New Food

# Tech Trends

## REPORT 2022

Emerging technologies to watch as we move towards a safer, more efficient and sustainable food system

# New Food Tech Trends Report 2022

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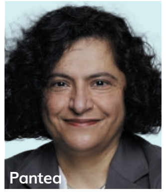

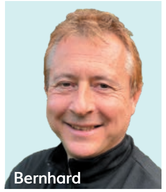

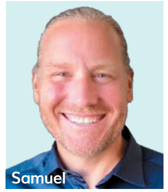


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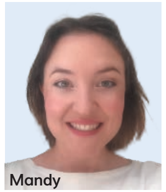


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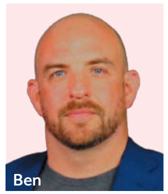
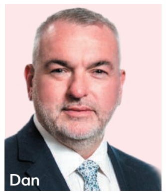





CLICK ON THE CONTRIBUTORS' PHOTO TO VIEW THEIR **'INDUSTRY COMMENT'**

# WELCOME

DEVELOPING THIS report was not a simple task. Even in the initial idea stage, the authors and I discussed various avenues it could take. The original plan to write a report that simply highlighted the emerging top tech was quickly thrown out of the window, as we agreed another trends piece was of relatively little value for the industry.

Of course, we still wanted to outline technologies of interest, but we also wanted the report to offer a balanced overview of up and coming tech.
In addition, we wanted the report to have substance – given that the application of this tech is addressing one of the biggest issues of our time, we felt it important to envisage how innovation can enable a way forward.

Within these pages, you will find an in-depth exploration of technologies that we believe will help forge a path to sustainable food production in the future. It is important to note here that sustainability is not only discussed in relation to the environment but also within a societal context (ie, socio-economic issues, whereby social inequalities emerge as a result of environmental problems).

With the world population expected to reach almost 10 billion by 2050, our impact on the Earth is only set to intensify. None of the technologies independently, nor technology as a solution alone, will resolve the crisis we find ourselves in, but a combination of innovative tools and the right education and mindset might just.

Also found in this report is a series of seven industry voices – Sagentia Innovation, HelloFresh, Small Robot Company, PepsiCo, Tyson Foods, JBS and Raynor Foods – wherein we hear from leaders about the technologies their companies have or are investing in.

I give a nod of appreciation to our valued sponsors, without whom this report would not have been possible. Along with sponsoring this original report, we also hear from Bruker and Agroknow in a video interview. On page 19, Dean Roberts, Director of Market and Technology Development at Bruker, discusses the latest developments in testing – an area that has had to keep pace with the fast-developing world of processing and manufacturing as a result of technology. In particular, Roberts examines the importance of conformity testing in helping to maintain integrity and food safety. Over on page 12, meanwhile, Giannis Stoitsis, CTO at Agroknow, gives us further insight into the benefits that artificial intelligence (AI) can offer a manufacturer in preventing and predicting risk, such as food recalls and incidences of fraud.

Finally, I'd like to extend my thanks to the three authors of this report – Dr Pantea Lotfian, Dr Bernhard Strauss and Dr Samuel Short – for their combined efforts in bringing this insightful and honest piece together.

On behalf of everyone involved in the creation of this report: happy reading! We do hope you find it a useful and informative tool.

Bethan Grylls
EDITOR, *NEW FOOD*

# CONTENTS

# Addressing sustainability with technology

AS SCIENTIFIC and media reporting has made abundantly clear, climate change, resource depletion, population growth and increasing consumer demand are major threats to our current food system. In isolation, each is a daunting challenge; yet we are dealing with these threats simultaneously and their effect on the planet and its inhabitants is greater than the sum of its parts.

Consequently, any solution in isolation may have minimal impact or possibly unintended adverse effects elsewhere. $CO_2$ is a prime example of our tunnel vision: many focus solely on this gas' environmental impact, while it is clear that many other factors are contributing to sustainability challenges.[1]

You cannot resolve the climate crisis by addressing carbon alone, we must also address areas such as legislation, food waste and packaging. It is vital we take a holistic approach, looking at sustainability from a broad societal and environmental point of view.

In this article we discuss these complex systemic challenges from the perspective of technology innovation in the current food system, and the extent to which it can help make food production systems more resilient and sustainable.

Aside from being essential for survival, food is also intertwined with our history, cultures and identity. We eat for nourishment, but we also eat together to enjoy, to share, and to acknowledge one another. These important cultural aspects that often motivate our food choices are usually overlooked when innovating manufacturing technologies to deliver mass production at scale and to produce consistent taste and texture and maximise economic returns.

Linear, fully industrialised processes that rely on highly controlled input streams with little flexibility to adapt and adjust to major change dominate most existing food production. However, consumers are driving innovation in the manufacturing sector by demanding more 'fresh-like', 'naturally tasting' and healthier products from mass producers. This may seem to be a contradiction of terms, but producers are paying attention, using innovative technological approaches to deliver to consumers' calls.

With regard to the above-mentioned global challenges, the question remains: will emerging technologies in the food sector be able to address the global challenges we are facing in manufacturing and supply? Often, novel technology is considered the only solution to such systemic challenges; however, adopting and scaling new technologies is a major challenge in itself and usually takes more time than anticipated.

Furthermore, technologies used to address major challenges have created an increasingly interconnected world. This interconnectivity introduces additional risks of system failure, which means any disruption in one small part of the system may cause wider disruptions throughout the whole system. Therefore, it is important to build resilience and robustness into the currently emerging food ecosystems.

Adoption of new tech and resulting changes in business models can lead to shifts in the industry, away from vertically integrated legacy structures to a networked model. Here, gaining competitive advantage will depend on having the highest number of relationships with customers and suppliers throughout the network, rather than a hierarchical and transactional step-by-step relationship throughout the various stages of a classic, linear value chain.[2] **Figure 1** shows both the classic linear value chain and the emerging food value ecosystem.

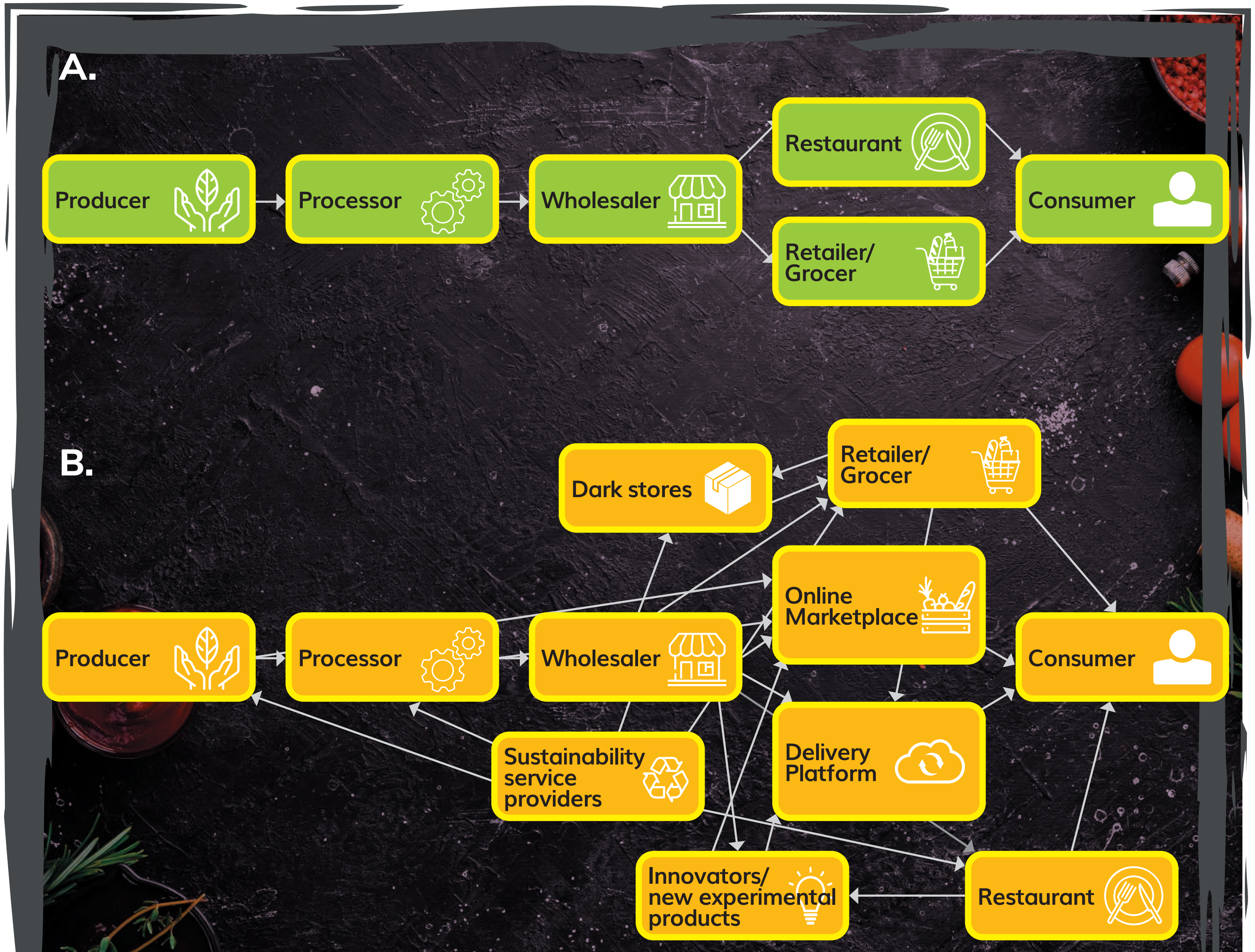



**Figure 1**

**A.** Traditional linear food value chain.

**B.** Emerging food value ecosystem with multiple connections between players.

(Adapted from Short *et al*, 2021[2])

# Your thoughts on technology

AS PART of our research, we conducted a targeted survey among a mixed group of respondents, covering large corporations, SMEs in the food manufacturing sector, and academia. The aim was to gain a better understanding of the current challenges that food companies face when trying to access and adopt new technologies, and the resulting change it creates in their organisation and business models. We received 64 replies to detailed questions regarding the role of novel technologies in their industries. Here, we briefly highlight the key takeaways.

## Current implementation of technology

More than 40 percent of respondents currently do not use sophisticated digital solutions such as artificial intelligence (AI) and/or Internet of Things (IoT) technologies in their manufacturing processes, while 33 percent report using these technologies in process and manufacturing, as well as in quality control (QC) and oversight. Sixteen percent said they use digital technologies in customer, supplier, inventory and production management. This indicates that diffusion and implementation of advanced technologies has started but might be far slower than media reporting implies. In addition, networked data connectivity of the factory floor with the rest of the business is still uncommon, with very few respondents using such technology.

