Final report

Global scan of technologies and systems enabling data capture and transfer across red meat supply chains

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Executive summary

Australia positioned itself as a global leader in livestock traceability systems approximately 20 years ago following the introduction of the NLIS and subsequent development of the LPA and NVD programs. The whole-of-life traceability conferred by these programs to the Australian red meat industry continues to be assessed as progressive, particularly in relation to several of Australia's major trading partners. Despite this advantageous position, ISC have acknowledged the increased demands of global markets and consumers for delivery of supply chains with elevated levels of transparency, provenance and integrity. Consequently, an opportunity exists to evolve or perhaps revolutionise the existing red meat integrity system and increase the competitive advantage of Australia's red meat industry. ISC have outlined 10 key elements that can be used as criteria for gauging the effectiveness of an integrity system moving forward. The criteria recognise the need to deliver gains across the entire supply chain through enhancements in traceability systems, automated verification systems, data management and analytics, and consumer confidence whilst reducing the compliance burden on supply chain participants. Therefore, an end-to-end red meat supply chain traceability system should ensure the transparency of relevant data to participants and consumers while preserving confidentiality and privacy of participants and business interactions

This report provides a global scan of the technologies and systems that underpin supply chain traceability with the intent of providing recommendations to ISC to inform future directions. It identified that the technologies and systems fall into two key categories: 1) the digital architecture that tracks or traces products as they move along the supply chain, and 2) the technologies that verify the product is indeed what is claimed. Technologies that verify a product can then split into two sub-categories comprising: a) those that test the product to verify, and b) those that identify the product to enable verification. The evaluation of the technology clusters within each of categories does identify high-rating opportunities for the Australia sector that are worthy of further investigation. Importantly however, it also highlights that a single supply chain solution does not exist currently and instead several solutions exist at each of the major supply chain stages. Furthermore, it is beyond the scope of this document to recommend specific technological solutions as the choice of a technology for a supply chain participant will be influenced by their relative position in the supply chain, the trust level between participants, and the value proposition attached to each solution. Thus, any complete end-to-end traceability system will require multiple types of technologies and consequently, interoperability will be paramount.

In order to systematically progress the red meat integrity system from its current whole-of-life-traceability design to a complete end-to-end traceability system, a set of preliminary recommendations for future action have been prepared. The following recommendations are presented in order of the priority considered necessary to address the 10 key elements outlined in ISC's 2025 strategic plan.

Recommendation 1: Define the overarching architecture of a complete end-to-end traceability system for 2025 and beyond.

ISC presently oversee Australia's red meat integrity system through the delivery of the NLIS, LPA and NVD programs. It is not anticipated that ISC will attempt to develop a 'complete' traceability solution by prescribing the traceability technologies or systems for the Australian red meat sector and supply chains. Rather, ISC should continue to oversee the management of an expanded traceability system by prioritising the development of the overarching digital infrastructure supporting a national traceability system and defining the standards and specifications for inclusion of identification/verification technologies and systems into this architecture. It is acknowledged that this recommendation is the basis of 'Project 1 – Defining overarching requirements for the future state traceability systems in terms of objectives, data points, collection, storage and analysis' of the recent ISC call for projects on 'Establishing new integrity system approaches and technology'. However, it should be noted that the project team reached the position outlined in this recommendation independently of the project call and therefore supports the direction proposed by ISC. This recommendation calls for specific emphasis on standards that are central to the interoperability of traceability technologies/systems and it critical that these standards undergo constant revision commensurate with the evolution of new and potentially disruptive technologies. This will enable more rapid introduction and implementation of new traceability technologies.

Recommendation 2: Harmonisation of regulations and clarification of roles and responsibilities in an enhanced traceability system at an industry (red meat) or sector (agriculture) level.

Prior to the release of the Australian Government's National Traceability Framework uncertainties around traceability roles and responsibilities and the acceptable level of harmonisation of regulation between Australian governments were noted, and the need for a single, national approach to traceability was proposed. Therefore, in addition to ISC overseeing the management of an expanded traceability system, it is recommended that ISC seek to provide cohesive, inclusive leadership at the national level for the development of harmonised regulations and role and responsibility clarifications for the red meat industry and subsequently for the agricultural sector.

Australia trades as a single entity in global markets with goals and objectives common to industry or the sector which span state and territory borders. In many ways these common goals are similar to the common goals of the National Cabinet in their COVID-19 response and there appears opportunity for ISC to apply similar design principles to achieve the outcomes desired.

Recommendation 3: Facilitate the extension of the red meat integrity system from whole-of-life to whole-of-supply chain through evaluation of technologies that facilitate individual animal traceability to the consumer.

Whilst individual animal traceability from birth to the end of the slaughter process is achieved via the existing red meat integrity system, it rarely continues through the remainder of the supply chain. Batch or lot identification beyond the point of slaughter is the limit of the current traceability system. This report has identified candidate technologies that would:

- deliver unequivocal traceability (e.g. genotyping)
- or may provide real-time, in-line traceability (e.g. ambient mass spectrometry)
- or generates tagged product that can be identified for the remainder of the supply chain (e.g. molecular tagging).

It is recommended that a more detailed evaluation of the applicability and value of the higher rating candidate technologies should be undertaken. Ideally, design led principles should be applied in this further evaluation such that solutions address the needs of the red meat sector and the market.

Recommendation 4: Assess the potential for advances in key foundational technologies to alter the technological landscape by changing what is possible in supply chain traceability.

Developments in the areas of AI, IoT, blockchain, global payments and 5G provide opportunities for the evolution of existing supply chain solutions that ultimately broadens their scope of applicability. For example, the evolution of smart ear tags has enabled additional functionality around animal management, biosecurity monitoring and provenance. There is an expectation that as traceability technologies evolve through the uptake of disruptive technologies, they will, as has been observed with the ear tag example, generate solutions with much broader supply chain scope. As necessary, candidate technologies with broadened supply chain scope or multiple functions should be assessed for value and practical applicability in the Australian context.

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1. Background

Food provenance and integrity are paramount to protecting markets and consumers. Systems that provide complete traceability throughout the red meat supply chain not only underpin provenance, but they are also pivotal in the context of food safety, biosecurity and attributing product authenticity, qualities and features, and thus adding market value. The science and innovation in traceability systems for agricultural products is rapidly evolving. Consequently, there is a need for Australian producers and distributors to pursue and adopt innovative integrity systems and technologies to underpin Australian red meat exports in an increasingly competitive global market. For the Australian red meat sector, the task of identifying traceability systems and technologies that meet the essential requirements (now and into the future) is both difficult and complex.

Lack of transparency and reliability of supply chain data are major problems faced by current food traceability systems and mechanisms. The data collected by supply chain participants is usually stored in isolated data silos and not shared with other participants and consumers. Furthermore, the stored data may not be reliable, or may be erroneous or not secure. Recently, blockchain-based traceability mechanisms have been proposed as a solution for increasing the transparency of supply chain data across the entire network and improving the integrity of the stored data. However, blockchain-based systems still rely on being able to link physical products to the digital records stored on the blockchain and thus are reliant on the integrity of the data entered and stored on the system. This creates a need for a mechanism to improve the trustworthiness of data generated by the supply chain participants and fed into the blockchain. An end-to-end food supply chain traceability system should ensure the transparency of relevant data to participants and consumers while preserving confidentiality and privacy of participants and business interactions.

2. Objectives

Harness the relevant domain expertise within CSIRO Agriculture & Food and Data61 to:

(i) Describe and review relevant and best practice systems and technologies from agricultural and non-agricultural sectors to enable traceability throughout red meat supply chains, and

(ii) Provide recommendations and advice to Integrity Systems Company (ISC) to inform future investment decisions relevant to data capture and traceability systems for the red meat sector in Australia.

3. Global scan of technologies and systems enabling data capture and transfer across red meat supply chains

3.1 Introduction

> *"It is timely for Australia to seize the opportunity to enhance our traceability systems, and respond proactively to global drivers for change, utilising existing and new technologies and positioning agricultural industries to reap the significant benefits that enhanced traceability offers."*
>
> - Australian Government National Traceability Framework 2019[3]

Food supply chains are a complex series of interconnected activities that involve production, processing, distribution and consumption. Consequently, they contain a variety of participants that shape the structure and dynamics of the system. Food supply chains continue to expand globally with increases in the efficiency of food production, the volumes of food being generated, and the distances food products travel to access international markets. Whilst the intent of any food supply chain is to deliver food products to consumers in a safe and secure way, there may be times where fragmentation can exist within the food system which leave it vulnerable to food safety incidents or food fraud activities. The result of such events is an increased emphasis on traceability systems and the integrity outcomes they provide for consumers, producers, processors, retailers and governments.

Traceability systems help:

- **Consumers** to know about what is in their food, how it was produced and where it came from.
- **Producers, processors and retailers** to secure the best possible value for their product, because a good traceability system helps provide confidence that the food being consumed matches what is on the label. It also allows producers to track their produce through the system, reduce waste, create new products, and has the potential to ensure payments are being made on time; and
- **Governments** to protect the biosecurity of the Australian agricultural sector, and the health and safety of Australian consumers.

Responses to the twin problems of food fraud and food safety incidents can be greatly enhanced through the implementation of improved food traceability systems. High profile incidents rapidly highlight the need for enhanced traceability systems (Table 1).

Table 1. High profile incidents where food traceability was required to either mitigate the risk of or expedite the response to food fraud and safety issues.

Incident	Year	Location	Description	Outcome	Traceability need
Melamine tainted milk scandal	2008	China	Milk powder was adulterated with melamine to give it a higher protein content in tests	An estimated 300,000 victims, mostly infants, made ill and six fatalities[13].	Better provenance could help prevent loss of life in future.
Horse meat scandal	2012-2013	Europe	Tests in multiple European countries revealed widespread food substitution and adulteration, most noticeably in beef that was actually horse meat	Numerous new regulations were introduced and companies were forced to recall products. Supermarket giant Tesco had 300 million pounds wiped off its value[14].	Traceability can help reduce food substitution and reduce risk for enterprises and consumers.
European *Escherichia coli* O104:H4 outbreak	2011	Central Europe	Thousands of people were infected with a novel strain of *E. coli* believed to associated with the consumption of fenugreek seeds.	Nearly 4,000 people were infected and 54 died. Multiple supply chains were incorrectly identified as the outbreak source and European production losses approached 200 million Euros[15].	Systems that can help authorities quickly trace the source of the crisis.
Adulterated honey scandal	2018	Australia	Nuclear Magnetic Resonancing (NMR) tests revealed Capilano and other honey brands may have been adulterated with sugar syrup, but the standard C4 tests showed they were not. The ACCC ruled that neither test was admissible in court.	Extensive brand damage to Australia's largest honey company[16].	Traceability and testing technologies can help protect against brand damage
First US report of a cow with	2003	USA	First case of BSE in USA was identified in	Within hours Asian nations	Identification system capable

bovine spongiform encephalopathy (BSE)			a dairy cow at slaughter.	including Japan, South Korea and Taiwan banned imports of US beef.	of tracking animals from birth to slaughter.

