
REPORT CONTRIBUTORS
Dr Grant Hamilton, Dr Levi Swann, Dr Sangeetha Kutty, Prof Greg Hearn, Assoc Prof Richi Nayak, Dr Jared Donovan, Dr Debra Polson, Dr Markus Rittenbruch, and Prof Roger Hellens.

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EXECUTIVE SUMMARY

This report is the final report of the Detecting Opportunities and Challenges for Australian Rural Industries Project. The project was conducted as part of Agrifutures Australia’s initiative to anticipate technologies that present potential opportunities and challenges to Australian rural industries. Developing this capability is critical for managing risk and informing future directions. Over the course of the project, a methodology was developed in line with this initiative. It incorporated a mix of foresight methodologies, including data mining, literature review, Delphi questionnaires and visualisation. Each of these methods were used in an interactive approach that focused on detecting emerging technologies from a range of different industries, and then through systematic assessment, reposition and imagine those selected technologies in an Australian rural context. The effectiveness of this methodology is evident in each of the Horizon Scans completed to date. These have led to a watchlist of emerging technologies that offer potential opportunities and challenges to Australian rural industries. The purpose of this final report is to summarise the watchlists and communicate the potential impact that these technologies have for Australian rural industries.

SUMMARY OF WATCHLIST

A total of twenty four emerging technologies were identified during the Horizon Scans. These technologies have origins in a diverse number of domains, including material science, artificial intelligence, robotics, genomics, and energy. The following table summarises the technologies on the watchlist and the technology groupings we have used in this report:
### DATA DRIVEN
- Smart Dust
- Augmented Reality
- Digital Twin
- Labour Tracking
- LoRaWAN
- Smart Contact Lenses

### GENOMICS AND BIOTECHNOLOGY
- Plant Genome Sequencing
- CRISPR
- Microbiome

### ROBOTICS AND ARTIFICIAL INTELLIGENCE
- Collaborative Robots
- Context-aware Computing
- Natural Language Interfaces
- Computer Vision
- Human-in-the-loop Machine Learning
- Wearable User Interfaces

### BUSINESS MODEL INNOVATION
- Blockchain
- Distributed Production

### RENEWABLE ENERGY
- Perovskite Solar Cells
- Sodium-ion Batteries
- Solar Retransmission
- Moisture Harvesting

### ADVANCED MATERIALS
- Programmable Materials
- Metamaterials
- Graphene

## IMPACTS ON AUSTRALIAN RURAL INDUSTRIES
Horizon Scan reports 1 to 4 explored the potential impacts and functional capabilities of each of these technologies. This report explores how the technologies align with the critical needs of Australian rural industries. Technologies were framed in relation to the focus areas of Australian rural industries that were developed during the scoping workshop at the beginning of the project. This led to the identification of three areas that the identified technologies have the greatest potential to impact: efficiency and productivity, skills and knowledge, and new products and markets.

**Efficiency and Productivity** are essential capabilities for Agriculture and are directly related to profitability and competitiveness. Developing capabilities to improve efficiency and productivity will be essential to deal with challenges such as climate change, diminishing resources and an increasing demand for food and fibre. The identified technologies have greatest potential impact for efficiency and productivity in relation to the following focus areas and sub-focus areas:
Skills and Knowledge development will be essential for Australian agriculture in the coming decades. The current workforce is aging and declining, and automation will impact a large percentage of agriculture jobs in the future. The identified technologies have greatest potential impact for skills and knowledge in relation to the following focus areas and sub-focus areas:

A. PRIMARY PRODUCTION INPUTS, PROCESSES AND PRACTICES

- Viable Alternatives to Reduce Costs
- Genetic Improvement
- Post-farm Gate Consideration

D. SUPPLY CHAIN LOGISTICS

- Relationships and Connectivity
- Disruptive Technology in the Supply Chain
- Optimisation of the Supply Chain

E. INDUSTRY SUSTAINABILITY

- Environmental
- Economic

New Products and Markets are emerging in both local and global contexts. Young and affluent consumers are conscious of the environment and looking for local and sustainably sourced food. Meanwhile, a growing Asian middle class is demanding more and better quality food. The identified technologies have greatest potential impact for skills and knowledge in relation to the following focus areas and sub-focus areas:

A. PRIMARY PRODUCTION INPUTS, PROCESSES AND PRACTICES

- Information and Skills to Support Decision-making

C. ADAPTIVE CAPACITY OF PRIMARY PRODUCERS AND SECTORS

- Leadership to Initiate and Respond to Change
- Skills and Knowledge to Implement Change

