environment and Climate Change
- Platforms and Ecosystems
- A Changing Workforce
- The Future of Work
- Shifting Power and New Markets
- Digital Readiness
- Food Safety and Food Fraud
- Liquid Expectations
- Inefficiencies and Declining Profitability
- Health and Lifestyle
Twenty-four potential emerging agriculture industries were identified during this project over the course of two Emerging Industries reports and this report. The first Emerging Industries report [1] was designed to provide a concise overview of ten industries to stimulate creative thinking and facilitate critical discourse. The second Emerging Industries report [2] was designed to provide a thorough analysis of an additional ten emerging industries. This included a detailed assessment of industry drivers, preconditions and uncertainties, opportunities and barriers, cost benefit analysis, strategic considerations, and applicable emerging technology. Building on both Emerging Industries reports, cost benefit analyses for an additional four emerging industries are outlined in this report. Each identified industry is listed in Table 2.

Table 2. Summary of emerging agriculture industries identified

<table>
<thead>
<tr>
<th>Emerging Industries 1 [1]</th>
<th>Automation-as-a-service</th>
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<tbody>
<tr>
<td></td>
<td>Automation Management and Strategy</td>
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<td></td>
<td>Digital Agriculture</td>
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<td></td>
<td>Automated and Digital Supply Chain</td>
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<td></td>
<td>Education and Training</td>
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<td>Provenance and Certification</td>
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<td></td>
<td>Cell Cultured Meat</td>
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<td></td>
<td>Personalised Health and Food</td>
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<td></td>
<td>Marketing and Stakeholder Engagement</td>
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<td></td>
<td>Microgrid P2P Energy</td>
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<td>Emerging Industries 2 [2]</td>
<td>Acellular Agriculture</td>
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<td></td>
<td>Cellular Agriculture</td>
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<td></td>
<td>Craft Hydroponics</td>
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<td>Hydroponic Hops</td>
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<td>Hydroponic Australian Edible Natives</td>
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<td></td>
<td>Insect Farming</td>
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<tr>
<td></td>
<td>Distributed Manufacturing and Repair</td>
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<td></td>
<td>Edge Computing Managed Services</td>
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<td></td>
<td>Wild Camel Harvesting</td>
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<td></td>
<td>Wild Goat Harvesting</td>
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<tr>
<td>Horizon Scanning, Final Report</td>
<td>Medicinal Marijuana</td>
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<td>Hemp Milk</td>
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<td>Hydroponic Berries</td>
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<td>Hydroponic Chinese (Asian) Vegetables</td>
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</table>

Each of the identified industries represent a direct response to key contextual factors posing significant challenges to Australia, as well as opportunities presented by emerging technology. These cases can be categorised as; emerging technologies that enhance viability of existing industries, through improving productivity and efficiency; transformational technology, using existing technologies and implementing them to facilitate new products to address both growing and emerging markets. In either case, it will be essential to identify opportunities for technology innovation in the agriculture to meet significant future challenges and ensure the long-term prosperity of the sector.
Introduction

This report is the final report of the Horizon Scanning - Opportunities for New Technologies and Industries project. The objective of the project was to expand on the watchlist of emerging technologies established during the Detecting Opportunities and Challenges for Australian Rural Industries project, and to identify new agriculture industries that have the potential to emerge due to the influence of emerging technologies. These two objectives are in line with AgriFutures Australia’s strategic vision to ensure the long-term prosperity of Australian rural industries through the anticipation of technologies that present potential opportunities and challenges now and in the future.

To expand on the existing watchlist of emerging technologies, Two Horizon Scans were conducted during this project. Developed over two projects and six Horizon Scans, the watchlist now stands at thirty-nine different emerging technologies from the technology domains of robotics and artificial intelligence, data, biotechnology and genomics, business and logistics, renewable energy, and material science. This number and variety of technologies demonstrates the openness to technology innovation and technology transferability within the rural industries. Many of the emerging technologies summarised in this report have been determined by technology sector experts to offer significant commercial impact and transferability to new domains and applications. Thus, there is significant opportunities for technology innovation within the agriculture sector.

Building on the opportunities presented by emerging technologies and their transferability to the agriculture sector, this project outlined technology-driven industries that have the potential to develop in the agriculture sector. Twenty technology-based agriculture industries were identified and analysed over two Emerging Industries - Agriculture and Technology reports [2], [3]. Further to this, this report adds analysis of an additional four potential emerging industries. While the influence of emerging technologies was a critical factor when investigating these potential emerging industries, consideration of the broader domestic and international contexts was also essential. This includes significant environmental issues such as climate change, resource scarcity and declining biodiversity. It also includes socio-economic trends, such as the unprecedented growth in developing nations’ middle-class, which is driving increased demand for food and material consumption. Meanwhile, consumers in developed nations are increasingly conscious about their consumption patterns, but are also becoming more demanding of the services and value they have access to due to the increasing ubiquity and capability of digital technologies. Major challenges such as these, and many others, have been central to identification of emerging industries during this project.

The first section of this report outlines the methodology used across each stage of this project. Following this, a summary of the watchlist of emerging technologies is presented. Each emerging technology is discussed in relation to one of six technology categories. Inclusive of this is the presentation of the potential impact and novelty of the technologies, as perceived by innovative farmers and rural industries experts. This is followed by a presentation of the commercial impact and transferability potential of selected technologies, as perceived by technology domain experts. The summary of the watchlist section concludes with key considerations for the technologies moving forward, as well as a timeline depicting when each technology is likely to reach mainstream commercial adoption. The final section of the report summarises the twenty emerging industries that were identified to potentially develop due to the influence of emerging technology. Building on this cost benefit analysis of an additional four potential emerging industries is provided.
Objectives

The objectives of the project were to:

i. Expand on the watchlist of emerging technologies established during the Detecting Opportunities and Challenges for Australian Rural Industries project. This has been achieved through two Horizon Scans.

ii. Identify new agriculture industries that have the potential to emerge due to the influence of emerging technologies. This has been achieved through two New Industry scans and subsequent reports.

Methodology

This project involved three primary activities:

i. Two iterative Horizon Scans designed to identify emerging technologies that present potential opportunities and challenges to Australian rural industries.

ii. Two New Industry scans designed to identify new industries in the Australian agriculture sector facilitated by emerging technologies.

iii. Iterative surveys conducted with technology domain experts to evaluate the potential commercial impact, transferability and timeline of select emerging technologies identified during Horizon Scans (i).

The methodological approach for each of the activities is outlined in the following sub-sections, beginning with Horizon Scans and then new industries scans, and last, iterative surveys with technology domain experts.

Horizon Scans

Horizon Scans involved scanning various information sources to identify emerging technologies from a broad range of domains, and then interpret and communicate their applicability to agriculture contexts. This process was deployed in a concurrent phase, iterative methodology:

i. Scan and extract data from a variety of sources;

ii. Synthesise this information to identify potential trends and innovations for further investigation;

iii. And, communicate issues through visualisations.

Implementation of each respective project phase, led by data mining, synthesis, and visualisation, occurs across three interactive streams: Discovery; Evaluation; and, Consolidation. These streams are continuous over the course of the project requiring different inputs from each project phase. The inputs from each phase, and their interactivity is represented in Figure 1.
Discovery

The objective of the discovery stream was to develop an initial list of candidate technologies for evaluation. Our approach to discovery was to apply data mining techniques to a large volume of Twitter data to extract information about emerging technologies being discussed by technology experts on the platform. Technology experts were strategically selected to ensure input from a diverse range of domains within international contexts. In addition to domain expert Twitter users, patent databases, industry reports, and technology news media sources were used to gain further insights. Scanning of these sources employed data mining and synthesis concurrently:

- Data mining focused on scanning the Twitter feeds of thought leaders and technology experts in a range of technology and industry domains. They were selected based on the recommendations of QUT experts working in relevant technology domains.
- Synthesis focused on scanning a broad range of technology news publishers, industry reports, and patent databases.

The data mining techniques enabled the efficient retrieval of a signals relating to emerging technologies from the Twitter data. Our data mining approach mitigated much of the noise present in the data, which allowed for the signals to be identified with relative ease. Noise is typically a major concern associated with using social media data as it can lead to the presentation of many redundant topics, which obscure the essential information [4].

