Can the ‘blockchain’ contribute to achieving global food security?

A report for the Science and Technology Facilities Council

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Executive Summary

This report explores the application of blockchains and ‘distributed ledger technology’ (DLT) for food supply chains, to investigate if these technologies have functionality that could contribute towards enabling global food security.

There are different types of distributed ledger technology and each type has different functionality and characteristics. Some types of DLT allow anyone to access and to update the ledger (open ledgers). Other types of DLT set up ‘permissions’ around who can see the transaction ledger and who can maintain the ledger. Blockchains are a specific type of distributed ledger that blend together pre-existing technology in innovative ways, incorporating peer-to-peer networks, public-private key cryptography and software algorithms known as ‘consensus protocols’ to create a ‘tamper-evident’ record of transactions for a community.

There have been a range of pilots exploring if blockchains/DLT can support supply chains across different sectors, and some pilots have been undertaken in the food sector. Most of the blockchain/DLT pilot projects we identified, have not been scaled up to full implementations. The reasons we were given for projects not progressing included: businesses were concerned about sharing their data, as they are worried about giving away their intellectual property and competitive advantage. And that businesses are struggling to identify a value proposition in blockchain technology.

We found that most of the blockchain/DLT projects in the food sector were focused on developing systems around single food stuffs, such as pork, or red meat, or lettuce, which are simple single-component food stuffs with relatively well-understood supply chains. This approach to development of new systems is very resource intensive, as each food stuff must be individually modelled. Additionally, none of the systems we identified, seemed to facilitate fully intelligent searching of the data on the ledger from across the supply chain.

We conclude that blockchain/DLT do have useful functionality that will support ‘end-to-end’ visibility of a supply chain, and so help to enable global food security though easier identification of food fraud, more sophisticated data analysis, and secure, controlled access to data by verified actors. Applications that facilitate this more sophisticated application of blockchain/DLT for food supply chains are still in development, but could potentially offer significant future value for the food sector.

To provide value across supply chains, blockchains/DLT will need to be integrated with other technologies, such as smart sensors, detectors and business systems to enable data on the ledger to be sourced in a trusted and verifiable way. Additionally, there will need to be strong governance around the data, to reassure food sector stakeholders that they will retain ownership and control of their data. We argue for an ‘information architecture’ approach, addressing the issues of data provenance and governance, as being the most appropriate way to progress towards enabling globally secure food supply chains.

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Introduction

This research explored if blockchains (a specific type of distributed ledger) could contribute towards achieving global food security.

In part 1, the report provides a review of blockchain and distributed ledger technology (DLT) functionality and characteristics, and discusses a range of pilot projects that have experimented with different configurations of these technologies in food supply chain contexts. This section includes an overview of how the research capability of the Science and Technology Facilities Council (STFC) could be exploited to fast-track the development of new technologies, including blockchain and distributed ledgers, to enable global food security, and position the UK as a world leader in food safety and food supply chain technology and expertise.

Part 2 provides an overview of the food supply chain, mapping out and identifying the major stakeholders who are needed to engage in work to design and implement an information architecture that would enable a secure food supply for the UK. The food supply chain in the UK is global in scale, with food being sourced from across the world and transported via complex logistics and operational processes. Current research into blockchains/DLT for the food supply chain have focused on single food stuffs such as mangoes, or pork, or red meat. To understand if these technologies offer a significant value proposition, we need to consider multi-component food products, which have much more complex supply chains. We demonstrate this by mapping out the stakeholders involved in supplying two well-known food products: a gluten-free fishcake and an Aberdeen Angus beef-burger. These use-cases offer a starting point for understanding the scale and difficulty of achieving global food security.

We conclude the report by arguing that blockchains and DLT do have functionality that can enable sensitive data to be held securely and to manage appropriate access and analysis of the data. It is also clear that other technologies, such as smart sensors, detectors and business systems, have a significant role to play in sourcing the data held on blockchains/DLT in ways that can be trusted and validated.

We argue that to successfully use blockchains/DLT to help address the challenge of global food security we need to consider the structural design for how information is shared across the whole environment, the relationships between data and sources of data across the supply chain. Applications that facilitate this more sophisticated application of blockchain/DLT for food supply chains are still in development, but demonstrate a potentially significant future value proposition for the food sector.

Part 1:
A State-of-the-Art Review of Blockchain Applications in the Food Supply Chain

1.1. Blockchain Technology

1.1.1 What are Blockchains?

Blockchains are a specific type of ‘distributed ledger technology’ (DLT) that blends together several pre-existing technologies in a novel way. Blockchains are made up of peer-to-peer networks, public-private key cryptography and software algorithms known as ‘consensus protocols’ to create a ‘tamper-evident’ record of transactions (De Filippi and Wright, 2018). These records of transactions, or ledgers, document exchanges of assets between parties. The ledger for a blockchain is distributed across a network, i.e. a copy of the ledger is saved at multiple sites (or nodes) and each copy is updated as transactions occur. The updating process can happen in minutes, or fractions of a second, depending on the governance protocols and the type of network that connects each node.

There are many different types of distributed ledgers each with unique characteristics. The term ‘blockchain’ usually (although not always) refers to distributed ledgers that have no centralized control to manage and update the ledger, they are collectively managed by peer-to-peer networks. These are examples of ‘public’ or ‘open’ distributed ledgers.

1.1.2 Public or Open Distributed Ledgers

These distributed ledgers have an ‘open membership’ policy, which means anyone can download the ledger to see what transactions have occurred, and anyone with the requisite skills and resources can participate in the work to update and maintain the ledger. These ledgers often also make their source code open to allow any software developers who are interested, to update and improve the software protocols over time. Blockchains such as Bitcoin and Ethereum, are examples of open distributed ledgers, these are explained in more detail in section 1.1.5.

1.1.3 Permissioned Distributed Ledgers

This type of distributed ledger controls who can participate in the network, through using layers of 'permission' (implemented through software) to determine what action specific participants can take. For example, only some members of a permissioned network will be able to update the software protocols to maintain the system and add transactions to the ledger. In these permissioned ledgers, the transaction ledger might be open for anyone (even non-members) to see, or the ledger might have controls managing who can see what data on the ledger. An example of a permissioned distributed ledger is Ripple.

1.1.4 Private Distributed Ledgers

These are closely controlled distributed ledgers, with the community usually made up of only a few members, who either already know and trust each other, or who are vetted before joining to establish trust between partners. These private ledgers are used to manage confidential trades between members and the ledger is only visible to those with the requisite permission.

1.1.5 The Characteristics of Blockchains

The term 'blockchain' comes from the way the transaction data is gathered into 'blocks' for the peer-to-peer (P2P) network to validate as being 'true', before the transaction record is added to the ledger. The ledger is created from a 'chain' of records, (or blocks), each cryptographically secured to the previous block of data creating a record that is 'tamper-evident', i.e. if anyone tries to change a specific record in the ledger, it will be immediately obvious to the P2P network maintaining that ledger. (For a full technical description of how blockchains and distributed ledgers work see: Nakamoto, 2008; or Narayanan *et al*, 2016).

Blockchains are best-known for their cryptocurrency applications e.g. in Bitcoin and Ethereum. Both Bitcoin and Ethereum are examples of an open distributed ledger, where anyone can download the ledger and participate in updating the ledger; the process of validating the data added to the ledger is referred to as 'mining' (see Narayanan *et al*, 2016). Cryptocurrency applications of blockchain reward the effort required to validate the transactions on the ledger by awarding tokens. For example, the bitcoin token on the Bitcoin ledger, and ‘ether’ on the Ethereum ledger. There are other types of cryptocurrency too. Ripple is an example of a cryptocurrency where the P2P network is made up of vetted members, although the transaction ledger is open for anyone to see.

Some blockchains, (for example, the Ethereum blockchain), have been designed with aim of supporting increasingly autonomous trading and exchange through the application of *Smart Contracts*. Sklaroff (2017), describes smart contracts as “decentralized agreements built in computer code and stored on a blockchain”. Proponents of smart contracts argue that by embedding decisions and contracts into code, secured on a blockchain, it will be possible to enable a future that operates autonomously without human intervention, and so support leaner and more efficient trade.

Blockchains (often in combination with smart contracts) are currently being tested as a means of controlling access to public services and to critical resources. For example, blockchains are being piloted as a platform and secure infrastructure for government information in the United Arab Emirates (Wall Street Journal, 2017); managing energy market transactions (Financial Times, 2017) and as an infrastructure capable of supporting the realization of the United Nations Sustainable Development Goals (United Nations, 2018). One suggested use case for blockchains is as a supporting infrastructure for food supply chains, where the functionality of blockchains could potentially facilitate transparency and assurance end-to-end across the supply chain, enabling improved certification capabilities, as well as facilitating identification of fraud and dishonest transactions.

1.2. Blockchains and Food Security

1.2.1 The value proposition

McDermott (2017) suggests that blockchains can help to address business challenges around achieving food security by holding a trusted source of data that can be speedily and securely communicated between partners, suggesting that "the trust [blockchain] delivers enables more efficient and complete sharing of critical data that derives enterprise transactions". Blockchains have been argued to have the potential to enable managers to remotely trace all information around a product. For example, Bottemelier (2011) suggested that in the event of a food product becoming tainted, blockchains could help to identify which specific products need to be withdrawn from sale, rather than having to remove the entire product line from sale, an event which happens currently. Del Castillo (2016) also suggests that blockchains could facilitate such tracking to occur in seconds rather than days.

Whitworth *et al* (2017), in a recent report for the Open Data Institute, regard the recent introduction of the General Data Protection Regulation act (GDPR) as an opportunity for the UK grocery retail sector to work more proactively with customers to explain their data rights and to make a case for the benefits of data-sharing, which they suggest would help to build trust and loyalty in the sector's customer base. The Open Data Institute (2018) has also called for a data working group for the Food sector to be set up to explore and encourage the sharing of non-personal data to benefit consumers, the report argues that " sharing this [data] would help build a culture of open innovation by getting retail sector organisations to work together […and connect] them with external organisations that could use the data to build valuable new products and services" (Whitworth *et al*, 2017, p. 19).

The Open Data Institute (2018) have demonstrated that sharing data with a wide community of potential interested users can create a foundation for increased innovation, sharing of best practice and management of risk. In other sectors, such as transport services, increased access to data has driven the development of new products and services, and has provided customers with much more choice. However, currently the food industry shares data on a ‘need-to-know’ basis, with information usually only being exchanged with direct partners in the supply chain, or with relevant parties in the case of a food recall.

