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EXECUTIVE SUMMARY

Horizon Scan 5 is the fifth in a series of reports that contribute to the watchlist of emerging technologies compiled during the completed Detecting opportunities and Challenges for Australian Rural Industries project. In addition, the technologies in this Horizon Scan have also been selected based on their potential to facilitate new technology based agriculture industries. Given this, eight emerging technologies have been identified and are outlined in this report. They span several domains, including additive manufacturing, neuroscience, tissue engineering and cellular biology, data analytics, behavioural psychology and robotics.

HUMAN 2.0

Human 2.0 is a set of technologies that are used to augment the emotional, physical and social capabilities of humans. They typically involve direct augmentation to create a synthesis between human and machine. Two human 2.0 technologies have been identified. Physical Human Augmentation is facilitated by assistive devices, often referred to as exoskeletons. Augmentation can include enhancing strength, endurance, and the capacity to work in challenging environments. Brain-computer Interfaces allow humans to communicate directly with a computing device by collecting human brain signals and translating them into digital signals. They have been used to restore function to disabled people and more recently are being developed for commercial applications that extend on human capabilities.
ENTERPRISE BEHAVIOURAL ANALYTICS
Enterprise behavioural analytics applies the principles of behavioural economics to understand customer and stakeholder interactions, and provide better experiences to these groups. Two emerging enterprise behavioural analytics technologies have been identified. Customer Journey Analytics employs qualitative and quantitative data to track customer interactions across multiple business channels. They are used to understand the experiences of different customer groups, and tailor products to them accordingly. Emotional Analytics employs data from human physical and physiological responses to understand the emotional characteristics of consumers. This is used to enhance customer experience and facilitate meaningful engagement.

DRONE DELIVERY
Drone Delivery is the delivery of commercial goods using drones. This is currently being explored as a same-day delivery service of small goods using quad- or multi-copter configurations over short distances. However, larger drones capable of greater distances are being developed. One of the strongest applications of drone delivery is in optimising last-mile delivery. For this application, drones are used alongside traditional ground transportation to simplify the last stages of delivery and significantly reduce the associated costs.

METAL 3D PRINTING
Metal 3D Printing technology is based on existing 3D printing techniques, however, uses metal feedstocks and is capable of producing fully functional end-use parts. Metal 3D printing is currently applied for specialised applications in technical industries, such as aerospace. As the technology becomes more accessible, however, metal 3D printing has the potential to facilitate distributed, on-demand and custom part manufacturing for a range industries that use heavy machinery and mechanical equipment.

CELLULAR AGRICULTURE
Cellular agriculture is the production of meat and other agriculture products using cell culturing techniques. It has gained significant interest as it has the potential to improve animal welfare and substantially decrease the environmental effects of meat and animal product production. There are two main approaches being developed for cellular agriculture. Tissue engineering based cellular agriculture involves extracting cells from an animal and culturing those cells in a bioreactor to produce animal meat. This meat can be processed so that it replicates the textural characteristics of popular meat products and cuts of meat. Fermentation based cellular agriculture does not require animal cells, and instead uses yeast that is genetically modified to produce the essential organic molecules that are contained within different animal products. Through processing and mixing with other ingredients, these molecules are used to form replicas of animal products such as milk, egg whites and leather.
INTRODUCTION

This project is a partnership between AgriFutures Australia and Queensland University of technology that extends on the Detecting Opportunities and Challenges for Australian Rural Industries project, completed in February 2018 [1]. Given the relationship to the previous project, this Horizon Scan implements the previously established approach for the discovery of emerging technologies and the synthesis of information to determine their potential impact in Australian rural industries. An outline of the approach is provided in the Appendix. Using this approach in the previous project, four Horizon Scans were completed which led to the identification of twenty four emerging technologies. These formed a watchlist of emerging technologies determined to have the potential to impact Australian rural industries. This watchlist was subsequently used as a starting point for the current project, Horizon Scanning – Opportunities for New Technologies and Industries, and led to the proposal of ten new agriculture industries that have the potential to emerge in response to or using new technologies [2]. This Horizon Scan has been designed to further expand the existing watchlist of emerging technologies for Australian rural industries, which in turn, will provide key information from which to identify and propose additional new technology based agriculture industries in later project milestones.