Although generally an efficient process, the data mining techniques did require manual selection of target Twitter users – the domain experts. This involved engaging with a variety of industry experts and researchers who were asked to provide the names and accounts of reputable Twitter users considered to be leaders in their respective domains. This process was essential in limiting the noise present in the dataset as it allowed us to only scan Twitter data relevant to emerging technologies.

Human input was also required following the extraction of data from the target Twitter users. Trending technologies were easily identified in the data as they were associated with a high number of mentions. Less salient technologies presented weaker signals in the data, thus requiring significantly more human input to sort and identify these technologies.
Interpretation was required for both strong and weak signals. An important factor contributing to the ease of interpretation was the structure of tweets present in the overall dataset. In data sets made up of tweets containing ‘hashtags’, interpretation was facilitated to some extent as less noise was present. Moreover, multiple hashtags in a single tweet often identified similar category technologies and relevant contextual information. Thus, we were able to identify technologies and the topics of interest around them. In contrast, tweets comprising only of sentences contained considerably more noise, resulting in greater human input to identify meaningful content. As signals were identified in the data, further interpretation involved the use of literature reviews to gain an establish understanding of the technology, applications and context. The confluence of data mining and synthesis in the discovery stream resulted in a list of technologies for further investigation in the subsequent evaluation and consolidation streams.

**Evaluation**

Having developed an initial list of candidate technologies in the discovery stage, the evaluation stage was designed to filter the list of technologies to only those that offered clear opportunities and challenges for Australian rural industries. The evaluation stage leveraged expertise from Queensland University of Technology, and AgriFutures Australia through the provided list of innovative rural industries experts. Delphi style surveys were sent to rural industries experts to gain their insights about, and assess the potential impact of, a broad range of emerging technologies. After each round, the results were shared amongst participants and they were given the opportunity to revise and expand on their original answers. The purpose of this was to structure a group communication [5]–[7].

The initial round of surveys focused on evaluating many of the emerging technologies identified in the discovery stream. This was achieved through presenting a series of simple statements describing the functionality of each technology to participants, who were then asked to rate the technologies’ potential impact. This approach allowed for the strengths of the panel to be maximised – their strength being their knowledge of rural industries. A shortlist of technologies was compiled based on the results of the surveys for further investigation and ongoing monitoring.

Successive survey rounds presented fewer technologies and also fewer questions to participants, but required increasingly detailed responses. It was through this process that we narrowed the scope of technologies that were included on the watchlist. As the evaluation stream progressed, we continued to develop an objective list of criteria to establish the possible scale of impact of each transformative technology. The criteria was re-introduced in successive discovery stages of the project to assist with filtering the large volume of data.

An important aim of our approach was to provide technology insights tailored to the context of rural industries. Therefore, it was important to be able to process domain general information from the discovery stream and develop it to be specific to the domain or rural industries. Qualitative responses given by the innovative farmers who completed each survey assisted with this by re-contextualising the technologies into the rural industries context.

**Consolidation**

The consolidation stream was designed to monitor technologies on the watchlist and analyse their potential impact for Australian rural industries. The consolidation stream utilised data mining and synthesis to receive input from a broad range of data and develop insight into each technology’s breadth of applications, innovation trends, and forecast.

Data mining focused on eliciting deeper analysis of the technologies identified and short-listed during the discovery and evaluation phase. Directed by specific technologies and related keywords, data mining targeted social media feeds and patent databases. The outcome of this stage provided assessment of candidate technologies based on metrics such as trends over time, associated keywords, and industries to identify the contexts in which each technology was active and where it was receiving innovation and location.
Outcomes from data mining, and results from the evaluation stream, informed the work and direction of synthesis. Synthesis investigated specific applications and implementations of the identified technologies to better understand and communicate their potential impact for Australian rural industries. Synthesis was important as data mining the available Twitter data set yielded little information about how the technologies were being used. By investigating associated literature, the synthesis approach allowed us to explore and understand the broad range of applications each technology was being developed for, and how these might transfer to the agriculture sector.

Visualisation was then used to bring together the inputs of synthesis and data mining, as well as inputs from the evaluation stream. This included the development of infographics and scenarios to communicate the watchlist issues and themes.

**New Industries Scans**

The scanning of new industries in the Australian agriculture sector involved synthesis of the technologies identified during Horizon Scans with additional insights generated within our multidisciplinary research team. One of the first steps to generate insights about potential new industries was to develop a framework outlining Australian agriculture’s strengths, weaknesses, opportunities and threats (detailed in [1], [7]). Based on this framework, fourteen contextual factors were specified, which identified critical challenges and opportunities for Australian agriculture. These are listed below and are further elaborated in Appendix A:

- Increased Food Demand
- Less Diversified Farming
- Natural Resource Limitations
- Technology Innovation
- Environment and Climate Change
- Platforms and Ecosystems
- A Changing Workforce
- The Future of Work
- Shifting Power and New Markets
- Digital Readiness
- Food Safety and Food Fraud
- Liquid Expectations
- Inefficiencies and Declining Profitability
- Health and Lifestyle

As the focus of this project was technology driven industries, it was also important to consider the underlying role of technology, including its transformational capacity in the Australian rural sector. Therefore, when generating potential new industries, it was essential to consider the role of technology [8] and to what extent the technology:

- Alters the sector, including the existing knowledge base and competencies;
- Affects existing patterns in the sector, including research and development, production, distribution, products, and market relations;
- Facilitates new patterns in the sector, including cooperative and competitive interaction;
- Expands the existing borders of the sector, including the generation of greater interpenetration of different sectors

With these considerations, three main opportunity areas were identified for new industries to develop. Each of these is briefly explained under the following subheadings.
Industries facilitated by technologies from outside the sector

Technologies originating from outside the agriculture sector present many new opportunities. New technologies and technology platforms often facilitate the development of new business models, which can alter many aspects of how an industry operates. This includes adjustments to the patterns of distribution and modes of competition and collaboration [8]. One approach to the implementation of technology from outside the sector is technology as a service. The Australian agriculture sector already has a considerable support services industry, supplying services including marketing and handling, cropping, livestock, shearing and crutching, and other (irrigation, pest control, seed cleaning or grading, fishing support, pruning) services. New agriculture technology will be a contributor to a larger services industry that assists the core primary production industry.

Industry transformation facilitated by technologies with a direct effect

Technology can have a direct and incisive effect on an established industry sector. Technologies with this effect tend to be transformational in nature, and can generate disruptive pressure on the established systems and infrastructure of an industry [8]. Innovative technology systems provide approaches that transform what is currently undertaken. This can lead to the creation of new segments within an already existing industry. The industry may offer a similar core product as an existing industry, but the technology allows for new business models, patterns of production/distribution, and competition landscape. It transforms the way that the industry is operated, and thus provides opportunities for new value creation.

Industry support facilitated by technologies with an indirect effect

Technology can have an indirect and subsidiary effect to support the functionality of an industry. Technology with an indirect affect tends to have a low transformative capacity [8]. Support can be provided along the supply and value chains to address limitations, develop new capabilities and create new opportunities. For example, the viability of an existing industry can be enhanced by widening the borders of operation and removing existing barriers of the industry. In this way, technology might be able to address limitations associated with cost of operations, access, efficiency and productivity.

Iterative Surveys with Technology Domain Experts

To build on the results gained from the iterative Delphi Surveys with innovative rural industry experts (described in Horizon Scans section) iterative Delphi surveys were also conducted with technology domain experts. Iterative surveys with technology domain experts comprised three stages:

Recruitment

Technology domain experts were recruited from several top Australian universities and were selected based on their work and familiarity with the watchlisted technologies. It was aimed to recruit experts to represent each of the six technology categories outlined in the Summary of Watchlist section in this report:

- Robotics and Artificial Intelligence Technologies
- Data Technologies
- Biotechnology and Genomics Technologies
- Renewable Energy Technologies
- Business Model Technologies
- Advanced Material Technologies

However, domain experts were recruited from only five of the six technology groups. No domain experts from advanced materials responded during the recruitment process. Therefore, this category was omitted from the surveys.
Survey 1

With an established watchlist of candidate technologies developed through the Horizon Scanning process, a selection of technologies was included in the surveys, based on the recruited domain experts’ principle areas of expertise. Twenty-one of the thirty-nine technologies across the Robotics and Artificial Intelligence, Data, Biotechnology and Genomics, Renewable Energy and Business Model technologies categories were included in the surveys. A separate survey was created for each category and sent to relevant technology domain experts. The design of Survey 1 questions focused on eliciting the domain experts’ insights about the chosen technologies’ potential commercial impact, potential to be transferred to other domains, and a timeline predicting when mainstream commercial impact is likely to occur.