Blockchain and DLT applications do have the potential to support a secure ‘end-to-end’ view of the data across supply chains. For such a system to be trusted however, the data needs to be sourced from a validated and trusted ‘origin’. The food supply chain incorporates a plethora of technologies and devices such as mobile devices; smart sensors on storage facilities or transport; smart packaging; surveillance equipment or detectors able to determine food product composition in a non-destructive way. Understanding how to verify the provenance and source of data stored on a ledger needs to be investigated as part of any research conducted in this space.

There is also a need for agreed governance principles and structures, to manage standards and appropriate data sharing between all stakeholders, including the regulators. In other words, blockchain/distributed ledgers can only securely manage access and appropriate sharing of data across the food supply chain, if implemented within a defined information architecture, operating with known and accepted open standards, where the data on the ledger is known to derive from a verified source, or provenance.

Achieving a value proposition from blockchain technology then requires three areas to be understood: the data provenance, open standards setting out an information architecture, and agreed governance principles for management of the data and architecture.

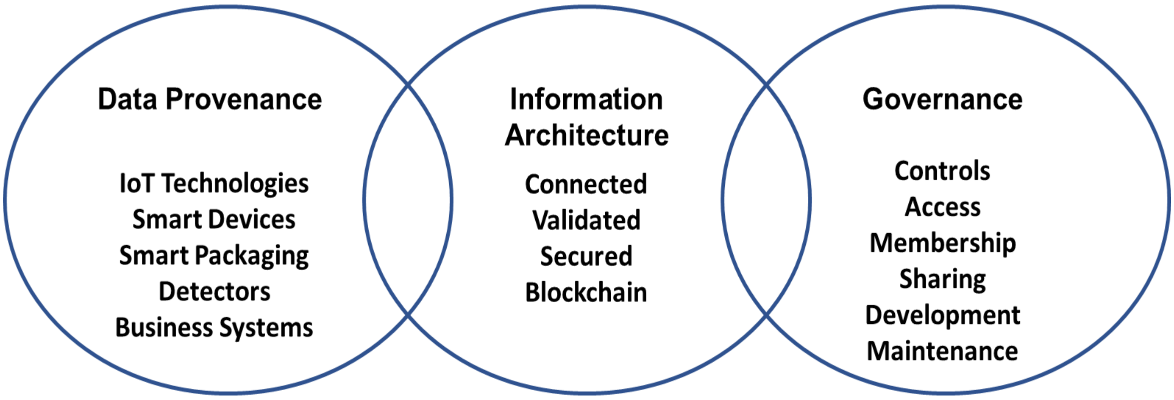

Figure 1: Data provenance, information architecture and governance.

In conducting this research, it became clear that there are industry concerns around sharing information across the whole supply chain, as businesses need to protect the intellectual property embedded their data. Additionally, there is some evidence that to date, many small pilots applying blockchains/distributed ledger technology to food supply chains have been reported to offer insufficient additional capability and 'value-add' to warrant significant further investment. This may be because, so far, most pilot projects for food have been limited in scope, focusing on individual food ingredients or food stuffs delivered over a small and well-defined supply chain.

The next section reviews some of the case studies and pilot projects that have explored the application of blockchains/distributed ledger technologies in the food sector.

1.3. Blockchain Case Studies in the Food Sector

1.3.1 The IBM-Walmart Pilot Studies

Kamath (2018) provides an overview of two pilot projects undertaken by IBM and Walmart to explore how blockchain can be applied in food supply chains. The first of these projects focused on providing assurance for the pork supply chain within China. This project tracked pork by ‘smart-tagging’ the animals with barcodes and this identifier then follows the product all the way to the packaged pork. The project incorporated information from radio frequency identification and cameras to record the movements of the pigs, and cameras in the slaughter house also recorded the production process. Using data from sensors, Kamath (2018) reports that the Walmart pork blockchain pilot integrated sensor data with internal business systems (such as the Walmart ERP system) to enable Walmart to monitor every aspect of the process, including monitoring the locations and routes of trucks, the activities in the slaughter house and the environmental conditions in the trucks (e.g. temperature). Walmart and IBM have reported this pilot demonstrated improved speed and accuracy in accessing the relevant information from the farm to the point of sale.

In addition to the blockchain pilot on pork, Burkitt (2014) reports that Walmart also conducted a pilot to track sliced mangos from the producers in South and Central America, to the retail stores North America. This project focused on demonstrating how data on the blockchain could enable traceability of a product across national borders (Andrew, 2012). Both the pork and mango pilot projects utilised existing open standards, such as the Electronic Product Code Information Services and Core Business Vocabulary of Global Specifications 1 (See Blanchfield and Welt, 2012). These Walmart pilot projects are reported to demonstrate that different types of data, gathered from diverse sources such as data from audits, information on agricultural treatments, data provided from scanning devices etc. can be secured through blockchain technology and then shared securely between partners who needed access to the information.

Frank Yiannis (Walmart's Vice President of Food Safety) described the mango pilot as only requiring mango farmers to upload digital images of food safety audits and assurance certificates. To participate in these pilot projects, the mango farmers needed access to a mobile phone (to photograph the food audit documentation and assurance certificates) and access to the internet. Any mistakes in the paper documentation were encapsulated in the image attached to the blockchain and, as the data on the blockchain was not directly interrogatable, the system relied on others further down the chain picking up on mistakes.

Both Walmart and IBM emphasize the need to continue to explore how to scale and implement such blockchain systems across the whole food supply chain, and there are significant challenges to overcome. Brigid McDermott (IBM's Vice President of blockchain business development) acknowledged that initially the data would not be of a higher quality than is currently achieved (reported in: McKenzie, 2018) but she argued that by putting this data onto a blockchain and making it visible, the increased oversight would in time drive an improvement in quality and allow better tracing of errors and fraud.

More recently Walmart have announced that they are introducing a blockchain to keep track of spinach and lettuce sourced from 100+ farms in North America. The aim is to be able to tack the source of these salad vegetables and to be able to move more quickly to remove impacted food stuffs in the event of an outbreak of E.coli for example (Corkery and Popper, 2018).

The type of blockchain being developed through the IBM and Walmart projects are examples of permissioned distributed ledgers, with data only being added to the chain by verified sources and with IBM managing the information and the blockchain. Critics point out that in these implementations, IBM control the data stored on the blockchain and so have inserted themselves as 'middlemen' in an infrastructure that was designed to operate without third parties managing transactions (Simon Taylor of 11:FS reported in: Corkery and Popper, 2018).

David Gerard (2017) has also criticised the IBM-Walmart projects as being a ‘publicity exercise’ with the systems offering no additional functional to an ordinary distributed database.

1.3.2 Provenance.Org

In the United Kingdom, Provenance (2018a) have developed and implemented a permissioned distributed ledger platform[1] to provide customers with information about the origin of food products. For example, Provenance have worked with The Co-Op to help make the origin of products transparent to consumers, where the Provenance platform gathers and links together the relevant data from “farm, factory, Co-op depot and retail branches” (Provenance, 2018b), to provide a digital history that integrates with the Co-op’s internal ERP systems and provides the customer with assurance of a product’s origin (Provenance, 2018b). This approach tracks a food product from source and along the supply chain for the retailer (the Co-op in this instance), and provides the customer with verified data (although not all the data gathered by the retailer) to show the journey that product took, from source to the point of sale. Provenance are also working with Sainsbury’s and Unilever to track products such as tea with the aim of supporting small-holders and growers to adopt sustainable practices on farms (Sustainable Brands, 2017).

In their whitepaper (Provenance, 2015), Provenance state they are working towards offering an alternative to the current method of ‘certification’ and are establishing ‘chains of custody’ for the food industry. Provenance aim to “assign and verify certifications of certain properties of physical products, e.g. organic or fair trade”, and they have focused on verifying four properties of food products:

[1] This platform is referred to as a ‘blockchain solution’ on the Provenance web page.

i. What the product is

ii. The quality of the product

iii. The quantity of the product, and

iv. The ownership of the product at any moment in time.

These properties can be gathered from pre-existing data sources, such as barcodes, or enterprise databases, or added by an authorised source as the product travels along the supply chain, offering an "*uninterrupted* chain of custody from the raw materials to the end sale" (Provenance, 2015, their italics). Other technical details are hard to ascertain. The whitepaper suggests that the application of a "blockchain removes the need for a trusted central organization that operates and maintains this system" (Provenance, 2015), but the Provenance 'blockchain' has been implemented, and is managed and maintained by Provenance, a service which members pay Provenance to provide. The Provenance business model is underpinned by the same principles as would underpin any outsourced IT service with clients paying for the provision of that service. It will be interesting to see if this model scales successfully, as other providers join the marketplace and as the principles of securing and sharing data tested out in these platforms become integrated into other technology offerings.

1.3.3 Food Standards Agency (FSA) Pilot.

The Food Standards Agency have conducted a pilot study in collaboration with IBM to track cattle from 'Farm to Fork' including all slaughterhouse processes, to investigate if such a system can provide better record-keeping and traceability for red meat. The pilot focused on providing the producers (cattle farmers) and the processors (Food Business Organizations, FBO) with access to inspection findings, the aim was to include official Veterinary Reports and Meat Inspector findings both before and after an animal was slaughtered. The collation of this documentation resulted in a network of "replicated, shared and synchronised digital data" (Bernal, 2018; also see: food.gov.uk, 2018). One of the researchers involved in the project commented that the project had a limited scope and so the learning from this project is likely to be similarly limited, but a further pilot is planned to extend the data and application of this system.

1.3.4 TE Food

A company called TE Food (2018), (which started life as TE Ltd.), a Vietnamese company, based in Ho Chi Minh City, have collaborated with ERBA 96 Ltd. (a Hungarian software development company based in Budapest) to create a food traceability system. The system was first developed as a decentralised ledger, with the ledger of transactions open to be read by anyone, and with a network of 'master-nodes' who manage the data and maintain the ledger. This permissioned ledger is connecting suppliers, regulatory authorities and consumers for food traceability across the pork supply chain, and for chickens and eggs. The website states they have 6000 customers who are using the TE Food traceability system to transfer information including animal profiles, feeding information, vaccinations, veterinary checks, slaughter data and transportation data (TE Food, 2018; Ven, 2018).