In each of the reports delivered during the previous Detecting Opportunities and Challenges for Australian Rural Industries project, the importance of technology confluence was been emphasised. This trend continues with the technologies reported
on in this Horizon Scan report. The eight technologies presented in this report each present opportunities from which to develop new industries and enhance existing industries. Moreover, several of the technologies presented in this report provide further support for the potential development of the ten new technology based agriculture industries outlined in the Emerging Industries – Agriculture and Technology report [2]. This report begins by outlining the relationship that the identified technologies have to these previously reported new industries, as well as their contribution to potential new industries. Following this, each of the identified technologies are outlined, including infographics and scenario images that outline technology trends, potential technology confluence and potential applications in Australian rural contexts.
This report presents eight emerging technologies, which through a process of discovery and synthesis, have been evaluated to be of potential impact to Australian rural industries. The presented technologies span several domains, including additive manufacturing, neuroscience, tissue engineering and cellular biology, data analytics, behavioural psychology and robotics. As the technologies presented in this Horizon Scan are situated in the context of investigating new technology based agriculture industries, they can be positioned in two ways:

1. Providing additional support for the new technology based agriculture industries that were identified in the Emerging Industries - Agriculture and Technology report [2].

2. Contributing to the identification of additional new technology based agriculture industries not yet reported on.

While these two options provide two distinct positions, it is possible that the technologies presented in this report are positioned to both support already identified industries and to inform new industries that have not yet been identified. Figure 1 summarises the position that each of the technologies presented in this report has been evaluated to have. As with previous Horizon Scan reports, each technology is presented on a single page explaining current applications and forecast. Infographics communicate the potential impact of the technology for rural contexts, as well as temporal and geographical trends of the technologies based on patent data, if available. Illustrative scenarios have been included for select technologies to further communicate potential applications in Australian rural industries and technology confluence.
Figure 1. Identified technologies and their relationship to emerging agriculture industries and opportunities.
Human 2.0 refers to a set of technologies that augment human potential [3]. The term has been used for over a decade by MIT media lab researchers (www.media.mit.edu) to describe technologies that augment the emotional, physical and social capabilities of humans. In recent years, rapid progress has been made with these technologies[4]. In previous Horizon Scans, various technologies have been presented that enhance human capabilities through human-machine collaboration. These have ranged from zero-touch interfaces that allow humans and machines to collaborate through natural language and gestural type interactions [5], [6], to technologies that learn from humans to develop autonomous decision-making capabilities and extend on cognitive abilities [7]. In this Horizon Scan, Human 2.0 covers technologies that create a synthesis between human and machine through direct augmentation. Through augmentation, the machine becomes an extension of human ability that can enhance human physical and cognitive performance [3].

In the following subsections, two Human 2.0 technologies are presented: physical human augmentation and brain-computer interface. These represent two key Human 2.0 technologies that are at different stages of development and implementation, and are capable of augmenting different aspects of human performance.
HUMAN PHYSICAL AUGMENTATION

Augmentation of human physical capabilities is achieved using assistive devices, commonly referred to as exoskeletons. These devices can be complex and electrically powered or they can be unpowered and passive [8]. Their purpose is to augment human performance using machine strength and precision [9].

APPLICATION

Many augmentation device makers began making devices to assist with human rehabilitation. Recently, however, there has been a shift toward commercial applications [10]. Work environments in which humans can benefit from increased strength, endurance and resilience are of most relevance [8], [11]. Suitable for military contexts, MIT researchers have developed a lower leg exoskeleton using actuators that apply assistive torque to the ankle joint. The exoskeleton reduces the metabolic power required to walk (equivalent to reducing a carrying load of 23kg by 30%) [11]. For manual work contexts, Ekso (eksobionics.com) and SuitX (suitx.com) offer passive exoskeletons to assist the performance of physical tasks. Ekso's exoskeleton uses counterweights and sprung arms, which allows workers to lift objects and tools well beyond their normal capabilities [12]. SuitX's LegX, TorsoX and ShoulderX form a modular system that can be used individually or together to: assist lifting heavy objects (LegX), reduce gravity-induced forces for working on overhead tasks (ShoulderX), and reduce pressure on the lower back (BackX). Sarcos' (sarcos.com) Guardian GT is a dual-arm force-multiplying robotic system that mirrors the operators arm movements. It can lift up to 454kg and perform highly dextrous tasks. Sarcos is also developing powered human-worn exoskeletons (Guardian XO and XO max), which aim to extend human capabilities and work sessions in a variety of physically demanding and high risk work contexts [10].