Survey 2

The results from Survey 1 were compiled and included in Survey 2 which also asked technology domain experts to evaluate the chosen technologies’ potential commercial impact, potential to be transferred to other domains, and a timeline predicting when mainstream commercial impact is likely to occur. The purpose of this was to give the participants an opportunity to view the groups opinions before revising and expanding on their own original answers. In effect, this provides an approach to structure anonymous group communication [5]–[7]. In addition to evaluating potential commercial impact, transferability, and timeline for commercial impact, domain experts were asked to provide a qualitative response justifying their overall evaluation. This enabled us to corroborate expert opinion with the prevailing literature.
Summary of Watchlist

The watchlist of emerging technologies, as it stands now, is the result of six Horizon Scans conducted over two projects:

i. Detecting Opportunities and Challenges for Australian Rural Industries
ii. Horizon Scanning - Opportunities for New Technologies and Industries

At the conclusion of the Detecting Opportunities and Challenges for Australian Rural Industries project, a final report summarised the watchlist as twenty-four emerging technologies [3]. With the Horizon Scanning - Opportunities for New Technologies and Industries project, and its two Horizon Scans, several additional emerging technologies have been added to the watchlist. A total of thirty-nine emerging technologies have now been identified; each evaluated to offer significant opportunities and challenges to the Australian rural industries.

In the Detecting Opportunities and Challenges for Australian Rural Industries Project’s final report [3], each of the identified technologies was categorised into one of six groups to provide a summary of the key technology domains that have the greatest potential impact on the Australian rural industries. In this section of this report, the summary of the watchlist is updated to include the additional technologies identified in the current project. For each technology category, a brief overview of its value and outlook is presented. Categorised technologies are plotted on a matrix measuring their potential impact and novelty in the context of Australian rural industries, as evaluated during iterative Delphi questionnaires that were completed by young and innovative experts working in the Australian rural industries. Further to this, results gained from iterative Delphi surveys with technology domain experts are also reported. This includes plotting surveyed technologies on a matrix measuring commercial impact and transferability to other domains. Each technology is also plotted on a timeline specifying when the technology is expected to achieve mainstream commercial impact. Finally, a summary of domain experts’ qualitative responses regarding select technologies’ potential to have impact and barriers to their implementation is provided.

Robotics and Artificial Intelligence Technologies

The technologies comprising the robotics and artificial intelligence group are: Wearable User Interfaces, Natural Language Interfaces, Human-in-the-loop Machine Learning, Computer Vision, Collaborative Robots, Context-aware Computing, Human Augmentation and Brain-computer Interface.

Robotics and artificial intelligence technologies are advancing rapidly. In particular, artificial intelligence has become a key strategy for many technology companies [9]. It is already common for people to talk and give instruction to intelligent devices that can respond in meaningful ways [10]. Brain-computer Interface technology has the ability to translate brain signals into meaningful commands to control robotic and computer systems and could have significant impact in a range of applications. However, it faces significant barriers for effective implementation despite there being considerable interest in its development [11]. The development of robotics technology is actively incorporating artificial intelligence technologies, such as computer vision and machine learning, to enhance the capabilities of robots [12]. This will drive new robotic platforms that are not restricted to routine and repetitive labour tasks, but instead can work collaboratively with humans on increasingly complex tasks. This collaboration will be the winning formula to provide strategic and creative problem solving as well as highly efficient and safe working environments [13]. Alongside autonomous robotics, human physical augmentation technologies have the potential to improve productivity and the safety of workers in repetitive and physically demanding tasks [14], [15]. As the future of work takes shape over the coming decades, the technologies covered in this group will be essential in driving the transformation.
Rural Industries Expert Opinions

Figure 2 plots each of the robotics and artificial intelligence technologies based on their average impact and novelty ratings given by rural industries experts. Robotics and artificial intelligence technologies were perceived to be of mixed impact and similar novelty. The technologies that offer contextual awareness and facilitate collaboration with human workers were perceived to be of highest impact and novelty. This is in line with prevailing views on the importance of human and machine collaboration in workplaces of the future.

![Impact - Novelty matrix for Robotics and Artificial Intelligence Technologies](image)

Technology Domain Expert Opinions

Figure 3 plots each of the robotics and artificial intelligence technologies based on their average impact and transferability ratings given by technology domain experts. Context-aware Computing and Collaborative Robots have a much higher perceived impact and transferability by sector experts. This is in line with the importance of human machine collaboration in the workplace. There is a considerable difference in opinion between rural industry experts and sector experts however in regard to brain-computer interfacing.
Robotics and Artificial Intelligence are technologies that have been introduced to various industries. Sector experts placed high value into Collaborative Robots and Context-aware Computing, which are two technologies that combine current robotics technology with the users’ capabilities. For Collaborative Robots to be viable, however, would require a shift in the relationship between how operators perceive automation as a process that doesn’t involve them into a cohesive partnership to achieve a common goal. Human Augmentation was revealed as a technology that could have vast application in agriculture, and large companies have already created working prototypes. The major challenge for this technology is the current high costs, due to the inherent complexity, and current battery technology not having the required longevity to support the operation. Brain Computer Interfaces were deemed unsuitable for commercial use due to their difficulty in distinguishing correct signals from the users.
Timeline

Figure 4. Timeline showing when Robotics and Artificial Intelligence technologies are expected to have mainstream commercial impact, and the consensus of these evaluations

Data Technologies

The technologies comprising the data driven group are: Smart Dust, Labour Tracking, Digital Twin, LoRaWAN, Smart Contact Lenses, Augmented Reality, Extended Reality, Quantum Computing, Edge Computing, High Altitude Wireless Delivery, and 5G.

Data driven technologies will deliver more data and better insights to improve efficiency and decision-making [13]. 5G, the next generation of wireless internet technology, is being rolled out in Australia and the world. This technology will deliver unprecedented speed and coverage allowing for new capabilities in terms of communication, sensing, and integration of smart technologies in the environment. Novel internet delivery technology is being developed to bring these capabilities to rural and remote locations [16]. Facilitation of connected smart objects and sensors in the environment will make it possible to represent and monitor the performance of complex networks of objects [10]. Over-time, these technologies will trend toward being smaller, more efficient, and more accurate. In some cases, nanoscale sensors will permeate the environment [17]. These sensor networks will link into advanced software ecosystems that are designed to process massive volumes of data and will deliver contextual and actionable insights in-real time [13], [18]. Central to this are new computing paradigms such as quantum computing and edge computing. Human workers will tap into newly created data streams with immersive technologies, such as Augmented and Extended Reality, resulting in the blurring of the physical and digital world [19]. People will be able to better interact with big data and engage in rich communication over long distances, which could transform education and training of the next generation workforce [20].
Rural Industries Expert Opinions

Figure 5 plots each of the data driven technologies based on their average impact and novelty ratings given by rural industries experts. **High Altitude Wireless Delivery and 5G were perceived to have the highest impact by rural industries experts.** These ratings reflect the critical needs of Australian agriculture: access to communications infrastructure. Developing these capabilities is likely to have significant impact in the rural industries. Figure 5 also highlights the high novelty rating of **Smart Dust** and **Extended Reality**, which reflects that these are speculative technologies in very early stages of development.

![Figure 5. Impact - Novelty matrix for Data Technologies](image)
Technology Domain Expert Opinions

Figure 6 plots each of the data driven technologies based on their average impact and transferability ratings given by technology domain experts. **Digital Twin and Edge Computing were perceived to have the highest impact by sector experts.** These ratings reflect the similar desires to that of the rural industry experts, in that access to communications infrastructure is integral. It also highlights the need for modelling the lifecycle of agriculture.