TE Food are also experimenting with token systems to support supply chain financial transactions across their system. This will require them to develop an open blockchain ledger, rather than continue to use the hybrid permissioned ledger approach they have currently. TE Food have patented TKD, a token for their users to buy access to their TE-Food blockchain ecosystem and they have also introduced: CAL, a token pegged to the USD to act as a clearing unit for services and products across the partners in the TE Food blockchain. The token system they have proposed (outlined in the white paper, TE Food, 2018), will mean every business and the food producer using the system will have to invest in the TE Token (TKD) before they can trade their goods on the TE Food blockchain. This approach could increase the costs to small producers, as each transaction will be charged, and small farmers are unlikely to be able to achieve benefits from 'economies of scale' such as putting through several items as one transaction. Although such issues can be managed through governance, the uncertainty in how transaction costs will be shared, could slow the uptake of this system.

1.3.5 Barriers to Adoption

One clear outcome from the research is that concerns about who owns the data saved to a blockchain/distributed ledger, and who might be able to extract value from that data is a barrier to further collaboration. Food chain participants, both large and small, do not want to share information that might give their competitors an advantage. This culture of keeping data private is reflected in the fact that the only fully implemented systems using blockchain/distributed ledger technology we found in the food sector, are using versions of permissioned, or private distributed ledgers (see Provenance, 2018 and TE Food, 2018).

One clear disadvantage of distributed ledger technology we identified is that these ledgers cannot easily replace internal established business processes, and currently, successful implementations such as the Provenance system, integrate with the internal ERP systems adding a further layer of business software to that already used by retailers and food manufacturers across the sector. This means that increases in efficiency that should come from the application of blockchain/distributed ledger technology are lost.

McKenzie (2018) reports the views of Mitchell Weinberg, a food fraud detection expert, as setting out two significant barriers to achieving value from blockchain applied to global food security: first, that blockchains require participation in the system to be honest, and second, that to achieve value, everyone needs to participate. Weinberg argues that "…the *value proposition for businesses to invest in blockchain applications for the food supply chain has not been clearly articulated" (*Weinberg quoted in McKenzie, 2018). This scepticism reflects many of the views we found across different sectors of the food industry with respect to blockchain.

1.4 Using Technology to enable Global Food Security

1.4.1 A Virtual Supply Chain

In the pilot projects we identified that were exploring the application of blockchain/DLT for food supply chains, it was clear people were conducting traditional ‘technology-focused’ projects, where they were expecting the technology, in and of itself, to provide a competitive advantage for their business. Every project described in this report so far, has first mapped out the supply chain for a simple food stuff, such as pork, or lettuce, or eggs, but the supply chains for these food stuffs are already well-understood, and are limited in scope and complexity compared to the supply chain for a multi-component food product. Several of the managers we spoke to, (both managers in the food industry and technology managers) held the view that for each food product they wanted to put onto the blockchain, they would need to map out the supply chain specific for that food stuff, and each food stuff/product would be different.

This approach has massive resource implications and it is unsurprising that food industry managers do not see the value in conducting such activity. This approach would take years to put composite and complex products, such as a ‘gluten-free fishcake’, or a ‘beef and vegetable pie’ onto a secure blockchain and each time a supply chain changed (perhaps due to climate change requiring new suppliers in a different geographical location to be integrated into the system) there would be a considerable delay in updating the system.

Re-imagining the supply chain as a ‘virtual supply chain’ offers a different approach to the problem space. What is needed is an architectural approach to understand the relationships that exist between participants in the food supply chain and the attributes of the data necessary to the functioning of that supply chain.

1.4.2 Resonance

A company called Resonance (2018) are approaching the challenge of a virtual supply chain by developing a chain-of-custody for supply chain data that can be uploaded onto a permissioned distributed ledger in a secure and encrypted way, and so open to be read only by those given specific permission to do so. The Resonance approach also enables searchable encryption, that is the encrypted data can be intelligently interrogated, while protecting if necessary, both the source of the query, the source of the data and how the answer to the query has been provided. In this approach, a secure index is used to show how different data in the system are related to each other. Resonance use distributed ledger technology to provide a secure and encrypted approach to proving two pieces of data are related to each other, which allows users to have trust in the system. Users can ask questions of people who they do not necessarily know, and the identity of the participants across the network is also protected through a decentralised identity scheme.

Resonance are approaching the problem of live 'end-to-end' supply chains by creating a chain of custody for the data, rather than focusing on tracking the product. This approach would provide a foundation for scaling across more complex food supply chains, and given the data is interrogatable, also offers a clear route to achieving value-add, through enhanced data analysis

1.4.3 Associated Technologies

Any approach to enabling global food security requires data to be sourced from appropriate and secure devices and systems. For example, SMART Packaging, which contains a unique Radio Frequency IDentification (RFID) code in each pack, is one form of technology that will provide the basis of a secure logistics system which can be trusted. Making sure that the RFID device cannot be removed or replaced from the pack is essential, and that the data provided by such devices is able to be securely connected to the main information infrastructure. Such devices would enable business to record and log temperature for example, during transport of sensitive food products via cold and chill chains. As RFID devices mature, other sensing options are becoming feasible because of additional sensor inputs being defined on the semiconductor chip, e.g. this could potentially allow humidity and gas composition to be measured and recorded; it is important to note here, that the on-chip power sources required to enable this type of input is not yet available. Thin film and polymer battery technology is in development and their integration with RFID and Near Field Communication (NFC) devices will in future enable standalone temperature logging. Such advances are not only of interest to the food industry, but are of value to the pharmaceutical, wines and beverages sector, and for the medical device sectors.

The benefits arising from integration of Internet of Things devices with established wrapping and packaging forms are of current interest to manufacturers of products which contain raw food ingredients and who provide the wrapping, packaging, transport (e.g. shipping containers, pallets, bags, totes, containers etc.) and labels for such products. The only UK company engaged in developing low cost IOT, RFID and NFC for the Pharmaceutical, Medical Device and Food Sector is Flexotronix Limited. However, the National Printed Electronics Centre in Sedgefield which is part of the High Value Manufacturing Catapult has invested in a pilot line to demonstrate the feasibility of producing RFID and NFC devices using Reel to Reel Technology. See Appendix 1 for a list of companies who are interested in developing IoT-enabled packaging.

1.5 Opportunities to exploit STFC research capability

1.5.1 STFC Hartree

The Hartree Centre is the natural partner for work on blockchains and distributed ledgers. This team use their expertise to support businesses who want to integrate blockchain applications into their business, also providing expertise in big data analysis, high-performance computing, energy-efficient computing, visualisation and Internet of Things applications. The team have focused on exploring applications using Ethereum and Hyperledger platforms and on developing applications with different blockchain consensus protocols to ascertain which protocols have better utility in a business context. There are new projects planned on EOS (2018), a blockchain platform designed to scale both horizontally and vertically offering more efficiency. The capability, resources and expertise at Hartree in particular, will be essential in pioneering the application of blockchains for global food security.

1.5.2 STFC Technology

This division has advanced technology and engineering capability in a range of specialisms relevant to the challenge of enabling global food security. For example, the Electronics Division develop and characterise semiconductor sensors, typically based on active pixel technology, but their versatility and underpinning knowledge of full custom silicon design will be of value to companies developing unique products such as high-speed imaging systems and semiconductor sensors and electronic devices. STFC technology has significant knowledge and expertise in control systems, pre-amplifiers and high-speed data storage. An area already being developed with Technology as part of a Bridging for Innovators (B4I) grant is novel interconnect techniques for SMART RFID and NFC labels. These technologies are likely to provide major sources of data across a secure food supply chain. The Technology Department also hosts EuroPractice, which provides access to the latest microelectronic design tools and is available to both Academia and Industry for Research and Development projects, and this capability will be valuable in projects testing out Internet of Things (IoT) sensors and devices.

Within STFC Technology, the Science Division has teams with expertise in cryogenics, cryogenic instrumentation and thermal analysis. This knowledge base will be helpful to companies developing flash freezing system for food storage and container and sensing system design. In addition, these teams have expertise in polymer composites, their manufacture and processing as well as characterisation to measure performance. This asset would be valuable to the packaging industry which is interested in developing bioplastic and compostable packaging technology. The division manages an extensive manufacturing facility for producing simple to complex components, and so would be able to assist in the design and fabrication of prototype parts for demonstrators, and adaptors to retrofit food manufacturing tools with advance sensing and robotic systems.

1.5.3 Technology at Daresbury (T@DL)

T@DL has expertise in developing tools for high precision motion control and this skill could be adapted into automated food processing technologies. This would be supported by power systems design and engineering, specifically designed for instruments with advanced sensing and imaging capabilities and advanced control systems. T@D have the necessary expertise to develop real time operating systems for system control and data handling and would be a valuable resource for supporting high data content processes. Within the division there is also a Computer Aided Design suite. CAD/CAM and Electrical Engineering System Integration all compliant to relevant ISO standards enable rapid prototyping. Additionally, Inspection and Metrology systems combined with Calibration services enhance the quality of services and products delivered by the division.

1.5.4 The Detector Systems Group

This group has a team of scientists and engineers who can build bespoke instrumentation and detector systems for both large- and small-scale facilities. The Central Laser Facility (CLF) houses extremely high-power laser systems for fundamental physics research as well as a suite of lower power laser systems for analytical sciences. The staff at CLF are experts in using lasers to probe the nature of matter and the techniques used are fast and non-contact. This pool of resources would be useful in research on enabling global food security to help produce instrumentation tailored for specific challenges in the food industry, such as developing non-destructive analysis methods. An example case study would be the development of new applications of the Spatially Offset Raman Spectroscopy technique to probe the molecular composition of food stuffs through packaging. Projects could also include the testing of new types of packaging materials developed to allow laser-based spectroscopy for contents analysis. Other areas of laser application would include the assessment of anti-counterfeit inks on packaging and within anti-tamperproof labels.

1.5.5 RAL Space

This team can also contribute to research in global food security with experts in wireless data transmission systems, RAL Space also has the resources to manufacture key components and sub-systems of transmission systems. Imaging systems have been developed in the 50GHz to 2THz spectral region which may provide new non-contact imaging techniques to measure food quality. RAL-Space produces imaging instruments to specifications which would be over engineered for terrestrial food monitoring systems in processing plants, but which could inspire and inform the design and build specifications for cheaper alternatives. For example, RAL Space has experience in designing and building autonomous vehicles which have been involved in land-based projects in the Agri-tech sector and to build robots which remove weeds from crops. The skills can be applied to design robotic food processing plant and autonomous vehicles for logistics and warehouse management. In addition to the Central Laser Facility, RAL Space has resources and resident experts in spectroscopy both optical and ion trap mass spectrometry, which are being used to analyse the composition of gases, liquids and solids and this capability could be applied to build food industry applications. RAL-Space also has numerous facilities for testing and fabrication, including for electronic circuit boards and optics.