Traceability systems not only help mitigate or manage food integrity and safety crises, they also have the potential to help improve recognition of value, achieve higher prices, expedite payments and maintain or strengthen competitive advantage for stakeholders along the supply chain. However, in each industry, there are different priorities in terms of what kind of supply chain enhancements are needed in good traceability and integrity systems. Some industries have a focus on preventing adulteration/substitution or food fraud, while others may be concerned with reassuring consumers the food was produced ethically or in line with religious requirements (Table 2).

Improving the efficiency of Australian meat supply chains is a core goal of the Integrity Systems Company (ISC). A key strategic plan from ISC[18] defines what success in Australian meat supply chains would look like in 2025 and beyond and summarises the approach of Australian supply chains through the 10 key elements listed below. These elements can be used as criteria for gauging the effectiveness of an integrity system moving forward—however, certain elements may only be relevant at certain points along the supply chain.

1. Whole-of-life traceability of livestock is achieved through automated identification of animals and locations.
2. Real-time monitoring and tracking of livestock.
3. National vendor declarations are replaced by automated verification systems.
4. The integrity system happens in the background.
5. Data and information is used to drive productivity through the value chain.
6. Data sharing is fundamental to day to day business operation and is driving business efficiencies.
7. Compliance is implicit within the integrity system.
8. Industry participants are proud of our integrity system and understand the value it delivers to their businesses.
9. Consumers are actively seeking out Australian red meat based on our integrity system.
10. Consumers can verify the origin of Australian red meat.

Table 2. The relative importance of different aspects of traceability systems to different industries (adapted from[17]).

Enhancement to supply chain	Importance to red meat industry	Importance to grain industry	Importance to dairy industry	Importance to wine industry	Importance to sugar industry
Prevent re-use of packaging	Low	Not important	High	High	Not important
Prevent counterfeiting of labels/package	High	Not important	High	High	Not important
Prevent substitution/dilution before packaging	High	Low	High	Low	Not important

Prevent contamination	High	High	High	Medium	Medium
Prevent spoilage	High	Low	High	High	Not important
Respond to recalls and supply chain crises	Medium	Medium	High	High	Not important
Ensuring authenticity of origin	High	Low	Medium	High	Medium
Ensuring contents and ingredients (for issues such as allergies, GM status or religious requirements)	Low	Medium	High	Medium	Medium
Ensuring production practices (such as ethical animal treatment)	High	Medium	Medium	Medium	High
Ensuring supply chain practices (e.g. date of harvest, proper packaging)	High	Medium	High	High	High
Enabling consumer feedback	Medium	Medium	High	High	Medium
Enhancing marketing	High	Low	High	High	Medium

3.2 The challenge of food fraud

Food traceability systems can help in a variety of contexts, including biosecurity threats such as foodborne disease outbreaks. However, one of the most difficult issues for a traceability system is food fraud, as it involves deliberate manipulation of the product at key point(s) in the supply chain. The five key types of food fraud are defined in Table 3.

Table 3. The five key types of food fraud

Adulteration	Substitution	Diversion	Misrepresentation	Identity theft
Lowering the quality of the product by adding additional substances	Replacing the product with something inferior that resembles it	Redirecting other products toward human consumption, like spoiled food or animal feed	Marketing a product as something it is not; e.g. deceiving consumers that it is Australian made	Food sold using fake company identification

Attempts to estimate the economic impact of food fraud for Australian producers puts the toll at $1.68 billion in 2017, and this was only considering the impacts of the substitution of fresh and minimally processed foods. The adulteration of foods was not analysed, nor the effects when foreign producers use fake or swapped “made in Australia” labels. The global toll of food fraud has been estimated to be around $50 billion each year[19]though extensive in-market testing of food products, including red meat, are yet to be conducted and therefore the accuracy of the estimates are yet to be robustly assessed.

In 1981, Australia experienced it's largest and most damaging food substitution scandal where kangaroo and horse meat were substituted for beef in consignments exported to the United States. This led to a Royal Commission to investigate the scandal and major systemic changes to the laws and regulations central to the export of commodities from Australia were subsequently implemented. More recently, there have been a number of concerning cases in Australia, like imported pork being sold as Australian meat, hogget being sold as lamb, or the sale of fake spirits[20]. In 2018, one of Australia's largest honey companies, Capilano Honey, was investigated by the competition watchdog over claims they were selling honey that had been adulterated with sugar syrup[16]. Due to differing test results, the watchdog ultimately could not achieve effective resolution.

Australia's key export markets are Japan and China, and food fraud is a problem in China in particular[19]. An analysis of media reports in China across a 10-year period from 2004 to 2014 gives some indication as to which products are common targets of food fraud. Of the 1554 media reports analysed, 593 (38%) related to animal foods, including dairy, seafood and other meats[21]. A breakdown of the specific types of animal food fraud in China is shown in Figure 1. Wine is another popular target and there are some indications that food fraud incidents involving French wine sold in China resulted in an increase of Australian wine imports[22]. With Australia aiming to boost its agricultural productivity from $60 billion in 2019 to a $100 billion industry by 2030[23], a large boost in exports will be needed. Reliable traceability technologies and regulatory frameworks will therefore be critical to enable this agricultural transformation.

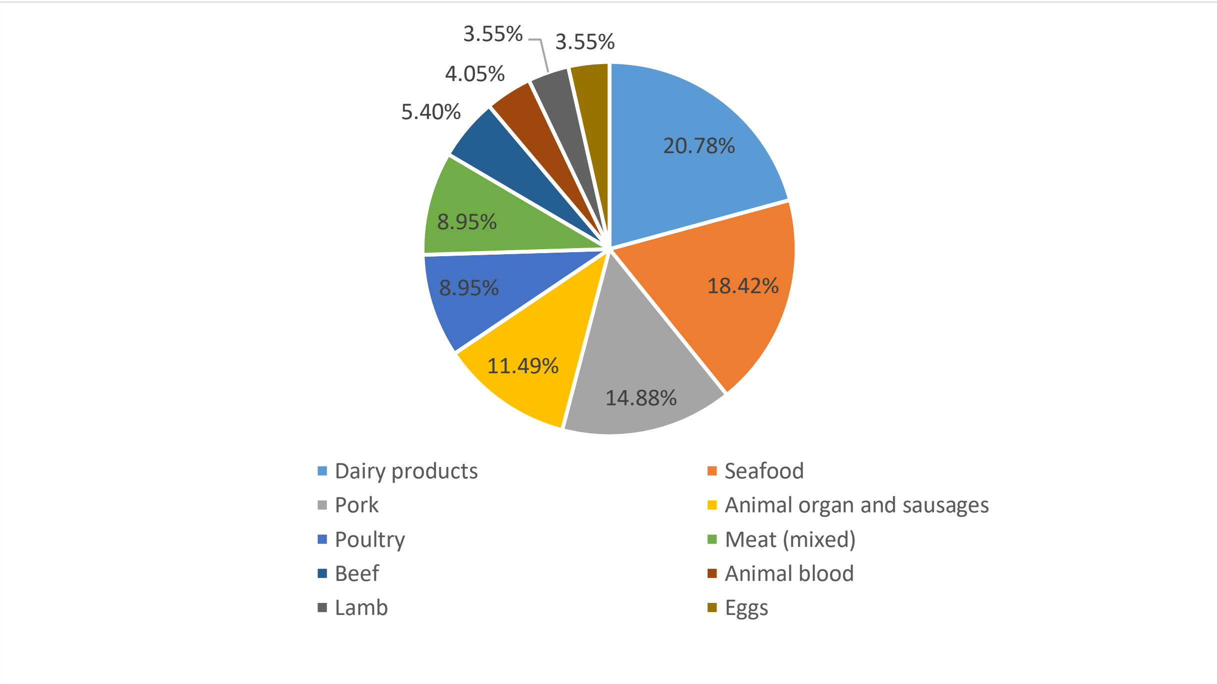

Figure 1. Specific types of animal food fraud in China, reprinted from[21].

3.3 The state of food traceability globally

Traceability systems for food supply chains vary dramatically from country to country. A wide variety of factors determine how reliable they are, ranging from the regulatory environment through to the level of technological uptake and the history of the country's supply chains. Traceability systems in the EU, and in some pan-European nations, benefit from the coordinated regulatory environment provided by the EU[24]. Charlebois et al examined food traceability in 21 OECD countries, primarily from the lens of regulatory frameworks. Many of the categories they assessed bear directly on the kinds of technologies that can be implemented in those jurisdictions. The study found that being within the EU, or a being a Pan-European participating country, conferred certain advantages via mandatory requirements on food and feed traceability. The pan-European nations universally received a "superior" rating. In comparison, countries such as Australia, Brazil, Canada, Japan and the United States of America were evaluated as "average" with China ranked as "poor" based on the comprehensiveness of traceability regulation for domestic and imported products [24].

It is difficult to separate the regulatory environment from the technological capability of various nations. Food traceability systems benefit significantly from the data-sharing environment, strength of regulators, unification of standards and data, and several other factors. However, certain indicators can be applied to gauge the favourability of the environment for using food traceability systems. Take, for example, the use of GS1 standards. The GS1 is an international non-profit organisation that promotes electronic commerce via improved transparency and efficiency of supply chains. They are responsible for managing the use of barcodes and their data around the world. GS1 has excellent penetration in most countries, but is limited in some areas, such as Russia[24]. Thus, any traceability framework that relied upon the GS1 system would have additional challenges there. Other indicators that point toward technological traceability capacity include electronic livestock tracking systems, and the comprehensiveness of the food labelling system. Australia is viewed as progressive[24] in these areas with programs such as the National Livestock Identification System (NLIS) and the food labelling regulations contained in the Food Standard 1.2.1-Labelling and Other Information Requirements.