E. INDUSTRY SUSTAINABILITY

- Social License
- Economic
- Perception

FUTURE WORK

Much of the work completed during this project has demonstrated the importance of technology confluence. In this report, technology confluence is an underlying feature. This begins in the summary of the watchlist where clear technology grouping are evident and have been expressed. In identifying specific areas of Australian rural industries that the technologies have greatest potential impact, technology confluence is again evident. Plausible futures that are explored show how the different technologies can
complement one another and deliver capabilities to address future challenges. This notion of technology confluence is where the future direction of this work lies. Although technology confluence is cited as something that often happens without planning, it is possible to foster and prepare for it with appropriate management and an interdisciplinary approach [64]. This process has already begun with the preparation of a parallel report that outlines potential technology-driven agriculture industries that have the capabilities to address the future challenges facing Australian rural industries.
INTRODUCTION

Fostering technology innovation is important for the rural industries. Technology development and integration are both drivers of efficiency and productivity [1], [2], and is therefore an essential part of ensuring profitability and competitiveness [3]. A strong track record of technology integration has been a key part of Australian rural industries’ long-term competitiveness and economic viability [4]. Despite this track record, the future promises new and significant challenges. A growing global population means that more food will need to be produced than ever before while relying predominantly on existing resources [5], [6]. Changes to the world’s distribution of wealth, highlighted by Asia’s growing middle class, mean that there is an increasing demand for protein, and other high value and resource intensive foods [6], [7]. Environmental threats including climate change and resource availability [8], [9] make these challenges significantly more difficult to address. It might not be possible to rely on existing technologies and their incremental improvement in this future.

This report is a response to this context of an uncertain world and the role that technology has in it. It is the final report of the Detecting Opportunities and Challenges for Australian Rural Industries project, which is part of Agrifutures Australia’s initiative to anticipate technologies that present potential opportunities and challenges to Australian rural industries. Developing this capability to anticipate technology advancements helps to inform research and development priorities, manage risk, and enhance competitiveness [10]–[12]. With the early identification of emerging technologies, organisations can position themselves to turn potential disruption into new opportunities, as well as mitigate threats that might be a catalyst to failure [13].
In each of the four Horizon Scans that have preceded this final report, a diverse range of emerging technologies were scanned, evaluated and synthesised to assess their potential impact for Australian rural industries. Through this process, a final watchlist of twenty four technologies has been compiled. The first section of this report summarises this watchlist by outlining key categories of emerging technologies that have the potential to impact Australian rural industries. Following this, the potential impacts of the technologies are framed in relation to the five focus areas of Australian rural industries that were identified at the commencement of the project. In doing this, a series of speculative, yet plausible, futures are outlined. These demonstrate how the projected capabilities of the technologies, and their confluence, might impact Australian rural industries in the future. The final sections of this report conclude the project by reflecting on the overall foresight methodology process employed and possible next steps to take.
SUMMARY OF WATCHLIST

During the Horizon Scans, a total of twenty four technologies were identified to offer significant opportunities and challenges to Australian rural industries. In this section of the report, each of the identified technologies has been categorised and assigned to a group to provide an overall picture of the key technology domains that have the greatest potential impact for the Australian rural industries. A brief overview of each technology group's value and future outlook presented. Finally, grouped technologies are plotted on a matrix measuring their potential impact and novelty in the context of Australian rural industries. These values were obtained during iterative Delphi questionnaires that were completed by young and innovative experts working in the Australian rural industries. Measuring the potential impact of a technology in the context of Australian agriculture, and the novelty of a technology compared to what is currently used, provides an indication of the disruptive potential of each technology.
The technologies comprising the data driven group are: Smart Dust, Labour Tracking, Digital Twin, LoRaWAN, Smart Contact Lenses and Augmented Reality.

Data driven technologies will deliver more data and better insights to improve efficiency and decision-making [14]. Today’s prevalence of connected smart objects and sensors make it possible to represent and monitor the performance of complex networks of objects [15]. Over-time, these technologies will trend toward being smaller, more efficient, and more accurate. In some cases, nanoscale sensors will permeate the environment [16]. 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 [14], [17]. Human workers will tap into these data streams with immersive technologies resulting in the blurring of the physical and digital world [18].

Figure 1 plots each of the data driven technologies based on their average impact and novelty ratings given by rural industries experts. Smart dust and LoRaWAN technologies were perceived to have the highest impact by rural industries experts. These ratings reflect two critical needs of Australian agriculture: access to communications infrastructure and the availability of farm data. Developing these capabilities is likely to have significant impact in the rural industries. The high novelty rating of smart dust reflects that it is a speculative technology in very early stages of development.
GENOMICS AND BIOTECHNOLOGY

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

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 [19]. Microbiome analysis is becoming similarly accessible [20]. 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 [19], [21], [22]. 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 [23]. Looking further ahead, advances in genomics and biotechnology present compelling possibilities for future food systems.

Figure 2 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. With CRISPR and plant genome sequencing technologies perceived to be of very high novelty, the results suggest that rural industries experts view these technologies to have transformative potential. This is consistent with views conveyed in the literature.
ROBOTICS AND ARTIFICIAL INTELLIGENCE

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 and Context-aware Computing.