Finally, the ISIS Neutron Source and the Diamond Light Source have extensive state of the art analytical instruments and beamlines to probe the four states of matter and interfaces between them. Although not readily deployable to the food sector, these resources do offer a capability to establish ‘gold standards’ against which IOT and image sensor data can be calibrated.

1.5.6 The STFC Food Network (SFN+)

The STFC has already invested in research in the Food sector, supporting a successful network, the STFC Food Network (SFN+) whose objectives are:

- To build an inclusive, dynamic, interdisciplinary network of researchers focused on innovative ways to use the skills and facilities funded by STFC.
- To kickstart interdisciplinary collaborations and research projects working towards safe, sustainable food systems both in the UK and developing countries.
- To enhance the impact of STFC/food interdisciplinary collaborations by encouraging codesign with the non-academic sector.

(See: https://www.stfcfoodnetwork.org/)

The SFN+ network, led by Professor Sarah Bridle from Manchester University, has instigated multiple new projects exploiting STFC research capability and linking this to business and food industry stakeholders. This network is focused on the challenge of providing “… safe, nutritious, and affordable high-quality food using less land, with reduced inputs, and in the context of global climate change and declining natural resources” (SFN+, 2018). The projects have been positioned mainly as ‘agri-tech projects, applying technology in the production of safe and nutritious food. A list of the projects funded by SFN+ are available on the website (see: https://www.stfcfoodnetwork.org/).

Part 2:

Mapping the Food Supply Chain

2.1. Food Supply Chain Challenges

2.1.1 A Food Sector Stakeholder Perspective

The research presented in part 2 has been conducted by industry experts in food quality assurance and compliance, Dr Rachel Ward and Andy Kerridge. Food supply chains are complex with multiple inputs and outputs from many diverse food producers, manufacturers, retailers and associated businesses covering activities such as packaging, analysis, regulation and audit. For example, a farmer would buy seed, livestock animals, fertilisers, pesticides, biocides, feed, packaging and/or water supplies from a range of suppliers. The impact of a farming or fishing operation on the wider environment would depend upon its land / watercourse management approaches, such as crops grown, rotation, deliberate support for local ecological diversity, degree of agrochemical use and water source use/reuse. A food manufacturer in turn will buy the raw materials including foodstuffs and packaging needed to make a food product, as well as chemicals for site cleaning and pest control, equipment for manufacturing, packing, temperature-controlled storage and shipping, utility services such as water, electric and fuel and various support services such as waste disposal, analytical testing, and transport/logistics. A food manufacturer site will also impact the environment surrounding its location due to the need for a supply of labour, water and electricity, and production of waste products – either up into the air, into drains, or solid waste needing removal/disposal, as well as needs for service roads/access to site.

Suppliers of materials and services could potentially be a source of issues, non-compliance and even fraud related to the foodstuffs produced by that food operator to be sold into the food chain. Each participant needs to be managed, scrutinized and assured as fit for purpose. In turn, food operators themselves will be scrutinized and monitored by its customers.

There are a wide variety of standards applied to the food supply chain defining expected good practices and compliance requirements across areas such as food safety, quality, environmental sustainability, provenance etc. For example, food with a protected provenance has Traditional Speciality Guaranteed (TSG) status, Protected Designated Origin (PDO) or a Protected Geographical Indication (PGI) each of which require assurance. Useful overviews of the current standards applied to the food industry can be found at ITC Standards Map (2018) and in a recent report commissioned by the UK Food Standards Agency (2013) on third party assurance schemes. Compliance to these standards, whether for food safety or to support a voluntary or regulated claim, form a critical part of commercial supply agreements and enforcement border controls. Supporting evidence to assure compliance, such as site audit reports, monitoring data from sampling of shipments or products in market, needs to be made available to a wide range of stakeholders for verification – usually 24/7 and sometimes live on demand.

The data / information produced by these diverse interfaces to track and trace supplied materials and services, and to provide evidence to assure that they are safe, fit for purpose and compliant to commercial and regulatory requirements is therefore considerable and exists in many different, non-standardised types of format. Data attributes will include information such as: locations of farms, stores and factories, company/food operator names and contact details, seed supply records, animal birth/parentage and slaughter records, delivery notes, truck inspection records, production batch codes, dates of manufacture, specifications, sanitation monitoring records, waste records, pesticide/veterinary drug application records, certificates of analysis, staff training records and assurance scheme audit reports. These data all need to be handled and managed securely and appropriately to fully ensure effective and efficient food supply chains, and supporting technology also needs to facilitate system interoperability between the various stakeholders.

2.1.2 Food Supply Chain Mapping

The Food Supply Chain is a complex system that can be broadly represented as the different divisions as described in Figure 2.

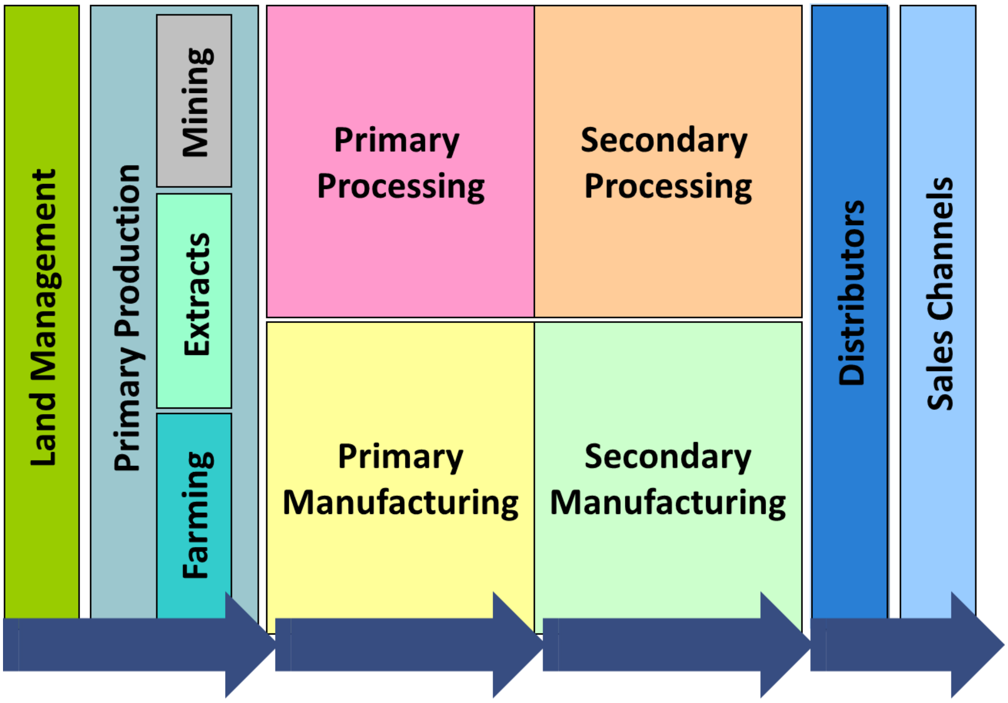

Figure 2: The main divisions making up the food supply chain.

Primary producers' plant and grow, or 'harvest' from ground/field/water to produce foodstuffs which can then undergo a variety of processes before being made available to the final consumer through a range of sales channels. Processing and manufacturing of foodstuffs will combine ingredients into increasingly complex food products. For example, foodstuffs might only be packaged and made "fit for consumption", or "fit to travel", without changing the essential nature of the food; this is called 'primary processing' and would include food produce such as: washed whole carrots, or cleaned/gutted whole trout. Secondary processing changes the physical state of a food stuff into a form which can then be used as an ingredient, or sold as a final product directly to consumers, such as grated or diced carrot, and fillets of fish. Manufacturing creates more processed products which have undergone treatments such as milling, baking, or fermentation to add value to them, creating food products such as flour, sausages, beer etc. which would usually undergo further cooking or processing by consumers. Secondary manufacturing produces complex products which are often sold ready to eat and/or heat by consumers such as sandwiches, breakfast cereals, ready meals, etc. The transport and distribution of foods and food products along the food supply chain between sites owned by the same company, or between different companies, can be undertaken by a variety of additional operators involving road, rail, sea and/or air transport. Foodstuffs can be sold to consumers by a variety of operators/retailers which vary in size, scope and mode of operation, from farm shops where primary producers sell at point of 'harvest', to multi-national retail and food service outlets, and include home delivery services.

A non-exhaustive list of the types of operators found in each division of the food supply chain represented in Figure 2 is provided in Appendix 2. The food chain also includes a variety of industries which provide 'allied' services such as: the supply of non-food raw materials needed for production, utilities, staffing, transport or provision of supporting technical and business services. Typical allied industries are also listed in the tables in Appendix 2 against relevant food chain divisions to illustrate the diversity and complexity of engagements.

2.1.3 Assurance and Compliance Standards

Most of the divisions in the food supply chain represented in Figure 2 have standards that define the expected practices to ensure compliance to defined requirements for food safety, quality, environmental sustainability, provenance and/or ethical trading. These can be developed by regulatory authorities, industry or special interest groups either individually or in collaboration. Government regulators own and manage these standards which are captured within regulatory requirements such as EU quality marks (e.g. PDO, PGI and TSG).

Assurance schemes own and continually improve voluntary third-party standards content and provide day-to-day management support. An extensive review of third-party assurance schemes has recently been completed for the UK Food Standards Agency (2013) to identify and evaluate such schemes currently active in the food supply chain, reviewing their scope and suitability for recognition and consideration when determining the risk presented by a food operation and the degree of enforcement scrutiny and frequency of inspection required. Appendix 3 provides examples of the types of standards / assurance schemes being applied in various sections of the food chain. Some are first party standards, developed by a retailer for example for their own supply chain, or second party standards developed by an external body for a specific purpose, e.g. Fairtrade, Rainforest Alliance. Third party certification is usual practiced to provide a degree of independence and separation between the party being assessed for compliance, the party who generated the standard, and the conformance assessor.