3.3.1 Australia

The Australian Government released its National Traceability Framework in March 2019, with the stated goal of "assisting industries and governments to approach the development and enhancement of national traceability systems"[3]. Working group reports in the lead-up to the release of the framework indicated that there was "uncertainty around traceability roles and responsibilities and the acceptable level of harmonisation of regulation between Australian governments"[25]. They found that while Australia has a reasonably robust system, there was room for improvement, which would be necessary to protect Australia's competitive advantage. The working group report states that in order to do this, "a single, national approach to property identification (including all properties with terrestrial and aquatic animals, and plant production activities) is a fundamental first step to improving traceability"[25].

The National Traceability Framework notes that enhanced traceability systems confer advantage which include[3]:

- Marketability and market development
- Consumer confidence
- Biosecurity

- Market Access
- Brand Protection
- Waste Reduction
- Emergency management
- Compliance with regulations
- Collaboration with supply chain partners

In terms of livestock tracking, Australia compares reasonably well, particularly against key beef export competitors. The key global beef exporters are Brazil (17% market share), Australia (17%), India (15%), the USA (12%), Canada (6%), New Zealand (5%), and the entirety of the EU has just 5% market share[26]. With Canada and the US rating poorly in Electronic Livestock Tracking systems, there may be further potential for Australia to increase the competitive advantage conferred by the NLIS. Canada does have some cattle tracking systems, which were first introduced by industry in 2001 and mandated by government in 2002[27]. While Canada has since developed more electronic livestock identification capabilities, particularly in its dairy industry, the US still lags behind[28].

3.3.2 European Union

Before 2005, EU producers largely adhered to the various requirements of their customers, predominantly large retailers. After 2005, EU regulations mandated that certain minimum traceability requirements be met[29]. Since then, the unifying characteristics of the EU legislative environment have helped create a relatively unified regulatory traceability framework, when compared against nations outside this bloc[24]. In addition, the "Internet of Food 2020" program includes five key trial programs—The Internet of Arable Farming, The Internet of Dairy Farming, The Internet of Fruits, The Internet of Vegetables, and The Internet of Meats. These all aim to better utilise IoT technologies in supply chains. In the case of the Internet of Meat, for example, the goal is to use sensors on pigs and slaughterhouse data to optimise pig production[30].

3.3.3 United States of America

In the US, under the Public Health Security and Bioterrorism Preparedness and Response Act of 2002, the federal government launched measures to protect the nation's food supply. This established the principle of "one step forward and one step back" which means participants in food supply chains operating all the way "from farm to fork" must keep records of where they obtained the product and whom it was sold to[31]. Also known as the "one up, one down" approach, this level of information sharing and collection has proven insufficient for the development of broader blockchain projects as it is not a full end-to-end record of the supply chain[32].

In 2011, with the Food Safety Modernization Act, government agencies were able to move more into preventing foodborne disease outbreaks rather than just containing them, and mandated improved record keeping in supply chains[31]. There was also a mandate to create a food traceability system across the nation's entire food supply. However, limited resourcing for the Food and Drug Administration, as well as various obstacles in governance and law-making, has left only some "building blocks" of a national food traceability system at the regulatory level[31]. The private sector is working on several significant projects that directly or indirectly enhance food traceability (e.g. Walmart and Hyperledger). Studies have identified the need for better traceability in the US system, and they note that in livestock supply chains globally, traceability systems have largely only been implemented as a response to food safety incidents, rather than as a proactive measure to value-add[28]. The US does not have a national cattle traceability system; however it does have an animal tracking system which is only required to be used when cattle are taken across state borders, and this is solely for disease management purposes [27].

Hyperledger traceability system (Walmart)

Walmart is in the process of scaling up its Hyperledger fabric-based blockchain system for tracing food products. In the 12 months following September 2018, Walmart required its fresh leafy green vegetable suppliers to shift across to an end-to-end traceability system, with a deadline of September 2019[2]. Two proof of concept projects had already been completed, including Mangos traveling from South America to North America, and a pork supply chain within China[5]. In March 2020 it joined the Hyperledger consortium, indicating continued support for its blockchain programs[7].

Carrefour is also utilising the Hyperledger system and is a participant in the Hyperledger Food Trust blockchain[8]. Carrefour has also introduced an app to allow consumers to scan a product and gain provenance details[8].

Walmart's system is based on the open source, Hyperledger Fabric blockchain. Walmart executives have been quoted in media as saying they chose Hyperledger because it met most of their needs and as a decentralised database, it could scale more easily than the centralised systems they had attempted to use in the past[5]. Australia is fairly advanced in its blockchain development, rating in the top 10 countries worldwide for blockchain patents[11], so there are existing legal and technological frameworks for blockchain deployment. The Walmart system is built on an IBM blockchain system that is already being offered on sale at USD $0.29 per allocated CPU hour. This does also require subscriptions to other IBM services, however[12].

3.4 South America – Brazil, Argentina and Uruguay

In 2012 the Brazilian Association of Supermarkets (ABRAS) collaborated with state associations and industry groups to launch a Food Traceability and Monitoring Program (RAMA) for fruit and vegetables. This created an interoperable structure around many of the private company-based traceability and inventory systems that had operated before. RAMA was based on collaborative tracking, monitoring of residues and a rectification mechanism for non-compliance to specified agricultural practice. It brought together retail chains, producers and suppliers and works with GS1 Brasil to bring Brazilian produce up to international standards and export quality. RAMA is continuing to innovate on validating and tracking technologies to improve trust in 'Product of Brazil'[33,34].

In addition, Brazilian livestock farmers through the Brazilian Agriculture and Livestock Confederation (CNA) have developed Agritrace, a dedicated data platform to assist compliance with the Brazilian Traceability Law. Agritrace records health, safety and other meat and livestock information to offer national and international traders health and biosecurity guarantees provided by the Brazilian Government. In addition, the platform gives consumers assurance that beef purchased is from verified cattle breeds – such as Angus, Hereford, Charolais, Bradford, Devon and Wagyu. Agritrace is also increasingly used to verify that beef bought has not been involved in Amazonian rainforest destruction. CNA audits producers and slaughterhouses using the system, and uses a range of technologies from satellite images, RFID tags, photos, audio, chemical analysis and DNA verification – to ensure that there is compliance within the system[35,36].

In 2004 Uruguay implemented a compulsory and world-leading national meat traceability system, the National Livestock Information System (SNIG - abbreviated from the Spanish) when the country battled foot and mouth disease, and before that, Bovine Spongiform Encephalitis (BSE). The system uses double ear RFID tags to track individual cattle to abattoirs and then provides beef product tracing from the abattoir to export and retail. The rigour of the system has assisted the development of Uruguay's beef export markets, which now includes the European Union, China, Japan and the United States[37,38].

Like Uruguay, Argentina battled BSE in its cattle herds from 1997. All of Argentina's food business are now required to have an effective food recall system. Labelling information on beef products allows them to be traced back to the abattoir, and then back to the region and farm on which the cow was reared. Auditing and compliance with the traceability system is done by SENASA – The National Food Safety and Quality Service, a government agency in the Ministry for Agriculture. Start-ups are now proposing to trial blockchain-based traceability systems for meat and cattle systems in Argentina[39].

3.3.5. Asia – Japan and India

Japan implemented their Beef Traceability Act in 2003 to guard against BSE outbreaks and infections. The National Livestock Breeding Centre, administered under the Ministry of Agriculture and Forestry and Fisheries (MAFF), collects information from farmers, abattoirs, wholesalers, retailers and restaurants as they track beef reared in Japan throughout the entire market – from paddock to plate. Consumers in Japan are also able to access information on beef products through their labels and identification numbers. MAFF audits processes administered under the National Livestock Breeding Centre through a range of technologies including by comparing DNA samples taken at abattoirs and in spot check on farms[40].

There is no national domestic meat traceability system in India for domestic products. Small street shops and restaurants in India still slaughter many animals for domestic consumption in unregulated conditions. There is increasing pressure on Indian suppliers to use registered abattoirs and slaughterhouses.

There are systems in place for the export of meat products and dedicated traceability systems in cattle and buffalo beef. Tracenet and Meat.net are export-focussed systems operated by the Agricultural and Processed Food Products Export Development Authority (APEDA). These systems collect information from livestock producers and undertake the biosecurity tests in order for the meat products to be exported. There is also use of RFID tagging for both dairy and beef cattle and buffalo, but these are restricted to certain suppliers[41]. There have been numerous calls for India to implement a national traceability program as it supplies more produce to neighbouring nations in the growing South-East Asian Region[42].

3.4 Significant potential for technological disruption

Advances in key foundational technologies have the potential to significantly alter the technological landscape by changing what is possible in supply chain traceability.

Artificial Intelligence. Advances in machine learning, computer vision, robotics and other technologies and processes known collectively as Artificial Intelligence (AI) have the potential to dramatically re-shape supply chains. Already, some warehouses are automating their operations, and these robotic systems have the potential to be equipped with sensors and other technologies that could aid traceability[43].

Internet of Things (IoT) Developments in sensor technologies and image recognition offer a wide variety of possibilities in areas ranging from improved automation capabilities in warehouses, through to improved product monitoring and cold chain management[30,44].

5G. Depending on the level of digital transformation that accompanies it, the rollout of 5G could boost the data-sharing capabilities of numerous pieces of technology, ranging from robots to IoT enabled sensors. In particular, 5G could potentially offer the ability to link more devices in supply chains[44].

3.5 Key types of traceability technologies

Market research estimates put the value of the food traceability market at AUD $16.35 billion in 2017, increasing to $33.2 billion by 2025[45]. In terms of the individual pieces of technology being bought (as opposed to broader traceability infrastructure), the market leaders are currently 2D and 1D scanners, followed by tags, labels and thermal printers. Sensors and PDAs with GPS round out the top technology categories[45]. These items can't operate in isolation, however, as they are tools to be used within an overarching traceability system that links the various elements of the supply chain.

Food traceability technologies can be divided into two key categories: the technologies that verify the product is indeed what is claimed, and the ledgers or databases that track or trace them as they move along the supply chain. However, traceability and integrity systems are not just confined to food products: in Australia, for example, there is a traceability system for blood products. Bloodstar and Bloodnet are pieces of software that help laboratories, doctors and other healthcare stakeholders track and trace blood, while monitoring blood supplies[46]. New blockchain systems can provide more transparent architecture for tracking a vast array of products, such as diamonds—3D scanned images of the cut of the diamond can be combined with documentation about its origins, and uploaded onto the blockchain[47,48]. Laser barcodes, or chemical tags can also be used[49]. Premium products draw a lot of market and research interest, given the high value of individual products[22]. Wine, too, is the subject of novel traceability initiatives like isotope scanning[1].