According to our survey, the main hurdle for technology adoption is identifying the right technology for purpose, as stated by 65 percent of respondents. This is followed closely by high capital investment costs, the complexity of technology and lack of appropriate skills (60 and 35 percent respectively). These results indicate that many, particularly mid to larger sized businesses, require access to expertise to help them implement such technologies.

> UPTAKE OF TECHNOLOGY IS SLOW DUE TO COST AND LACK OF EXPERTISE

Interestingly, only 25 percent of businesses found a lack of compatibility with legacy processes and settings to be a challenge.

Despite the obstacles, it is clear from our survey that food manufacturers view the adoption of new process technologies (45 percent) alongside AI (35 percent) as most likely to impact business models in the future.

## Applications of technology

Our research also discovered that the industry is moving away from classic, linear value chains and retail models towards direct from producer to consumer platforms. Forty-four percent believe these will involve more localised and distributed production and shorter supply chains (eg, a shift towards local produce, micro-breweries etc.)

Moreover, as we become more aware of the waste occurring in our food system (up to a third of all food produced),[3] and see increasing interest in recycling and reuse systems, we are likely to witness the emergence of circular models based on waste streams (ie, creating new value from using waste from another process). In fact, 74 percent of respondents consider circular business models in combination with new technologies aimed at reusing food, side streams and/or by-products, as important elements in reducing food waste.

**65% OF RESPONDENTS DON'T KNOW WHICH TECHNOLOGY TO USE**

Furthermore, while 58 percent of respondents acknowledged that the industry would be increasingly moving towards a distributed network of players, vertical integration remains important (56 percent). In essence, companies that work with many different suppliers and those which control their supply chain will both remain essential. Our research also pointed to further consolidation, with larger food producers acquiring smaller ones (21 percent).


The main driver for business model change, however, is still perceived to be a shift in the behaviour of consumers and what they value (60 percent). In particular, we are seeing demand for better quality foods that offer novel experiences and cater to new, often conflicting consumer trends, such as demand for more variety, affordability, freshness, health and convenience.

It is worth noting, however, that such behavioural changes may well include increasing pressure on businesses to address food waste and carbon emissions, including a reduction in food miles.

Technology is considered key to process efficiency and productivity improvements to meet growing demand (86 percent), followed by improving food safety/quality (70 percent), and novel production and food types such as synthetic biology (53 percent).

Novel packaging to extend shelf life for food waste reduction (44 percent) and other innovations in packaging, for example reusable and biodegradable packaging, as well as concepts such as zero packaging (65 percent), are viewed as avenues to waste reduction and solutions to some of our sustainability challenges.

Packaging is an area in which technology is likely to have a significant role, with innovative materials offering enhanced shelf life and protection, and subsequently, a reduction in food waste, among other things.

**AI AND NEW PROCESS TECHNOLOGIES ARE SEEN AS BIG WINNERS**

Novel production processes and foods (eg, biosynthesised food and cultured meat) are viewed as potential solutions to meet the growing demand for food, while reducing environmental impact.

Companies are increasingly aware that business models must change in order to achieve sustainable food systems. As such, circular business models based on novel technologies (for example, reusing food by-products and side streams) and rapid delivery and access for enhanced

**74% CONSIDER CIRCULAR BUSINESS MODELS COUPLED WITH TECHNOLOGIES THAT ALLOW FOR FOOD UPCYCLING AS IMPORTANT IN LOWERING FOOD WASTE**

consumer convenience will be key components of future food ecosystems and sustainability.[4]

Beyond addressing global threats to the food system and achieving more sustainable production through technology, strategies to redress global food inequalities and increase access to quality nutrition for all must be built into the system. This can only be achieved via business models that enable localised, distributed production while maintaining affordability. Among those we surveyed, local production and distribution was also considered vital in supporting rural livelihoods (60 percent).

## Ill equipped for the future

The industry is well aware of the wave of disruption that has already started, but it's not sufficiently equipped to address the challenges head on. Our survey points to obstacles that fall broadly into three categories: namely, technology identification and adoption, managing changes to a business that result from new technologies acquired, and adapting to the changing nature of the food industry ecosystem using advanced technologies.

At the technology strategy level, identifying the right problems to solve and how to approach technology identification, evaluation and selection is a considerable challenge itself, particularly for SMEs with constrained budgets and skills.

Technology turnover/obsolescence is another hurdle, as digital technologies are advancing rapidly and require updating on a regular basis. Manufacturers need robust and modular technologies that ideally would enable them to upgrade existing machinery, so they can get maximum return on capital investment already made. This means compatibility of advanced technologies with legacy systems becomes a deciding factor, particularly for smaller businesses.

Managing change in a business due to the adoption of advanced data-driven technologies, will require companies to develop new skills and ways of communicating.

Finally, adaptation to, functioning within, competing, and excelling in an ecosystem industry needs a rethink of supply chains, enabling connectivity and data flow within the organisation and with the external ecosystem hubs and nodes. It will also mean refocusing modes of production and supply to reduce waste, achieve greater product traceability, and even reduce volume of production in favour of smaller, high-value products for local tastes and needs.

## SUMMARY OF REPORT

In this extensive report, we review three key technology transformations that are a source of disruption and can potentially provide solutions for food manufacturers and other players in the value chain, enabling them to adapt to the emerging ecosystem model. These technology areas are AI, new processing technologies, and novel packaging technologies. We will briefly assess the importance of business model innovation in relation to new technologies, and how rapid business model innovation might change the nature of competition in the future food system.

# Artificial intelligence, IoT and the cloud in food manufacturing

IT IS WORTH noting that AI is not a single technology, but rather a series of different pieces of tech working together. Combined, they constitute machines that are capable of understanding their environment, taking action and learning as they go. In principle, the use of sensors combined with AI can link each step within the supply chain – from farm to fork.

Sensors are pieces of hardware used to measure change, both physical and chemical, and are capable of detecting different characteristics. Examples include e-noses for the identification of volatiles, machine vision, and gyroscopes. These can be used at various stages of a production process or along the supply chain, with applications ranging from controlling the direction of an autonomous tractor, to measuring soil acidity, to tracking food waste in manufacturing or even monitoring temperature.

Sensors generate data, which are then fed into software capable of analysing it. High computational capacity and complex mathematical models are used to detect patterns in the data, which in turn can identify anomalies or predict future events. Together, this ensemble of sensors, analysis systems and feedback mechanisms – usually connected via fast wireless communication – makes up the Internet of Things (IoT). Technologies such as machine learning and neural network processing are applied to data analytics and the connected physical systems, before being assembled into multi-layered AI systems.

Although we may not realise it, we encounter AI every day with varying degrees of sophistication. There are two forms of AI, namely 'narrow' and 'general or strong'. The former focuses on performing a single action to increase efficiency – for example, technologies like image recognition, chemical sensing, chat bots or self-driving vehicles.[5] General or strong AI, conversely, attempts to emulate human intelligence and imitate abstraction and creativity, making it capable of engaging in more complex tasks. The latter form doesn't really yet exist outside the realms of science fiction, so humans remain essential for creating and monitoring AI processes. However, AI capable of programming new AI is a well advancing field.[5]

## Types of artificial intelligence

Applications in today's manufacturing systems mainly fall under narrow AI. Nevertheless, scaling this form of technology, even in its more basic form, can create considerable competitive advantage. For this to succeed, installing technology and applying algorithms is not enough; manufacturers must restructure their decision-making and operations alongside investment in human capabilities to be able to integrate AI into their business.

> NEARLY 40% OF CROPS ARE LOST DUE TO DISEASE AND INFECTIONS WORLDWIDE

Global management consultancy BCG reports that companies that successfully scale AI across their business and realise the value of their investment, typically dedicate funds in the following way. Just 10 percent is spent on algorithms, 20 percent on enabling technologies, and 70 percent on embedding AI into business processes, which also includes adapting to new ways of operating. Consequently, when budgeting for AI solutions, business leaders should be aware that only a fraction goes towards the software and algorithms involved and much more must be spent on making it work in any given industry context.[5]

When it comes to food manufacturing, different AI components can be used to detect change; for example, in machinery performance, the presence of volatile chemicals in food and even differences in form, shape, structure and texture of the ingredients, end product and/or packaging.[6] In other words, AI technology can be applied to any step of the processing chain to automate, optimise, monitor, predict and respond to minute changes, provided all the required downstream technologies are set up and well-integrated to enable it.[7]

A key feature of AI at scale is its ability to provide intricate detail as well as an overview of the wider process/es that it controls. Data can also be used to trace back any defects or issues that may have occurred throughout the supply chain previously. These attributes will help manufacturers keep food safe and ensure authenticity, enabling preventative rather than reactive maintenance and intervention. Furthermore, it will allow manufacturers to make more informed decisions in the future, as well as enable increased transparency – a key attribute as consumers become more conscious of environmental and ethical impacts.

INDUSTRY COMMENT

# Key disruptors

Earlier this year, we outlined three key trends for 2022 that could disrupt our food system. We highlighted these in the context of challenges around the fragility of extended supply chains, changing consumer habits, and a longer-term need to offer more sustainable products and those that offer a definable benefit to consumers in terms of health and wellbeing.

Those three trends can be summarised as:

1. An evolution of the alternative protein market, which is fuelling demand for regulatory change and a new wave of ingredients (eg, fats, emulsifiers, preservatives) which may be derived from fermentation processes.
2. Supply chain resilience. Pressures on global supply chains, coupled with demand from consumers for transparency, are driving investments in technology that delivers traceability as well as agritech (eg, precision agriculture, gene editing) with the aim of shortening supply chains.
3. While some changes from the pandemic – such as the rise of at-home dining – will experience retrenchment, certain behavioural shifts are expected to remain. As such, leveraging digital technologies to deliver experiences that were once found elsewhere (eg, recreating the bar experience with draught quality at-home beverage dispensing) can be expected.

Clearly the nexus of life science and digital technology will have a major role to play, in addition to traditional product development, food science and nutritional skillsets.
We suggest keeping a close eye on the following four technology spaces.

## Genomics

Insights from genetic analyses may enable a raft of consumer wellness opportunities, allowing consumers to take better care of themselves and improve their quality of life.

## The gut microbiome

While models for scaling truly individualised products remain elusive, consumer segmentation and stratification on the basis of microbiome may be within reach.

***Clearly the nexus of life science and digital technology will have a major role to play, in addition to traditional product development, food science and nutritional skillsets***

## Bioprocessing

Delivering cultivated meats at scale and at a viable price point represents a key area of development. However, culturing cells can require high input costs (eg, growth media, scaffolding materials, energy, water, etc) and this will stimulate a need for expertise in precision biology as well as in modelling, design and process engineering to enable scale of biological processes.

## AI and data science

AI and powerful data science could provide a compelling new type of consumer experience in terms of understanding preferences and predicting choices.