FORECAST

Many industries are redesigning work to facilitate automation and improve process efficiency [13]. Effective collaboration between humans and machines will be essential in these automated contexts [14]. In a move toward this, Sarcos has formed X-TAG (Exoskeleton Technical Advisory Group) in 2018, which is participated by executives from BMW, Caterpillar, GE and other leading industrial companies. This suggests the push for commercial human augmentation devices is gaining traction [10]. Major obstacles for human augmentation devices to overcome will be adequate power storage and providing meaningful enhancements that justify the high costs [8].
BRAIN-COMPUTER INTERFACE

A brain-computer interface (BCI) provides a direct link between a computing device and the human brain and nervous system [4]. BCIs work by acquiring human brain signals, analysing them, and translating them into meaningful commands that can be understood and performed by a computing device [15], [16].

APPLICATION

The first BCI was implanted into a human in 2004 [17]. Throughout their development, BCIs have primarily been intended for replacing or restoring function to people disabled by neuromuscular disorders [15]. For example, Case Western scientists have given a paralysed man control of his arm by linking his motor cortex to a computer that electrically stimulates muscles in his arm [4].

The recent emergence of transformative digital technologies has been a catalyst for interest in commercial application of BCIs for enhancing human capabilities. The integration of BCIs with platforms such as virtual reality, augmented reality and the Internet of Things offers the potential for real-time control of objects within virtual and physical environments [16], [18], [19]. For example, electroencephalogram (EEG) technology can measure humans' error responses, which can then be used to provide basic feedback to automated technologies. Similarly, passive EEG signals can be used to differentiate between alertness and fatigue, which can be applied for improving safety in high risk environments [20]. As technology becomes more intelligent, BCIs are projected to optimise the interoperability of humans and machines [19]. This position is held by Neuralink and Kernel, both new companies developing advanced neural interfaces. Bryan Johnson, Kernel’s CEO, believes that BCIs will provide people with the capacity to realise the potential of artificial intelligence [4].

FORECAST

BCIs are shifting from the laboratory to commercial applications [4]. Although excitement surrounds commercial BCIs, many challenges must be overcome. Most significant of these is the issue of accurately interpreting the intent behind brain signals [16]. Non-invasive techniques, such as EEG, have difficulty picking up high resolution brain signals. Although companies including Facebook [21] and CTRL-Labs [22] have clear intentions to develop minimally invasive BCIs, the only current method reliable enough for high level applications is implants that directly interact with neurons. These are invasive, pose risks to users, and are subject to complex regulatory approval processes [22].
HUMAN 2.0
HUMAN AUGMENTATION • BRAIN-COMPUTER INTERFACE

EXPERT OPINION

Experts were surveyed and asked to rate the impact of Human 2.0 technologies on a 5-point scale. On average, applications of brain-computer interfaces were perceived to have high potential impact for Australian rural industries. In comparison, technology used for augmenting human physical and sensory capabilities was evaluated to have only moderate potential impact for Australian rural industries.

The ability to acquire human brain signals and turn them into useful commands for controlling machines
Augmentation of intellectual abilities that allow humans to communicate neurologically with computer devices
Enhancement of human physical capabilities through the use of wearable devices, such as exoskeletons
Augmentation of human senses through the use of implants or wearable devices

INNOVATION TRENDS

Innovation of brain-computer interface technology has been more extensive than human augmentation technologies. Analysis of number of patents published by country identifies that the vast majority of patents have been published in the USA for both technologies.

Analysis of number of patents published per year shows an increase in the innovation of brain-computer interface technology from 2014, and steady innovation since quarter 3 in 2015. Human augmentation technologies have had consistently few patents published over the past several years.

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HUMAN-MACHINE CONTINUUM

The use of technology to augment human capabilities has been a central practice of humans throughout history. The mechanisation of industry is a prime example of human augmentation in the pursuit of efficiency and productivity gains. As many industries move beyond mechanisation and toward automation, the optimal design of future work will seamlessly integrate human and machine workers to take advantage of the strengths of each. This collaboration will be facilitated by developing and integrating effective human-machine technologies. The Human 2.0 technologies presented in this section of the report extend upon the human-machine technologies that have been reported on throughout this series of Horizon Scans:

- Human-machine Interfaces: Natural Language Interfaces, Wearable User Interfaces
- Ambient Intelligence: Context-aware Computing, Collaborative Robots
- Cognitive Computing: Human-in-the-loop machine Learning, Computer Vision

These technologies can also be linked to other reported technologies that blend the digital and physical worlds, creating a channel for interacting with smart machines:

- Augmented Reality
- Smart Contact Lenses

Each of these technologies, including the Human 2.0 technologies, are positioned to improve collaboration between humans and machines. Some technologies are ready to be, and indeed have already been, implemented. Others are building toward commercial use, while some are only in early stages of development and it will likely be some years before they can have commercial impact. This infographic demonstrates some of the relationships between the current and previously reported human-machine technologies relative to a time-line of their potential application.
HORIZON SCAN 5

TRANSFORMATIVE TECHNOLOGY

- Human physical augmentation
- Conversational interfaces
- Digital twin
- Augmented reality
- Collaborative robots
- Human-in-the-loop machine learning
- Brain-computer interface
- Full automation
Enterprise behavioural analytics is based on the principles of behavioural economics, which aim to understand human behaviour through integrating insights from psychology, judgement and decision-making, and economics theory [23]. Using data generated through business interactions, enterprise behavioural analytics aims to understand consumer and stakeholder behaviours to better facilitate customer experience and engagement. This approach is increasing in prominence as digital business develops and digital platforms, such as the web and mobile, become the dominant channels for business and customer interaction [24].

In the following sub-sections, two enterprise behavioural analytics technologies are presented: customer journey analytics and emotional analytics. These are enterprise behavioural analytics technologies that are currently in early stages of use, and are expected to grow as the technology is refined and as digital business environments develop more integrated ecosystems.
CUSTOMER JOURNEY ANALYTICS

Customer journey analytics combine qualitative and quantitative data to track and analyse customer interactions at various touchpoints across all possible channels of a business [24], [25]. This includes interactions with both humans and automated systems, as well as one way interactions and those mediated by third parties [24]. Through gathering, collecting and visualising customer journey data, businesses can map out an integrated view of the customer and generate insights about their behaviour. These insights can be acted on in real-time and be used to predict future customer behaviours [25].

APPLICATION

Insights gained from customer journey analytics are applied to enhance customer experience and engagement, and boost operations efficiency [24], [25]. Implementation is particularly valuable for digital commerce, marketing, IT, product management, customer service and user experience teams within a business [24].

In digital business environments, customer interactions are time-based, and occur continuously across many and varied pathways. When these continuous interactions are mapped as pathways over time, insights can be gained [26] about distinct customer groups, new trends and how journeys change over time [27]. In addition to leading to better customer experiences [24], [27], insights can be used to influence customer decision journeys [26]. The customer decision journey refers to the life cycle of a customer, starting from initial trigger interaction to post-purchase events including enjoyment and loyalty [26]. With successful application of customer journey analytics, business strategies can be devised to improve customer retention, offer personalisation of service, and adapt to changing consumer trends [24], [26].

FORECAST

Customers no longer engage in simple interactions with businesses. They are participants in the experience economy and seek value and engagement from brands [28]. As digital experiences continue to grow, businesses will need to tailor experiences to ensure that customers are engaged at the right stages of the journey [24], [26]. While the benefits of customer journey analytics are acknowledged, widespread adoption is still some years away [24]. Part of the reason for this is the difficulty of tracking customer interactions that occur in siloed parts of the journey [24]. However, as more businesses and industries undergo digital transformation, customer journeys are likely to become easier to track [25].
EMOTIONAL ANALYTICS

Emotional analytics is a type of data analytics that focuses on analysing and understanding human emotions [29]. Emotional information, including mood, attitude and personality, are conveyed by physical and physiological characteristics. These can be captured as data from indicators such as heart rate, muscle activity, physical interactions, speech and text [30].

APPLICATION

Emotional analytics has current applications for improving health and wellbeing. Using medical records data, a research group from the Vanderbilt University Medical Centre has developed an algorithm that can detect whether mental health patients will attempt self-harm with an accuracy of over 80% [31]. Facebook is developing similar algorithms that scan user posts and flag any users showing signs of poor mental health that might lead to more severe consequences [32].

The technology also has commercial applications. Neuroscience has shown that emotional sub-conscious processes are triggered much faster than deliberative conscious processes. The standard quantitative data analysis methods used by business do not often capture this emotional level. Capturing data at this level helps to better understand and influence people's behaviour [33]. Emotion-driven behaviour can help determine the likeability of a product offering for a particular consumer group, and then be used to better target products at that group [34]. For example, Dolby is implementing emotional analytics to improve its products and enhance customer experience. Their team of neurophysiologists use electroencephalogram (EEG) caps, heart rate monitors, biosensors and thermal imaging to analyse people's biophysical and emotional responses to identify characteristics of entertainment that are most engaging. This information is used to improve their products and enhance the experiences of the audience [35].