Strontium isotope testing - wine

Researchers in Australia are experimenting with various forms of strontium isotope testing that identify how trace elements in wine are affected by the specific conditions of the region where they are grown[1]. The weather, water and soil composition of the region help determine the isotopic signature of that wine, and that signature will be unique to wine grown in that region. This is particularly useful in determining whether wine has been substituted for a cheaper variety grown elsewhere. Unlike DNA tests which can tell you which plant or meat species is in a product, isotope fingerprinting can, in some cases, tell you where the product came from. In addition to wine isotope testing, there have also been experiments testing dairy products from different alpine regions of South America, which were able to distinguish between products that came from different altitudes[6].

A key question is whether or not the traceability system is designed to just trace the product back along the chain so regulators or consumers can have assurances about its provenance, or to actually track the product forward along the chain, which requires information to be updated much more quickly[27]. Whether it is tracking or tracing will play a significant part in what kind of technology is appropriate. If trust between supply chain participants is strong enough, then full tracking may not be necessary. If trust is low, then it may be necessary to track products more comprehensively. However, the adoption of a supply chain solution in a low trust environment may be challenging due to a lack of cooperating supply chain participants.

Another challenge in dealing with fraud is ensuring that the digital record of the product actually matches the physical product, so often some kind of 'tag' is created. This can be a piece of technology affixed to the product, or it might be something within the product itself, like a DNA trace marker, or perhaps a code burned onto it with a laser. There are various tagging technologies that create a digital record of a product. Australia's NLIS, for example, attaches RFID tags to cattle ears or via a rumen bolus[50]. The tag's number then exists as a unique digital identity for that animal. This alone is just one component. There needs to be effective ways to read the tag, an effective platform for registering the product's movements and these tags are only relevant to the live animal, meaning much of the product's journey from paddock to plate is not captured within the system. In addition, food fraud activities mean that tags may be removed, or the product may still be tampered with without it being clear which point on the supply chain has been compromised.

Given the context above, the food traceability technology/system landscape is, not surprisingly, rapidly evolving and there are a range of current and emerging technologies that are under evaluation and development, respectively.

Scotch whisky and smart packaging

One of the most common food fraud activities is refilling empty alcohol bottles with a substitute product. The high margins of premium alcoholic goods make them an attractive target for substitution[4]. Currently, barcodes and RFID tags are the most common means of tracing food products and are a limited form of smart packaging[4]. However, these are not necessarily helpful when a bottle has simply been refilled and the product tag no longer matches the product.

Anti-counterfeiting technologies need to be "difficult to duplicate, hard to re-use and yet easily applied and to identify visually, and easily noticeable when tampered with"[9]. Whisky brands are using Near Field Communication (NFC) technology which allows consumers to tap their phone to the product to get information on its validity. In order to ensure it has not been substituted, the tag is applied in a way in which it will be broken if the seal to the bottle is broken[4].

3.6 Australia's red meat supply chain

In 2018-19 the Australian red meat supply chain produced approximately 2.35 million tonnes carcase weight of beef and veal with an off-farm value of $19.6 billion[51]. Australia trades globally as a provider of clean, green and wholesome red meat products with its reputation underpinned by its red meat integrity system which manages and delivers the industry's on-farm assurance and through-chain traceability programs[52]. Australia's position as a leader in livestock traceability systems was achieved twenty years ago following the decision to develop and implement the NLIS. This was followed in 2004 by the introduction of the Livestock Production Assurance (LPA) program and was further complemented shortly after by the National Vendor Declarations (NVD) program which enabled the recording and sharing of livestock management and movement history through the supply chain[18].

The Australian red meat industry is progressive in its thinking with respect to traceability systems and embraces the evolving challenge presented by consumers demanding greater insight to the provenance, quality and safety of red meat products but also assurances around animal welfare, sustainability and biosecurity. The extent to which technology and systems enabling data capture can assist Australia's red meat supply chain requires an understanding of the supply chain and the points of risk or vulnerability throughout. Figure 1 summarises the points of risk and vulnerability and indicates some of the challenges that technology or data system integration would need to overcome and reiterates the need for traceability solutions that address all stages of the supply chain.

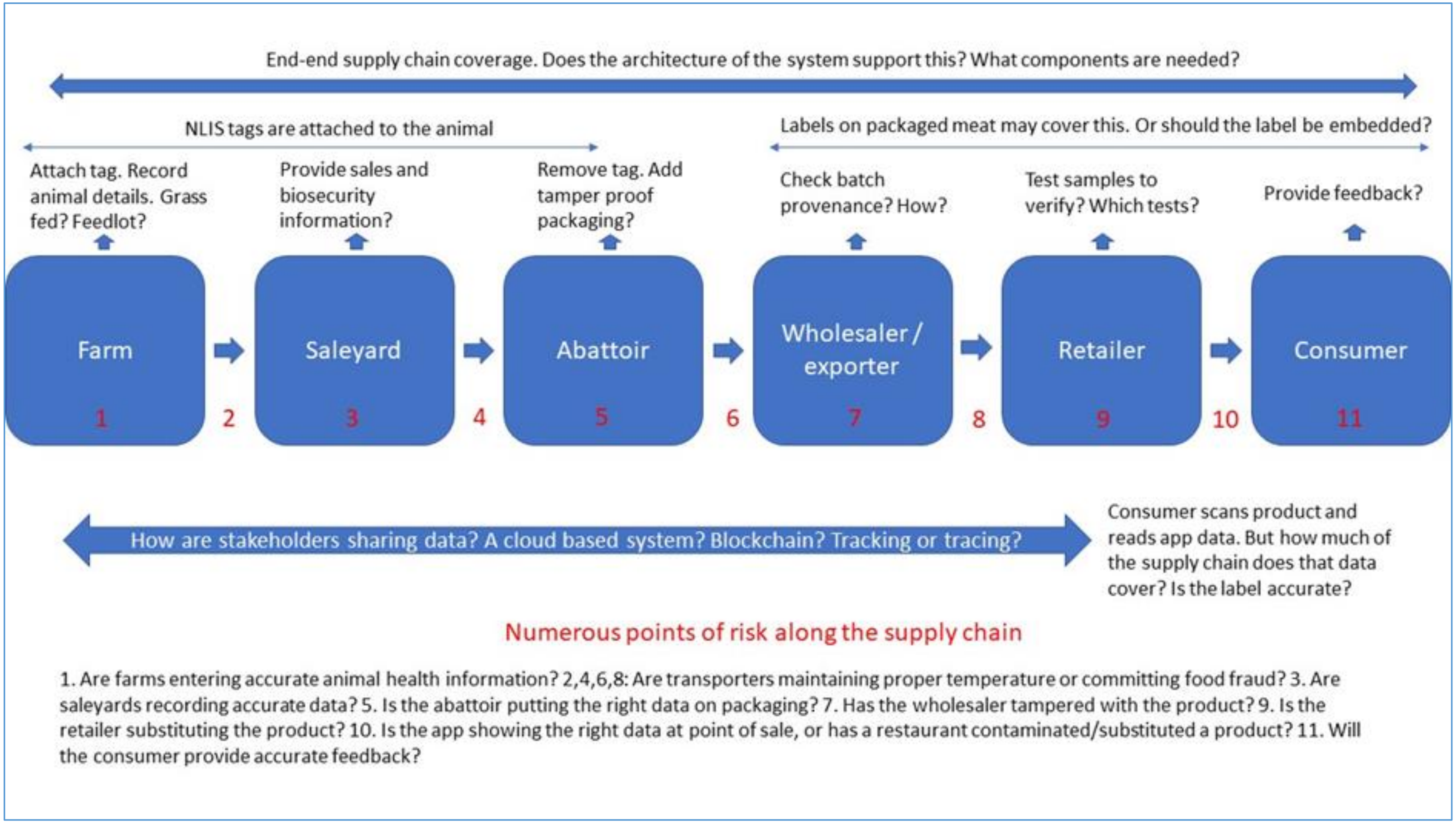

Figure 2. The points of risk and vulnerability across the red meat supply chain

3.7 Global scan of traceability technologies and systems for red meat supply chains

The Integrity Systems Company strategic plan "Integrity System 2025 and beyond"[18] details a vision for a future red meat integrity system along with three key indicators of success:

- The integrity system will be simple to use and interact with. In fact, it will be happening automatically in the background.
- Industry participants recognise the value of the integrity system to their individual businesses and are proud of their role in making the integrity system a success, and
- Consumers are actively seeking out Australian red meat based on their trust in the integrity system.

The indicators of success focus across the supply chain and at a variety of supply chain participants. Similarly, traceability systems can't rely on a single technology, which is why many companies offering traceability products have diverse and specialised offerings for different supply chains. Thus, any paddock-to-plate end-to-end traceability system will require multiple types of technologies and potentially require different solutions at various points of the supply chain. Given this, interoperability will therefore be paramount.

3.7.1 Technology scan and evaluation framework

Technologies that underpin traceability and thereby enhance the integrity of the supply chain can be divided into two key categories: 1) the digital architecture that tracks or traces products as they move along the supply chain, and 2) the technologies that verify the product is indeed what is claimed. Technologies that verify a product can then split into two sub-categories comprising: a) those that test the product to verify, and b) those that identify the product to enable verification. The scan of technology or systems further identified that technology clusters exist within each category or sub-category and that these provide a suitable basis on which to evaluate their applicability for integration into an enhanced integrity system.

To achieve the project objective of developing recommendations of future ISC investment decisions an evaluation framework that enabled multi-factorial assessment of each technology cluster was developed. Table 4 details the six main factors we have applied to evaluate the features, benefits and suitability of each technology cluster. A rating scale of 1-5 was used to assess each technology cluster against each factor with a rating of 1 and 5 indicating the least and greatest level of benefit, respectively. An overall score is achieved by combining the ratings of each factor for each technology cluster.

Table 4. Evaluation framework for the assessment of traceability technologies and systems

Factor	Feature	Benefit	Criteria
Choice/ control	Supply chain participants obtain greater choice or control from a new product or service.	Technology/innovation adoption rates increase across the supply chain.	• Added value • Traits being measured • Resolution/accuracy
Convenience	The technology/ innovation reduces the burden on the user whilst delivering equivalent or greater outputs.	Increased convenience facilitates the change process.	• Automation • Trust and security • Practicability • Data integrity
Community	The extent to which the technology/innovation addresses the breadth of supply chain correlates with the level of industry support.	Technology/innovation solutions that address greater portions of the supply chain will result in greater adoption levels.	• Whole or part of supply chain solution • Useability (traceability and management)
Completeness	Is the technology/innovation a new technical capability or a supply chain ready solution.	Technology/innovations that can deployed into supply chains have increased industry appeal.	• Technology readiness level • Efficacy and broadness of applicability of tech
Compatibility	Can the technology/innovation operate in the existing integrity system.	Technology/innovations that are interoperable with existing systems yet scalable and futureproofed to emerging standards have higher adoption rates.	• Interoperability/ Scaleability • Futureproofing
Customer's Cost	The cost to acquire/implement the technology/innovation is derived from market pull considerations.	The value proposition for the technology/ innovation is understood.	• Cost-benefit • Who's paying?