**Phil Mackie**

MANAGING PARTNER – F&B, SAGENTIA INNOVATION

## Artificial intelligence and climate change

For some time, our global food system has been recognised as a major contributor to climate change due to its excessive use of resources such as land and water, along with its high output of greenhouse gas emissions.[8,9] These effects are further exacerbated by the various forms of energy it takes to store, transport and process food and drink.[10]

With 10 of the 17 sustainable development goals (SDG) defined by the United Nations General Assembly directly related to the food system, its mode of production, geographical land use and sustainability, it's vital we find a solution. AI, arguably, can play an important role in reshaping our food's future by transforming it into a more transparent, efficient and sustainable system.[11]

Increasingly, businesses need technologies that not only enhance efficiencies within their internal manufacturing processes, but also help them connect with the rest of the supply chain, enabling them to co-ordinate and respond to changes in the external environment. This will allow the sector to strengthen food security and supply, while reducing its environmental impact. As such, a system change is required to facilitate the transition to a more sustainable food system. AI at scale is a disruptive technology that can be an enabler of that change.

**Giannis Stoitsis**, Chief Technology Officer at Agroknow talks to *New Food*'s Editor **Bethan Grylls** about **How AI can help prevent risks in the food supply chain**

Agroknow

Below we have grouped several key examples of AI technologies, based on their application area and field of impact, to give an overview of the opportunities they afford as well as challenges.

## Key examples of AI applications in food manufacturing and processing

### Machine vision

Machine vision (MV) has a number of applications, from minimising machinery downtime to increasing product quality. Its optical sensors identify objects, capture images and process them using algorithms to make decisions in real time. MV can replace visual inspections and sampling and can automate both complex and/or routine inspection tasks. The technology is increasingly becoming a key part of quality control and inspection in food manufacturing.

Other applications for MV include tracking ingredients and the inspection of goods as they are processed in the factory. If products become damaged, or a product code error is made, it can be flagged using image data. The data are then stored and can be accessed in the future to review past trends and improve efficiencies.[12]

Even at the beginning of the value chain, in agriculture, MV can be used to enhance efficiency and safety, for example, in detecting crop disease. Traditionally, this was achieved by taking leaf samples from the field for human inspection. By using machine/computer vision and software, the detection of plant diseases in the field can now be increasingly automated via drones or even satellite remote sensing.[13]

Automation in this area could also help to considerably reduce crop waste; it is estimated that nearly 40 percent of crops are lost due to disease and infections worldwide.[14] Early detection in fields will not only reduce loss but also avoid the indiscriminate routine use of pesticides.[15]

### E-nose

The electronic or 'e-' nose uses an array of gas sensors capable of detecting a variety of chemicals at different concentrations. Pattern recognition algorithms can then distinguish volatile compound patterns (organic chemicals that evaporate easily at room temperature) from a specific food material, which is commonly referred to as a 'fingerprint'.[16]

Such gas sensor technology comprises a complex assembly of metal oxide semiconductors, metal oxide semiconductor field effect transistors, organic conducting polymers and piezoelectric crystal sensors. Other materials and technologies for


the measurement of chemical volatile compounds have been in development for a long time, including sensors based on fibre optic, electrochemical, and bi-metal principles, but their time for applications at scale is only just approaching.[17]

Volatiles fingerprint technology has a variety of applications within the food and beverage sector, from quality control, to process monitoring, freshness evaluation, shelf-life determination and even authenticity validation. The e-nose fingerprint has already been demonstrated within a range of sectors, including meat, grains, coffee, mushrooms, cheese, sugar, fish and beer.

## Predictive maintenance, remote monitoring and condition monitoring

Predictive maintenance is not unique to the food industry but is becoming widely used in manufacturing in general. By using sensors connected to analytics software, a near real-time stream of data can be continuously analysed to identify changes in machinery behaviour. This data is used to pre-empt any breakdowns or machinery part fatigue, reducing the time previously required for inspection and stoppage periods in production lines. The historic sensor data can also be used to identify root causes in case of product failures, which may help to avoid expensive product recalls.

## Pervasive computing/ Internet of Things

Pervasive (ubiquitous) computing is a term used to describe the embedding of sensors and computational capability into objects to perform specific tasks. This is often used synonymously with IoT. One very successful example that illustrates how connectivity can transform sectors is the digital ordering platforms we now see in most restaurants. These systems connect the

INDUSTRY COMMENT

# Catering to the rise in e-commerce

Despite food and drink only representing five percent of e-commerce adoption, its market share far outweighs any other category, coming in at $1,113 billion. While there was momentum prior to the pandemic, the trend towards e-commerce has certainly accelerated since then and the world is moving at an even quicker pace.

In the last two years we have observed a massive, sustained shift towards buying groceries online. We were seeing an uptake in HelloFresh, but during this period we've witnessed significant year-on-year growth, and in 2021 served a total of 964.3 million meals.

The use of effective technology is vital in helping us deliver food safely at every stage of the chain. Moreover, we are seeing huge demand for transparency – and we have a responsibility to deliver on this. The issue for a lot of companies is that they have the data but don't know what to do with it. Businesses must also consider how scalable their technology is; what is relevant now may not be in a few years.

HelloFresh has introduced different tech tools that increase supply-chain visibility, improve data quality, and support our international and local food safety teams in decision making and risk management.

In particular, we have a maniacal focus on temperature management. With our partner Sensitech, we can make sure our suppliers are adhering to the standards we mandate. Additionally, their technology lets us track the boxes and advise on arrival times.

Data also enables our business model, which is based around personalisation. By analysing our customer preference data points each week, we can match them to meals. This also allows our recipe development team to identify the best performing dishes.

Local insights around taste and preferences across markets are also taken into consideration, and as a result we can recommend meals based on individual needs, such as low calorie, vegetarian or family friendly.

Yet it is worth noting that people are still vital; technology cannot replace them. Innovation is not just a case of focusing on technology; we must also develop legislation and people alongside the tech.

We need to work more closely with regulators to help them understand the pace of e-commerce – we cannot wait for guidance in the digital world, we need it now.

Janet Cox
ASSOCIATE DIRECTOR FOOD SAFETY & COMPLIANCE, HELLOFRESH

customer table to the kitchen, inventory and suppliers; the main advantage, apart from increasing the speed of service and lowering staff numbers, is a reduction in food waste both in the kitchen and inventory.[18]

Considering pervasive systems in agriculture, these technologies can be applied to increase efficiency in both animal husbandry and crop production. Examples include reduced water waste and fertiliser usage, and improved yields through measuring humidity and control-timed irrigation.[19]

As the cost of capturing and storing data has decreased, the amount of data that is being recorded has risen exponentially across all industries. A key value of this data when processed and used is in the creation of traceable processes. As consumers and regulators demand more visibility, this will be an imperative feature going forward. Equally, this data can be used to manage environmental impact, safety, processing and stock.[20]

## Equipment cleaning and sanitisation

Cleaning manufacturing equipment uses a considerable amount of water and is often labour intensive.

With ultrasound and ultraviolet sensors, researchers at Nottingham University in the UK are currently developing a system that can help reduce water use in industrial cleaning applications. Sensor systems are used to identify fouling on surfaces and once contamination is removed send feedback to stop the cleaning process. The AI-based control system is being designed to optimise parameters such as flow rates, temperature and chemical concentration to reduce time and resources, while increasing the sustainability profile of the process.[21]

## Traceability

The labelling and tracking of food from farm to fork brings a new level of transparency to the supply chain. From inventory management to production process optimisation, logistics and dynamic pricing, tracking technologies like blockchain can now not only determine the geographical origin of the food product, but also trace its entire journey. This could be a gamechanger for food safety, regulatory compliance, and transparent management.

## Conclusions on artificial intelligence

AI in the food sector has great potential to impact all points in the value chain from farm to consumer, including fulfilling sustainability objectives. Currently, large players are leading with implementation, but even SMEs can reap great benefits with AI.

Technology upgrades are notoriously difficult in a regulated sector like food production, and smaller operators often lack the necessary training, capital and incentives to invest in novel technologies. It would therefore be helpful if governments would support technology implementation of AI-driven solutions in the food sector to enable more sustainable growth and increase efficiencies of existing processes with goals such as food waste reduction in mind.

One often overlooked aspect of AI technologies is the fact that it is not a single, magic bullet technology; it can only be applied to well-integrated networked technology components that need a much larger upfront capital investment than the actual AI software layer that employs the data integration, optimisation and analysis.

Collaborations and partnerships between small and large players and specialist AI solution providers will help widen the implementation of AI technologies; a method which Unilever and others have successfully employed in a sustainability context.[22]

# Novel technologies in food processing

THIS SECTION gives an overview of several new food processing technologies that are increasingly finding their way into the industry. The need for novel processing technologies can mostly be attributed to two factors: first, changing consumer tastes and their demand for fresh-like, high quality and healthy products. This requires reduction or elimination of chemical preservatives, as well as consideration for the impact of processing conditions on taste and nutritional value.

The second factor is thermal processes, which presently have high operational costs and carbon footprints, so cheaper alternatives are of commercial interest for producers.

Consequently, there is growing interest in research and development to find milder and more energy-efficient technologies capable of better preserving nutritional content and other food qualities, while keeping food safe and pathogen-free, and contributing to sustainability goals. A number of promising technologies have been undergoing testing for well over a decade.[23]

Thermal processing of food materials is mainly required for microbial inactivation. However, application of higher temperatures alters the structure of the food and induces browning and caramelisation that damages natural flavours and colouring. Moreover, it considerably lowers the nutritional content due to protein, enzyme and other biomolecule damage. For these reasons, a key area of development in novel processing methods has been in non-thermal food processing technologies, which are capable of inactivating microorganisms with little or no heat application. **Figure 2** shows an overview of the non-thermal processes discussed in this report. These processes are categorised as either physical or chemical food treatments. Physical treatment technologies include pulsed electric field, pressure processing, ultraviolet light, pulsed light, ultrasound and ionising radiation. Cold chemical treatments such as ozone processing and cold plasma are not discussed here due to limitations of space.

## Key novel food technologies

In this section, we examine the mechanisms of action of these technologies, their efficacy and their advantages and disadvantages in food processing.

**Figure 2**

Overview of non-thermal processing technologies.