Robotics and artificial intelligence technologies are advancing rapidly. In particular, artificial intelligence has become a key strategy for many technology companies [24]. It is already common for people to talk and give instruction to intelligent devices that can respond in meaningful ways [15]. The development of robotics technology is actively incorporating artificial intelligence technologies, such as computer vision and machine learning, to enhance the capabilities of robots [25]. This will drive new robots that are not restricted to routine and repetitive labour tasks, but that can work collaboratively with humans on increasingly complex work. This collaboration will be the winning formula to provide strategic and creative problem solving, as well as highly efficient and safe working environments [14]. As the future of work takes shape over the coming decades, the technologies covered in this group will be essential in driving the transformation.

Figure 3 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.

Figure 3. Impact - Novelty Matrix for Robotics and Artificial Intelligence Technologies.
BUSINESS MODEL INNOVATION

The technologies comprising the business model innovation group are: Distributed Production and Blockchain.

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 [26]. Although decentralised production won’t replace large and centralised production in the near future [27], [28], decentralised operations have several advantages; they are resource efficient, have shorter supply chains, and are agile [29]. 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 [30]. For agriculture, blockchain promises the capability of transparency and traceability [31], [32]. 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.

Figure 4 plots each of the business model innovation technologies based on their average impact and novelty ratings given by rural industries experts. Both distributed production and blockchain technologies were perceived to be of high impact for Australian rural industries. Moderate novelty ratings suggest that the capabilities that these technologies offer are partially present in agricultural contexts. Opinion in the literature is that blockchain will be transformative in many industries. It will likely emerge as a platform in the rural industries.

FIGURE 4. IMPACT - NOVELTY MATRIX FOR BUSINESS MODEL INNOVATION TECHNOLOGIES
RENEWABLE ENERGY

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

New technology will be the driving force behind a smarter and more reliable energy infrastructure [33]. 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 [33], [34]. These are independent from the main electricity grid, and in many cases are democratically operated by the participants of the microgrid [35]. 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 [33]. 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 [36]–[38].

Figure 5 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 perovskite solar cells and moisture harvesting 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.
ADVANCED MATERIALS

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 [39]–[41]. Beyond improving existing technology, material innovation will bring entirely new capabilities. This is highlighted in 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 [42].

Figure 6 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.

**Figure 6.** IMPACT - NOVELTY MATRIX FOR ADVANCED MATERIALS TECHNOLOGIES
DETECTING OPPORTUNITIES AND CHALLENGES FOR AUSTRALIAN RURAL INDUSTRIES

Determining the disruptive potential of a technology to an organisation first requires the identification of candidate technologies and then defining their functional capabilities [13]. These stages of analysis reflect the key outcomes of the Horizon Scans that preceded this report. With a watchlist of candidate technologies and an understanding of their current and projected functional capabilities previously established, this section of the report looks to develop ideas about the context of their impact for Australian rural industries. Developing this context helps to understand how the characteristics of the technologies align with the critical needs of Australian rural industries. It does not intend to present definitive predictions about the implementation of technologies, but rather plausible relationships between technologies and the needs of Australian rural industries.

The following sections highlight three key areas of the Australian rural industries that the identified technologies have the potential to impact. These areas of impact were established based on the data analysed during each of the Horizon Scan stages, including results generated from interactions with experts working in the Australian rural industries. Each section begins with a brief overview of context. Following this, the technologies that are likely to be of greatest impact are framed in relation to the five focus areas that were identified at the beginning of this project (Appendix B). This includes the presentation of plausible futures that describe technology implementations in the context of the relevant focus areas.
EFFICIENCY AND PRODUCTIVITY

In agriculture contexts, efficiency and productivity are intrinsically linked; productivity growth is often reflected in increases in efficiency [3]. A key driver within this relationship between efficiency and productivity is technology [2]. Technology change and the appropriate adoption of technology pushes operators toward the productivity frontier [1], [43]. The closer to this frontier, the more efficient an operator is with their inputs and processes [1].

While productivity and efficiency have been mainstays of importance in Australian agriculture, there will be an ever increasing importance placed on both factors in the coming decades. Efficiency and productivity are important mechanisms for ensuring market competitiveness [3], and Australian agriculture is fully exposed to international competition in both its domestic and global markets [3]. The intensity of competition on both fronts is likely to increase as shifts in power and capabilities occur in the global marketplace [44]. Australia is also vulnerable to the risks of climate change and declining natural resources [9]. Inefficient use of inputs has negative environmental effects and results in added costs for farmers [45]. It will be essential to deliver consistent improvements in efficiency and productivity to maintain competitive in the future.
FRAMING TECHNOLOGY IMPACTS