3.7.2 Technology evaluation

The evaluation of each technology cluster is shown in Appendix 1 with the ratings for each of the categories: digital tracking and tracing, verifying the product, and tracking or tagging the product, shown in Tables 5-7. Insights to each of the technology clusters are provided below with more detailed descriptions provided for at least two clusters from each category. Whilst it would be natural to provide more detailed descriptions for the highest rating technology clusters in each category, some of those (e.g. GS1 product code applications) are well known to ISC and red meat supply chain participants. Emphasis was placed on technology clusters that rate highly but are also less known to ISC and the sector and likely to bring an enhanced offering to multiple parts of the supply chain.

3.7.3 Digital tracking and tracing along the supply chain

Digital platforms for use in the red meat supply chain fall into two broad clusters: blockchain and cloud. The main difference between the platforms is that blockchain is typically characterised by a decentralised network of nodes aimed at recording agreed transactions between users in a supply chain. Cloud platforms, on the other hand, are typically centralised, controlled by a single company and designed to store data and information online. Cloud platforms can be further divided into cloud platforms for business and cloud platforms for the whole supply chain with the latter platforms consisting of a number of modular traceability solutions that can be coupled together to provide the supply chain solution being requested.

Blockchain technology enables users to store information on a decentralised peer to peer network providing increased transparency, better user control and enhanced confidence around its ability to prevent fraudulent activities. Not surprisingly, examples of blockchain platforms in operation are more numerous that cloud-based systems for supply chain management. This is evident regardless of the supply chain being considered with many agricultural and non-agricultural examples available. Blockchain platforms rated highest when compared to the cloud-based platforms with choice/control and convenience the factors most advantaged (Table 5). Whilst digital tracking technologies such as blockchain will underpin modern traceability systems, they are effective at checking the details of products as they move through a supply chain. Additional trust mechanisms or independent data verification are needed to prevent data tampering before the data is stored on a digital platform.

Table 5. Evaluation of digital tracking and tracing systems and technologies for use in red meat supply chains.

Digital platforms	Choice/control	Convenience	Community	Completeness	Compatibility	Customer cost	Overall Rating
Cloud Platforms for Whole Supply Chain	2	2	5	5	4	3.5	21.5
Blockchain Platforms	4	3	5	4	4	3.5	23.5
Cloud Platforms for Businesses	3	2.5	2.5	5	4	3	20

3.7.3.1 Cloud-based platforms for the whole supply chain - Inexto

Name of company/technology: Founded in 2016, Inexto (http://www.inexto.com/) is a Swiss based company specialized in tracking and authentication for supply chains. The company provides software for verification of production volume, product serialisation, tracking and tracing to enable trusted, transparent, and ethical trade.

Functionality:
The initial system (Codentify) was designed for fighting illicit trade of tobacco and tobacco products by monitoring the production and supply. For tracking the products and tracing their origins, the system uses unique codes marked on the product or its packaging. Inexto provides

- Verification of product integrity at the level of single unit to highest level of packaging
- A centralised data repository that can be shared with all stakeholders improving the visibility of data
- Authentication for anti-counterfeiting using un-hackable and unique codes for individual products
- A platform connected to a cloud to record tracking events and for supply chain optimisations
- Interfaces with many data architectures and complies with GS1/ISO EPCIS standards
- Greater trust and transparency for end-consumers through the use of a mobile app to access the product data on the cloud

What part of the supply chain does it cover:
Inexto provides end-to-end tracking and traceability from farm to consumer.

Stage of development:
Currently, the technology is used to cover more than 100billion products worldwide.

Advantages:
- Data compression through aggregation (linking the items and their containers) improves the scalability
- Low cost for generating and printing codes.

Disadvantages:
- The system only allows for code and not product verification. Counterfeiting may be possible through code recycling, code cloning, and code migration.
- It may be inefficient when compared to other solutions. For the example of tobacco supply chains, it is reported that to achieve a 95% certainty of not missing a fraudulent pack, Codentify (the system used by Inexto) requires to inspect 31000 packs, whereas a material-based tracking and tracing solution requires to inspect only 59 packs.
- Since the system is centralised, the security and trust rely on the brand holder using the platform to generate codes. The factory-level keys used to generate the codes are stored on company and government servers. Anyone who has access to these servers can generate additional codes.
- The system has been criticised as a black box created using unsecured equipment.

3.7.3.2 Blockchain platforms - Samsung SDS Cello Trust

Name of company/technology: Samsung SDS Cello Trust (https://www.samsungsds.com/global/en/solutions/off/cello/cello.html)

Samsung SDS Cello Trust is a blockchain-based traceability platform currently being applied to various supply chains such as agribusiness, processing food, chemistry, electronics and medicines. Since 2017, Samsung SDS has been developing PoC implementations with various industry partners using a Quorum blockchain-based platform that integrates IoT and digitisation technologies (such as OCR).

Functionality:
Growing consumer awareness of food safety and sustainability urges producers and retailers to implement traceability systems that can provide transparent and reliable data on the production and distribution of food products. Furthermore, the changing requirements of global retailers and trade measures of importing countries require seafood producers to comply with global standards for seafood sourcing and exports such as the US SIMP (Seafood Import Monitoring Program).

Samsung SDS Cello platform uses IoT, digitisation and blockchain technologies for producers and retailers to collect, manage, and share data in a tamperproof and reliable way. In the abalone traceability PoC, Korea Meteorological Administration, abalone farmers, processors, exporters, importers, wholesalers, and retailers stored and managed the supply chain data (e.g. nursery data, feed data, shipping data, receiving data, distribution data, and export data) on the Cello platform. At each supply chain step, data is tracked with order, progress, and lot numbers for traceability. Cumulative information is available to supply chain stakeholders and can also be revealed via a scan of a QR code on the product. Government certifications are visible across the entire supply chain.

What part of the supply chain does it cover:
Cello platform provides end-to-end tracking and traceability for supply chains from producers to export and end-consumers.

Stage of development:
Currently, the technology is implemented as Proof of Concept (PoC).
Advantages:

- The platform uses government offices, certification authorities, public services, and non-profit organisations as validators of the blockchain network for improving trust and assuring neutrality. The other stakeholders of the supply chain act as common nodes of the network.
- Data accessibility - The supply chain data is recorded on a blockchain-based platform to enable selective information sharing with pre-approved parties.
- Greater trust and transparency for end-consumers through scanning a QR code to access the tamper-proof product data.
- It helps producers to manage the data acquired by IoT devices or manual data entry (aquaculture records, energy efficiency, quantities, feed, etc.) to prepare for audits and assessments for global certifications.

Disadvantages:

- To store data on the product package, the platform uses QR codes, which may be copied and reused. The system relies on physical audits and sampling for inspection to prevent product relabelling. A better alternative could be to either link the code to the individual product and have a mechanism to verify that link or use alternative tracking or tagging technologies such as anti-counterfeiting labels.
- There is no mechanism for evaluating/improving the trustworthiness of the collected data. Although the data stored on the blockchain is tamperproof, the trustworthiness of the data is not guaranteed.

Discussions:

Although the platform has not been used for red meat supply chains yet, the abalone

3.7.3.3 Cloud-based platforms for business

Cloud platforms for businesses offer tracking and tracing functionality by managing data at the individual business level. The users of cloud platforms store their business data on the cloud and use the data to manage their production and logistics operations by monitoring performance, inventory, quality, and pricing. The cloud technology improves the reliability of the system. Furthermore, IoT integration enables automation. As a mature technology that is used for a broad range of supply chain applications, cloud platforms comply with global standards and regulations, and provide integration with existing data collection and management systems.

As a business solution, cloud platforms provide limited tracking and tracing capability and do not enable the propagation of provenance data of products across the supply chain, since data is siloed and not shared with other supply chain participants. Furthermore, due to the lack of transparency, data owners are able to manipulate their data, which raises security and data integrity concerns though some cloud-based platforms may have mechanisms to restrict the manipulation of data once it is recorded on the database. Although cloud platforms help businesses to improve the efficiency and achieve cost savings, the cost of the services, in particular third-party audits, may be a barrier for adoption by all supply chain participants.

3.7.4 Verifying the product via testing

Australia is a global exporter of red meat products, aiming to deliver high quality, high value products to a variety of markets in a safe and secure way. The red meat supply chain, like most supply chains, is highly complex and by its nature, creates vulnerabilities that have the potential to disrupt a safe and secure supply chain. Red meat products are often traded as a commodity in bulk with an expectation that the receiving market or customer is likely to transform the product into more retail ready formats. This process routinely separates the meat product from all its packaging and provides opportunity for food fraud activities to occur. Whilst the frequency and cost of food fraud to the Australian red meat and live animal trade is difficult to accurately determine, estimates of approximately $272 million per annum have been made[19]. Similarly, non-compliance to customer or market specifications costs the beef industry an estimated $127-$163 million per annum[53].

Technologies and systems that verify that a product matches the digital record associated with it and furthermore, it complies to the provenance, safety and quality specifications is an important component of enhanced traceability systems. This report identifies eight technology clusters associated with product verification with the ratings for each of the clusters shown in Table 6. Whilst there are some established technology clusters such as genotyping and federated spectroscopy and spectrometry, the notable feature of the remaining clusters are the relatively low ratings for completeness. The low ratings stem from most technologies requiring yet to be developed databases for red meat supply chain applicability and the lack of field-ready or processing-ready solutions. These limitations are, to some degree, being addressed through industry-led initiatives for database development and via the miniaturisation of the test systems.

Table 6. Evaluation of product verification systems and technologies for use in the red meat supply chain.