## High-pressure processing

High-pressure processing (HPP) utilises hydrostatic pressure between 100 and 800 MPa and temperatures ranging from five to 30°C to inactivate (pasteurise) microorganisms in food products. The advantages of this process compared with traditional thermal methods include processing conditions at room temperature, post packaging applications, as well as the preservation of the food's original colour, flavour, texture and nutrients. However, the technology requires careful optimisation for different food products due to the huge variety of microorganisms present in foods with diverse physiological and physical characteristics, resulting in highly diverse pressure tolerance characteristics for different microbial loads.[24]

To increase treatment efficacy, HPP can be employed alongside other 'hurdle technologies' (tech for reducing microbial load), such as acidic pH or chitosan-based films in packaging. This process can be used on a wide range of foods, including fruits, meats, liquid foods such as juices and milk, vegetables, dairy products, and seafood. HPP is applied post packaging and works best with plastic packaging materials with capacity for compression and tolerance to presence of water.[25]

## Ionising radiation

Ionising radiation is used to generate free radicals that in turn reduce or deactivate microorganisms and their toxins without raising the temperature of treated food products. Once again, careful optimisation of irradiation dose and duration for each specific food item is key to successful deactivation of microorganisms.[26]

There are three types of radiation currently used in the food industry. The first is gamma ray emissions via radioactive Cobalt 60 or Caesium 137, which has high penetrating power. The second is high-penetration X-rays with energy levels lower than 5MeV; and the third is radiation, ie, low-penetration high-energy electron beams generated by accelerators with energies of less than 10MeV.[25]

Various international organisations, such as Food and Agriculture Organization of the United Nations (FAO), the International Atomic Energy Agency (IAEA), the World Health Organization (WHO) and the Scientific 212 Committee on Food of the European Commission (EC) approve of the use of ionising radiation up to dosages of 10kGy for food products. However, consumer perception and acceptance of irradiated food is an issue and may differ depending on the market.

There are some drawbacks for ionising radiation technologies, including damage to sensory characteristics after prolonged exposure and accelerated oxidation of lipids, creating hyperoxides and off-flavours. In addition, industrial-scale plants may pose occupational hazards to operators, while large capital investment is required for setup.[25]

## Ultrasonics

Application of ultrasound waves with a frequency between 20 and 100kHz is another non-thermal method for food preservation. The key process here is sonication – the destruction and fragmentation of bacterial cells through the formation of microbubbles and their subsequent breakdown inside an aqueous solution.

As the bubbles burst, they temporarily create a confined local pressure of approximately 1,000atm and temperatures of 5,000K (4726.85°C), which destroys all microorganisms in the foodstuff. The formation of free radicals under these conditions enhances the antimicrobial effect but the setup and optimisation of this technology is important too as it influences the technique's effectiveness.

Critical factors to consider are wave amplitude, type, exposure and contact time of microorganisms, as well as the composition and volume of the food being processed. Furthermore, because ultrasound leads to plant cell disruption, it can also be used as a means of extraction; for example, of the protein, lipids and/or oil from the seeds and beans, and of the pigments from beets. It can also be used in other processes such as emulsification, dispersion, homogenisation and crystallisation.[27]

The technology, however, has limitations when applied to liquid foods due to the potential for forming free radicals during the bubble cavitation process. Free radicals lead to the oxidation of lipids, denaturation of proteins, and degradation of vitamin C, resulting in changes to sensory attributes and nutritional composition of the sonicated food. Scaling up sonication equipment to industrial capacity can also be challenging because of the occupational risks it may pose to operators.

## Ultraviolet radiation

Ultraviolet (UV) radiation is a non-ionising radiation with germicidal effects in the spectral range of 200 to 280nm wavelengths. It can destroy a microorganism's genetic material, preventing it from multiplying and causing disease.

The efficacy of UV radiation is dependent on several factors, including the source, dose and wavelength of radiation, the duration of exposure, nature of the food, type of microorganism and apparatus alignment at the time of use.[27]

The main disadvantage of UV radiation is its inability to penetrate solid foods


INDUSTRY COMMENT

# The fourth agricultural revolution: farming goes digital

How can we feed nine billion people sustainably by 2050? Arguably this is one of the biggest challenges facing humanity today.

Unfortunately, the current farming system is inherently wasteful, with up to 90 percent of chemicals being wasted. This causes an array of environmental problems, including soil erosion, poor soil and water quality, and a knock-on impact on biodiversity. Farming is also one of the primary emitters of greenhouse gases.

Yet there's light at the end of the tunnel. We're now on the cusp of a fourth agricultural revolution and living on the edge of the greatest change that food production has ever seen. Arguably the last analogue industry, farming is now taking big strides into a digital future.

Innovation is gathering pace in a number of different areas, with drones, autonomous vehicles, satellites, robots, artificial intelligence (AI) and blockchain all set to form part of the digital ecosystem, as well as interesting developments in vertical farming, biological controls and even genetically modified (GM) mosquitoes. In the wake of AI, a specific transformation is occurring – both in terms of what happens on the farm and throughout the food supply chain.

We've now entered the next chapter in precision agriculture; one where the ability to understand and act on each individual plant will be centre stage, alongside the capability to feed the world while regenerating the planet.

We call this 'per plant farming'; this technology will bring radical and exponential changes to food production. Less inputs, more outputs; less impact, and more in line with nature. It will also be transformative for farming's carbon footprint: we could cycle tens of millions of tonnes of carbon a year in the UK alone.

***[We're] living on the edge of the greatest change that food production has ever seen***

Per plant farming will become the dominant form of farming system in the world by 2040. Eventually, it will enable permaculture at scale – completely changing what's possible on the farm. Any farm of any size, growing any crop anywhere in the world, will be able to manage their crops on a per-plant basis: the ultimate sustainable farming system.

Ben Scott-Robinson
CEO AND CO-FOUNDER,
THE SMALL ROBOT COMPANY

or turbid liquids deeply and reach into the depths of irregular surfaces. Currently, UV irradiation has limited application, despite attempts to make it more widely relevant for food processing. Mostly, it is employed to irradiate surfaces of food and packaging materials, or to sterilise them prior to packaging – applications that have been around for several decades.[28]

Moreover, UV radiation is not well received by consumers due to a perceived negative impact on foods. Furthermore, higher radiation dose and prolonged exposure can cause isomerisation and oxidation of Lycopene, a carotenoid red pigment found naturally in vegetables and fruits and sometimes added to food products for colour and antioxidant effects. Consequently, this may cause decolouration of food items. Further restricting its implementation is the expense of scaling the technology for industrial use.[25]

## High voltage arc discharge

High voltage arc discharge (HVAD) can be used on fluid foods and is based on rapidly discharging an electric arc through an electrode gap in the liquid food/media. This generates intense electrical waves throughout the liquid and inactivates microorganisms through electrolysis.

Efficacy of the process depends on factors such as applied voltage, type and total

load of microorganisms in the fluid, total volume of the fluid, and distribution of chemical radicals and electrode material. Its major disadvantage is the possibility of formation of highly reactive chemicals during the electrolysis and damage to food texture through shock waves. However, when the process is properly controlled it has been shown to increase shelf life in fruit juices such as grapefruit juice, preserving freshness and flavour well.[28]

## Pulsed electric field

In pulsed electric field (PEF) processing, an electric pulse of (usually) 10 to 80 KV/cm is applied for several microseconds instead of using a conventional heat treatment. The electric pulse is directed towards the food material using two electrodes, resulting in heat generation (around 40°C).

PEF is based on electroporation and the electrical breakdown of microbial cell walls, which causes the disintegration of microorganisms. The technique can be applied to liquid products such as milk, yoghurt, juices, liquid eggs, soups and brines, but is not suitable for solid foods.

Once again, certain variables will influence the success rate of this method, with pulse amplitude and frequency, electrical field intensity, temperature and length of exposure all being critical. The pH, ionic compounds, ionic strength and electrical conductivity of the food material also impact process efficiency. Furthermore, there is a possibility that some bacteria will develop resistance to the PEF.

This method still faces challenges to reach wider commercial application, including difficulties with industrial scale-up, the presence of bubbles within food items which reduce effective and homogenous treatment, and operational and safety issues.[25,27,29]

## Pulsed light

Pulsed light (PL) is applied through short, highly energised pulses of the white light spectrum, which contains infrared, visible and ultraviolet light. PL impacts microorganisms by clumping/aggregating proteins and destroying cytoplasmic membranes and their genetic material. Critical process success factors for PL include light intensity, duration, wavelength and number of pulses.

Food attributes such as colour and transparency also play a role, as opaque and irregular surfaces will not let light permeate deep enough into the food material. This technology can be used with both liquid and solid foods with 'simple surfaces' (ie, smooth), including some fish, fruits, vegetables and meat. The process is best suited for use on product surfaces, for example in the sanitisation of packaged goods surfaces or to extend chilled seafood shelf-life.

Again, this is a costly process and a key challenge is the price of setup, in addition to its unsuitability for opaque or irregularly shaped foods. Furthermore, extended periods of use can result in increased heat, which will have a detrimental effect on the food material.[24,27,30]

## Dense phased carbon dioxide

Dense phased carbon dioxide (DPCD) is used both in food and pharmaceutical processing. Within the food sector, it has been examined (for several decades) as a potential, non-thermal replacement for pasteurisation.[31] With typical processing temperatures around 40°C throughout the process and a lower pressure offering, it is ideal for preserving nutrients and quality attributes such as taste, colour and texture.[32] The process is also suitable for cold pasteurisation.

The presence of $CO_2$ also impacts microorganisms in several ways, including lowering the pH, inactivating microbial enzymes through the formation of bicarbonate complexes, lipo- and hydrophilicity of $CO_2$ acting as a solvent on microorganism membranes, and destabilising intracellular electrolyte balance.[31] In other words, either one or a combination of these effects leads to the destruction of microorganisms.


**Dean Roberts**, Director of Market Technology Development at Bruker talks to *New Food's* Editor **Bethan Grylls** about **conformity testing**

DPCD is currently used on fruit and vegetable juices, beer and dairy products; however, its use on solid foods proves challenging. Diffusion of $CO_2$ into the body of solids is slow and there are concerns that the process may alter food texture and other surface qualities due to cellular damage. The process also reduces free water at the surface of food material, which limits the solubility of $CO_2$ into the food. This in turn limits its efficacy in deactivating and damaging bacterial cells and enzymes.[33]

## Conclusions on novel technologies

The technologies reviewed in this section represent a selection of non-thermal technologies that are currently used or tested for the preservation of liquid and solid foods – some quite widely adopted, others still at an early stage. Other technologies such as the use of magnetic fields, ozone and cold plasma have not been addressed here due to limitation of space and the fact that they are at an earlier stage of development for realistic industrial scale applications.

Generally speaking, non-thermal technologies are not yet fully effective on their own, particularly when the parameters are set to maximise preservation of taste, texture and freshness of foods. We therefore often see these tools used in combination with other hurdle technologies to achieve maximum reduction in microorganisms in the food material while preserving desired food attributes. Moreover, the choice of processing technology is closely linked with the packaging materials, and therefore implementation of these technologies usually goes hand-in-hand with innovation in packaging solutions (see next section).