FORECAST

Embedding emotional analytics into mobile platforms will create new dimensions of interactions with customers [29]. Businesses looking to adopt a data-driven business model must take steps to engage with and understand customer emotions [33]. As digital and automation technologies become more prominent in business, emotional analytics will play a greater role in mediating human-computer interactions. The technology will move beyond customer insights and will help computers and robots have more natural, affective and complex interactions with humans [36].
**EXPERT OPINION**

Experts were surveyed and asked to rate the impact of enterprise behavioural analytics technologies on a 5-point scale. On average, customer journey analytics was perceived to have very-high potential impact for Australian rural industries, while emotional analytics was perceived to have moderate potential impact. Unanimous favour was shown toward end-to-end understanding of customer interactions and its implementation to facilitate value and personalisation.

Understand human emotional responses under a variety of circumstances to provide tailored products and services

Understand customer moods and attitudes toward products and services

Data of the interactions that customers, processors, wholesalers and retailers have with all aspects of a business

Data to assist personalising products and services to create value-added and customer-centric experiences

**INNOVATION TRENDS**

One implementation of enterprise behavioural analytics is identifying specific customer segments and understanding the interactions they have with a product through the various channels in the supply chain. For example, gaining detailed insights into the interactions that premium and convenience customer segments have with wine can identify new opportunities to better engage with those customers and provide valuable experiences. It could be possible to identify when and why customers move between segments, and develop product offerings to facilitate movement to preferred customer segments.
DRONE DELIVERY

Drone delivery is the use of drones (unmanned aerial vehicles) for the delivery of goods. The drones used for this purpose are usually four- or eight-rotor copters. However, other types of drones exist: fixed-wing drones resemble single wing planes, and fixed-wing hybrid drones share features of both fixed-wing drones and multi-copter drones. Each configuration has benefits and limitations in terms of payload capacity, range, flight distance, flight speed and efficiency [37].

APPLICATION

Several companies are exploring drone delivery programs to provide on-demand and same-day delivery of goods; Amazon, Google, UPS and DHL are among the largest [37], [38]. Compared to ground transportation, drones have the potential to reduce the cost and time of parcel delivery. Drones are inexpensive to maintain, well equipped for autonomous delivery, and not restricted by road infrastructure [39]. While beneficial in these ways, drones have several challenges to overcome before they are a viable logistics method [37], [39]. Most multi-copter drones currently being trialled are limited to a payload capacity of 5-10kg and flight time of 15-30 minutes [37]. With such restrictions, deliveries over long distances will require way stations at regular intervals and integration with existing air, land and sea transport [37], [38].

Drones have received considerable interest as a solution for last-mile delivery. Last-mile delivery, which is the final stages of delivery, is highly problematic and costly. For business to customer deliveries, last-mile delivery often reaches or exceeds 50% of the total delivery cost [40]. UPS claims that cutting off the last-mile of a delivery from their 60,000+ fleet of trucks could lead to savings exceeding US$50 million [41]. One drone-based last-mile delivery solution being explored by US startup, Workhorse, is HorseFly. These are small drones that launch from trucks and carry small packages the last-mile [42]. UPS and Amazon are testing similar configurations [41], [43].

FORECAST

Drone delivery technology is already here [41] and is set to launch a new industry [37]. Initially, the focus will be on short distance deliveries and will integrate with existing transportation methods [37]. As the technology improves, capabilities will expand. Drone manufacturers, such as EHang (ehang.com), have conducted test-flights of autonomous drones that can transport single passengers up to 16 km. Beyond technology, the speed at which drone delivery services develop will be dependent on regulations [40], [41]. Work is underway in Europe and the USA to develop tracking systems for commercial drone operations in urban areas [38], [44].
**DRONE DELIVERY**

**EXPERT OPINION**

Experts were surveyed and asked to rate the impact of drone delivery technology on a 5-point scale. On average, responses show that drone delivery is perceived to have moderate to high potential impact for Australian rural industries. Collection and transportation of goods to and from remote areas and other locations was rated highly. Improving efficiency in the supply chain was rated to have slightly lower potential impact.

**INNOVATION TRENDS**

Continued development of drone technology, especially in the areas of battery technology, will lead to longer flight times and further distances travelled. This will increase the future viability and reliability of the technology for both short and long distance delivery.

As the technology does develop, it will be essential to provide good integration with existing supply chain infrastructure, such as ground transportation, while also building new infrastructure, such as warehousing and waypoint facilities. These integrations will be essential for last-mile drone delivery in remote areas.