Compliance to a standard is usually assessed by a third party certification body either to assure the competency of individuals, businesses or parts of business operations to carry out a particular service, to confirm food safety management systems are in place pertinent to the activities being performed, to confirm particular unethical practices are absent such as child / slave labour, or to confirm positive beneficial activities are actively implemented such as animal welfare, avoidance of agrochemical use, recycling or environmental support for biodiversity. Certification bodies and their auditors who carry out audits to confirm conformance to a standard, are also subject to certification to ensure their independence and competence through standards such ISO 17065 to assure independence, impartiality and confidentiality, and ISO/IEC 17020 addressing requirements for the operation of various types of bodies performing inspection. Analytical testing laboratories used for the generation of test data relating to foodstuff regulatory compliance and/or safety would be expected to be accredited/certified to ISO/IEC 17025 which specifies the general requirements for the competence of testing and calibration laboratories and expects them to have quality management systems in place.

2.2 Complex Food Product Case Studies

2.2.1 Multicomponent food products

The pilot projects described in Part 1 of this report, are applying blockchain/distributed ledger technology to single food stuffs, such as pork or chicken. Most supply chains for food products are significantly more complex. To provide insight into the data and relationships that are found in food supply chains for more complex, multi-component food stuffs, we have mapped out the food supply chain for two common, but more complex food products consumed in the UK: a gluten-free smoked haddock fishcake with 'West Country Cheddar Cheese' sauce (see Appendix 4) and a chilled, seasoned Aberdeen Angus beefburger (see Appendix 5).

Even a simple fishcake or burger made at home could use several different types of fish or meat, and herbs such as parsley, spices such as black pepper and salt. The ingredients would be sourced from a number of different countries, for example spices such as black pepper could originate from Vietnam, Indonesia, Brazil, Malaysia or India.

These case studies show the typical sourcing of components used to make individual recipes for common food products, the cases also demonstrate what associated data and evidence of compliance is needed to assure these raw materials and map out the various interested parties and stakeholders related to each component in the recipe.

2.2.2 Claims and Authenticity

Claims made relating to products, such as 'gluten free' and 'West Country Cheddar' will increase the need for assurance, and thus the need for generation of, and access to, evidence for compliance. Gluten free claims often require production batch data to verify compliance as products can be made on shared production equipment and lines. As an added complication to traceability challenges for our case study example, burgers are often made from a mixture of fresh and frozen meat. This is for two reasons – firstly to support processing control – the mincing process generates heat, so using frozen meat keeps the temperature at a level that is microbiologically, and technologically acceptable; and secondly from a supply situation to enable purchase of frozen meat at a time when price is attractive. Meat used in a burger could come from as many as 200 cattle, so verifying a claim that all the beef in a burger originates from Aberdeen Angus cattle becomes a challenging exercise based upon traceability records from multiple operators, which often includes brokers depending on the specific supply chain model in play.

Claims made relating to a variety of fruit/vegetables or breed of livestock/fish are common. A geographical / regional claim for an ingredient would usually only be verifiable through batch traceability – currently a time-consuming exercise routinely verified by 'paper trail' evidence of sourcing and often reliant on supplier's 'say-so', which are technically difficult to independently verify. Fraud is sadly commonplace with respect to such claims, and tools for independent verification to assure authenticity are urgently needed. New technology utilising DNA markers capable of distinguishing breeds in meat from pigs and cattle exists and work is underway to translate these still relatively costly tests into more routine assurance tools (Vlachos *et al,* 2016). Likewise, integration of a range of analytical tools are beginning to be employed to confirm the authenticity of food stuffs such as varieties of rice (Lakshminarayana *et al,* 2015) and botanical extracts (Simmler *et al,* 2018). These techniques, once fully developed and ready for practical implementation, would generate further types of analytical data which would need to be stored and shared for use in assurance.

2.3 Food Law

2.3.1 Food Safety and Standards in the UK

Feed and food safety and standards are devolved matters in the UK. The Food Standards Agency (FSA) has responsibility at central Government level for the main body of feed and food safety law in England, Wales and Northern Ireland, with dedicated offices working to the relevant Parliaments in England and Wales and the Northern Ireland Assembly. (Note: Food Standards Scotland (FSS) was established 1 April 2015 as the national food body for Scotland, with responsibility for those central Government functions previously carried out by the FSA in Scotland). Following government changes introduced in 2010, FSA responsibilities for food law across England Wales and Northern Ireland is no longer harmonised. For example:

- **In England,** Defra is responsible for food labelling, other than for matters of food safety such as 'Use By' dates and Allergens Labelling etc. The Department of Health has central government responsibility for nutrition-related food legislation in England.
- **In Wales**, the FSA retains responsibility for general food labelling. The Welsh Government is responsible for nutrition related to food legislation.
- **In Northern Ireland** the FSA retains responsibility for general food labelling and nutrition related to food legislation.

Appendix 6 sets out the legislative responsibilities across England, Wales and Northern Ireland. In addition, the National Food Crime Unit has been established as a criminal intelligence function within the FSA to improve understanding of the food crime threat at a strategic level, to identify specific instances of dishonesty within food supply chains and to instigate action by others capable of addressing it.

Conclusion

In investigating the application of blockchain/DLT across the food sector, we found there were few full implementations deployed in practice. We did identify several pilot projects, but these projects were focused on mapping out the supply chain for single-component food stuffs, such as pork. The projects were then limited in scope and were not delivering the value-add required to make a compelling case for investment by food businesses.

Re-imagining the supply chain as a 'virtual supply chain' offers a different approach to the problem space. What is needed is an architectural approach to understand the relationships that exist between participants in the food supply chain and the attributes of the data necessary to the functioning of that supply chain.

We conclude that blockchain/DLT do have functionality that can be useful in enabling global food security, but that the relevant functionality is not related to the well-known cryptocurrency applications of blockchains. These technologies can facilitate distributed and secure digital identities and so *as part of an information architecture* incorporating secure smart devices on packaging, in logistics operations, in detectors etc., applications of permissioned distributed ledger technology could contribute towards enabling global food security.

Applications that facilitate this more sophisticated application of blockchain/DLT for food supply chains are still in development, but demonstrate a potentially significant future value proposition for the food sector.

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Appendix 1: Companies interested in developing smart packaging.

Company	Area of Activity	Products
George UTZ	Logistic Systems	Pallets, Totes, Containers
CCL Industries	Speciality Films. Labels. Leaflets	Labels, Films, Cartons, Shrink Sleeves, Tubes
RPC Group PLC	Label printing, Injection Moulding, Blow Moulding, Thermoforming, Rotational Moulding, Blown Film Extrusion, Extrusion Blow Moulding	Labels, Films, Bags, Flexible Packs, Rigid Packs, Pots, Tubs Trays, Carboard packaging
Coveris	Label printing, Injection Moulding, Blow Moulding, Thermoforming	Labels, Films, Bags, Flexible Packs, Rigid Packs, Pots, Tubs Trays, Carboard packaging
Shalam Packaging	Injection Moulding	Buckets, Rigid Containers, Tubs
TetraPak	Carton Filling Machines, Cartons	Carton
Verstaete	Label printing, Injection Moulding, Blow Moulding, Thermoforming	Labels, Solid Packaging
Reflex Labels	Label Printing	Labels

Appendix 2: Divisions of the Food Supply Chain and Allied Services

Food Supply Chain Division	Description	Allied / Service Industries
Land Management	Forestry, mining, leisure/tourism, urban, transport incl. rail, road, canals	Agronomists Environmental / geological scientists - Water management (irrigation/quality), Location (contamination from adjacent) or run-off, Previous land use, Trace metals, Conservation /Wildlife, Public access, Game shooting rights
Primary Production	Operators who plant & grow or 'Harvest' from the ground/field/water Includes: 'Farming' – Livestock, Fishing, Insects (as meat alternatives and as additives e.g. cochineal), Arable, Herbs and spices, Sugar beet/cane, Mushrooms/Fungi, Honey, Sprouted seeds, Foraging (e.g. sloes, Yarg nettles, truffles), Hunting (e.g. game, fish), Mineral / Spring water Mining – Salts, Chalk, Additives e.g. Au, Ag, etc. Extracts – Yeast, Enzymes (esp. rennet), Isinglass, Caviar, Gases e.g. N_2, CO_2	Veterinarians, Animal nutritionists, Agronomists, Agricultural engineers Farm quality assurance, Water quality (fish farming), Oxygen (fish farming), Pest control Transport – feed, materials etc., Utilities supply (Water / electric/ fuel), Waste removal Supplies – Feed, agrochemicals, cleaning chemicals, laundry Materials - Ingredients / additives / flavourings, processing aids / enzymes, Packaging - Closures/caps, form fill, formed, glass bottles, sleeves, labels, outers (card and plastics), pallets, wrap, printing inks Cleaning chemicals Utilities – Water, Electricity, Fuel: Gas / Oil Waste treatment / Biomass Site Services - Engineering/Maintenance, Waste collection/disposal, Pest control, Water monitoring, Analytical testing / calibration laboratories, Laundry Business Services – Legal, Insurance, Finance, PR/Marketing, Assurance / Certification, Project management Agents & Brokers - Import/Export, Distributors, Wholesalers

Food Supply Chain Division	Description	Allied / Service Industries
Primary Processing	Package and make product “fit for consumption” / “fit to travel” without changing its nature, even if just washing or heating Includes: Meat - Slaughter Houses, Cutting facilities Fish/Shellfish – Gut, Clean Shellers/Cleaners & Millers - Whole/Pieces, Flour, Flakes (Cereals, Nuts, Herbs, Spices) Packaging Houses – Produce (e.g. apples, lettuce, new potatoes), Eggs, Water, Milk (Unless raw, then processing changes nature)	Building Infrastructure – Buildings, Flooring, Surfaces (walls, floors, ceilings), doors/windows, fixtures and fittings (lighting, electrics, plumbing, drains, barriers, signage), Storage (racking, silos), HVAC / Air Conditioning, Refrigeration Production Engineering – Cooking, Cooling, Forming, Blending/Mixing, Conveyors, Packing, Pallet wrapping Plant Equipment - Fork Lift Trucks / Lifting Equipment, Ladders / Cherry-pickers, Cleaning equipment / Bins, Workwear / Personal protective equipment, Temperature Probes, Detectors: Metal, X-ray, Optisort etc.), Scales and Balances, Printers – and associated chemicals Office Equipment Information Technology - Software, hardware, network, servers Transport / Logistics - Own fleet/contract, Fleet Machinery, Fleet fuel, Own storage/contract Transport Infrastructure – Road / rail / air / sea, Storage & Transport Depots, Customs holding points & Checkpoints Recruitment Agencies – Temporary, Permanent, Seasonal
Primary Manufacturing	Combining primary and secondary processed products which then have value added to them Includes: Meat/Fish/Shellfish – Cooked, Sausages (Raw and Cooked), Burgers Beverages – Wine, Cider, Beer, Milk Drinks, Carbonates, Juices, Squashes/cordials Blending Houses – Flour, Starches, Herbs and Spices, Colourings Produce – Cooked, Assembled Oils/Fats – Butter, Margarine, Oils, Cream Blocked and Formed Products – Marzipan, Pastries, Icing	