The main barrier to adoption, apart from the need to carefully optimise the processes for every food material, is the high cost of setting up multiple processes in tandem and at scale. Therefore, these technologies are mainly applied to premium foods, such as functional foods and supplements, which can carry higher margins.

Functional foods are foods that offer potential health benefits beyond basic nutrition and are becoming increasingly popular. This fast-growing market is driven by socio-demographic trends towards longer life expectancy, higher levels of affluence and greater health awareness. Use of combined non-thermal methods is thus a growing field in the food industry, responding to consumer demands for minimally processed foods, while ensuring microbial inactivation, food safety and prolonged shelf life of food products.[34]

# Novel food packaging technologies

IN THE food sector, packaging plays a diverse role, but its primary responsibility is to protect food from the environment and spoilage, in turn extending its shelf-life.

Food packaging is also important for product presentation and as a medium for consumer information (content, allergy advice and instructions).

Increasing environmental awareness and advances in materials, technology and food science have created demand for smart packaging that can extend shelf-life and preserve quality and integrity of the product, while being recyclable or biodegradable. One main driver for novel packaging technologies is the commitment of many countries to reduce plastic waste. Currently 44.4 percent of all packaging worldwide is made of flexible or rigid plastics.[35]

In this section, we review emerging packaging technologies divided into three areas: active packaging, intelligent packaging and bioactive packaging.

## Active packaging

Active packaging directly interacts with the food, resulting in prolonged shelf-life. It also enables use of non-thermal processing technologies and enhances food preservation.

Active packaging materials mainly comprise biopolymers that are either biodegradable or non-biodegradable, with intrinsic characteristics or additional additives that can, for example, impart antimicrobial or antioxidant agents. Polymers in active packaging can also carry scavenger molecules, such as cyclodextrins, that may absorb compounds like ethylene, oxygen and water, which contribute to food spoilage.[36]

Examples of biodegradable polymers from natural sources include pectin, gelatine, chitosan and polylactic acid.[37] Taking chitosan as an example; this has intrinsic antibacterial and anti-fungal capabilities, resulting from its electrostatic properties that cause permeability of the cell walls of microorganisms. Active agents can be incorporated into the packaging material in different ways, for example through surface coatings, inside bottle caps or applied to a pad inserted in the packaging to reduce concentrations used.

Active agents are a diverse group of molecules, including organic acids, enzymes, bacteriocins, fungicides, ions, ethanol, polyphenols and natural extracts, to name a few. The use of natural extracts is increasingly recognised as preferable to synthetic agents due to potential health hazards posed by the latter. Natural agents for use in active packaging can also be derived from fruit and vegetable processing waste, or from wine, beer, dairy and meat industry by-products.[38]

Advances in enzyme encapsulation and immobilisation in combination with novel protective films from natural biodegradable molecules, such as polysaccharides and proteins, can lead to reduced degradation and volatilisation of antimicrobial compounds. Through controlled release, antimicrobial properties can be sustained for longer periods of time, resulting in an increased shelf-life.[4]

> CURRENTLY, OVER 44% OF ALL PACKAGING WORLDWIDE IS MADE OF FLEXIBLE OR RIGID PLASTICS

## Intelligent packaging

Intelligent packaging benefits from recent advances in digital technologies and enables enhanced monitoring of food products throughout the supply chain.

Using sensors, cloud computing and data technologies, this tech can monitor, record, trace and provide information about the current status of food quality, without the need to analyse samples for quality control. Intelligent packaging, unlike active packaging, does not actively modify the food, it only reports on its condition.

Intelligent packaging elements fall into three main categories, which are: data carriers, indicators and sensors. Indicators may be used alone or in combination with sensors and data carriers. To enable a comprehensive intelligent packaging concept throughout the supply chain, all three elements must work together to provide the sensing and traceability function that constitutes intelligent packaging.[38]

## Data carriers

These are information storage and processing networks that connect individual packaged food items throughout its supply-chain network, ensuring end-to-end traceability. They are often placed on tertiary packaging and transmit information about location, storage and distribution of the item. The most common data carriers are barcode labels and radio frequency identification (RFID) tags. Further iterations of the technology and its integration with time-temperature indicators (TTI) – which provide additional information on temperature throughout its journey – are helping to further reduce food waste.[39]

## Indicators

These are chemical sensors that identify the presence or absence of a specific substance or compound, resulting from a chemical reaction between substances (eg, bioamines, ethylene, hydrogen sulphite, ethanol, or other metabolites from microorganisms) within the foodstuff.

The information is usually reported through a colour change on a display, placed either inside or outside of the package. One example is FreshCheck's smart use-by date technology, a TTI that, with a simple colour change from blue to orange, enables the consumer to decide whether the food can still be consumed or should be discarded.[39]

## Sensors

These are devices that detect, locate and quantify change in energy or matter and translate that shift into an electrical signal. Sensors usually contain two parts; one is the receptor, which detects the presence, activity, composition or concentration change of chemical or physical factors, the other is the transducer that creates the signal. It is the transducer that converts the measured signal of the receptor into an electrical, chemical, optical or thermal signal that can be further processed and transmitted to a network of data carriers.[39]

## Bioactive packaging

Bioactive packaging aims to use food packaging to add health benefits for consumers. Technologies such as enzyme encapsulation, nano- and microencapsulation of active compounds, and enzyme immobilisation help to preserve some of the natural molecular

INDUSTRY COMMENT

# Thinking outside the box

PepsiCo believes that investment in technology will be one of the driving forces for creating a more sustainable world. We're leveraging emerging technologies to drive sustainability goals and positively impact the food system. For example, we're working with partners to trial artificial intelligence (AI) to determine its role in solving the recycling and sorting challenge in Europe.

In 2019, more than 79 million tons of packaging waste was generated in Europe, of which only 65 percent was recycled. We need a step change in infrastructure and sorting technology to ensure these materials can be identified and sorted for recycling.

***In 2019, more than 79 million tons of packaging waste was generated in Europe, of which only 65 percent was recycled***

AI is already addressing some of society's biggest challenges, but for this technology to be scaled in European sorting plants, we need collaboration. The infrastructure and sorting challenge cannot be solved by one company alone. We have recently formed The Perfect Sorting Consortium to enable open, pre-competitive collaboration to evaluate, develop, test and prove the optimum AI sorting technology that can be scaled for the benefit of all.

The Perfect Sorting Consortium is another route PepsiCo is exploring alongside the Holy Grail initiative, for example, to understand alternative routes and solutions to scale rapidly. Holy Grail is exploring how digitally watermarked packaging can deliver the same (or even more accurate) packaging identification outcomes for sortation. These trials are bringing us one step closer to a circular economy for flexible packaging, which is the ultimate goal.

Gareth Callan

SUSTAINABILITY PACKAGING MANAGER, PEPSICO EUROPE properties of functional or bioactive compounds in packaged food.

Bioactive packaging uses biodegradable packaging materials that enable the release of bioactive compounds. This type of packaging is currently used in the premium price functional foods segment and for supplements, including marine oils, prebiotics, probiotics, encapsulated vitamins, phytochemicals, bioavailable flavonoids and lactose-free foods. However, some applications may also find their way into more general food packaging.[36]

## Other novel packaging technologies of note

Other packaging methods worth a mention include nanomaterials, nanofibres and nanocomposites that provide enhanced water and oxygen barrier properties, mechanical strength, heat resistance and lighter weight, as well as antimicrobial and light blocking benefits.

Such technology can also be combined with active and intelligent packaging concepts for enhanced performance. For example, nano-clay particles have been used to reduce permeability to oxygen, $CO_2$ and moisture to protect fresh meats. Nanomaterials have also been used in nano-sensors to detect chemicals, bacteria, viruses, allergens and toxins in foods.

Despite the potential for innovation and expansion of modes of food preservation through nano-technology applications, there are concerns regarding the leaching of nanoparticles from packaging into the human body. It therefore requires further investigation and validation.

Another noteworthy novel packaging innovation is the use of biodegradable polymers for edible coatings and packaging as a means to reduce plastic use. The concept involves applying a protective coating to foods such as fruit and vegetables to offer a barrier to contaminants, gases and moisture.

A commercial example is US-based Apeel, which has developed molecular films to cover fruits, based on plant skin molecules that naturally possess preservation functions. Apeel's efforts have been successful so far, with the technology considerably extending the shelf-life of avocados. It is anticipated that it will also be successful in extending the life of other quickly perishable fruits such as strawberries.

Low-tech options to generally reduce packaging and the environmental footprint of the food industry also include options such as refillable, returnable packaging.

Zero packaging supermarkets are now emerging, where consumers select and pack their food into containers and bags they bring and reuse in store.[4]

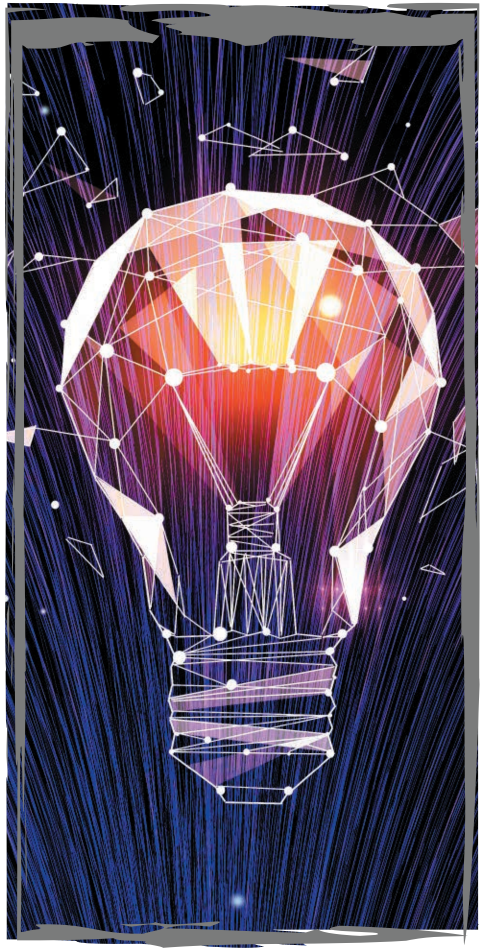
## Conclusions on packaging

Novel packaging technologies are well placed to increasingly combine consumer demands for freshness, safety, convenience, health and sustainability. However, as many of these technologies are still at an early stage with regard to upscaling and industry-wide implementation, there remains a need to update smart packaging regulation. Clear guidance on material safety, testing and labelling is required, particularly for packaging material in direct contact with food, such as molecular films, or edible packaging.

For the widespread use of such technologies, we must also be cautious of the unintended consequences that could occur, for example bacterial resistance.

Issues like the recycling of sensors and smart components and sophisticated new materials in packaging are currently not fully addressed and may present a challenge for sustainability, but future investments in that area may help tackle these issues. As with most novel technologies, implementation at scale will be driven by large players that are able to make considerable upfront investments.