Figure 6 Impact - Transferability matrix for Data Technologies

Sector Experts have expressed that data driven technologies do have a place in the future of agriculture. **Digital Twin** and **Edge Computing** are two technologies that have been targeted as key, with both technologies being labelled as already available for adaptation. Edge computing in particular was described as a means to alleviate ‘security risks of allowing international cloud data providers to hold/control Australia’s data’. Regarding Digital Twin, it was stated that this technology is ‘vital to improving Australia’s environmental, social, and economic sustainability’, but will require a major shift by the users to generate the necessary impact. Technologies such as **Augmented Reality** are still considered too gimmicky, and that time should be better spent working on creating better back end decisions making support systems that can be more easily accessible to end-users through means such as SMS and other non-intrusive interfaces. **LoRaWAN** was mostly ignored by the sector experts, as it is most likely going to be quickly superseded by 5G networks or the use of old 2G spectrums. Finally, **Smart Dust** is a technology that was considered ‘a long way off’ and most likely a technology we won’t understand how to utilise effectively until working prototypes have been developed. There was also concern of environmental impacts this technology may have due to scattering of the nanoparticles by various weather conditions.
Figure 7. Timeline showing when Data technologies are expected to have mainstream commercial impact, and the consensus of these evaluations

Biotechnology and Genomics Technologies

The technologies comprising the genomics and biotechnology group are: Plant Genome Sequencing, CRISPR, Microbiome, Cellular Agriculture and Acellular Agriculture.

Advances in genomics and biotechnology are providing deeper knowledge of plant and animal organisms. Over just a short period of time, genome sequencing techniques have become highly accessible, in terms of both cost and speed of process [21]. Microbiome analysis is becoming similarly accessible [22]. There is significant commercial interest in cellular agriculture with several start-ups producing both acellular and cellular products, some of which are already available in the market. These two technologies provide the greatest potential to facilitate environmentally friendly production of animal-based food products without the need for actual animals. While these industries have significant challenges to face in terms of cost reduction [23] and consumer acceptance [23], [24], they have significant potential to be transformational. As knowledge is developed across the spectrum of plant and animal types, and the environments they are grown in, better planning and decision-making will be possible [21], [25], [26]. The emergence of CRISPR in recent years is poised to transform plant and animal breeding. Already it is showing its value in gene edited plants that grow more efficiently, are more resilient to pathogens, and taste better [27]. Looking further ahead, advances in genomics and biotechnology present compelling possibilities for future food systems.
Rural Industries Expert Opinions

Figure 8 plots each of the genomics and biotechnology technologies based on their average impact and novelty ratings given by rural industries experts. Each of the technologies in the genomics and biotechnology group were perceived to be of very high impact. **Cellular Agriculture and Genome Sequencing** are perceived technologies to have the highest impact by rural industry experts.

![Figure 8. Impact - Novelty matrix for Biotechnology and Genomics Technologies](image-url)
Technology Domain Expert Opinions

Figure 9 plots each of the genomics and biotechnology technologies based on their average impact and transferability ratings given by technology domain experts. **Genome Sequencing is rated as having the highest impact and transferability by sector experts.** This confidence is related to the potential capabilities that genome sequencing allows. It is interesting to note that cellular agriculture, which was ranked highly by the rural industry experts, is the lowest ranked by the sector experts.

![Figure 9 Impact - Transferability matrix for Biotechnology and Genomics Technologies](image)

When addressing Genomics and Biotechnology, sectors experts revealed that **CRISPR, Plant Genome Sequencing**, and **Microbiome** are the most likely technologies to make a major impact into the industry. CRISPR and Microbiome are the two technologies that have been touted as powerful research tools with tremendous potential having a major impact on productivity of soils, plants, and animals. However, there is concern that the long-term impact of gene editing will not be evident for years to come. **Cellular Agriculture** is considered a very disruptive technology, which can significantly change the landscape of conventional agriculture, but this is highly dependent on if the technology is willing to be adopted by the end users.
Timeline

![Timeline](image)

Figure 10. Timeline showing when Biotechnology and Genomics technologies are expected to have mainstream commercial impact, and the consensus of these evaluations

Renewable Energy Technologies

The technologies comprising the renewable energy group are: Solar Retransmission, Perovskite Solar Cells, Sodium-Ion Batteries, Moisture Harvesting and Artificial Photosynthesis.

New technology will be the driving force behind a smarter and more reliable energy infrastructure [28]. The increasing availability of low cost and efficient electricity generation and storage technologies will facilitate entirely new models of energy consumption. One example of this is microgrids [28], [29]. These are independent from the main electricity grid, and in many cases are democratically operated by the participants of the microgrid [30]. Advances in renewable energy technologies are timely, and they will play a key role in the short- and long-term future. Large volumes of sustainable energy generation will be needed to reduce environmental impact and to power the electrification of transportation and other equipment [28]. If commercially viable, artificial photosynthesis technology can generate both direct electricity and liquid fuels. This has immense potential in applications such as transportation and wherever industrial energy is required[31]. Beyond the immediate future, current interest in harvesting energy from space and the development of novel ways to extract resources indicates a willingness and capability to power future energy needs [32]–[34].
Agriculture Expert Opinions

Figure 11 plots each of the renewable energy technologies based on their average impact and novelty ratings given by rural industries experts. **Renewable energy technologies were generally perceived to be of high impact and novelty.** This was particularly true for artificial photosynthesis and perovskite solar cells technology. If realised, these technologies will give farm operators access to resources that are sustainable and that facilitate greater self-sufficiency. This will reduce costs and also provide new revenue streams for farmers.

![Impact - Novelty matrix for Renewable Energy Technologies](image-url)

**Figure 11. Impact - Novelty matrix for Renewable Energy Technologies**
Technology Domain Expert Opinions

Figure 12 plots each of the renewable energy technologies based on their average impact and transferability ratings given by technology domain experts. **These technologies were generally perceived to have a similar medium impact and transferability.** However, sodium-ion batteries were considered a technology with a much higher transferability. Renewable energy technologies had a much larger variance between rural industry experts and sector experts than any of the other technology clusters. This is likely due to the unpredictable nature of renewable energy and the uncertainty of their potential. When comparing Figure 11 and Figure 12, Figure 11 depicts the value that rural industry experts place on energy generation and resource generation technologies, such as perovskite solar cells and moisture harvesting. In contrast, Figure 12 represents technology domain experts’ evaluation of how feasible these technologies are as commercially viable products. In this case, perovskite solar cells and other energy generation technologies face considerable development costs and competition from incumbent technologies, specifically silicon solar cells.

Artificial Photosynthesis, Perovskite Solar Cells, and Sodium-ion Batteries all have a high commercial impact. Although sodium-ion batteries was evaluated to be the most transferable, it is also a technology that is least likely to improve over time. Perovskite solar cell technology is considered very efficient, but with major concern around the toxicity and unstable nature of the necessary materials. Artificial photosynthesis is projected as an inefficient technology, but to become more viable it requires more investment into improved catalysts. Moisture Harvesting was determined to be the least likely technology to be viable.
Timeline

Figure 13. Timeline showing when Renewable Energy technologies are expected to have mainstream commercial impact, and the consensus of these evaluations

Business Model Technologies

The technologies comprising the business model innovation group are: Distributed Production, Blockchain, Drone Delivery, Emotional Analytics, Customer Journey Analytics and Metal 3D Printing.

Technology is a catalyst for business model innovation. Increasing availability of technology such as sensors, robotics, and growing lights is facilitating the emergence of smaller and decentralised farming operations that are closer to urban centres [35]. Although decentralised production will not replace large and centralised production in the near future [36], [37], decentralised operations have several advantages; they are resource efficient, have shorter supply chains, and are agile [38]. A recent innovation that is facilitating decentralised business models is blockchain. This technology allows peers to engage in transactions that have fewer intermediaries and thus fewer costs [39]. For agriculture, blockchain promises the capability of transparency and traceability [40], [41]. If it delivers on this promise, it will be transformative for large companies with complex supply chains, as well as small producers who differentiate themselves with locally sourced and ethical products. Drone delivery and Metal 3D printing are similar technologies in that they exist in digital business ecosystems, but have the capacity to enhance organisational flexibility and agility. Bringing together on demand manufacturing and automated transportation could be powerful in mitigating the cost of unplanned downtime and the associated intangible costs[10]. Behavioural analytics technologies, Customer Journey and Emotional Analytics, provide the capability to capture the complex interactions and experiences the customers have throughout supply and value chains. These technologies have the
potential to allow organisations to tailor experiences to specific customer segments to improve customer engagement and identify opportunities for new product development[42], [43].

Rural Industries Expert Opinions

Figure 14 plots each of the business model innovation technologies based on their average impact and novelty ratings given by rural industries experts. **Rural Industry experts perceive that metal 3D Printing has a much greater impact and novelty than all the other technologies.** This is most likely due to the impact that 3D plastic printing has had to so many other industry sectors. The majority of the other technologies all had a relatively similar rating.