Verifying the product via testing	Choice/control	Convenience	Community	Completeness	Compatibility	Customer cost	Overall Rating
Hyphenated mass spectrometry	3	2	3	3	4	3	18
Elemental profiling (destructive)	2	2	2	2	3	3	14
Elemental profiling (non-destructive)	2	2	2	2	3	3	14
Ambient mass spectrometry	3	4	3	2	4	3	19
Federated spectroscopy and spectrometry	4	3	5	4	4	3	23
Spectroscopy (NMR)	4	2	2	2	3	2	15
Omics	5	3	4	2	3	3	20
Genotyping	4	4	5	4	4	5	26

3.7.4.1 Hyphenated mass spectrometry

These test systems use separation techniques such as gas or liquid chromatography coupled with mass spectrometry to produce chemical profiles of food products. The chemical profiles or fingerprints as they are commonly referred can then be utilised to provide insights of the chemical compounds or as a differentiator from other similar food products. Whilst these types of approaches yield high quality data that is highly reproducible, they do require a substantial amount of sample preparation prior to and during the analysis.

More recently, these approaches have been used to measure stable isotopic ratios of H, C, N, O and S for the verification of geographical origin. Isotopic molecules differ in their physical and chemical properties resulting from the effects of climate, altitude, latitude and metabolic processes of living systems[54]. The Australian pork industry use the technology as part of their Physi-Trace system enabling them to trace fresh pork back to a kill lot or to determine if processed product is Australian or not[55]. Oritain (https://oritain.com/) is a commercial provider of isotope ratio testing and has developed databases for beef, lamb and venison that are intended to facilitate country and region of origin determination.

3.7.4.2 Elemental profiling

The elements found in animals and plants reflect the environment in which it is grown, including soil, water and feed making them ideal indicators of geographical and regional origin. Elements can include macro-elements (e.g. sodium, calcium and potassium), trace elements (e.g. copper, zinc and selenium), rare earth elements (e.g. lanthanum and cereum) and others such as gold and iridium that occur at very low abundances. The key to a successful elemental profiling strategy is to select out the elements that have demonstrated uniqueness to the region of interest. Whilst this does require the development of an underlying database, it does enable analysis to occur in very short timeframes and at low cost. Accessing the technology for sample analysis is also relatively simple with many food testing labs routinely using systems such as inductively coupled plasma mass spectrometry for quality control of food products.

Elemental profiling has been used in the research setting to distinguish beef from multiple countries, including Australia[56]. It may also be used in conjunction with isotope analysis to classify beef samples from geographical areas of close proximity (e.g. within a state or province)[57]. An area of elemental profiling that is yet to be explored adequately is the impact of cattle movement or production system. As the elements are a function of the consumption of inputs by the animal it remains to be seen how quickly they change when an animal is transported from a backgrounding property to a feedlot, for example. Additionally, consideration would need to be given to the source of the purchased feed and its impact on the profile measured when the animal is processed.

Technologies for elemental profiling are improving with portable and hand-held devices becoming available that enable analysis to occur at any point from processing through to retail. There is high potential for mobile phone applications to exist in the near future thereby providing an everyday tool for consumer verification of product.

3.7.4.3 *Ambient mass spectrometry - REIMS*

Name of company/technology: Rapid Evaporative Ionisation Mass Spectrometry (REIMS) - Waters Pty Ltd (https://www.waters.com/nextgen/au/en.html)

Functionality:
REIMS is a novel ambient mass spectrometry approach originally developed in the 2000's as a surgical tool to discriminate cancerous cells from healthy cells during surgical procedures. It uses an electrosurgical knife (iKnife) to heat tissue samples and produce a vapour plume containing ions from the sample. The ions are analysed and a spectral profile (fingerprint) of ions is produced within seconds of sampling. The spectral fingerprint can be used to assess key attributes and differences of, and between specimens. The unique feature of ambient mass spectrometry approaches is the ability to analyse samples without the need for prior chromatographic separation as is typical for hyphenated mass spectrometry approaches. The biggest advantage of REIMS is that it can sample remotely which means it can integrated to existing food processing environments.

What part of the supply chain does it cover:
From slaughter to retail. Applications focus on provenance and traceability but also extend to safety and quality attributes.

Stage of development:
REIMS systems are commercially available through Waters Pty Ltd. Proof of concept studies include but are not limited to the following application areas:

- Identification and classification of animal tissue with different anatomical origin, breed or species.
- Detection of offals in raw or cooked minced beef samples at concentrations as low as 1%.
- Classification of animals of the same breed or species based on production system (e.g. grass- or grain-fed) or catch method (e.g. trawl or long-line caught fish).
- Detection and classification of pork boar taint and dark-cutting beef carcasses.

Advantages:

- Suitable for integration into existing processing plants.
- Real-time, in-line sampling.
- No sample preparation and analysis is completed in seconds.
- Automation of the system is possible.

Disadvantages:

- Requires database development.
- Uses a destructive sampling process at present though non-destructive approaches are in development.
- Analysis is generally qualitative.

3.7.4.4 Federated spectroscopy and spectrometry

There are a range of key product attribute claims that the Australian red meat sector leverages to generate the highest value for their products. At different times there may be a need to have technologies or systems available that can verify multiple claims efficiently and in a cost-effective way. Source Certain International (https://www.sourcecertain.com/) have developed a platform of chemical based profiling methods to deliver supply chain security to its clients. By locating multiple technologies and experienced personnel in a single location they are able to provide an effective service that has demonstrated the ability to trace food products such as eggs and seafood back to individual farms or fisheries. Source Certain International have multiple service offerings that move from batch and manufactured product identification and traceability through to the ability for anyone to verify product at any point in the supply chain.

3.7.4.5 Spectroscopy (NMR)

Nuclear magnetic resonance spectroscopy generates a quantitative profile of each compound within a food sample that can be used to classify or distinguish foods. The non-destructive sampling approach coupled with high accuracy, reproducibility and a lack of requirement for sophisticated separation and purification steps gives NMR great potential and it is often used in food science research. However, it remains underutilised away from the research environment due to its high cost, relatively low sensitivity and the requirement for specialised expertise to analyse the complex data sets produced during analysis. Applications of NMR appear to focus on the detection of adulterated products such as milk, honey and wine. Whilst similar application strategies could be developed for red meat products, less complex and costly approaches would deliver the same outcome.

3.7.4.6 Omics

Omics refers to a suite of molecular tools capable of determining features of a genome, proteome or metabolome. At its simplest, technologies such as polymerase chain reaction (PCR) have been used extensively to determine the species of origin in foods. There are several PCR based systems that are field-deployable and inexperienced users can generate low-complexity data sets that are easily interpretable. However, omics approaches typically generate large data sets that require bioinformatic and chemometric approaches to provide meaningful, actionable outcomes. DNA fingerprinting is a common genomics approach used in the red meat industry and will be discussed later. The use of proteomics and metabolomics are being used to assess geographic origin, production system or instances of food fraud. In these scenarios, omics technologies assist in the identification of unique biomarkers that can be used to verify product as it moves through the supply chain. At this point though, they are often used in tandem with other verification technologies or systems and the absence of non-targeted approaches may limit the commercial applicability of these tools for traceability.

3.7.4.7 Genotyping – Identigen

Name of company/technology: Identigen (https://www.identigen.com/) – DNA TraceBack

Functionality:
Animals possess a unique DNA code, which is permanent throughout life and in the products that are derived. DNA traceability technologies use specific DNA markers known as Single Nucleotide Polymorphisms (SNPs) to identify an individual animal from birth until the product is consumed. DNA TraceBack is a proprietary traceability solution that ensures a finished product can be unequivocally matched to its original source. It uses patented sampling devices to sample carcases (or live animals) and meat and uses its proprietary IdentiSeq and ID-GENerator technology to complete a simplified, low-cost analysis.

What part of the supply chain does it cover:
Birth to retail – farm to fork solution

Stage of development:
Commercially available

- Grocery chain Marks and Spencer (M&S) has contracted the DNA food testing company Identigen to run independent DNA tests on beef samples taken from every single cattle used in M&S beef.
- Tyson Fresh Meats has partnered with Identigen to further its traceability efforts for its Open Prairie Natural Meats program.

Advantages:

- DNA genotyping is the leading technology for individual animal verification.
- Genotyping technology already underpins breeding and genetic evaluation programs.
- Applicable at all points of the supply chain.
- Can be used to underpin additional product claims.
- Affordable.

Disadvantages:

- A reference database that is continually updated is required.
- Requires additional technologies to verify geographical origin or production system.

3.7.5 Tracking or tagging the product

Being able to track food through all stages of the red meat supply chain, including production, processing and distribution is necessary to ensure that products entering markets meet expected quality specifications and safety standards. Additionally, it ensures unexpected events or outcomes can be adequately investigated and rectified. In Australia, traceability through animal production is achieved via the NLIS where all livestock are identified by a visual or electronic eartag or device. NLIS enables whole of life traceability that assists in ensuring access to global markets, maintaining consumer confidence and reducing the impact of livestock disease. Whilst this is readily achievable, the traceability of products from individual animals through processing remains highly problematic with batch or lot-based identification strategies typically used by processing plants, distribution and retail.

This report identifies six technology clusters associated with the tracking and tagging of animals or meat products through the red meat supply chain. The technology clusters are well known and at first glance it may appear that little has changed in recent times. However, there are improvements in several technology clusters that provide additional value to the supply chain or potentially enable the technology to overcome barriers to adoption. The ratings for each of the clusters are shown in Table 7 and are discussed in further detail below.

Table 7. Evaluation of tracking or tagging systems and technologies for use in the red meat supply chain.

Tracking or tagging the product	Choice/control	Convenience	Community	Completeness	Compatibility	Customer cost	Overall Rating
RFID & GPS	4	3	5	5	4	3	24
Molecular Tagging	4	4	3	5	4	5	25
Tagging	4	4	3	5	4	5	25
anti-counterfeit / tracking labels	4	3	3	4	3	4	21
Computer vision	4	4	3	3	2	2	18
GS1 product code applications	4	4	3	5	4	4	24

3.7.5.1 RFID & GPS – Implantable RFID chips/devices

Name of company/technology: (i) EZid (https://www.ezidavid.com/) (ii) PELIT (https://id-ology.com/products/#pelit) (iii) PIT Tags (http://bts-id.com/)

Functionality:
PIT tags and PELIT are implantable RFID microchips for livestock similar to those used for domestic pets and other animals (eg. fish). EZid use PIT tags and have developed their own reader technologies and electronics. RFIDs are passive and do not have an energy source. Rather, a low-power radio signal is directed to the chip via the scanner or reader to obtain the identification number. These microchips are small (2- 4 mm in width and 10 – 32 mm in length) and are typically encased in a glass capsule.