Five technology groups were identified to have impact on **efficiency and productivity** in the context of Australian agriculture:

| DATA DRIVEN          | • Smart Dust  
|                      | • Augmented Reality 
|                      | • Digital Twin  
|                      | • Labour Tracking  
|                      | • LoRaWAN  
| ROBOTICS AND ARTIFICIAL INTELLIGENCE | • Collaborative Robots  
|                      | • Context-aware Computing  
|                      | • Wearable User Interfaces  
|                      | • Computer Vision  
|                      | • Human-in-the-loop Machine Learning  
| RENEWABLE ENERGY     | • Perovskite Solar Cells  
|                      | • Sodium-ion Batteries  
|                      | • Solar Retransmission  
|                      | • Moisture Harvesting  
| GENOMICS AND BIOTECHNOLOGY | • Plant Genome Sequencing  
|                      | • CRISPR  
|                      | • Microbiome  
| ADVANCED MATERIALS   | • Programmable Materials  
|                      | • Metamaterials  

The potential impact of these technology groups can be framed in relation to the five focus areas that were identified during the scoping workshop at the beginning of this project (Appendix B). Three focus areas were identified to be potentially impacted by these technology groups:

| A. PRIMARY PRODUCTION INPUTS, PROCESSES AND PRACTICES | • Viable Alternatives to Reduce Costs  
|                                                       | • Genetic Improvement  
|                                                       | • Post-farm gate Consideration  
| D. SUPPLY CHAIN LOGISTICS                              | • Relationships and Connectivity  
|                                                       | • Disruptive Technology in the Supply Chain  
|                                                       | • Optimisation of the Supply Chain  
| E. INDUSTRY SUSTAINABILITY                            | • Environmental  
|                                                       | • Economic  

Two plausible futures are presented on the following pages that highlight the relationships among the above emerging technologies and focus areas of Australian rural industries.
Viable alternatives to reduce costs; Genetic Improvements; Post-farm gate considerations

As the cost and difficulty of finding labour in Australia increases, automation technologies will reach cost parity in many food production processes. On-farm, small-scale robots equipped with computer vision systems will replace and work alongside the existing workforce. These robots will be connected to data collected from in-field sensors and precision agriculture technologies. They will work 24/7 and be able to interpret threats that are likely to affect crops, as well as understand specific requirements of individual plants. This will enable highly efficient use of pesticide, fertiliser and water inputs. On-farm microgrids will fuel these robots and other smart machines as they become more prominent due to electrification.

Efficiency and productivity gains generated on-farm will originate from pre-farm gate research and development and planned production programs. Central to this will be the genetic improvement of plants to be more resistant to pathogens and more tolerant to drought and other effects of climate change. These plants will require less water, fertiliser and pesticide inputs, and result in fewer negative environmental externalities. Precise control over crop trait design will lead to the development of new location specific crops. Availability of these options to farmers will enable accurate planning and yield forecasting, and therefore reduce the financial risks associated with agriculture.
FOCUS AREA D. SUPPLY CHAIN LOGISTICS
Relationships and connectivity; Disruptive technology in the supply chain; Optimisation of the supply chain

Robots, AI and Data Driven technologies will spread throughout the supply- and value-chains to reduce input costs and maximise productivity. Transportation, aggregation, distribution, processing, packaging and domestic supply channels will all incorporate some level of automation and intelligence. As new technology is embedded throughout these stages, inter-process communication will be made possible to ensure the most efficient movement of product. This will reduce the downtime of transportation and processing assets, and it will ensure that transportation shipments are optimised to reduce the number of partially-empty and empty vehicles on the road.

Digitisation of agriculture information and the capacity to share this data will make detailed information available for all stakeholders to improve the efficiency of the supply chain. This has the potential to identify new areas for development and lead to new and disruptive agribusiness ventures. It will be possible for farmers to have live interactions with customers and stakeholders and thus to develop market driven production plans. This abundance of information will reduce market risk, uncertainty and poor decision-making. Reducing these factors will benefit all involved parties and has the potential to support more investment in agriculture ventures.
SKILLS AND KNOWLEDGE

Human resource availability will be a significant factor for the future of Australian agriculture. The present trend in Australian agriculture is an ageing and declining workforce. The median age of farm workers in Australia is currently 48 [46] and there is no indication of where a younger generation of farm workers will come from. There are more workers leaving the industry than are entering it, and the younger generation is not showing an interest in agriculture careers. This is highlighted by a considerable reduction in the number of students studying agriculture qualifications over the last decade [47].

Alongside a declining workforce in Australian rural industries, it is uncertain what the future workforce will look like. It is estimated that 60% of tasks performed in agriculture jobs have the potential to be either fully or partially automated. These include routine and non-routine manual labour, data collection and data analysis tasks [48]. Although there is a strong sentiment that automation will negatively impact labour forces in many industries, there is also a view that automation will create jobs. Importantly for Australian rural industries, these newly created jobs will likely be skill- and knowledge-based [48]–[51]. They will involve close collaboration with automation technologies, at all levels of implementation. Humans will be required to design, program, install, service, repair and interpret autonomous technologies [51]. With the expected pace of technology development, life-long learning will need to be supported by appropriate training and re-skilling opportunities [52].
FRAMING TECHNOLOGY IMPACTS