# Business model innovation



AS SHOWN in **Figure 1** (see page 6) the supply chain structure in the food industry is rapidly changing from the classic, linear model, wherein food travels from the farm to processes, wholesales, and then onto grocers and/or restaurants where it finally reaches the consumer. Indeed, we are now seeing a shift to an interlinked web of actors who collaborate and compete in different parts of the network.

Digital technologies disrupting the current food distribution model and consumer demand for product quality and convenience of delivery are the main forces driving change to business models in the food industry, depending on the nature of the business and its position in the supply chain. However, business models in the food industry are also impacted by current social, economic and environmental trends that are reflected in other specific consumer demands.[40]

In addition, regulators increasingly expect technology-enabled transparency and monitoring of agricultural and food supply chains, and in the future may demand clear reporting on sustainability measures – as has been predicted for a while.[41]

Therefore, creating a unique and successful business model in the industry becomes ever more relevant for survival and competitive advantage.

Even 10 years ago, in a survey by the Economist Intelligence Unit of 4,000 senior managers, 54 percent of participants stated that new business models were their favoured mode of securing future competitive advantage. A study conducted around the same time by IBM across industries showed that companies with faster operating margin growth than their competitors (over a period of 12 months) had favoured new business models twice as much as new product and service innovation as a way of enhancing competitiveness.[42]

A more recent study of industry SME representatives in the food and beverage sectors across eastern and western European countries, confirmed the current impact of sustainability objectives on business models.[43] Given that a business model is an interconnected, multi-dimensional system usually built for robustness, it takes a change in several of its components to achieve true business model innovation.[44] Five strategies have been identified to achieve business model innovation in the food sector;[40] these are:

1. Redefining or innovating the value proposition
2. Rethinking value delivering mechanisms
3. Innovating the value creation process (operational activities)
4. Devising new value capturing models
5. Design of an entirely new business model.

Adoption of new technologies plays a key role as part of the above-mentioned strategies. Looking back at the technologies presented in the previous sections of this report, it becomes clear that adoption of the aforementioned tech will inevitably have an impact on business models. For example, given the high capital cost of most new non-thermal processing technologies, it might be necessary to redefine the value proposition for products benefitting from milder processing conditions and better nutritional and sensory profiles, and enter premium markets. Furthermore, these processing technologies may enable the use of new ingredients with a range of sensory and/or health benefits, which in turn will require new models for capturing value from new products.

When businesses adopt sophisticated digital technologies such as IoT, smart process control, big data optimisation

> A KEY AREA OF FOCUS FOR CREATING SUSTAINABLE BUSINESS MODELS IN THE FOOD INDUSTRY IS IN ADDRESSING THE DISCONNECT BETWEEN PRODUCTION AND CONSUMPTION

and sustainable production and monitoring, in effect they are creating 'smart production', well equipped to address sustainability objectives that can feed into the value creation process and delivery mechanisms.[45]

In a commentary in 2018, Paul Polman, a former CEO of Unilever, stated that a key area of focus for creating sustainable business models in the food industry is in addressing the disconnect between production and consumption.[22] Tackling this disconnect requires goal-oriented coordination between multiple players within the food supply network, such as farmers, manufacturers, distributors and regulators. Digital technologies are essential to enable this collaboration, so that data can be used efficiently to track food products within the supply network, and to, for example, connect startups with governmental initiatives working towards reducing food waste at retail stage.

One such case study is i-REXFO (increase in reduction and recovery of expired food), an EU-funded initiative in partnership with the FAO that seeks to take a holistic approach to tackling food waste in the industry. Too Good To Go and Karma are examples of startups connecting players along the food supply chain, particularly retailers with consumers, to shift food nearing its expiry date faster, thus reducing waste.

Looking at large producers, access to product tracking data has enabled optimisation of resources and productivity, enabling businesses to better accommodate production demand and quickly react to customer feedback.

## INDUSTRY COMMENT

# Why we're investing in tech

Tyson Foods is actively working to increase its manufacturing capacity outside the US to support its growth objectives. Those objectives will be met not only through investment in manufacturing and food production plants, but in the supportive infrastructure we have in place – including our technology teams. The decision to create 200 new tech roles at this time was driven by two factors: our need to build technical teams and skills as part of our international growth plans, and Lisbon's unique benefits as a location.

What made Lisbon stand out was its excellent emerging talent, alongside very good support structures and quality of living for implementing our Tech Hub. Tyson Foods strives to be an employer of choice, and the establishment of an IT hub in Portugal marks another step toward ensuring its team members have the necessary tools and resources to be successful.

The roles within the IT Hub itself will be hugely varied. More than that, we see the Hub as being a vital part of our overall innovation mission. We expect the Lisbon IT Hub to deliver the latest ideas for human and food safety, working with our international teams on everything from developing new products to meet evolving consumer needs, to employing more automation in how we produce our products.

With this IT Hub we are investing in the future of not just our company, but of food production and manufacturing in general. Developing AI-driven technologies that deliver automation across physical production sites as well as systems that can optimise efficiencies in logistics, research and development, and human decision making, are crucial to ensuring a sustainable future for our industry. The new roles at the Tyson Foods IT Hub in Lisbon will help keep us at the forefront of that development.

> ***Developing AI-driven technologies that deliver automation across physical production sites as well as systems that can optimise efficiencies in logistics, research and development, and human decision making, are crucial to ensuring a sustainable future for our industry***

**Dan Barrett**
VICE PRESIDENT, IT EUROPE, AT TYSON FOODS

# Conclusion

When drawing actionable conclusions from this report, relevant for the food industry, it is worth revisiting the starting point, acknowledging that building sustainable food systems is a matter of urgency for humanity.

Governments, institutions and businesses are increasingly driving initiatives that make that urgency clear to industry. The gained efficiencies of our existing food systems are the culmination of considerable unaccounted for negative externalities on the environment for at least two centuries. **Figure 3** (see page 26) shows the 'problem tree' for the whole food system as described by the European Commission in 2014, which outlined areas of concern and their contributing factors.[46]

Today we face a plethora of issues, from food insecurity, price volatility and inflation, to environmental impact on soil, water, habitats and greenhouse gas emissions, as well as low system resilience leading to rigidity and inability to deal with future change. These are a result of the long-term, unsustainable use of the resources that underpin the food system.

Changing course may not be easy; however, by looking at the foundational factors that contribute to these problems, each player in the food system can start identifying where and how they can best help build in system resilience and address resource depletion.

The contributing factors underlying the food system problem tree were identified as:

- Efficiency of resource use in food production
- Levels of food waste
- Population size
- Composition of diets
- Competition for resources from other sectors.

In this report we provide you with at least some of the answers to the question of how and where in the food system emerging technologies could help address some of the complex and systemic challenges faced. Novel technologies can assist in at least two of the above listed, helping to improve resource efficiencies and mitigating food waste, and potentially contributing to healthier composition of diet.

According to an estimate in 2014, 18 percent of all energy in the UK is used within the food sector,[47] and globally food systems account for 30 percent of total energy consumption. Given that most current systems rely on fossil fuels, they also account for 20 percent of global greenhouse gas emissions. Nearly 50 percent of this energy is used in the handling of food products at packaging, retail, restaurants, and also at consumer level.[48] Tackling energy consumption and carbon emissions in the sector is therefore critical in achieving climate goals and the net-zero transition.

The 2014 European Commission document identified food waste as one of the major sources of inefficiency in the food system, representing at least 30 percent of all food produced. This means globally it may represent around three to five percent of total global warming impact, more than 20 percent of biodiversity pressure, and nearly 30 percent of all the world's agricultural land.

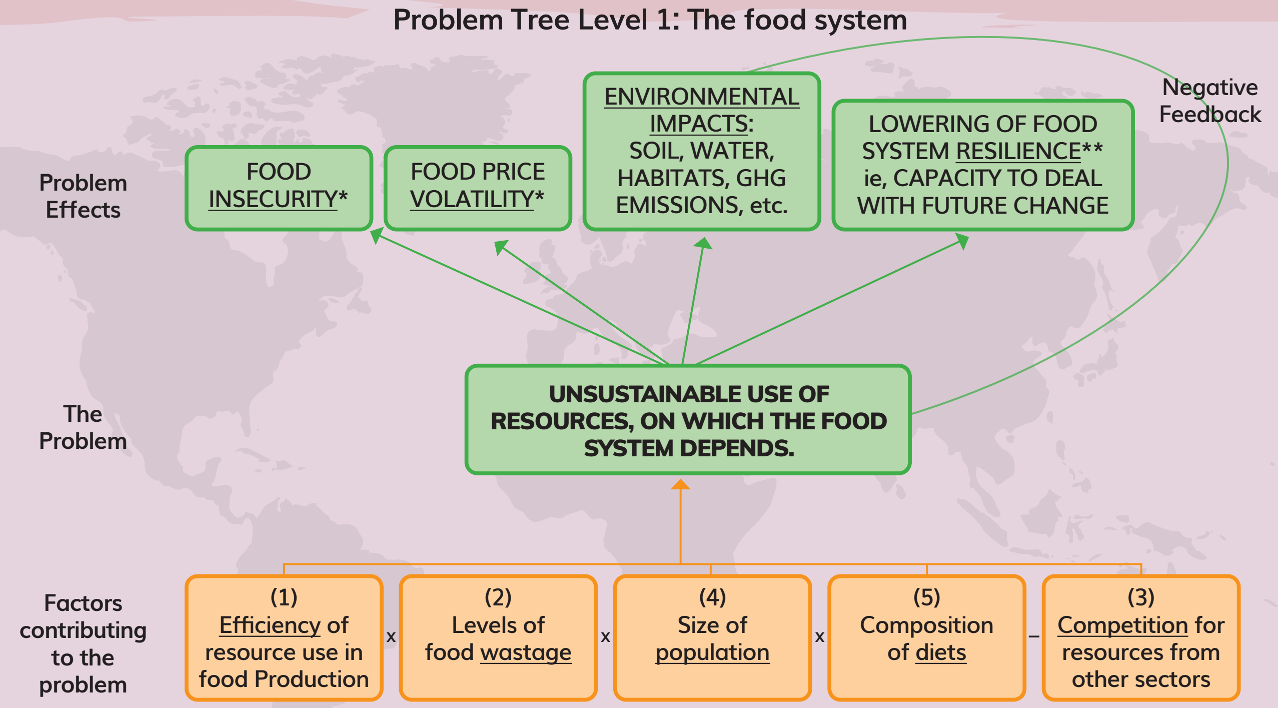
The systemic nature of these interdependencies requires new systems-based approaches to challenges at every level of the food supply chain and acknowledgement of the fact that sustainability is only attainable when addressed in its systemic context. Therefore, all players in the food supply chain, including manufacturers, will benefit from adopting a systems perspective for future strategic planning, technology adoption and business model creation.