- Lightweight drones for short distance delivery from local warehousing
- Fixed-wing and hybrid drone designs for longer distances
- Lightweight drones integrated with existing transport services for last-mile delivery

Drones or other autonomous vehicles that can collect and transport goods to various locations
Improving transport efficiency between links in the supply chain
Automated delivery of supplies to remote operations
Metal 3D printing follows the same principles as other 3D printing technology. Material is deposited on a build platform in successive layers to create a 3D object. Metal 3D printing uses two primary approaches: i. Material deposition, where metal feedstock is deposited as a powder or filament and undergoes rapid melting and solidification [45] to bond layers [46], [47]; ii. Powder bed fusion and binding, where layers of metal powder are deposited onto a build platform, and metal that makes up the part is either sintered using a heat source [47], [48] or bound using an adhesive [46], [48]. Both processes generally require post-processing stages to create final parts.

**APPLICATION**

Metal 3D printing can produce functional end-use metal parts [49]. This, combined with the customisation possible with 3D printing [50], [51] is driving the applications of metal 3D Printing. Metal 3D printing is having significant impact in limited run and highly complex part production. Aerospace companies, including GE Aviation, Boeing, Airbus and Relativity Space, use metal 3D printing to manufacture engine parts that reduce assembly complexity, significantly reduce part weight, and deliver performance and efficiency gains [50].

Continued improvement of Metal 3D printing technology has the potential to alter industry business models. Short term, on-demand manufacturing of parts will be possible to reduce standing inventory and operating costs. Long-term, there could be a shift away from centralised mass-manufacturing centres to small distributed manufacturers that can adapt to customer and industry needs [51], [52]. Distributed manufacturing allows manufacturers to be closer to demand, thus reducing supply chain complexity. This is particularly relevant in remote or challenging environments where traditional supply-chains are inconvenient and expensive [51].

**FORECAST**

Metal 3D printing is projected to be a $12 billion global market by 2028 [53]. Scenario planning approaches are being used by various industries to explore potential impacts [51]. There have been two persistent trends that 3D printing has followed in the past: i. the technology continues to improve; and ii. the cost of the technology continues to decrease [49]. This has held true for metal 3D printing. Although the cost of metal 3D printers often ranges from $1,000,000 to $5,000,000 [54], recent innovation challenges this. MarkForged (markforged.com) and Desktop Metal (desktopmetal.com) both offer systems at the $100,000 mark, and have received backing from companies including Google, BMW, Ford, Porsche and GE [55], [56].
**METAL 3D PRINTING**

**EXPERT OPINION**

Experts were surveyed and asked to rate the impact of metal 3D printing technology on a 5-point scale. On average, responses show that metal 3D printing was perceived to have very-high potential impact for Australian rural industries. Highest rated was the capability to print fully-functional replacement parts, and to repair damaged equipment to minimise unplanned breakdowns and downtime. The design and printing of customised parts was rated slightly lower.

**INNOVATION TRENDS**

As metal 3D printing technology improves and becomes more accessible due to lower cost technology, it will become viable for part production in a range of industries. In particular, it can provide opportunities for large operations to vertically integrate maintenance services for large equipment fleets. As a service, 3D printing facilitates distributed manufacturing of parts. Manufacturing can be done on demand and closer to operations in remote areas. This provides the opportunity to increase rural infrastructure and employment, while significantly reducing part lead times and operation downtime.

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On-site fabrication of fully-functional replacement parts for damaged equipment
On-site customisation of equipment parts to make them more suitable to specific environmental conditions
Rapid equipment repair capabilities to minimise equipment breakdown and downtime

Very low impact
Very high impact

Replacement parts manufactured on-site and on-demand
Agile replacement of damaged parts to reduce unplanned equipment downtime
Drone delivery and metal 3D printing technologies are similar in that they exist within digital business ecosystems that have the capacity to enhance organisational flexibility and agility. One such ecosystem is referred to as the Digital Thread [57], and it is leading the confluence of 3D printing with other emerging technologies, including artificial intelligence, data analytics and the Internet of Things. Digital Thread is based on Digital Twin technology, which we have previously reported on in Horizon Scan 2. A Digital Twin is a digital representation of a physical product generated from a software model that incorporates sensor data, product specification, material properties and other associated information [5], [58], [59]. Digital Twins can be used to simulate and make predictions about future equipment operation and implement predictive maintenance [5]. This has the potential to mitigate losses associated with estimating and scheduling planned equipment downtime [60].