Three technology groups were identified to have impact on **skill and knowledge** in the context of Australian agriculture:

| DATA DRIVEN                  | • Augmented Reality       |
|                             | • Digital Twin            |
|                             | • Graphene                |
|                             | • Labour Tracking         |
|                             | • LoRaWAN                 |
| ROBOTICS AND ARTIFICIAL INTELLIGENCE | • Context-aware Computing |
|                             | • Wearable User Interface |
|                             | • Computer Vision         |
|                             | • Human-in-the-loop Machine Learning |
| BUSINESS MODEL INNOVATION   | • Blockchain              |

The potential impact of these technology groups can be framed in relation to the five focus areas that were identified during the scoping workshop at the beginning of this project (Appendix B). Two focus areas were identified to be potentially impacted by these technology groups:

| A. PRIMARY PRODUCTION INPUTS, PROCESSES AND PRACTICES | • Information and Skills to Support Decision-making |
| C. ADAPTIVE CAPACITY OF PRIMARY PRODUCERS AND SECTORS | • Leadership to Initiate and Respond to Change    |
|                                                       | • Skills and Knowledge to Implement Change         |
| E. INDUSTRY SUSTAINABILITY                            | • Social License                                    |
|                                                       | • Economic                                           |
|                                                       | • Perception                                         |

Two plausible futures are presented on the following pages that highlight the relationships among the above emerging technologies and focus areas of Australian rural industries.
FOCUS AREA A. PRIMARY PRODUCTION INPUTS, PROCESSES AND PRACTICES
Information and skills to support decision-making

While agriculture has relied on the knowledge of highly experienced individuals, the future will rely on human-technology collaboration to augment the capabilities of a new generation of agriculture workers. Sensor networks and artificial intelligence enabled robotics deployed throughout the farm will deliver data to sophisticated software platforms capable of modelling entire farm operations. Real-time measurement of environmental conditions, input requirements and use, predicted outputs, worker status, and equipment status will allow farm managers and decision-makers to be agile in response to change. With the collection of this data overtime, it will be possible for farmers to run predictive models to inform their decisions before they need to be made.

Workers in the field will collaborate with robotics and artificial intelligence technologies to perform tasks more efficiently. Communication between humans, robotics technologies, and the environment will be seamless. Augmented reality will provide field workers with an in-depth view of equipment and environment status so that they can make more accurate decisions and allocate their attention to where it is needed most. Similarly, Robotics equipped with computer vision and machine learning will be able to organise their tasks around that of human workers and other robotics technologies. There will be passive and active communication at all levels.
FOCUS AREA C. ADAPTIVE CAPACITY OF PRIMARY PRODUCERS AND SECTORS
Leadership and initiative to respond to change; Skills and knowledge to implement change

Technology innovation and digital transformation have the potential to incentivise a new generation of workers and develop new leadership capabilities in Australian rural industries. A younger generation with qualifications in technology fields and an interest in social enterprise will be equipped with the necessary skills to tackle critical issues – many of which relate to the world's food production systems and their capabilities to meet complex global challenges.

Technology innovations will empower the next generation of leaders to push for novel and innovative business solutions. Business platforms built on blockchain will allow for a democratic and cost-effective way for small operators to compete among the big corporations. Cost-effective operations will be powered by small and agile teams of humans and robots. Immersive technologies, such as augmented reality will provide new and engaging ways to connect with and create value for the next generation of consumers.
NEW PRODUCTS AND MARKETS

The world is undergoing rapid change. Climate change and declining natural resources are expected to worsen in the coming decades [9]. A connected society in developed nations is engaged and more informed about these issues than ever before [53]. The ‘experience economy’ is booming and young and affluent consumers are opting to choose lifestyle and quality over cost and quantity [54]. This includes choosing to buy local and sustainably sourced products [55]. Businesses are aware of this shift, and many industries are positioning themselves to address these needs by supplying convenient and customisable experiences [49]. As these become more available to consumers, there will be an expectation that the same level of experience is present throughout their interactions with businesses and organisations [56], [57].

In developing nations, particularly Asia, wealth creation is expanding the middle class. As an expected 1 billion people shift out of poverty, there will be a dramatic increase in food demand, particularly for higher quality produce and sources of protein [6], [7]. While this will create immense challenges for the world’s food systems, it will also provide significant opportunities. In this context, technology innovation can help pursue objectives of product quality, diversity, safety, sustainability and animal welfare [2].
FRAMING TECHNOLOGY IMPACTS

Two technology groups were identified to have impact on new products and markets in the context of Australian agriculture:

<table>
<thead>
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<th>GENOMICS AND BIOTECHNOLOGY</th>
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<td>• Microbiome</td>
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Two plausible futures are presented on the following pages that highlight the relationships among the above emerging technologies and focus areas of Australian rural industries.
FOCUS AREA A. PRIMARY PRODUCTION INPUTS, PROCESSES AND PRACTICES
Genetic Improvements; Post-farm gate considerations

Pre-farm gate innovation is boosted by advances in microbiome, genome sequencing and precise gene editing using technologies such as CRISPR. These technologies expand our understanding of crop and environment traits dramatically. New varieties are designed to enhance the diversity of crops available to farmers. This includes the design of crops suited to growing in Australian conditions but destined for sale in expanding overseas markets. An increased diversity of cash crop varieties are also made available so that farmers can maximise the value of their land between growing seasons.