![Figure 14. Impact - Novelty matrix for Business and Logistics Technologies](image-url)
Technology Domain Expert Opinions

Figure 15 plots each of the business model innovation technologies based on their average impact and transferability ratings given by technology domain experts. **Customer Journey Analytics is perceived to have a very high impact on the industry and highly transferable.** This supports the literature, which states that working with those that deal with the products leads to better outcomes. Metal 3D printing had a varied response between the agriculture experts and the sector experts, as seen in Figure 14 and Figure 15. Figure 14 portrays the value that the agriculture experts place on the impact that this technology could have in agriculture. Whereas, Figure 15 represents the viability of the technologies based on the technology domain experts’ opinions. This difference in perspectives may be due to issues surrounding scalability of this technology.

![Figure 15 Impact - Transferability matrix for Business and Logistics Technologies](image)

**Customer Journey Analytics** was highlighted as the technology with the highest impact and transferability potential from the Business and Logistics technology group. However, privacy and security of data are major issues that will need to be addressed before taking up this technology. **Blockchain, Metal 3D printing,** and **Drone Delivery** also have potential for high impact in the agriculture sector and each of these technologies are currently being used in other industries. Similar to customer journey analysis, privacy, data management, and policies need to be addressed for both Blockchain and drone delivery to be viable. Metal 3D printing, although currently achievable, may be difficult to scale due to the cost of raw materials used in the process (e.g. powder metal for 3D printing is expensive). **Emotional Analytics,** although rated to be highly transferable, was also determined to have the highest ethical implications associated with being able to collect the required personal data.
Figure 16. Timeline showing when Business and Logistics technologies are expected to have mainstream commercial impact, and the consensus of these evaluations
Advanced Material Technologies

The technologies comprising the advanced materials group are: Programmable Materials, Metamaterials and Graphene.

Material innovations permeate the technology landscape and they underlie many technology advances. Graphene is perhaps one of the most hyped technologies in recent years. It promises to improve many categories of consumer technology, as well as technology essential for rural industries in the future. Perhaps the most notable of these is sensor and renewable energy technologies [44]–[46]. Beyond improving existing technology, material innovation will bring entirely new capabilities. This is highlighted by the early capabilities of programmable materials and metamaterials. Although both are in experimental stages of development, they bring the potential to drive new classes of technology with entirely new functionalities [47].

Rural Industries Expert Opinions

Figure 17 plots each of the advanced materials technologies based on their average impact and novelty ratings given by rural industries experts. Each of the advanced material technologies were perceived to be of high impact and novelty. These technologies promise wide ranging capabilities in rural industries. Their impact, if realised, will be the improvement of many current technologies, and facilitating entirely new and potentially transformative capabilities.
Technology Domain Expert Opinions

Technology domain expert opinions were not obtained for advanced material technologies due to difficulty recruiting survey participants with the relevant expertise.

Timeline

Figure 18. Timeline showing when Advanced Materials technologies are expected to have mainstream commercial impact, and the consensus of these evaluations.
Emerging Agriculture Industries

Two emerging industries reports were completed as part of this project, which resulted in the identification of twenty potential new agriculture industries. The first new industries report [7] was designed to provide a concise overview of ten industries to stimulate creative thinking and facilitate critical discourse. The industries, summarised in Table 3, were a direct response to the emerging technologies included on the watchlist, as well as the fourteen context factors (See Appendix A) determined to present critical challenges and opportunities for Australian agriculture.

Table 3. New Industries 1 list, see [7] for details.

<table>
<thead>
<tr>
<th>Industry</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Automation-as-a-service:</strong></td>
<td>A hybrid industry in which autonomous agriculture technology is provided by means of pay-per-use and subscription services rather than private ownership. This industry has the potential to make new technology more accessible, enhance efficiency and productivity, and mitigate future labour shortages.</td>
</tr>
<tr>
<td><strong>Automation Management and Strategy:</strong></td>
<td>A knowledge-based industry to support the large-scale adoption of automation in Australian agriculture. This industry will provide services to plan, implement and manage automation alongside the existing workforce. The industry has the potential to provide and facilitate skilled employment opportunities, increase operations efficiency, and ensure social responsibility as automation disrupts the labour force.</td>
</tr>
<tr>
<td><strong>Digital Agriculture:</strong></td>
<td>A product and service industry that will develop digital agriculture platforms and facilitate the widespread transition to decision agriculture. The industry has the potential to improve access to digital technologies, improve efficiency and productivity, improve the speed and accuracy of on-farm decision-making, and reduce uncertainty.</td>
</tr>
<tr>
<td><strong>Automated and Digital Supply Chain:</strong></td>
<td>Digitisation and automation will result in hybrid supply chain industries that streamline existing capabilities and develop new paths to market. The industry has the potential to improve decision-making agility, meet the raising expectations of consumers, improve interoperability throughout the supply chain, reduce costs and improve efficiency.</td>
</tr>
<tr>
<td><strong>Education and Training:</strong></td>
<td>Automation and the need to develop new skills will facilitate the emergence of a new agriculture education and training industry. The industry has the potential to improve knowledge retention, create meaningful employment opportunities, deliver novel and engaging training programs, and ensure secure employment for agriculture workers.</td>
</tr>
<tr>
<td><strong>Provenance and Certification:</strong></td>
<td>A provenance and certification hybrid industry will emerge as a supply chain service. Provenance and certification services will be important for companies to maintain brand and product integrity in emerging markets. The industry will potentially mitigate food fraud and food safety breaches, and provide added value and improved food experiences for consumers.</td>
</tr>
<tr>
<td><strong>Cell Cultured Meat:</strong></td>
<td>An industry based on ‘growing’ meat in controlled conditions, rather than by raising an entire animal. A cell cultured meat industry has the potential to reduce the environmental impacts of meat production. If accepted by consumers, cell cultured meats could provide a nutritious and ethical food source in local and global markets.</td>
</tr>
<tr>
<td><strong>Personalised Health and Food:</strong></td>
<td>A food product and service industry that provides mass personalisation of food products. This industry would likely align with personalised health services, and could provide nutritious and novel food experiences to health conscious consumers and consumers who are at risk of health issues.</td>
</tr>
<tr>
<td><strong>Marketing and Stakeholder Engagement:</strong></td>
<td>New opportunities that arise from digital transformation of agriculture will require a new marketing and stakeholder engagement industry. This industry could facilitate strategic partnerships and the creation of value networks so that operators can develop new products and services, and better engage with consumers.</td>
</tr>
<tr>
<td><strong>Microgrid P2P Energy:</strong></td>
<td>A hybrid energy industry will emerge based on the development of microgrids in the agriculture context. This industry will facilitate new revenue streams for participants of the microgrids and the communities in which they are located. Microgrids will also facilitate the intensification of off-grid farmland and offer an efficient and reliable alternative to main grid power sources.</td>
</tr>
</tbody>
</table>

The second new industries report [2] was designed to provide a more thorough analysis of an additional ten emerging industries. This included a detailed assessment of industry drivers,
preconditions and uncertainties, opportunities and barriers, cost benefit analysis (see Appendix B for cost benefit analysis methodology), strategic considerations, and applicable emerging technology. The industries, summarised in Table 4, were a direct response to the emerging technologies included on the watchlist, as well as the fourteen context factors (See Appendix A) determined to present critical challenges and opportunities for Australian agriculture.

Table 4. New Industries 2, see [1] for details.