<table>
<tr><th>Food Supply Chain Division</th><th>Description</th><th>Allied / Service Industries</th></tr>
<tr><td>Secondary Processing</td><td>Change the product’s initial physical state, which can then be used as an ingredient, or final product for retail sale

Includes:
Meat – Cure, Bone, Slicers, Mincers
Fish/Shellfish - Fillet/Shuck, Smoke
Produce/Herbs & Spices – Peel, Chop/Slice, Puree
Dairy - Semi-skimmed milk, Cheese, Yoghurt
Refineries - Fats and Oils, Starches, Stabilisers
Other - Egg (liquid and dried yolk, white, whole)</td><td rowspan="2">Building Infrastructure – Buildings, Flooring,
Surfaces (walls, floors, ceilings), doors/windows, fixtures and fittings (lighting, electrics, plumbing, drains, barriers, signage), Storage (racking, silos), HVAC / Air Conditioning, Refrigeration

Production Engineering – Cooking, Cooling, Forming, Blending/Mixing, Conveyors, Packing, Pallet wrapping

Plant Equipment - Fork Lift Trucks / Lifting Equipment, Ladders / Cherrypickers, Cleaning equipment / Bins, Workwear / Personal protective equipment, Temperature Probes, Detectors: Metal, X-ray, Optisort etc.), Scales and Balances, Printers – and associated chemicals

Office Equipment
Information Technology - Software, hardware, network, servers

Transport / Logistics - Own fleet/contract,
Fleet Machinery, Fleet fuel, Own storage/contract

Transport Infrastructure – Road / rail / air / sea, Storage & Transport Depots, Customs holding points & Checkpoints

Recruitment Agencies – Temporary, Permanent, Seasonal</td></tr>
<tr><td>Secondary Manufacturing</td><td>Produce food product for consumer ready to eat and/or heat

Includes:
Meat - Ready Meals, Sausage Rolls, Quiches, Pies, Canned meat
Fish & Seafood - Ready Meals, Coated, Topped
Poultry & Eggs - Ready Meals, Coated, Cooked
Sugar Processors - Peel/ Pulp/ Crystallize, Colour/ Mill
Produce – Pies, Canned Vegetables, Prepared Salads
Dairy - Cheese with inclusions, Processed cheese, Flavoured yoghurt / fromage frais
Bakery – Bread, Cakes, Biscuits
Grocery - Breakfast Cereals, Condiments, Soups/Sauces, Stocks/Gravies, Jams/Conserves, Pickles/Chutneys
Convenience Foods - Pies/Ready meals, Desserts, Ice cream, Confectionery, Crisps and Snacks
Sandwiches/Wraps</td></tr>
</table>

Food Supply Chain Division	Description	Allied / Service Industries
Distribution	Transport and distribute foods along the food supply chain between sites owned by the same operator and between operators In the UK wholesale distributors transport foodstuffs from each compartment in the food chain to depots and on to retail and foodservice outlets (from FWD figures representing ~85% of food distribution sector) - Depot operations sites 53,270, HQ operations sites 6,110, FTE employees 47,800	Building Infrastructure – Buildings, Flooring, Surfaces (walls, floors, ceilings), doors/windows, fixtures and fittings (lighting, electrics, plumbing, drains, barriers, signage), Storage (racking, silos), HVAC / Air Conditioning, Refrigeration Plant Equipment - Fork Lift Trucks / Lifting Equipment, Ladders / Cherry-pickers, Cleaning equipment / Bins, Workwear / Personal protective equipment, Temperature Probes, Detectors: Metal, X-ray, Optisort etc.), Scales and Balances, Printers – and associated chemicals Office Equipment Information Technology - Software, hardware, network, servers Transport / Logistics - Own fleet/contract, Fleet Machinery, Fleet fuel, Own storage/contract Transport Infrastructure – Road / rail / air / sea, Storage & Transport Depots, Customs holding points & Checkpoints Recruitment Agencies – Temporary, Permanent, Seasonal

Food Supply Chain Division	Description	Allied / Service Industries
Sales Channels	Operators selling foodstuffs to the final consumer are very varied in size, scope and mode of operation, from farm shops where primary producers sell at point of 'harvest' to multi-national retail and food service outlets and to home delivery. Includes: Retail – Multiples, Freezer Centres, Markets, Convenience Stores, Concessions, Petrol Stations, Specialist shops (e.g. fishmongers, butchers, greengrocers), Delicatessens, Farm Shops, Farmers Markets, Pick Your Own, Van Sales (e.g. travelling shops, fishmongers, milkman), Mail order / Home delivery, Vending Wholesale - Cash & Carry (Trade, Food Service and Retail, Membership), Specialists (Ethnic, Specialist Ingredients), Wholesale Markets Food Service - Retail: coffee shops, sandwich bars, bakery stores, supermarket cafes, Travel: roadside, petrol forecourts, railway stations, airports, ports, Leisure: sports clubs, event catering, stadia, visitor attractions, entertainment venues, Hotels: full service, budget, guest houses, holiday parks, conference centres, Pubs and bars: branded and managed, tenanted and leased, independent, social clubs, nightclubs, Restaurants: fine dining, independent, fast food outlets, street food / van sales (e.g. burgers, sandwiches, hot food/drinks), Contract catering for business: contracted, in-house Contract catering for public sector: defence, justice, healthcare, local authorities, oil rigs, education	Building Infrastructure – Buildings, Flooring, Surfaces (walls, floors, ceilings), doors/windows, fixtures and fittings (lighting, electrics, plumbing, drains, barriers, signage), Storage (racking, silos), HVAC / Air Conditioning, Refrigeration Plant Equipment - Fork Lift Trucks / Lifting Equipment, Ladders / Cherry-pickers, Cleaning equipment / Bins, Workwear / Personal protective equipment, Temperature Probes, Detectors: Metal, X-ray, Optisort etc.), Scales and Balances, Printers – and associated chemicals Office Equipment Information Technology - Software, hardware, network, servers Transport / Logistics - Own fleet/contract, Fleet Machinery, Fleet fuel, Own storage/contract Transport Infrastructure – Road / rail / air / sea, Storage & Transport Depots, Customs holding points & Checkpoints Recruitment Agencies – Temporary, Permanent, Seasonal

Appendix 3: Standards for Assurance /Certification for the Food Supply Chain

Type of Assurance / Certification								
Farm/Sea	**Primary Storage & Distribution** e.g. Grainstore	**Agents & Brokers**	**Primary Process** e.g. Slaughter house, vegetable/fruit packhouse	**Secondary Storage & Distribution**	**2nd Process**	**Packaging**	**Tertiary Storage & Distribution**	**Retail**
Quality and Food Safety Management Systems								
ISO9001 Global GAP (Good Agricultural Practice) standards E.G. Global Aquaculture Alliance; Red Tractor; Quality Meat Scotland (QMS); Farm Assured Welsh Livestock (FAWL); Feed: Agricultural Industries Confederation (AIC) Lion Mark (eggs)	ISO9001 Global GAP standards E.G. GlobalGAP. International Feature Standards (IFS). UK: farm/dairy assurance e.g. Red Tractor Customer specific e.g. M+S Field To Fork	ISO9001 Global Food Safety Initiative (GFSI): E.G. IFS; British Retail Consortium (BRC); Safe Quality Food (SQF); PrimusGFS, (Food Safety Audit Scheme); Food Safety System Certification, FSSC22000.	ISO9001 GFSI e.g. BRC, IFS, SQF, PrimusGFS, FSSC22000 Customer specific e.g. M+S Field To Fork/Protein Audits	ISO9001 ISO22000 GFSI e.g. BRC, IFS, SQF, PrimusGFS, FSSC22000	ISO9001 ISO22000 GFSI e.g. BRC, IFS, SQF, PrimusGFS, FSSC22000	ISO9001 ISO22000 GFSI e.g. BRC IoP, IFS PACsecure, SQF, FSSC22000	ISO9001 ISO22000 GFSI e.g. BRC, IFS, SQF, PrimusGFS, FSSC22000	ISO9001 ISO22000 GFSI e.g. BRC (Retail) Food Hygiene Rating

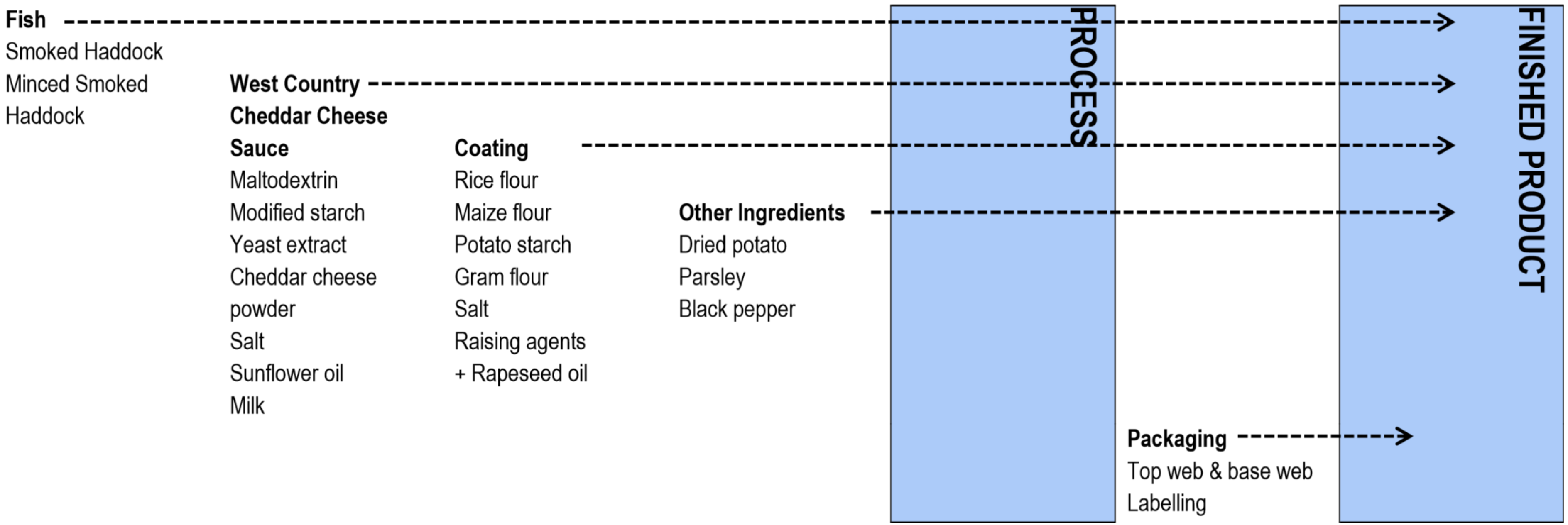
Type of Assurance / Certification								
Farm/Sea	**Primary Storage & Distribution** e.g. Grainstore	**Agents & Brokers**	**Primary Process** e.g. Slaughter house, vegetable/fruit packhouse	**Secondary Storage & Distribution**	**2nd Process**	**Packaging**	**Tertiary Storage & Distribution**	**Retail**
Sustainability / Environment								
e.g. LEAF Marque; Marine Stewardship Council (MSC); RSPO (Roundtable on Sustainable Palm Oil), Rainforest Alliance, Forest Stewardship Council Carbon Trust	Carbon Trust	Carbon Trust	Carbon Trust	Carbon Trust	Carbon Trust	Carbon Trust	Carbon Trust	Carbon Trust
Welfare								
Freedom Food (RSPCA Monitored); World Organisation for Animal Health (OIE).	Freedom Food (RSPCA Monitored); Individual company standards e.g. McDonalds World Organisation for Animal Health (OIE)		Freedom Food (RSPCA Monitored).					