Post-farm gate, blockchain technologies provide the means to target the emerging global markets while maintaining brand integrity. As food products move through complex global supply chains, each transaction is logged on the blockchain. Transparency of this process enables producers, distributors, sellers and buyers to trace product through the entire process. For producers this ensures that their brand reputation remains in-tact and price in ensured. For eventual customers, this provides the peace of mind that they are getting safe and legitimate food products.
FOCUS AREA B. MARKET AND CONSUMER PREFERENCES

Differentiated products

Gene editing and microbiome technology enable the possibility of designer and personalised foods. These foods are mass customisable and targeted at specific people for very specific requirements. At the top of this list are foods that address the increasing prevalence of chronic diet related illness such as obesity and diabetes. It is possible that the design, production and distribution of these foods become integrated in specialised health services.

Beyond health, emerging technologies such as blockchain and distributed production have the potential to provide novel food experiences to consumers in the experience economy. A highly efficient and agile network of distributed food production systems made up of automated urban farms produce local food and deliver it fresh to consumers. These services target environmentally conscious consumers who are looking for convenient, healthy and sustainable food options. This provides farmers the opportunity to grow value-added niche crops and alleviates the reliance on commodity crops.
REFLECTION ON APPROACH

The format of this project was to conduct iterative Horizon Scans with the purpose of developing a watchlist of emerging technologies that offer potential opportunities and challenges for Australian rural industries. Regular intervals between each Horizon Scan, and the integration of several methodological inputs necessitated their effective management and planning. Therefore, evaluating the effectiveness of the overall process requires reflection on the various methodological inputs and their contribution to each of the stage-gates within the Horizon Scans.

At a macro-scale, Horizon Scans involved scanning information sources from a variety of domains to identify emerging technologies and then understand their applicability to Agriculture contexts. At a more granular level, this process comprised of several stage-gates. Without meeting the outcome requirements of each stage-gate, it would not be possible to move through the Horizon Scan process. In each of the Horizon Scan reports, and included in Appendix A, three primary project streams are identified: discovery, evaluation and consolidation. Each of these streams had specific outcomes to achieve that formed the stage-gates of the project. These will be used as the framework to reflect on the overall process.

DISCOVERY

The outcome of the discovery stream was to develop an initial list of candidate technologies for evaluation. Achieving this outcome comprised the following stage-gates:
1. Identifying experts and compiling the data set
2. Identifying strong and weak signal technologies
3. Interpretation of signals

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. The data mining techniques employed demonstrated significant value and were effective for retrieving signals of emerging technologies in the Twitter data. This effectiveness, to a large degree, was because our data mining technique mitigated the noise present in the data. Noise is typically a major concern associated with using social media data as it can lead to the presentation of many redundant topics [58].

The data mining techniques, while proving to be effective, did require notable human input at different stages of implementation. This included the compilation of an expansive list of target Twitter users prior to implementing the data mining technique. The identification of these Twitter users was achieved by engaging with researchers and industry experts working in the domains we were interested in scanning. These experts provided the names and accounts of reputable Twitter users and accounts 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. For strong signals of emerging technologies, this input was minimal. Trending technologies were easily identified by individual ranking, which was based on the number of times the technology was mentioned in the data. Weak signals, on the other hand, required significantly more human input as they were often present much deeper in the extracted data. 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.

EVALUATION

Having developed an initial list of candidate technologies, the outcome of the evaluation stage was to refine the list of technologies to only those that offer clear opportunities and challenges for Australian rural industries. Achieving this outcome comprised the following stage-gates:
1. Evaluation of technologies' potential impact in rural contexts

2. Narrowing down technologies

The evaluation stage of the project was the first step toward recontextualising the technologies into the rural industries context. Where notable technology reporting groups, such as Gartner and Forbes provide predominantly domain general analysis of technologies, our approach aimed 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.

This recontextualisation required the effective integration of methods based on attributes of evidence, creativity and expertise. Key to this were Delphi questionnaires with rural industries experts who had demonstrable understanding of innovation and technology in agriculture. Delphi questionnaires are an expertise- and creativity-based method which involves iterative and anonymous rounds of questionnaires. After each round, the results are shared amongst participants and they are given the opportunity to revise and expand on their original answers. The purpose of this is to structure a group communication to deal with complex issues [59]–[61]. One of the challenges for this project was structuring effective communication with rural industries experts about technologies they might not be familiar with. Our strategy for this was to maximise the strengths of the expert panel. This was done by developing questionnaire content that encouraged creative outcomes and consideration of the plausible impact that the technologies might have in the agriculture domain, which the experts have detailed knowledge of. We then relied on evidence-based methods, data mining and literature review, to explore other aspects of the technologies' feasibility. This included breadth of applications, innovation trends and forecast. Combining each of these approaches proved to be effective for narrowing down the list of candidate technologies.