<table>
<thead>
<tr>
<th>Industry Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acellular Agriculture</strong></td>
<td>Industry operators produce food products and ingredients using acellular agriculture techniques. Products include animal-free replicas of dairy and meat items, as well as raw ingredients, such as proteins and fats. Driving the industry is the concurrent advancement of acellular agriculture technology and trends of health and environmental consciousness.</td>
</tr>
<tr>
<td><strong>Cellular Agriculture</strong></td>
<td>Industry operators produce animal protein products using cellular agriculture techniques. Products produced include structured animal protein (e.g. carcase meat) and unstructured animal protein (e.g. processed meat) products. The industry is driven by the unsustainability of the meat and livestock industries. Consumers are conscious of these issues, while also demanding quality animal proteins.</td>
</tr>
<tr>
<td><strong>Craft Hydroponics</strong></td>
<td>Industry operators grow edible craft plant varieties in controlled environments. These include high-value aromatics and herbs with manipulated phenotypic expressions to produce distinct flavour profiles. The industry is driven by an increasing importance that consumers place on experiences. Memorable dining experiences provided in unique locations with unexpected menus are becoming popular in the experience economy.</td>
</tr>
<tr>
<td><strong>Hydroponic Hops</strong></td>
<td>Industry operators grow local and imported hop varieties in controlled environments. Producers will supply fresh, dried and pelleted hops to the craft brewing industry. The industry is driven by the growing demand for hops in Australia on the back of a growing craft brewing industry. Australian beer consumers are becoming more adventurous, preferring local and unique craft beers.</td>
</tr>
<tr>
<td><strong>Hydroponic Australian Edible Natives</strong></td>
<td>Industry operators grow Australian edible native plant varieties in controlled environments. Candidate varieties are fast-growing leafy herbs and aromatics with similar traits to plants typically grown in controlled environments. The industry is driven by consumers’ developing interest in food experiences and food provenance. As native foods enter the mainstream, there is interest in developing improved cultivation techniques and consistency of supply.</td>
</tr>
<tr>
<td><strong>Insect Farming</strong></td>
<td>Industry operators produce insects for human and animal consumption. For humans, products are processed food items with insects as ingredients. For animals, insects can supplement or replace soymeal and fishmeal. The industry is driven by insects having a nutritional profile comparable to other animal proteins, while requiring significantly less resources to produce. Such properties align well with trends of health and environmental consciousness.</td>
</tr>
<tr>
<td><strong>Distributed Manufacturing and Repair</strong></td>
<td>Industry operators provide on-demand distributed manufacturing and repair services using 3D printing technology. Services provided are replacement part manufacture, part repair, and design and manufacture of custom parts. The industry is driven by continual improvements to 3D printing technology in terms of speed, accuracy and functionality, while also decreasing in cost. Improvements to metal 3D printing have made the technology a viable manufacturing approach.</td>
</tr>
<tr>
<td><strong>Edge Computing Managed Services</strong></td>
<td>Industry operators provide edge computing devices as a managed service dedicated to data collection and data analytics. Primary devices include in-field sensors, gateways, agbots, drones and other IoT devices. The industry is driven by the decreasing viability of processing ever increasing amounts of data in the cloud. Thus, processing is being done closer to where it is collected by edge devices with powerful compute capabilities.</td>
</tr>
<tr>
<td><strong>Wild Camel Harvesting</strong></td>
<td>Industry operators harvest camels from wild and semi-managed populations. The main products produced by the industry are camel meat for human and animal consumption. By-products, including camel leather and fat have value. The industry is driven by a large wild camel population in Australia. Without harvesting and culling the population can grow at an estimated rate of between 6% and 12%.</td>
</tr>
<tr>
<td><strong>Wild Goat Harvesting</strong></td>
<td>Industry operators harvest goats from wild and semi-managed populations for meat production and live export. The main products produced by the industry are rangeland goat meat and live goat exports for human consumption. The industry is driven by Australia’s large wild goat population, which ranges from 2.6 to 5 million, according to recent estimates. If not harvested, wild goat populations can grow quickly, and they can be detrimental to the environment.</td>
</tr>
</tbody>
</table>
In addition to the twenty new industries identified in [7] and [1] and summarised in the previous two tables, four new industries have been identified and are briefly reported as cost benefit analyses in the following sub-sections. The cost benefit analysis methodology is detailed in Appendix B.

**Medicinal Marijuana**

**Table 5. Medicinal marijuana industry cost benefit analysis**

<table>
<thead>
<tr>
<th>Cost Benefit Analysis</th>
<th>$AUD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total costs for year 1</td>
<td>234,884,000</td>
</tr>
<tr>
<td>Total benefits for year 1</td>
<td>814,458,340</td>
</tr>
<tr>
<td>Net Present Value @4% over 10 years</td>
<td>3,541,225,284</td>
</tr>
</tbody>
</table>

**Assumptions**

The Department of Health – Office of Drug Control is currently issuing licenses for outdoor Medicinal Marijuana (MMJ) plantation as well as in indoor greenhouse settings. They also issue licenses to grow MMJ for research purposes. Based on license holding companies and a report from Deloitte prepared for the Department of health – Office of the Drug Control, the cost of growing MMJ outdoor is approximately $475/sqm considering it is situated at least 100km away from the manufacturing site, whereas for indoor or greenhouse operations it averages at $2300. Calculations for ‘Year 1’ have been done on the basis of current 50 licence holders and their operation costs with a 10% per annum increase in all three types of license holders on the supply side, including variable costs like salaries, and overheads. Another assumption that has been incorporated for direct costs is government incentives, which will not increase more than $3 million per annum until recreational marijuana is legalised in Australia [48]–[50].

Revenue calculations are done on two markets – primary market represents the current vetted patients and medical conditions allowed for MMJ intake, along with visitors on medical tourism, and purchase from research laboratories. The primary consumer population is then multiplied by amount of doses and frequency. To simplify the calculation, the average cost of MMJ intake per patient per month is multiplied to the patient population rather than MMJ volume because it gets sold as dried flowers, oil, or other forms with varied cost structures. Furthermore, for the secondary markets, estimates from the Department of Health suggest that another 1% of the market will start using MMJ for medicinal purposes due to ageing population and inclusion of other medical conditions [51], [52].

In conclusion, there are more than 50 companies that are manufacturing, growing, and or using MMJ for research & medical purposes in Australia. These companies are adding $350 million to the Australian agriculture industry, along with another $3-5 million in other industries like manufacturing, packaging, and allied health services. Medicinal Marijuana industry has the potential to contribute over $3.5 billion to the industry and will create 1700 direct and 3000 indirect jobs in various key sectors like manufacturing, pharmaceuticals, health services, and agricultural [53].

**Hemp Milk**

**Table 6. Hemp milk industry cost benefit analysis**

<table>
<thead>
<tr>
<th>Cost Benefit Analysis</th>
<th>$AUD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total costs for year 1</td>
<td>50,439,180</td>
</tr>
<tr>
<td>Total benefits for year 1</td>
<td>71,301,772</td>
</tr>
<tr>
<td>Net Present Value @4% over 10 years</td>
<td>312,576,889</td>
</tr>
</tbody>
</table>
Assumptions

IBISWorld released a report in July 2018 highlighting how falling soybean prices have affected the profitability of the alternative milk market and have influenced the growth of a whole new category. Revenue from two major alternative milk products – Soy and Almond (95% of the market) – is expected to grow 5-6% from 2015 to 2020. ABARES prepared a report on industrial hemp production in 2012 highlighting a production capacity of 100 ton in approximately 200-hectare land, with 10 to 12 producers with license to grow industrial hemp (<1THC) for fibres, seeds, animal feed, clothing and other industrial products. Research papers released at the Australian Industrial Hemp Conference in 2018 suggested a growth rate of 10-15% in land farming, and estimated 5-7% for indoor farming for research purposes. Cost of growing industrial hemp on land is around $2200 per hectare along with indirect costs of maintenance, salary and equipment [54]–[56].

In terms of the revenue calculations, hemp milk is calculated on total production and total sale value of the category. Given the price points for hemp milk is higher than Soy and Almond, the calculations are done on hemp milk’s 1.2% of value share in the Australian market. With further acceptance on hemp milk production and cultural introductions (like latter art, wellness value, market trends) the value share for hemp milk is likely to capture another 1.9% of the market with its packaging, retail, and by-products [57]–[59].

In conclusion, there are more than 20 growers who sell hulled hemp seeds for production of fibres, savoury dips, milk and cheese products, and other confectionary items. It may appear that the direct cost is not proportional to the direct benefits and overall net present value of the hemp milk, however, hemp milk is a by-product of hulling along with oil production and animal feed. Therefore, the Hemp Milk industry has potential to contribute over $312 million to the current $200 million alternative milk industry, and will create 150 direct and 350 indirect jobs in various key sectors like manufacturing, agriculture, retail, and apparel [60].