Type of Assurance / Certification								
Farm/Sea	**Primary Storage & Distribution** e.g. Grainstore	**Agents & Brokers**	**Primary Process** e.g. Slaughter house, vegetable/fruit packhouse	**Secondary Storage & Distribution**	**2nd Process**	**Packaging**	**Tertiary Storage & Distribution**	**Retail**
Organic (Note: Organic certification bodies have to be formally approved and listed by government for UK/EU)								
Organic Farmers & Growers CIC (GB-ORG-02); Organic Food Federation (GB-ORG-04); Soil Association Certification Ltd (GB-ORG-05); Biodynamic Association Certification (GB-ORG-06); Irish Organic Association (GB-ORG-07); Organic Trust Limited (GB-ORG-09); Quality Welsh Food Certification Ltd (GB-ORG-13); Global Trust Certification Ltd (GB-ORG-16); OF&G (Scotland) Ltd (GB-ORG-17).			Organic Farmers & Growers CIC (GB-ORG-02); Organic Food Federation (GB-ORG-04); Soil Association Certification Ltd (GB-ORG-05); Biodynamic Association Certification (GB-ORG-06); Irish Organic Association (GB-ORG-07); Organic Trust Limited (GB-ORG-09); Quality Welsh Food Certification Ltd (GB-ORG-13); Global Trust Certification Ltd (GB-ORG-16); OF&G (Scotland) Ltd (GB-ORG-17).		Organic Farmers & Growers CIC (GB-ORG-02); Organic Food Federation (GB-ORG-04); Soil Association Certification Ltd (GB-ORG-05); Biodynamic Association Certification (GB-ORG-06); Irish Organic Association (GB-ORG-07); Organic Trust Limited (GB-ORG-09); Quality Welsh Food Certification Ltd (GB-ORG-13); Global Trust Certification Ltd (GB-ORG-16); OF&G (Scotland) Ltd (GB-ORG-17).			

Type of Assurance / Certification								
Farm/Sea	**Primary Storage & Distribution** e.g. Grainstore	**Agents & Brokers**	**Primary Process** e.g. Slaughter house, vegetable/fruit packhouse	**Secondary Storage & Distribution**	**2nd Process**	**Packaging**	**Tertiary Storage & Distribution**	**Retail**
Ethical								
Trade e.g. Sedex Members Ethical Trade Audit (SMETA); Fairtrade; Int. Council Mining and Metals (ICMM); Labour e.g. ILO (Int. Labour Org.); McDonalds supplier workplace accountability	Trade e.g. Sedex Members Ethical Trade Audit (SMETA); Fairtrade; ILO; McDonalds supplier workplace accountability	Trade e.g. Sedex Members Ethical Trade Audit (SMETA); Fairtrade.	Trade e.g. Sedex Members Ethical Trade Audit (SMETA); Fairtrade; Diet e.g. halal, Kosher; ILO.	Trade e.g. Sedex Members Ethical Trade Audit (SMETA); Fairtrad; Labour e.g. ILO	Trade e.g. Sedex Members Ethical Trade Audit (SMETA); Fairtrade; Diet e.g. halal, Kosher; Labour e.g. ILO (Int. Labour Org.), McDonalds supplier workplace accountability	Trade e.g. Sedex Members Ethical Trade Audit (SMETA); Fairtrade; ILO; McDonalds supplier workplace accountability	Trade e.g. Sedex Members Ethical Trade Audit (SMETA); Fairtrade; Labour e.g. ILO Labour Org.).	Labour e.g. ILO (Int. Labour Org.); McDonalds supplier workplace accountability
Other								
Pest control operator	Pest control operator	Pest control operator	Pest control operator Slaughter house operatives If export then EU vets or FDA	Pest control operator	Pest control operator If export then EU vets or FDA	Pest control operator	Pest control operator	Pest control operator

Appendix 4: Case Study of a Gluten Free Smoked Haddock Fishcake with West Country Cheddar Cheese Sauce

Supply Chain Map



Appendix 4: Case Study of a Gluten Free Smoked Haddock Fishcake with West Country Cheddar Cheese Sauce CTD.

SOURCING: Gluten-free Fishcake						
Fish	**Cheddar Cheese sauce**	**Coating**	**Other Ingredients**	**Process**	**Packaging**	**Finished Product**
Chill direct from fish merchants	Direct Agents + Brokers	Coating & oil suppliers	Mostly agents/ brokers	NA	Direct	NA
Frozen bought via brokers						
ASSOCIATED DATA / EVIDENCE OF COMPLIANCE: Gluten-free Fishcake						
Fish	**Cheddar Cheese sauce**	**Coating**	**Other Ingredients**	**Process**	**Packaging**	**Finished Product**
Supplier certification	Supplier certification	Supplier certification	Supplier certification	Site certification	Supplier certification	Ingredients declaration
Source – Geography	Recipe - % cheese	Bulk ingredients	Traceability	Temperatures	Food contact / migration	Gluten free claim
Haddock – Species	Source, traceability	Gluten free	Purity / Authenticity	Process time	Same as used in shelf-life testing	Visual
Traceability esp. minced fish	Substitution / Dilution	Substitution / Dilution	Origin	Cooking	Right label- allergens, shelf-life, nutrition, claims	Taste
Sustainability status (MSC certification)	Fat content	Traceability	'Proper dried potato' re-constitution (substitution)	Cleaning	Sealed	Shelf life
Time from catch to smoking?	Veterinary residues	Contaminants e.g. mycotoxins, pesticides	Contaminants e.g. mycotoxins, pesticides	Gluten cross-contamination – shared line/equipment	Gluten cross-contamination – shared line/equipment	Microbiology

ASSOCIATED DATA / EVIDENCE OF COMPLIANCE: Gluten-free Fishcake						
Fish	**Cheddar Cheese sauce**	**Coating**	**Other Ingredients**	**Process**	**Packaging**	**Finished Product**
Contaminants e.g. heavy metals, dioxins, POPs	Microbiology	Microbiology esp. Salmonella	Microbiology esp. Salmonella	Recipe		Effect of freezing
Process contaminants from smoking e.g. PAHs	Cook time/temp	Oil quality (oxidation)	Size of herb flakes	Fat content		Distribution temperatures
Microbiology incl. parasites	Chill post cook	Oil Fatty acid profile		Dimensions		Cookability
Illegal colours	Shelf life post cook	Coating to fish ratio		Weight		Nutrition check
Fat content				Chilling		Cooking instructions
Fresh/frozen						

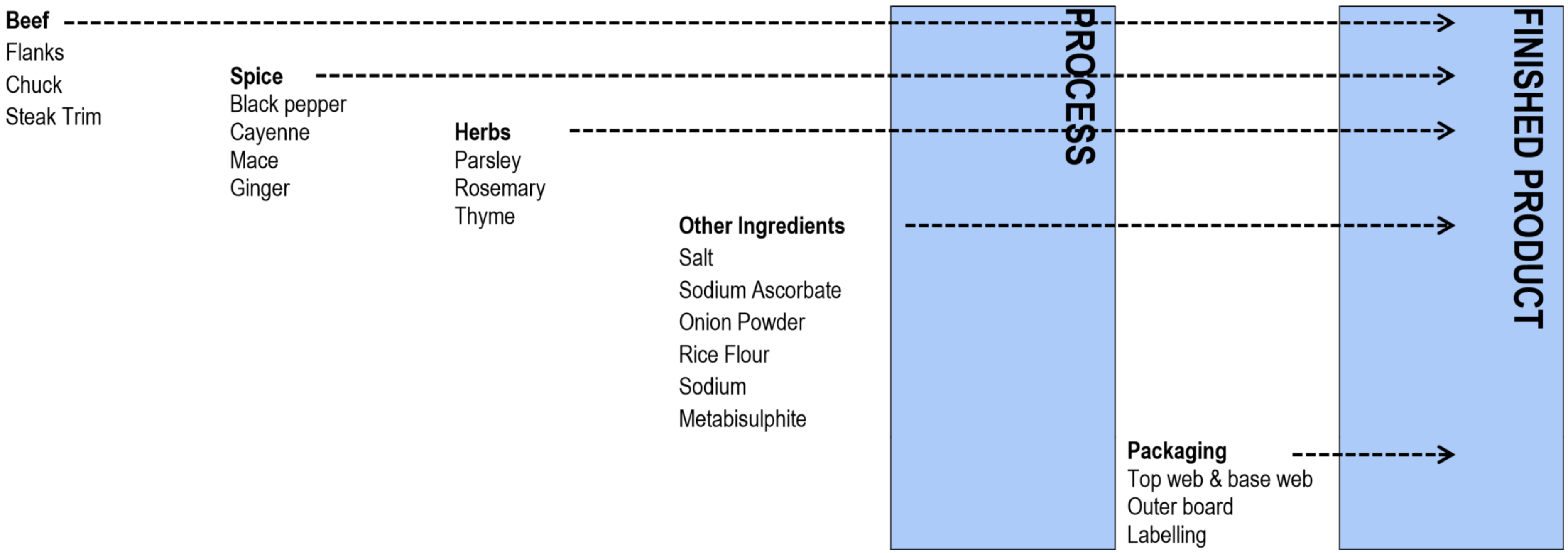
INTERESTED PARTIES: Gluten-free Fishcake						
Fish	**Cheddar Cheese sauce**	**Coating**	**Other Ingredients**	**Process**	**Packaging**	**Finished Product**
Fishermen	Growers	Farmers	Growers	Equip suppliers	Manufacturers	Consumers
Vets	Agents	Agents	Driers	Analytical testing laboratories	Analytical testing laboratories	Retailers
Fish smokers	Brokers	Brokers	Processors	Laboratory supplies	Laboratory supplies	Wholesalers
Fish processors	Co-operatives	Co-operatives	Manufacturers	Laboratory equipment	Laboratory equipment	Foodservice
Analytical testing laboratories	Wholesalers	Wholesalers	Agents	Trade Associations[2]	Transport	Distributors
Analytical equipment	Transport	Coating suppliers	Brokers	Certification [3]	Storage	Transport
Temperature monitoring equipment	Storage	Oil refiners	Wholesalers		Trade Associations	Storage
Refrigeration engineers	Trade Associations	Transport	Transport		Certification Bodies	Temperature monitoring equip
Transport (fish)	Certification Bodies	Storage	Storage		Equipment suppliers	Trade Associations
Trade Associations		Trade Associations	Trade Associations		Engineers	Certification Bodies
Certification Bodies		Certification Bodies	Certification Bodies			FSA
Ports/Customs						
DEFRA / FSA						