CONSOLIDATION

The outcome of the consolidation stream was a final list of technologies offering potential opportunities and challenges to Australian rural industries, accompanied by supporting written and visual content. Achieving this outcome comprised of the following stage-gates:

1. Evaluating the technologies' potential applications in the rural industries

2. Synthesis of findings

3. Visualisation of findings

Just as the evaluation stage required integration of methods with attributes of evidence,
creativity, and expertise, so too did the consolidation stage. Data mining was effective for exploring the application potential of each technology. As our previous dataset obtained from Twitter contained little information about how the technologies are used, we used each technology name as a topic of interest to scan patent databases. This approach allowed us to explore and understand the broad range of applications each technology was being developed for. Literature reviews were used to support and validate these outcomes.

The outcomes of the data mining and literature reviews were used as content for the second round Delphi questionnaires with rural industries experts. Open ended questions were used to elicit the experts' opinions about how the technology applications might transfer to rural industries, and to provide specific examples of these applications. This process facilitated the development of creative content to explore plausible applications of the technologies. It also served as a method for evaluating the efficiency of the data mining framework. Specifically, if our methodology was able to accurately and efficiently capture sufficient detail to explore technology applications, and link in with the other aspects of the methodology. The final stages of the consolidation stage were focused on bringing together each of the inputs, including literature, questionnaire and data mining inputs. This comprised of writing up technology overviews, and visualising data from Delphi questionnaires and data mining outcomes.

**FINAL METHODOLOGY STATEMENT**

The effectiveness of our methodology was predicated on the capability to first detect emerging technologies from a range of different industries, and then through systematic assessment, reposition and imagine those selected technologies in an Australian rural context. For effective technology foresight of this kind, is important that the approach taken can account for the inherent complexity of researching and anticipating technologies of the future [11], [12], [62], [63]. Our approach recognises this complexity by incorporating a mix of foresight methodologies that provide balance and ensure that no one method is dominant. This allows the short comings of any single method to be covered by the strengths of the accompanying methods [12], [62]. In doing this, we have demonstrated the capability to adapt to short-term trends that occur in technology contexts, and then validate and extrapolate the findings by testing them amongst the broader literature, and with experts working in the context of inquiry. While this method has been employed to inquire about technology trends, it is expected to be transferrable for the scanning and synthesis of other topics and trend areas.
CONCLUSION

Technology driven disruption is expected to experience exponential growth in the coming decades [4]. With this, many existing industries will be transformed and entirely new industries will be created [13]. Technologies with these transformative capabilities are of great relevance to Australian rural industries. Development and access to advanced agriculture technology has resulted in efficiency gains by decreasing inputs and maximising outputs [1], [2]. The adoption of new innovations therefore plays a key role in increasing farm productivity, profitability and competitiveness [3]. In the past, Australian agriculture’s strong track record of technology integration has been a key part of ensuring its long-term productivity and economic viability [4]. Despite this track record, the increasing speed of technology innovation and the emergence of significant global and domestic challenges makes the scanning and identification of high impact technology a priority for Australian rural industries.

The Detecting Opportunities and Challenges for Australian Rural Industries project has recognised this priority and has developed a capability to anticipate key technology advancements through their early discovery, evaluation and synthesis. The resulting outcomes have been presented in three iterative Horizon Scans. Each Horizon Scan has employed a novel methodological approach involving the interaction of data mining, literature review, Delphi questionnaires and visualisation methodologies. The effectiveness of this approach has been demonstrated in its capability to first detect emerging technologies from a range of different industries, and then through systematic assessment, reposition and imagine those selected technologies in an Australian agriculture context.
This report consolidates the work that has been completed over the duration of the project, and in doing so presents opportunities and next steps for future work. The first section of this report has provided a summary of the watchlist of emerging technologies by outlining six technology domains that have potential impact for Australian rural industries. Building on this watchlist and summary, the second section of this report has framed the potential impact of the identified technologies in relation to five focus areas of Australian rural industries. The discussion of potential technology impacts in relation to these focus areas has shown plausible relationships between emerging technologies and the critical needs of Australian rural industries. Moreover, the discussions have focused on exploring technology confluence rather than isolated applications of technology. Technology confluence has long been considered an important driver of innovation [64]. The plausible futures discussed in this report illustrate the significant potential of technology confluence in the context of Australian agriculture and the effect that it might have if developed effectively.