In cattle, microchips have been implanted in a range of sites (upper lip, armpit, penial sheath) but have most commonly been implanted in the ear (above the scutulum). A purpose-built needle injector is used to implant the microchips.

What part of the supply chain does it cover:
From birth (on-farm) to slaughter.

Stage of development:
Microchip technology has been available for some time (TRL 9) however, it's application in livestock has been slow to evolve, primarily because of several limitations with the technology (see below). It is worth noting that rumen bolus technology was the first "implantable" identification system which emerged during the nineties. Despite their higher retention rates and tamper-proof attributes, rumen boli have been less favoured compared to RFID ear tags in commercial beef operations.

Advantages:
Implantable RFIDs are effectively tamper-proof and not subject to the same retention issues that have been observed with RFID ear tags.

Disadvantages:
There are three primary issues associated with implantable RFIDs that limit their utility in livestock identification. Firstly, relative to externally deployed RFID tags, the read range (distance between the scanner and animal) is reduced due to their reduced size and signal attenuation by the overlying tissue. Consequently, this could compromise the functionality or require re-engineering of autonomous animal management systems based on RFID (eg autodrafters). Secondly, read failure can be higher due to the fragility of the glass microchips especially in large animals where the collision force and/or impacts between animals or with infrastructure (yards, crushes) can be quite severe. Encapsulation with a more robust material might overcome this issue but it is unclear at this stage whether this has been explored. Finally, microchips have been known to migrate from their insertion site which potentially increases the risk of meat contamination at the point of slaughter. Idology, the manufacturer of the PELIT implant, state that it has been designed with an anti-migratory cap to anchor it where it is injected but there is no supporting evidence of the effectiveness of this design.

Name of company/technology: Applied DNA Sciences (https://adnas.com/)

Functionality:
Applied DNA has developed a technology to produce small DNA tags or identifiers on an industrial scale. The DNA tags represent a "molecular bar code" and function similarly to an ordinary ink bar code on a label or package. Applied DNA's CertainT® platform has three technology pillars (Tag, Test, Track) which enables raw materials and products to be tagged with a unique molecular identifier. This tag can then be tracked and authenticated right throughout the supply chain. The tagging and tracing data is uploaded and maintained on a secure cloud database. The testing can be conducted centrally in the laboratory (PCR-CE) or in the field using portable qPCR technology. The platform has been used in various industries including textiles, leather, fertilizer and pharmaceuticals.

Each molecular tag is created as a unique sequence and is incorporated in Videojet ink designed to permanently adhere to a product after printing. It can be embedded within the raw material or applied to its surface. The tags are designed to be safe, inert and robust. The latter was clearly demonstrated in a recent denim authentication study where the molecular tags were applied during the cotton ginning phase. The manufactured denim was then subjected to multiple stone and bleach washings and the integrity of the tag was not compromised. Given the size of the tags (generally < 200 bp) they are compliant with US FDA and WHO standards for pharmaceutical products (Jung et al 2019).

What part of the supply chain does it cover:
Potentially this could provide an end-to-end platform (farm to consumer).

Stage of development:
The technology is being deployed and tested in several different manufacturing industries and also government agencies (eg military). It appears to be gaining a growing foothold in the textiles and apparel sector.

Advantages:
Based on the available information, molecular tagging appears to offer the red meat sector the following benefits:

- Unique, tamper-proof and robust product identification.
- Traceability is feasible throughout the entire supply chain. Importantly, traceability could be maintained through the essential carcass and meat fabrication stages which are inherently problematic in terms of traceability.
- Potentially, all animal products could be traced at the point of slaughter (meat, offals, by-products, hides).
- Field-based traceability. Tag detection was possible within 20-60 min [10]

3.7.5.2 Case study – Molecular tagging/tagging

Disadvantages:

- Whilst the technology is applicable for pharmaceutical products, it is not clear whether it is appropriate for food applications.
- Limited applicability for animal identification. The tag would most likely need to be embedded in tissue and this raises concerns regarding stability over time and detection/readability. Difficult to identify advantages over conventional genotyping as a means for animal identification.
- The transfer of molecular identification from animal to carcass to meat would require additional tags to be printed and deployed.

3.7.5.3 Anti-counterfeit / tracking labels

Anti-counterfeit and tracking labels can be applied directly to products, or packaging of products. They provide product authentication against counterfeiting and illicit trade across multiple sectors and industries. The labels may also provide rapid access to information regarding traceability, provenance, and sustainability claims of the products with a resolution determined by the applicant. Consumers can authenticate products by visual verification of the labels or using a digital platform that enables label verification. Applying anti-counterfeit/ tracking labels on products or packages is highly automatable and integratable with existing processing and packaging lines providing a cost-effective solution for manufacturers and processors.

There are limitations for the use of anti-counterfeit/ tracking labels in red meat supply chains. Firstly, anti-counterfeit/ tracking labels provide solutions for part of the supply chain with an emphasis on processing and manufacture through to end-consumers. Secondly, labels on the packages limit the applicability of the technology for products which require further manufacturing or processing. Furthermore, the security of the system depends on the technologies used to generate, apply, and verify labels. Thus, future-proofing requires research and development of new anti-counterfeiting technologies.

3.7.5.4 Computer vision for identification

Computer vision (CV) systems can be used for animal detection, identification, authentication, tracking and behaviour monitoring. It has the potential to offer a non-intrusive (passive) means to identify animals at a reasonable cost due to advances in camera and computing technologies. Most of the cost for current approaches is for the required significant signal processing and/or increasingly machine learning (ML) (including deep learning).

Recent advances in ML have enabled near human level and better capabilities in the detection and labelling of objects (such as cow, feed, sheep, fence etc). While much research has been invested into facial authentication (validating that a face is who it claims to be – like an owner of a phone), the technological approach (and performance) greatly differs from the identification challenge (i.e. determining who this is). For most livestock situations, identification is necessary, however, particularly in field conditions, there is a significant challenge to achieve performance that would be acceptable for typical operations. Claims of 98% accuracy (Finding Rover) without specification of the false non-match rate (FNMR) versus false match rate (FMR) or reference to enrolment database size, cannot be used to assess the practicality in real livestock management applications. For example, 98% accuracy could imply that 2% of animal classifications are incorrectly identified as other animals. Such a rate (i.e. 1 in 50) would not be acceptable for a national traceability system.

Cainthus, additionally utilise hide colour patterns which could offer higher recognition performance. For human facial identification, identification remains very challenging when false (positive) identification is required to be low, despite the vast research investment. As such, it is very unlikely that facial recognition for animals will offer the uniqueness achievable by other non-computer vision technologies and may never achieve a practical utility in large scale livestock production systems due to the asymptoting improvements in facial recognition performance.

Alternate emerging CV-based approaches, such as gait recognition and iris scanning, may one day offer superior performance to animal facial recognition and have the potential for being integrated in commercial livestock systems.

3.7.5.5 GS1 product code applications – ProductDNA

Name of company/technology: ProductDNA (https://productdna.gs1uk.org/)

ProductDNA was launched in May 2018 evolving from a collective initiative by the UK food and retail sector to develop an agreed common language for products. ProductDNA is owned and governed by the retail industry through the GS1 UK Retail Grocery Advisory Board.

Functionality:
The growing regulatory landscape coupled with more discerning consumers has challenged product manufacturers to populate their packaging with more data than ever before (e.g. detailed ingredient and allergen information, nutritional values, provenance). In recognition of this and the need for a common language and to reduce the time retailers spent validating product data were the key drivers behind the development of ProductDNA.

Using a centralised system, ProductDNA enables producers and suppliers to manage and share their product data stored on a cloud-based platform. On this GS1 compliant platform, every step about the production is traced with accessible, summarised and detailed data about the product, its social conditions and environmental impact and its supply chain mapping. An independent third-party verification step ensures the accuracy of the data stored on the platform.

ProductDNA provides:

- A common data model using an industry-agreed set of product attributes (up to 150 attributes can be determined for a product) – streamlines and standardizes data sharing by creating a shared language across all retailers and suppliers
- A centralised system for suppliers to enter their new lines data once and share it with multiple trading partners – improves efficiency by removing admin and duplication
- A simpler, more intuitive product catalogue shared between retailers and suppliers – reducing the time spent on data collection and increasing the time available to focus on improving the customer experience
- Independent third-party physical product verification underpinned by GS1 standards – checks on dimensions, barcodes and on packaging and improves the overall quality of product data
- Greater trust and transparency for consumers, improving the overall shopping experience.

What part of the supply chain does it cover:
Potentially this could provide an end-to-end platform (farm to consumer).

Stage of development:
The technology is mature and in use by major product manufacturers (Unilever, Nestle, General Mills) and retailers (TESCO, Sainsbury).

Advantages:
One of its stated benefits is that it is an inherently fairer system where it spreads the load between retailers and suppliers – existing systems lean heavily on the latter in order to carry favour with the former.

For red meat supply chains, ProductDNA may offer:

- Common language that could be integrated from animal through to ready-to-eat products
- Unifying platform that integrates diverse criteria/attributes at different segments of the red meat supply chain
- Adaptable and high-quality product catalogues allowing inclusion of new provenance attributes for red meat products.
- Integration with existing systems through APIs. Furthermore, the verified data can be extracted and shared with non-ProductDNA retailers.
- Third-party physical verification for the product data stored on the platform. According to GS1 UK, a third of the new product data is inaccurate and fails independent physical checks.
- A rewards mechanism based on reduced verification costs for producers and suppliers that consistently submit accurate product data.

Disadvantages:

- There may be limitations when the number of retailers/end-users is large and geographically diverse? For example, Australia exports beef to multiple countries and to multiple companies within country. It would require acceptance and buy-in by most to drive implementation.
- The product data is printed on the package of the product. The system does not guarantee the authenticity of the product in the package as the packages can be copied and the product labels can be reused.

Further comments:

- The platform was launched in 2018, and the available data about the platform and its use cases are limited. We have not found any information about the platform specific to red meat supply chains.
- Although the platform can capture data regarding many product attributes, the amount of data printed on the products will ultimately be determined by its value to end-users/consumers to avoid information overload.

3.7.6 Delivering value add

Technology and system development often occur with a specific issue or question in mind that needs addressing. On occasion, the solution that eventuates has a greater impact that initially perceived. The solution may be applicable at more points in the supply chain than had previously been considered or the implementation of the solution provides opportunity for enhanced management of the supply chain. For instance, the evolution of the smart eartag improved the tracking capability but added functionality around biosecurity monitoring and provenance. A product such as Ceres Tag (https://www.cerestag.com/) transforms the existing eartag offering to a complete animal welfare platform capable of delivering GPS location, health and welfare monitoring and theft detection. An eartag that provides clear benefits to animal management and welfare will encourage application as close to birth as possible and will provide much greater insights to producers than existing eartags.