Hydroponic Berries

Table 7. Hydroponic berries cost benefit analysis

<table>
<thead>
<tr>
<th>Cost Benefit Analysis</th>
<th>$AUD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total costs for year 1</td>
<td>165,500,000</td>
</tr>
<tr>
<td>Total benefits for year 1</td>
<td>619,928,050</td>
</tr>
<tr>
<td>Net Present Value @4% over 10 years</td>
<td>4,105,157,179</td>
</tr>
</tbody>
</table>

Assumptions

Economic modelling for hydroponic berries consists of blueberries, raspberries, strawberries, and blackberries (Rubus). Calculations for direct and indirect costs have been taken primarily from NSW Blueberry farmers, retail and production capacity of Costa Group, & Strawberry Association. Based on the cost structure explained in the Nuffield report, and some costs obtained from Australian Berries (individual) associations and Horticulture Australia, the cost of putting up an outdoor hydroponic greenhouse comes at $85K per hectare multiplied by the total number of berry growers, i.e. 150 (there are more than 350 traditional growers). Other costs components have been taken from other fruit and vegetable industry reports on ABARES [61]–[63].

Revenue calculations are adopted on market size calculations from IBISWorld’s report on Hydroponic Berries, and annual reports and journals from various Australian Blueberry, Strawberry, and Rubus Industry Associations. A few of the costs like large-scale hydroponic systems, lighting, and chemicals have been taken from Horticulture Australian (Hort Innovation), and Government of NSW’s current industry initiatives for Blueberry [64]–[66].
In conclusion, according to Protected Cropping Australia, there are more than 350 berry growers in Australia, however, only 150 or so use small or large-scale hydroponic farming. Costa group is the market leader in horticulture innovation in berries industry and holds 45% of the market share. Due to benefit campaigns, berries in Australia are growing at combined average of 12-15% and has potential to contribute over $4 billion in the next 10 years with 2000 direct and 4500 indirect jobs [63].

Hydroponic Chinese (Asian) Vegetables

Table 8. Hydroponic Chinese (Asian) vegetables industry cost benefit analysis

<table>
<thead>
<tr>
<th>Cost Benefit Analysis</th>
<th>$AUD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total costs for year 1</td>
<td>$87,396,200</td>
</tr>
<tr>
<td>Total benefits for year 1</td>
<td>$379,730,170</td>
</tr>
<tr>
<td>Net Present Value @4% over 10 years</td>
<td>$2,741,482,852</td>
</tr>
</tbody>
</table>

Assumptions

The cost benefit analysis for Chinese vegetables is adopted directly from the Australian Vegetable growing sector’s industry reports and analysis of ABARES Australian vegetable-growing farms surveys. The surveys and reports suggest that only 13% of all vegetable farming in Australia use hydroponic or protected cropping systems such as glass or shaded cloth. Based on mixed estimates, the share (18-20%) of leafy vegetables or Chinese (Asian) vegetable was deducted and applied to the unit cost to arrive at the direct and indirect costs calculations. To note, one of the largest invariable costs in Hydroponic Chinese/Asian vegetable industry is the labour cost, which is variable and often done by family members and backpackers for small-scale (<20 ha) farms [67], [68].

Revenue calculations were adopted from the data obtained by ABARES and AusVeg on leafy vegetables - for both farm gate prices and retail prices. Similar to lettuce farming, a 4-week crop cycle and 10% crop loss has been accounted. Based on newsletters and blog posts by farmers like Hydro Produce, Apex Greenhouses, and Hydroponic Farmers Federation, a majority of the hydroponic growers are shifting towards 52-week growing solution to ensure the continued supply of leafy vegetables in a controlled environment. The revenue has been calculated for a primary market – on farm price or wholesale/retail price of leafy/Asian/Chinese vegetables, and then additional 10% from restaurant sale and batch order contracts (Paddock to Plate Business Models, including exports) [67], [69].

In conclusion, there are more than 3000 vegetable growers in Australia and according to peak vegetable industry body, AusVeg, there are more than 30% of Australian farmers growing produce in some form of soil-less culture system. After the labour salaries, energy prices are one of the fastest growing cost components for hydroponic farms. With energy pricing and crop efficiency as constraints, Hydroponic Chinese or Asian Vegetable industry has a potential to contribute $2.7 billion (including exports) to the economy in the next 10 years supporting 1300 direct and 2700 indirect jobs [69], [70].
Conclusion

The objectives of the Horizon Scanning - Opportunities for New Technologies and Industries project were to identify emerging technologies that have the potential to impact the Australian agriculture sector and contribute to the development of new agriculture industries. These objectives align with AgriFutures Australia’s strategic vision to ensure the long-term prosperity of Australian rural industries through the anticipation of technologies that present potential opportunities and challenges now and in the future. Consideration of emerging technology as a catalyst to industry growth is highly relevant in today’s context, where technology driven disruption expected to increase in the coming decades [71]. The anticipation of relevant technologies has the potential to improve the existing capabilities of the Australian rural industries, as well as create new opportunities from which to deliver value to the sector and to the Australian economy.

The two Horizon Scans completed as part of this project consolidated on the watchlist of emerging technologies established during the preceding project, Detecting Opportunities and Challenges for Australian Rural Industries. Combined, the watchlist now identifies thirty-nine emerging technologies that have the potential to impact Australian rural industries. Not only does this number represent the vast opportunities for integrating emerging technologies into the agriculture sector, but it demonstrates the effectiveness of our horizon scanning methodology. Our methodology was designed to handle the inherent complexity of researching and anticipating emerging technologies. It brought together a mix of foresight methodologies and research personnel from a broad range of disciplines. This breadth of methodology and expertise allowed for any shortcomings of one part of the approach to be mitigated by others. In particular, the engagement of various rural industry and technology domain experts throughout the project facilitated the identification of emerging agriculture industries that have the potential to develop as a result of emerging technology.

The identification of emerging industries was communicated over the course of two Emerging Industries - Agriculture and Technologies reports. The first of these [5] focused on providing a concise overview of ten potential industries to develop a discourse around what exactly emerging technology-based agriculture industries are and how they align with the strengths, weaknesses, opportunities and threats present in Australian agriculture. The second Emerging Industries - Agriculture and Technologies report [6] provided a more detailed and layered analysis of potential emerging agriculture industries. To further emphasises the opportunities present for integrating emerging technology into the Australian agriculture sector an additional four potential technology-based agriculture industries have been presented in this report. For each of the industries identified, they represent a direct response to key contextual factors posing significant challenges to Australia, as well as opportunities presented by emerging technology. In some cases, the role of emerging technologies is to enhance the viability of existing industries, such as through improving productivity and efficiency. In others, technology assumes a transformational role, developing entirely new ways of doing things and facilitating new products to address both growing and emerging markets. In either case, it will be essential to identify opportunities for agriculture technology innovation to meet significant future challenges and ensure the long-term prosperity of the sector.
Appendices

Appendix A: Context Factors

This appendix outlines fourteen contextual factors that are impacting Australia and the rest of the world. This list is not intended to be exhaustive and is specific to the scope of this report; each of the contextual factors identified necessitates and facilitates the emergence of new technology-driven industries in the context of Australian agriculture.

Increased Food Demand

The world population is increasing at the rate of 1.1%, with a higher growth rate in Asia. In 2016 the number of undernourished people in the world was estimated to have increased to 815 million [72]. To meet increasing demand and to provide food security for undernourished people, food production may need to be increased by 60-110% by 2050 [73]. Cereal production is predicted to exceed twice what it is now [74], [75], and crop production for use as alternatives for non-renewable energy places further strain on food production [76]. Global food systems will need to produce food in greater volumes, more efficiently, and cheaper than before [74], [77].

Natural Resource Limitations

The pressure on existing land, water and energy resources is increasing. Upwards of 70% of fresh water supplies are currently used by agriculture [78]. With food demand increasing, water demand is predicted to increase by 19% by 2050 [79]. At the same time, arable land is declining due to the effects of land contamination and climate change [80]. To meet increasing global food demands [74], [75], sustainable food production increases need to be fulfilled by generating more productivity from existing resources [81].

Environment and Climate Change

Climate change is a focal issue of the environmental debate, and it is contributed to by many industries [82]. Australian agriculture has a significant role to play in mitigating the effects of ongoing climate change as well as other environmental issues, such as pest resilience and intensified land use. Currently, meat production is responsible for approximately 15% of global greenhouse gas emissions. Livestock consume 1/3 of harvested crops that would otherwise be used for human consumption [83], and conversion of forests to livestock feed production is one the main drivers of deforestation [83]–[85]. The long-term effects of these types of practices are becoming clear. Increased frequency of natural disasters such as drought, floods and cyclones result in increased risk and uncertainty, and can cause significant financial costs [86]. The variability of these uncertain weather events also mean that it is becoming harder to predict and adapt to change [87].