The notion of technology confluence and its capability to address the future challenges of Australian rural industries is where the future direction of this work lies. Although technology confluence is cited as something that often happens without planning, it is possible to foster and prepare for it with appropriate management and an interdisciplinary approach [64]. This process has already begun with the preparation of a parallel report that outlines potential technology-driven agriculture industries that have the capabilities to address the future challenges facing Australian rural industries.
REFERENCES


APPENDIX A: APPROACH AND PROJECT STREAMS

This project employs a concurrent phase, iterative methodology to:

1. scan and extract data from a variety of sources;
2. synthesise this information to identify potential trends and innovations for further investigation;
3. and, communicate these 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. These inputs from each phase, and their interactivity is represented in Figure 2.
DISCOVERY

Discovery focuses on scanning selected sources to extract relevant data and detect signals of emerging and transformative technologies. Data sources are strategically selected to ensure input from a diversity of domains within an international context. In the current implementation of the discovery stream, sources included select twitter users, patent databases, industry and market reports, and technology news media. Scanning of these sources employs data mining and synthesis concurrently:

- Data mining focuses on scanning the twitter feeds of thought leaders and technology experts in a range of technology and industry domains. These are selected based on the recommendations of QUT experts working in relevant technology domains.
- Synthesis focuses on scanning a broad range of technology news publishers, industry and market reports, and patent databases.

The confluence of data mining and synthesis outputs in the discovery stream results in a list of technologies for further investigation in the subsequent evaluation and consolidation streams.

EVALUATION

Evaluation focuses on filtering the signals identified in the discovery stream. Its implementation leverages expertise from QUT, and Agrifutures Australia through the provided list of innovative farmers, to assess the potential impact of a broad range of emerging technologies. This process uses Delphi style surveys which are deployed in successive rounds.

The initial round of surveys focuses on evaluating a large volume of technologies identified in the discovery stream. This is achieved through presenting a series of simple statements that describe the functionality of a technology, and asking for a rating based on its perceived impact. From these ratings, a shortlist of technologies is compiled for further investigation and ongoing monitoring. Successive survey rounds present a lower volume of questions but require increasingly qualitative responses. It is through this process that we narrow the scope of technologies that are included on the watchlist and that will be monitored throughout future reporting periods. As the evaluation stream progresses, we continue to develop an objective list of criteria to establish the possible scale of impact of each transformative technology. These criteria are re-introduced in successive discovery stages of the project to assist with filtering the large volume of data.
CONSOLIDATION

Consolidation focuses on monitoring technologies on the initial watchlist, and providing a detailed analysis of their potential impact for Australian rural industries. This involves a detailed analysis of the technologies' potential impact for Australian rural industries and developing a rationale for why they should be monitored. This consolidation stream utilises both data mining and synthesis to receive input from a broad range of data, and gain the requisite detail.

Data mining focuses 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 targets social media feeds and patent databases. The outcome of this stage provides assessment of candidate technologies based on metrics such as trends over time, associated keywords and industries to identify the contexts in which the technology is active and where it is receiving innovation, and location.

The data gained from this stage of data mining, and from the evaluation stream, feeds into and directs synthesis. With this direction, synthesis can focus on specific applications and implementations of the technology to better understand and communicate its potential impact for Australian rural industries. Visualisation is then used to bring together the inputs of synthesis and data mining, as well as inputs from the evaluation stream. This includes the development of infographics and scenarios to communicate the watchlist issues and themes.
APPENDIX B: FOCUS AREAS AND SUB-FOCUS AREAS

The following are the focus areas and sub-focus areas identified during the workshop attended by stakeholders of Australian rural industries, held on August 15, 2016.

A. PRIMARY PRODUCTION INPUTS, PROCESSES AND PRACTICES
1. Information and skills to support decision making
2. Natural resources and other input costs
3. Viable alternatives to reduce costs (including practices)
4. Genetic improvement
5. Post-farm gate considerations

B. MARKET AND CONSUMER PREFERENCES, TRADE REQUIREMENTS
1. Geopolitical landscape
2. Market characteristics (consumer preferences, size, affluence, access, intel)
3. Differentiated products – new and premium (safety, social responsibility, brands, nutrition, provenance)
4. Commodity (exchange rates, supply, capacity, products, waste)

C. ADAPTIVE CAPACITY OF PRIMARY PRODUCERS AND SECTOR
1. Leadership to initiate and respond to change (organisation, individual)
2. Skills and knowledge to implement change
3. Access to capital and financial tools
4. Regulation (encourage enabling regulation)
5. Organisational capacity to deal with change (structures, culture)

D. SUPPLY CHAIN LOGISTICS
1. Relationships and connectivity
2. Market intelligence
3. Degree of vertical (degree of complexity in the value chain)
4. Disruptive technology in the supply chain
5. Optimisation of the supply chain (supply chain efficiency, cost reduction)

E. INDUSTRY SUSTAINABILITY – SOCIAL, ENVIRONMENTAL, ECONOMIC
1. Social license (wellbeing, ethical employment, infrastructure, services, health)
2. Environmental (climate change mitigation, adaptation, opportunities, dealing with variability, endemic and exotic threats)
3. Economic (infrastructure, energy, transport, labour, profitability)
4. Perception (domestic and global) and policy (how industry is perceived and repercussions)