The use of genotyping is a familiar practice in the Australian red meat industry with an emphasis on genetic improvement. Identigen's DNA TraceBack uses the same underlying scientific principles to facilitate a traceability solution that provides indisputable evidence of which animal a meat product has come from. With genotyping costs falling quickly and the possibility of crush-side genotyping on the horizon, there would appear to be a strong value proposition behind the implementation of a similar approach to Australia's industry. The value addition from other technologies and systems detailed in this report are a little harder to quantify at this stage and further investigations are warranted. REIMS, for example, provides an opportunity to conduct in-line analysis of carcases and meat products with almost instantaneous assessment. Although developed as a product verification tool there is the potential for REIMS to overcome the traceability issues that occur during the boning of carcases by enabling the matching of spectral fingerprints of incoming carcases with outgoing primal cuts. Numerous opportunities similar to those discussed are likely to exist and it's therefore the upstream or downstream applications become an essential consideration during any technology implementation phase.

3.7.7 Global shifts affecting Australia's largest markets

There are several global shifts affecting Australia's large export markets that may need to be considered when choosing the most suitable food integrity system for the coming decades.

Development of central bank digital currencies (CBDCs), and crypto currencies associated with retail and social platforms. The Bank of International Settlements (BIS) reports that over 80% of the world's central banking agencies are in the process of trialling or developing central bank digital currencies (CBDCs). Most of these are on a blockchain or distributed ledger system, similar to Bitcoin[58,59]. Some of these efforts have been brought forward in the move towards a cashless society post COVID-19.

Digital Yuan: Of note is work being done in China on the digital Yuan. On 17 April 2020 Chinese authorities confirmed that they were conducting the first 'internal closed pilot tests' for the digital yuan (also known as DC/EP) in four major cities: Shenzhen, Suzhou, Xiong'an New District and Chengdu[60]. State-owned commercial banks are developing wallet applications to monitor and transactions using the digital Yuan. China's four state-owned commercial banks are involved in the trial, along with large retailers, Ant Financial, Tencent as well as 19 restaurants, entertainment and retail outlets. Included in the trial are US companies McDonalds, Starbucks, and Subway. The impact on international trade with China is unclear. Some suggest that it will make payments for products via WePay and AliPay redundant and give the Chinese Government far greater transparency on the informal economy – including money laundering and crime - as well as being able to better harvest trade tariffs and taxes due on imports via international platforms.

There is speculation that the Chinese government will also seek to make international trade payments and investments in Chinese Renminbi (RMB) or Yuan – rather than US dollars – via their digital wallets[61]. In June 2019 only 1.88% of International Trade payments from China were done in RMB[62]. Trade via the digital Yuan could also bypass the Western banking system, including the SWIFT platform, negating many transaction payments and decreasing the risk of losing currency in international transactions or hacking events.

Digital Euro: The Banque de France is trialling a digital Euro in settlement procedures. In an official announcement issued on 27 March 2020[63] the bank called for technology partners to assist in running experiments to test payment systems using the digital Euro. The digital Euro will potentially use digital tokens to replace cash and central bank money in the payment of large cash settlements.

Platform-based digital currencies: In mid 2019 regulators around the world became conscious and alarmed at the prospect of an international currency being developed by one of the world's largest social network platforms: Facebook. The proposed digital currency, Libra, is currently being developed as a 'stablecoin' – or a cryptocurrency that would be 100% backed by a range of securities and fiat currencies such as the US Dollar, Euro, British Pound and Yen. Fiat currencies have far less volatility, and so tying the Libra to other currencies would stabilise its value and increase its use as a transactional token to buy and sell goods– as opposed to a token to be invested in and stored like Bitcoin. The proposal is that Libra will be run by Facebook with partners in Visa and Uber, although there are recent reports that Facebook is stepping back from creating Libra – which will still be created by a non-profit group, Libra Association - but will launch a digital wallet, Calibra, that can store Libra along with a number of other digital currencies[64]. Regulators around the world have been concerned that Libra will threaten national fiat currencies controlled by the central banks, and that it will be used increasingly for international trade transactions that can bypass national taxation, tariff and other systems[65,66]. Food integrity systems will need to be built to be interoperable with a range of digital currencies in the future, particularly Australia's primary markets such as China.

4. Summary and recommendations

Australia positioned itself as a global leader in livestock traceability systems approximately 20 years ago following the introduction of the NLIS and subsequent development of the LPA and NVD programs. The whole-of-life traceability conferred by these programs to the Australian red meat industry continues to be assessed as progressive, particularly in relation to several of Australia's major trading partners. Despite this advantageous position, ISC have acknowledged the increased demands of global markets and consumers for delivery of supply chains with elevated levels of transparency, provenance and integrity. Consequently, an opportunity exists to evolve or perhaps revolutionise the existing red meat integrity system and increase the competitive advantage of Australia's red meat industry. ISC have outlined 10 key elements that can be used as criteria for gauging the effectiveness of an integrity system moving forward. The criteria recognise the need to deliver gains across the entire supply chain through enhancements in traceability systems, automated verification systems, data management and analytics, and consumer confidence whilst reducing the compliance burden on supply chain participants. Therefore, an end-to-end red meat supply chain traceability system should ensure the transparency of relevant data to participants and consumers while preserving confidentiality and privacy of participants and business interactions

This report provides a global scan of the technologies and systems that underpin supply chain traceability with the intent of providing recommendations to ISC to inform future directions. It identified that the technologies and systems fall into two key categories: 1) the digital architecture that tracks or traces products as they move along the supply chain, and 2) the technologies that verify the product is indeed what is claimed. Technologies that verify a product can then split into two sub-categories comprising: a) those that test the product to verify, and b) those that identify the product to enable verification. The evaluation of the technology clusters within each of categories does identify high-rating opportunities for the Australia sector that are worthy of further investigation. Importantly however, it also highlights that a single supply chain solution does not exist currently and instead several solutions exist at each of the major supply chain stages. Furthermore, it is beyond the scope of this document to recommend specific technological solutions as the choice of a technology for a supply chain participant will be influenced by their relative position in the supply chain, the trust level between participants, and the value proposition attached to each solution. Thus, any complete end-to-end traceability system will require multiple types of technologies and consequently, interoperability will be paramount.

In order to systematically progress the red meat integrity system from its current whole-of-life-traceability design to a complete end-to-end traceability system, a set of preliminary recommendations for future action have been prepared. The following recommendations are presented in order of the priority considered necessary to address the 10 key elements outlined in ISC's 2025 strategic plan.

Recommendation 1: Define the overarching architecture of a complete end-to-end traceability system for 2025 and beyond.

ISC presently oversee Australia's red meat integrity system through the delivery of the NLIS, LPA and NVD programs. It is not anticipated that ISC will attempt to develop a 'complete' traceability solution by prescribing the traceability technologies or systems for the Australian red meat sector and supply chains. Rather, ISC should continue to oversee the management of an expanded traceability system by prioritising the development of the overarching digital infrastructure supporting a national traceability system and defining the standards and specifications for inclusion of identification/verification technologies and systems into this architecture. It is acknowledged that this recommendation is the basis of 'Project 1 – Defining overarching requirements for the future state traceability systems in terms of objectives, data points, collection, storage and analysis' of the recent ISC call for projects on 'Establishing new integrity system approaches and technology'. However, it should be noted that the project team reached the position outlined in this recommendation independently of the project call and therefore supports the direction proposed by ISC. This recommendation calls for specific emphasis on standards that are central to the interoperability of traceability technologies/systems and it critical that these standards undergo constant revision commensurate with the evolution of new and potentially disruptive technologies. This will enable more rapid introduction and implementation of new traceability technologies.

Recommendation 2: Harmonisation of regulations and clarification of roles and responsibilities in an enhanced traceability system at an industry (red meat) or sector (agriculture) level.

Prior to the release of the Australian Government's National Traceability Framework uncertainties around traceability roles and responsibilities and the acceptable level of harmonisation of regulation between Australian governments were noted, and the need for a single, national approach to traceability was proposed. Therefore, in addition to ISC overseeing the management of an expanded traceability system, it is recommended that ISC seek to provide cohesive, inclusive leadership at the national level for the development of harmonised regulations and role and responsibility clarifications for the red meat industry and subsequently for the agricultural sector.

Australia trades as a single entity in global markets with goals and objectives common to industry or the sector which span state and territory borders. In many ways these common goals are similar to the common goals of the National Cabinet in their COVID-19 response and there appears opportunity for ISC to apply similar design principles to achieve the outcomes desired.

Recommendation 3: Facilitate the extension of the red meat integrity system from whole-of-life to whole-of-supply chain through evaluation of technologies that facilitate individual animal traceability to the consumer.

Whilst individual animal traceability from birth to the end of the slaughter process is achieved via the existing red meat integrity system, it rarely continues through the remainder of the supply chain. Batch or lot identification beyond the point of slaughter is the limit of the current traceability system. This report has identified candidate technologies that would:

- deliver unequivocal traceability (e.g. genotyping)
- or may provide real-time, in-line traceability (e.g. ambient mass spectrometry)
- or generates tagged product that can be identified for the remainder of the supply chain (e.g. molecular tagging).

It is recommended that a more detailed evaluation of the applicability and value of the higher rating candidate technologies should be undertaken. Ideally, design led principles should be applied in this further evaluation such that solutions address the needs of the red meat sector and the market.

Recommendation 4: Assess the potential for advances in key foundational technologies to alter the technological landscape by changing what is possible in supply chain traceability.

Developments in the areas of AI, IoT, blockchain, global payments and 5G provide opportunities for the evolution of existing supply chain solutions that ultimately broadens their scope of applicability. For example, the evolution of smart ear tags has enabled additional functionality around animal management, biosecurity monitoring and provenance. There is an expectation that as traceability technologies evolve through the uptake of disruptive technologies, they will, as has been observed with the ear tag example, generate solutions with much broader supply chain scope. As necessary, candidate technologies with broadened supply chain scope or multiple functions should be assessed for value and practical applicability in the Australian context.

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6. Appendix 1 – Technology evaluation

Table A1 Evaluation of digital tracking and tracing systems and technologies for use in red meat supply chains.

Table A2 Evaluation of product verification systems and technologies for use in the red meat supply chain.

Table A3 Evaluation of tracking or tagging systems and technologies for use in the red meat supply chain.