A Changing Workforce

Australian rural industries have an aging and declining workforce, which has resulted in shortages of both skilled and unskilled workers. Younger generations are not interested in agriculture due to higher opportunity cost of farming, higher risk and uncertainty, less investment and lack of social recognition. Over the last decade, the number of students studying agriculture qualifications has roughly halved. Recently, it has been predicted that more workers will be leaving the industry than are entering it [88]. As automation becomes more cost effective in the coming decades, the agriculture workforce is likely to change further. It is predicted that 73% of jobs in Australia will be impacted by automation and artificial intelligence by 2035 [89].
Shifting Power and New Markets

As one billion people in Asia transition out of poverty, economic power will shift from West to East. With this, Australia has an opportunity to tap into a rapidly expanding market that will be demanding more and higher-value food [74], [90]. In particular, economic growth in Asia is predicted to drastically increase global meat consumption [74], [85], [91]. Though Australia is a net food exporter, it accounts for only about 3% of the global food trade. At present, Australia produces food sufficient to feed only 2% of the Asian population [92].

Food Safety and Food Fraud

Although increasing wealth in developing countries creates new market participants, it also creates new logistical challenges. Longer and higher-velocity food supply chains create new food fraud and food safety concerns [93]. Food fraud is not limited to developing nations, however, and incurs an estimated US$40 billion annual cost to the global food industry [94]. Food safety breaches can have similar impact on food industries. In currently siloed supply chains, it can take weeks to trace a food product to its origin, subsequently incurring significant costs to producers and retailers in the case of product recalls [95].

Inefficiencies and Declining Profitability

Inefficient practices and processes throughout the food supply chain result in declining profitability. On-farm, inefficiently used fertilisers and pesticides create unnecessary costs for producers and negative environmental externalities [96]. Post-farm gate, transactions among different points in the supply chain are heavily controlled by intermediaries and freight brokers. This results in a siloed supply chain and substantial hidden information, which consequently adds significant costs and subsequent downstream price mark-ups [97]. Additionally, poor supply chain practices can lead to considerable food waste [98]. Globally, it is estimated that 1/3 of total food produced is wasted. In Australia, this equates to a cost of $950 billion to the economy [99].

Less Diversified Farming

Although Australia is a food secure country, there is great potential to diversify agricultural production for international markets based on comparative advantage. For example, the advantage of expanding grain legume production for the Indian and other Asian markets has been well publicised [100]. Diversification of farming is also essential to maintain biodiversity. It is important that agriculture operations develop strategies and capabilities to increase yield while not resulting in biodiversity loss [101].

Technology Innovation

Technology advancement and technology driven disruption is expected to experience exponential growth in the coming decades [102]. Many emerging technologies from domains as diverse as finance, health, robotics, material science and genomics show promising application in the rural industries and have potential impact throughout the supply and value chains. Emerging technologies will help make operations more efficient and productive. They will deliver real-time insights to help operators anticipate and respond to future challenges. As new technologies emerge, and the capabilities of existing technologies expand, expect their transferability across domains to increase [3].

Platforms and Ecosystems

As digital transformation occurs across industries, the near-term future will see a proliferation of product and service offerings that focus on pay-per-use, software services, and the monetisation of data [244]. The long-term future will see the rise of the outcome economy, characterised by pay-per-outcome services, connected ecosystems and platform-enabled marketplaces [244]. The importance of
digital platforms is already evident in the form of companies that include Uber, Airbnb, eBay, and Amazon. The platforms provided by these companies allow individuals and small businesses to access large consumer bases efficiently and cost effectively. They also establish considerable control for the platform creator [103]. Given this, it is expected that most large manufacturers and service providers will aim to develop and maintain their own platforms [244].

The Future of Work

The Australian economy is trending toward more skilled jobs and thus a greater demand for skilled workers [104]. This is largely driven by increasing levels of automation [89]. It is estimated that 60% of tasks performed in agriculture in the USA have the potential to be fully- or partially-automated [105]. Automation of this scale will change the structure of organisations and transform labour markets. Humans will increasingly perform actions that are complimentary to machines [89], [105]. The prevailing view is that the current workforce does not have the skills to meet the demands of this future [106]. Thus, appropriate education and digital literacy will be essential in the coming decades [104]. Those at risk of displacement will need to engage in regular reskilling to stay up to date with new technologies and approaches [88], [107].

Digital Readiness

Technology innovation is blurring the boundaries between the digital and physical worlds. Physical assets and environmental events can be accurately tracked and turned into valuable data. Infrastructure development will be essential for ensuring the interoperability among different technologies and the data they create [244]. Australian agriculture’s current infrastructure and digital capabilities are not ready for this. Recent reports indicate that Australia’s adoption of digital agriculture is ‘ad hoc’, highlighted by poor and inconsistent internet access, fragmented regulatory frameworks, incomplete access to data and limited interoperability among different data sources. Among farmers, there is uncertainty over the value proposition of digital agriculture [108]. This includes little understanding about the terms and condition of data ownership, and concern over companies having access to their farm data [109].

Liquid Expectations

Proliferation of customised and convenient digital services in many industries has led consumers to expect and demand the same level of quality, flexibility and cost competitive services in other industries [103]. This process of expectations seeping over from one industry to an entirely different industry is known as ‘liquid expectations’ [103], [110]. Organisations around the world are positioning themselves to better meet these expectations by hiring executives and teams with diverse expertise that focus on customer experience and engagement [89]. Liquid expectations are not limited to consumers. As business transactions grow and data is increasingly available, decision-makers, managers and executives will demand information that is real-time, customisable and actionable [252].

Health and Lifestyle

Increases in chronic diet-related illness and the associated medical costs have raised the awareness and importance of adopting a healthy lifestyle. At present, however, implementing changes toward more healthy lifestyles has been hard to achieve for many [89], [111]. Consumers are also increasingly aware of and interested in environmental issues. These consumer groups are looking to lead conscientious and ethical lifestyles, and this includes being selective about the food they eat [82], [112], [113]. Awareness of food provenance and demand for sustainable and locally sourced food is on the rise [114].
Appendix B: Cost Benefit Analysis Methodology

Cost benefit analysis (CBA) is a method of evaluation that attempts to estimate and compare the total benefits and costs of a particular policy proposal, infrastructure development or regional/sectoral analysis. It is a simple systematic approach that aims to estimate the dollar value of direct and indirect costs and benefits of a change. There are three major steps in a cost–benefit analysis:

**Step 1 - Specify the set of options:** Identify a range of genuine, viable, alternative cost options to be analysed. Consider and use all available direct and indirect cost options for a minimum viable analysis.

**Step 2 - Decide whose costs and benefits count:** For most industry analysis, measuring the national costs and benefits is appropriate, rather than measuring any international impacts. That is, as far as is practical, this report has calculated the costs and benefits to all people residing in Australia.

**Step 3 - Identify the impacts and select measurement indicators:** Modelling has identified a full range of impacts for each industry segment. It was important to identify the incremental costs and benefits for each segment, relative to the base case (e.g., ‘what would happen if we maintain business as usual?’).

This CBA does not calculate additional economic, social, or environmental benefits other than gross value added to the industry and net job creation. This CBA presents the best estimates of expected costs and benefits, along with a description of the major uncertainties and how they were taken into account.

*GDP = private consumption + gross investment + government investment + government spending + (exports - imports) [115].

Current Price GVA = Compensation of employees (COE)
+ Gross operating surplus (GOS) and Gross mixed income (GMI)
+ Other taxes on production
- Other subsidies on production

Based on ABS’s Input-Output multiplier reports for various industries, on average every direct job or $1m of investment creates two indirect jobs. ABS Cat 5209.

It is difficult to predict the effects of sectoral growth over a 10-year horizon — or in some cases, even to attach objective probabilities to various scenarios — necessarily decisions must be made regarding assumptions. This report lists the assumptions transparent.

**Calculating net present values:**

To determine the net present value (NPV) of an option, the costs and benefits need to be quantified for the expected duration of the proposal. NPV is calculated as:

\[ NPV = \frac{B_t - C_t}{(1 + r)^t} \]

where \( B_t \) = the benefit at time \( t \)
\( C_t \) = the cost at time \( t \)
\( r \) = the discount rate
\( t \) = the year
\( T \) = number of years over which the future costs or benefits are expected to occur (the current year being year 0).
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Horizon Scanning
Opportunities for New Technologies and Industries

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