Digital Thread extends on Digital Twin technology by providing a data-driven architecture that connects elements of a whole product’s lifecycle [61]. This includes data from all organisations, devices and contexts that the product interacts with, even if they are traditionally siloed [58]. The purpose of this is to have a framework that can draw together important information and allow for products to be monitored in increasingly complex digital environments [62]. Digital Thread can be considered as containing relevant information that can be used to update Digital Twins. The benefit of this is the ability to improve on the current instance of a product. For example, improving design or operation parameters to enhance efficiency [61]. Metal 3D printing is already a key part of the Digital Thread as it allows for rapid manufacture of optimised parts in a digital manufacturing context. If parts can be monitored in real-time, and then rapidly iterated on using 3D printing, there is the potential to reduce the supply chain from a few months to almost zero [62]. Beyond manufacturing stages of the supply chain, automated services, such as the inclusion of drone delivery, can form part of the Digital Thread to optimise the transportation of goods between suppliers and buyers; On-demand manufacturing can be linked with on-demand and automated transportation. Bringing together predictive maintenance with on-demand part production and transport has the potential to significantly reduce standing inventory and supply chain complexity. Perhaps the most significant contribution, however, is in response to unplanned downtime, which results in significant intangible costs that are difficult to estimate and plan for [60]. An integrated manufacturing and logistics solution using a Digital Thread has the potential to significantly mitigate these costs.
CELLULAR AGRICULTURE

Cellular agriculture is the use of cell-culturing techniques to artificially manufacture products that are typically obtained from livestock farming and processing [63], [64]. Cellular agriculture techniques are yet to be fully defined, but there is some consensus that they comprise of two main approaches: tissue engineering based, and fermentation based [64]. Tissue engineering based cellular agriculture employs regenerative medicine technologies in which cells are extracted from animals [65]. Fermentation based cellular agriculture uses a process that employs genetically modified yeast or other bacteria to produce the organic molecules that are usually contained within animal products [64]. Each approach has unique capabilities that present significant implications for meat and other animal-based product industries.

In the following sub-sections, tissue engineering based and fermentation based approaches to cellular agriculture are presented.
TISSUE ENGINEERING BASED CELLULAR AGRICULTURE

Tissue engineering based cellular agriculture uses regenerative medicine technologies. The process starts with a biopsy of an animal to extract cells [63]–[65]. Cells can also be produced using genetic-modification, by which animals are only required to source the original cells [66]. The cells are cultured in a bioreactor to produce strings of muscle cells, which are combined to form a final product for human consumption [63]–[65].

APPLICATION

Initially, the focus of tissue engineering based cellular agriculture techniques was mince-meat products, such as ground beef [63]. The first of these was a hamburger patty that debuted in 2013 [67]. This eventually led to the formation of Mosa Meat (mosameat.eu), a start-up targeting a commercial cell-cultured beef product. Competing company, Memphis Meats (memphismeats.com), has a similar target and has shown progress with their cell-cultured meatball in 2016. Since 2016, companies have gone beyond mince-meat products and have begun targeting naturally textured meat products. This is a complicated process in which scaffolds are required to organise the tissue into shape. 3D printing has been considered for this purpose [63]. Memphis Meats has made some progress toward naturally textured products with their chicken strip in 2017 [68]. Supermeat (supermeat.com), an Israeli start-up, is also targeting a commercial chicken product. Beyond beef and poultry, Finless Foods (finlessfoods.com) is developing cell-cultured seafood products that have the same textural characteristics as fish fillets and steaks. Seafood is advantageous as culturing the cells takes place at room temperature while other meats require body-heat temperature, and thus greater energy inputs [69].

FORECAST

Tissue engineering based cellular agriculture meat products are not yet available. Over the last five years, however, new entrants to the industry have received substantial funding [70], [71] and production costs have decreased significantly [65]. The process also has many advantages in terms of sustainability. It requires significantly less land and water resources than traditional meat industries [63], [72], and is projected to produce fewer greenhouse gases than traditional meat industries [72], particularly if renewable energy sources are used [63]. Two major challenges are scaling the technology up to produce an affordable product [63] and getting consumers to accept the products [63], [73]. If these issues can be overcome, the potential is there for a sustainable meat industry [65] that can challenge industrially-produced meat products [73].
FERMENTATION BASED CELLULAR AGRICULTURE

Fermentation based cellular agriculture produces animal products through a fermentation process that typically uses a genetically modified yeast. However, bacteria and algae can also be used. The genetic modification process enables the yeast to produce specific organic molecules such as collagen, casein and gelatine, which are found in a variety of animal-based products [64]. The organic molecules are separated from the genetically modified yeast and used as the basis for products [73].