Adoption of digital technologies and AI, particularly in the logistics and delivery sector of the food supply chain, has already started to rapidly transform the way in which the food value chain operates.

As the ecosystem network grows in its hubs and nodes – with hubs being key platforms in the value chain that aggregate data and nodes representing smaller players trading their products and services on the hub platforms – interdependencies between players increase, creating impetus to build partnerships to increase access and connectivity throughout the ecosystem (see **Figure 4** on page 27).

**GLOBALLY, FOOD SYSTEMS ACCOUNT FOR 30% OF TOTAL ENERGY CONSUMPTION**

The key point in this development is the centrality of the connection to the consumer (see **Figure 5** on page 29). Competition will increasingly focus on building the highest number of connection points within the ecosystem and with the consumer. Each player in the value chain will need to directly connect with the consumer, not only to advertise and sell to them, but also to educate and familiarise them with the detail behind their new value propositions, namely the investment made in technology and the strategic change that is required to become a sustainable player in the ecosystem.




* Food security <<when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life >> (FAO)

**Resilience: the capacity of a system to absorb disturbance and reorganise while underoing change, so as to still retain essentially the same function, structure, identity and feedbacks

**Figure 3**

The problem tree for the whole food system as by EU commission.

(Source: European Commission 2014 report[46])

> COMPETITION WILL INCREASINGLY FOCUS ON BUILDING THE HIGHEST NUMBER OF CONNECTION POINTS WITHIN THE ECOSYSTEM AND WITH THE CONSUMER

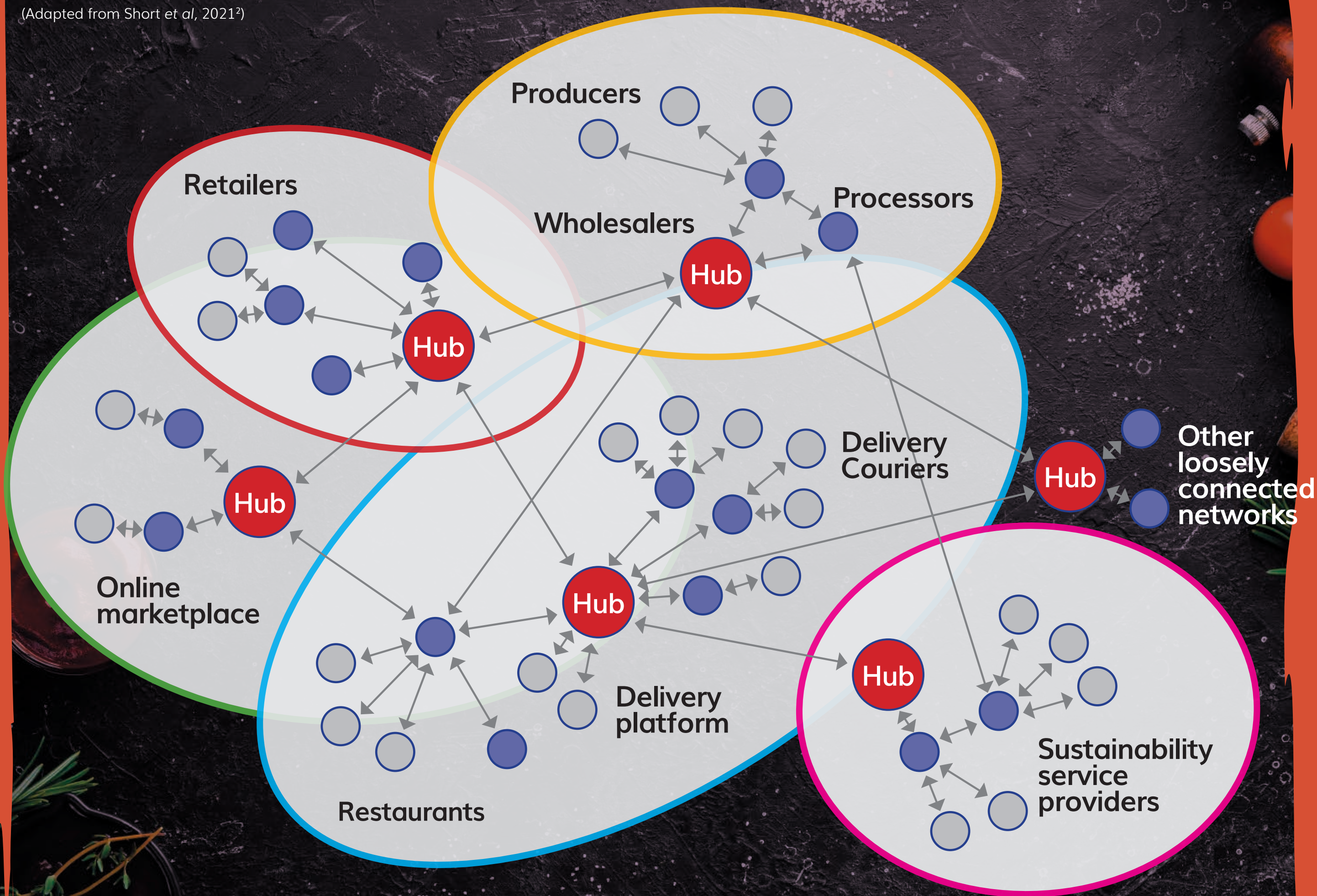
For food system players, particularly manufacturers who are operating in a regulated environment where optimisation and validation of new technologies itself may be a challenge, managing this transition successfully will be key in developing a more sustainable food system, and as a result, lead to a more profitable business.

Collaboration, especially in the pre-competitive phases of designing sustainability solutions, technology development and sharing data and best practices, is a deciding factor for helping

**Figure 4**

Example representation of the relationships between different actors of the emerging food value ecosystem made up of hubs, nodes, and vendors, connected by dynamic, often simultaneous interactions. The modular structure of such a food system also highlights the important influence of well-connected hubs, also for implementing change in the system.

(Adapted from Short *et al*, 2021[2])




Hubs (major network entity, such as delivery, marketplace platforms)

Nodes (local and/or specialist platforms)

Vendors (producers, manufacturers, processors, restaurants, innovators and new experimental products and services etc.)

Link or transactions between nodes

the industry shift towards sustainability. We suggest an eight-step process for breaking down the challenge of starting the sustainability journey and for initiating change. The following steps are adapted from the academic literature:[49,50]

1. Defining scope and scale of the initiative
2. Identifying essential drivers of change
3. Identifying essential food systems outcomes
4. Developing a causal model by selecting the essential interactions, drivers and outcomes
5. Selecting system intervention points and change levers
6. Examining respective systems exposure sensitivities (risk assessment)
7. Recovery potential
8. Strategy definition and implementation.

These steps can be broken down into a classic why, what and how approach.

INDUSTRY COMMENT

# Alternative proteins are here to stay

JBS has a commitment to – and invests heavily in – food technology and innovation. We are dedicated to offering a diverse range of proteins in line with consumer demand and consistently develop new technologies to meet the global demand for responsibly produced food.

The JBS Global Innovation Team is constantly working to identify new technologies, sources of protein and products, and we understand that plant-based is more than a trend – it is here to stay.

In 2019, JBS began using management tools to optimise development efforts for products with higher demand among customers. During this same period, an analysis of consumer demand for vegetable proteins led one of our subsidiaries, Seara, to launch the Incredible Seara range, which now offers a complete range of products made with 100 percent plant-based protein.

JBS already has a leadership position in the plant-based market in Brazil due to Seara's popular Incrivel brand. Our global presence was strengthened in 2020 with the launch of Planterra in the USA (OZO brand) and in 2021 through the acquisition of Vivera, the largest independent producer of plant protein in Europe. Vivera has a presence in more than 25 countries and the enterprise value was $406 million.

We have also been investing heavily in cultivated meat, as we believe this technology will drive the future of food. Last year, JBS announced an investment worth $100 million in cultured meat production with the acquisition of Spanish cultivated protein company Bio Tech Foods. This will include the construction of a new European plant and the establishment of a Centre for Research and Development in Biotechnology and Cultivated Protein in Brazil. These initiatives coincide with our strategy of expanding into new forms of protein production to reflect new consumer trends.

At JBS, we strive to contribute to innovative technologies that will sustainably propel the food industry forward.

Eduardo Noronha

GLOBAL HEAD OF HR AND OPERATIONAL EXCELLENCE, JBS

## Why?

### Defining scope and scale of the initiative

This step is about articulating the vision for transition towards sustainability and the scope of its impact on the organisation, its suppliers, partners and customers.

### Identifying essential drivers of change

This step requires in-depth analysis or inspection, along with introspection. In other words, inspection of the environment in which the business operates, the market, competitors and the wider structural trends shaping the industry and how they impact the business now. In terms of introspection, we mean considering organisational readiness and required resources for undertaking the initiative. It also possibly means the need for a shift in company culture to new ways of thinking and acting.