[2] Trade associations exist representing the interests of each actor in the food supply chain as well as the affiliated industries.
[3] Certification Bodies certify primary producers, manufacturers, transport/distribution/storage organisations, calibration organisations and analytical testing laboratories.

PACKAGING: Gluten-free Fishcake Top web and base web, time/date stamped with paper labelling on the individual product SKU (stock keeping unit). In an outer cardboard shelf-ready case, with a label per case. Cases will be supplied on pallets which will have pallet shrink wrap and a pallet label.						
Top web	**Base web**	**Pack label**	**Shelf-ready carton**	**Case label**	**Pallet wrap**	**Pallet label**
Flexible PET (Polyethylene terephthalate)	Rigid formed PET	Paper	Corrugated board	Paper	LLDPE (linear lowdensity polyethylene)	Paper
Inks		Inks	Inks	Inks		Inks
		Adhesive		Adhesive		Adhesive

Appendix 5: Case Study of a Chilled Seasoned Aberdeen Angus Beefburger

Supply Chain Map



Appendix 5: Case Study of a Chilled Seasoned Aberdeen Angus Beefburger CTD.

SOURCING: Angus Beefburger						
Beef	**Spices**	**Herbs**	**Other Ingredients**	**Process**	**Packaging**	**Finished product**
Chill direct from slaughterhouse	Mostly agents and brokers	Mostly agents and brokers	Mostly agents and brokers	NA	Direct	NA
Frozen bought via brokers						

ASSOCIATED DATA / EVIDENCE OF COMPLIANCE: Angus Beefburger						
Beef	**Spices**	**Herbs**	**Other Ingredients**	**Process**	**Packaging**	**Finished product**
Farm assurance	Supplier certification	Supplier certification	Supplier certification	Site certification	Supplier certification	Ingredients declaration
Abattoir assurance	Origin/Source – Geography	Origin/Source – Geography	Origin/Source – Geography	Temperatures	Food contact / migration	Visual
Animal welfare	Traceability	Traceability	Traceability	Process time	Same packaging as in shelf-life test	Taste
Feed	Purity / Authenticity	Purity / Authenticity	Purity / Authenticity	Cleaning	Right label	Shelf life
Origin/Source – Geography	Substitution / Dilution	Substitution / Dilution	Substitution / Dilution	Recipe	Sealed	Microbiology
Parentage / Genetics	Irradiated	Irradiated	Irradiated	Grind size		Effect of freezing
Traceability	Microbiology esp. Salmonella	Microbiology esp. Salmonella	Microbiology esp. Salmonella	Fat content		Distribution temperatures
Veterinary drug residues	Contaminants e.g. mycotoxins, pesticides	Contaminants e.g. mycotoxins, pesticides	Contaminants e.g. mycotoxins, pesticides	Dimensions		Cookability

ASSOCIATED DATA / EVIDENCE OF COMPLIANCE: Angus Beefburger CTD						
Beef	**Spices**	**Herbs**	**Other Ingredients**	**Process**	**Packaging**	**Finished product**
Microbiology incl. parasites	Illegal dyes	Illegal dyes	Illegal dyes	Weight		Nutrition check
Collagen content	Foreign bodies e.g. stones, stalks	Size of herb flakes	Foreign bodies e.g. stones, stalks	Cookability		Cooking instructions
Foreign bodies e.g. bones, splinters		Foreign bodies e.g. stones, stalks		Chilling		

INTERESTED PARTIES: Angus Beefburger						
Beef	**Spices**	**Herbs**	**Other Ingredients**	**Process**	**Packaging**	**Finished product**
Farmers	Growers	Farmers	Growers	Equipment manufacturers	Manufacturers	Consumers
Vets	Agents	Agents	Driers	Analytical testing laboratories	Analytical testing laboratories	Retailers
Welfare organisations	Brokers	Brokers	Processors	Laboratory supplies	Laboratory supplies	Wholesalers
Animal nutritionists	Co-operatives	Co-operatives	Manufacturers	Laboratory equipment	Laboratory equipment	Foodservice
Analytical testing laboratories	Wholesalers	Wholesalers	Agents	Trade Associations	Transport	Distributors
Analytical equipment	Transport	Coating suppliers	Brokers	Certification Bodies	Storage	Transport
Temperature monitoring equipment	Storage	Oil refiners	Wholesalers		Trade Associations	Storage
Refrigeration engineers	Trade Associations[4]	Transport	Transport		Certification Bodies	Temperature monitoring equipment
Slaughterhouse operations	Certification Bodies[5]	Storage	Storage			Trade Associations
Transport (animals)		Trade Associations[4]	Trade Associations[4]			Certification Bodies
Animal movements		Certification Bodies[5]	Certification Bodies[5]			FSA
Transport (meat)						
Trade Associations[4]						
Certification Bodies[5]						
Ports/Customs						
DEFRA/FSA						

[4] Trade associations exist representing the interests of each actor in the food supply chain as well as the affiliated industries.
[5] Certification Bodies certify primary producers, manufacturers, transport/distribution/storage organisations, calibration organisations and analytical testing laboratories.

Appendix 6: Division of Responsibility for Food Law in the UK[6]

	General	Import Controls	Labelling	Composition & Standards	Biological Safety	Chemical Safety	Biotechnology
ENGLAND							
FSA	Food safety, Traceability, Hygiene controls, food incidents, Rapid Alert System for Food and Feed (RASFF)	Public Health aspects of food & feed	Food Safety aspects (inc. allergens) only Feed safety, nutritional content and PARNUTS	Standards for feed materials as set out in the feed catalogue	Transmissible Spongiform Encephalopathies (TSEs)[7]	Food and feed additives, Contaminants, Food contact materials; Chemical safety of feed.	Genetically Modified (GM) food and feed
Defra (and Defra Agencies)	Animal By-Products Feed ban	Animal By-products	All - Beef Labelling & protected food names Labelling General where not related to food safety or nutrition	Organic Products Composition & Standards except for food for particular nutritional uses	TSEs	Medicated feed, Specified Feed Additives, Residues of Veterinary Products (VMD[8])	N/A
Dept. of Health	N/A	N/A	Foods for Particular Nutritional Uses Nutrition and Nutritional Health claims (England)	N/A	N/A	N/A	N/A
HSE (CRD)[9]	N/A	N/A	N/A	N/A	N/A	Pesticide Residues Biocide products	N/A

[6] FOOD STANDARDS AGENCY FOOD AND FEED LAW GUIDE Updated January 2018
[7] In relation to specified risk material, mechanically separated meat and slaughtering techniques
[8] Veterinary Medicines Directorate
[9] Chemicals Regulation Directorate

	General	Import Controls	Labelling	Composition & Standards	Biological Safety	Chemical Safety	Biotechnology
WALES							
FSAW	Traceability, Hygiene, Rapid Alert System for Food and Feed (RASFF)	Public Health aspects of food & feed	All General Labelling, Food safety aspects	All except for organic products	Transmissible Spongiform Encephalopathies (TSEs)[10] in relation to food for human consumption	Food and feed additives, Contaminants, Food contact materials Chemical Safety of Feed	Genetically Modified (GM) food
Welsh Government	Animal By-Products Feed ban	Animal By-products	Nutrition and Nutritional Health Claims Foods for Specific Groups, (replaced Foods for Particular Nutritional Uses) Beef Labelling & protected food names	Organic Products	TSEs in relation to animal disease	Medicated feed, Specified Feed Additives, Residues of Veterinary Products	N/A
HSE (CRD)	N/A	N/A	N/A	N/A	N/A	Pesticide Residues	N/A

[10] In relation to specified risk material, mechanically separated meat and slaughtering techniques

	General	Import Controls	Labelling	Composition & Standards	Biological Safety	Chemical Safety	Biotechnology
NORTHERN IRELAND							
FSA	Traceability, Hygiene, Rapid Alert System for Food and Feed (RASFF)	Public Health aspects of food and feed	All General Labelling, Food Safety aspects, Foods for Particular Nutritional Uses, Nutrition & Health Claims	All except for organic products	Transmissible Spongiform Encephalopathies (TSEs)[11]	e.g. additives, contaminants, food contact materials	Genetically Modified (GM) food
Department of Agriculture, Environment and Rural Affairs (DAERA)	Animal By-Products Feed ban	N/A	Beef Labelling & protected food names	Organic Products	TSEs	Chemical Safety of Feed, Medicated feed, Specified Feed Additives, Residues of Veterinary Products	N/A
HSE (CRD)	N/A	N/A	N/A	N/A	N/A	Pesticide Residues	N/A

Note: Food Standards Scotland (FSS) was established 1 April 2015 as the national food body for Scotland, with responsibility for those central Government functions previously carried out by the FSA in Scotland. The Food Law Guide therefore does not include details on food law in Scotland.

[11] In relation to specified risk material, mechanically separated meat and slaughtering techniques

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