APPLICATION

Two notable companies working on fermentation based cellular agriculture products are Perfect Day Foods (perfectdayfoods.com) and Clara Foods (clarafoods.com). Perfect Day Foods' engineered strain of yeast produces the six proteins comprising milk. Separated from the yeast, these proteins are combined in a mixture of plant-derived fats, vitamins and minerals to replicate milk. The company is also working on other dairy products including cheese and ice cream [63]. While no products are available yet, early reports are favourable [74]. Using a similar process, Clara Foods is developing an egg white that replicates the same properties as the real thing [73]. Impossible Foods (impossiblefoods.com) uses the fermentation process to produce heme, an iron containing molecule responsible for the flavour of meat, which is added to its plant-based burger patty [65].

Fermentation based cellular agriculture is not limited to food. Modern Meadow (modernmeadow.com) uses genetically modified yeast to produce collagen from which their bioleather product, Zoa™, is formed. It comes as a thin pourable liquid leather and a traditional thick hide leather. Both can be processed to have the sensorial characteristics of leather [75]. Collagen is also produced by Geltor (geltor.com), and is used in N-Collage™, a commercially available and award winning cosmetics product [63].

FORECAST

Fermentation based cellular agriculture products are likely to face challenges with consumer acceptance. However, unlike the tissue engineered technique, the fermentation technique has an advantage as it does not require tissue from a living animal [64], [75]. The fermentation technique has also shown it can be scaled for commercial production, evident from both Impossible Foods' Impossible Burger, which is available in over 1000 restaurants [73], and Geltor's N-Collage™. Furthermore, Modern Meadow claims that the cost of their product is on par with traditional leather production [75], and other companies, such as Perfect Day aim to release products in 2018 [63].
**EXPERT OPINION**

Experts were surveyed and asked to rate the impact of cellular agriculture technologies on a 5-point scale. On average, cellular agriculture technologies were perceived to have high potential impact for Australian rural industries. Artificial production of meat products was perceived to have highest potential impact. Synthetically produced food items with enhanced health benefits were also perceived to have very high potential impact.

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Food and drinks produced by combining organic molecules and flavours, rather than from naturally sourced ingredients

Using synthetic biology to personalise food items so that they provide novel health and nutrition benefits

Animal protein grown artificially in laboratories to produce processed meat items for human consumption

Whole foods grown artificially to enhance their nutrition profile, health benefits and environmental sustainability

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**FIGURE 2. ESTIMATED ENVIRONMENTAL IMPACT OF PRODUCING 1 KILOGRAM OF MEAT (USA)**

Figure adapted from [72]
CONCLUSION

This is the first Horizon Scan report of the Horizon Scanning – Opportunities for New Technologies and Industries project. The project is a partnership between AgriFutures Australia and Queensland University of Technology that aims to identify new agriculture industries that may be developed in response to or based on emerging technologies. The first stage of this project, the Emerging Industries – Agriculture and Technology report [2], outlined ten potential new technology based agriculture industries. The selection of the ten proposed industries was informed by a framework of Australian rural industries’ present strengths, weaknesses, opportunities and threats, as well as the watchlist of emerging technologies compiled during the previously completed Detecting Opportunities and Challenges for Australian Rural Industries project [1]. This report has extended upon the previously compiled watchlist of emerging technologies by identifying an additional eight technologies that have the potential to impact Australian rural industries. In doing this, the work presented in this report also contributes further insights about new technologies that have the potential to facilitate new agriculture industries in the Australian rural context.

Of the eight new technologies presented in this report, a number have clear relationships to, and support the new agriculture industries that have already been proposed. For example, customer journey analytics is a technology that facilitates new marketing and stakeholder engagement industries, while tissue engineering based cellular agriculture is the underlying technology of a cell cultured meat industry. In addition to providing further evidence for already identified industries, these technologies also assist with
identifying opportunities for new industries. Customer journey analytics, for example, could develop into an industry of its own.

Evaluation of the eight technologies included in this report also shows that some technologies have only been evaluated to have moderate impact. This is the case for Human Physical Augmentation, Emotional Analytics and Drone Delivery. As emerging technologies that have generated considerable interest, these evaluations provide interesting information to explore further. As this project progresses through Horizon Scan 6, and then to the second New Industries report and Final Report, these perceptions will be further explored from the perspective of people working in Australian rural industries as well as individuals working directly in the technology areas. The aim is to develop multiple perspectives on the technology areas to accurately inform new technology based agriculture industries.
REFERENCES


APPENDIX: 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.