## What?

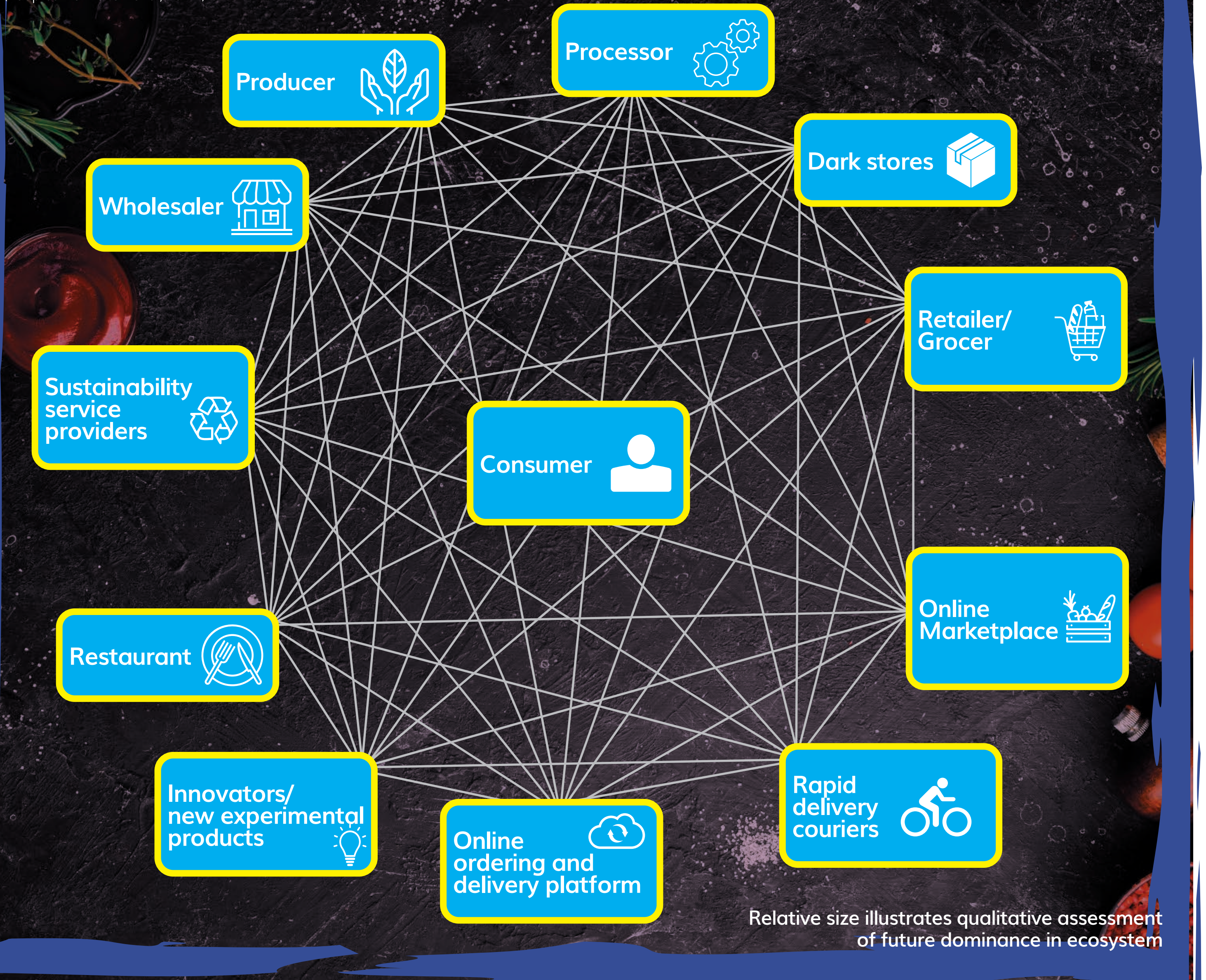
### Identifying essential food system outcomes

This step identifies and shapes the impact of the vision for a sustainable business on the food system. It is in this step that food system-specific issues of concern, which need to be addressed through change, are defined. The UN global sustainability goals are a useful guide.

**Figure 5**

Our food system is evolving into a highly connected ecosystem of players who not only interact increasingly among each other but also aim to establish often multiple direct links with consumers.

(Adapted from Short *et al*, 2021[2])




## Develop a causal model by selecting the essential interactions, drivers, and outcomes

In this step the systemic nature of sustainability will be accounted for. From the business perspective, this can be a design step where the relationships between drivers for change and the food system outcomes are considered, translating first steps toward a new business model by identifying interdependencies and workability.

## How?

### Selecting change levers

With the causal map in place, you can start devising solutions. It is at this stage that technology adoption, stakeholder maps, change in processes and practices, and other operational and tactical details will be addressed.

### Examining systems exposure sensitivities

This step corresponds to risk assessment in business; however, it is important to keep the systemic nature of the exercise

INDUSTRY COMMENT

# Tech vs. climate change

This report is a good summary of the current state-of-the-art technologies emerging within the food and drink industry. It's an exciting but turbulent time for our sector; we are seeing a convergence of digital technologies and food systems pressures, which are significantly exacerbated by climate change.

Our current work at Raynor Foods is focused on the exploration and co-development of several digital technologies, including AI in the form of machine learning and deep thought, optimisation systems, and distributed ledger technologies (blockchain) for immutable unit-level traceability and trusted financial transactions that allow valuable information to be accessed up and down the supply chain and permit a significant reduction in supply chain food waste and associated costs.

We are also investigating the deployment of IoT and sensors to track processes/environments, secured with zero-trust cybersecurity, which allows the creation of digital twins of products and materials as they pass through supply chain processes. This project – The Digital Sandwich – consists of an 11-partner-strong consortium and our supply chain partners, and we have been fortunate to secure £4 million of government funding through the Innovate UK Made Smarter Programme.

Via a separate project and smaller consortium, we are also developing food industry precision-robotics, capable of handling a large array of sandwich fillings and bread carriers which can be deployed in high-care manufacturing facilities and at pace.

We have also designed and deployed a vertical hydroponic farm called Rosemary Gardens, which allows us to grow micro salads and herbs for our products. Utilising ebb and flow hydroponic systems and next-generation grow lights, we have significantly reduced the 'bullwhip effect' for these salad materials, while demonstrating that a 'high care' growing environment removes the need to chlorinate and wash the grown salads. This has resulted in a further reduction of CO2e.

The growth and deployment of digital technologies will only expand, and we believe that only through collaboration and mutual data sharing can we tackle climate change and achieve a Net Zero food industry.

Tom Hollands
FOOD SCIENCE AND INNOVATION DEPARTMENT, RAYNOR FOODS



>GO TO CONTENTS PAGE<

in focus – where risk should also be considered with respect to multiple causal relationships.

## Recovery potential

Recovery potential is synonymous with resilience and adaptive capacity of a system after exposure to a stress or challenge. This step is about clarifying uncertainties and consciously differentiating between assumptions and facts with respect to interpreting and predicting system behaviour. This will help with reducing risk and failure during implementation by accounting for challenges in decision making due to lack of, or incomplete, information.

## Implementation

Undertaking these steps is not just an academic exercise, which might be perceived as time consuming and may require certain skills. In the survey conducted for this report, respondents expressed their major challenge in starting sustainability initiatives as:

- Not knowing where to start
- Identifying the right technologies
- Complexity of technology and business change management.

**Figure 6** shows the eight-step model in an 'innovation funnel' context, describing how these steps lead to business model


**Figure 6**

The eight-step model in the context of the innovation funnel for sustainability to help with strategy design and planning. This model starts with defining the sustainability initiative leading through required steps toward sustainable practices and business model.

innovation and help businesses connect with the food ecosystem as a sustainability player. This model connects the steps with the why, what and how concept of vision and strategy design.

Once a strategy is agreed upon through the eight-step model, implementation requires choice of technologies, partnerships within the food ecosystem, and relationships with consumers and communities.

**Figure 7** illustrates how the three novel technology areas mentioned in this report, namely AI, new food processing and novel packaging technologies together with ecosystem relationship-building enables transformation to become a sustainable ecosystem player. AI and digital technologies essentially connect every step in the process of moving towards more sustainable food production.

The role of consumers as levers for change, through demanding more sustainable food products and in turn adopting behaviours and habits that reinforce sustainability, is crucial for forming sustainable communities and moving towards achieving national and global sustainability goals. As the food industry and its current supply chain moves toward an ecosystem model at every level there is also a need for recognising a shift from resource-based value creation to value creation which is centred around connectivity and network effects.

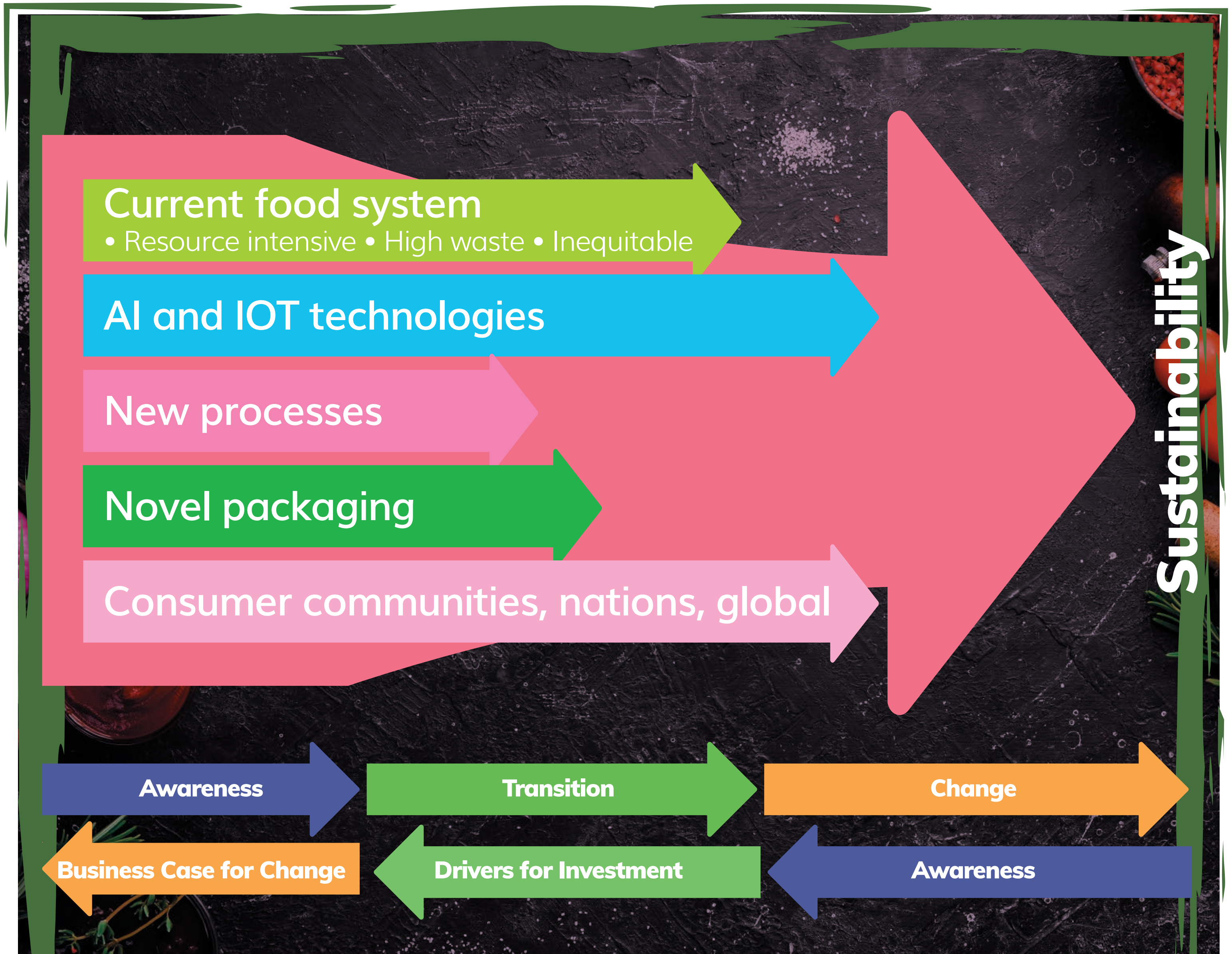



**Figure 7**

For implementing sustainability in the food industry AI, new food processing and novel packaging technologies together with ecosystem relationship-building enable transformation to become a sustainable ecosystem player.

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