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First for food analysis
First for scientific integrity
The theme for December is the use of artificial intelligence (AI) in the food industry. AI technologies use huge datasets to find better ways of completing complex tasks – their application can vary from process automation to more advanced machine learning. This technology is already beginning to transform the global economy. The factory of the future is beginning to make its own decisions about improving production efficiency.

AI is one of the key technologies enabling the 4th industrial revolution, often known as Industry 4.0 – the use of digital technologies in the manufacture of products. Developments in a range of sensor technologies are supporting the trend towards automation and the potential advantages include increased productivity, reduced costs and lower environmental impact. Online sensors have the potential to be easily integrated into existing equipment and so can have particular benefits in the food and drink sector, where many businesses are SMEs with limited resources (p20). Combining these online sensors with machine learning can have a wide range of applications, for example, food quality inspection and detection of contaminants.

AI can be applied in almost every area of the food industry where routine tasks are integral to operations, for example in label and date code verification in food packaging lines, where it has the potential to reduce recalls, improve consumer health and reduce waste (p24).

Smart factories making use of the IoT (Internet of Things) are increasingly enabling consumer demand to be instantly connected to a production facility, allowing a rapid response to changing market conditions (p28). In addition AI is being used to predict maintenance requirements helping to reduce downtime and increase productivity (p28).

A new programme, known as the Internet of Food Things Network Plus led by the University of Lincoln, is aiming to foster collaboration across the disciplines to embed digitalisation into the UK food system (p32). The Network is investigating a raft of areas including trust in food supply systems and governance as well as applications for digitalisation in factory cleaning, food safety and farming.

Although the food industry may not have been the first sector off the blocks to adopt AI, it seems that change is on the way.

I wish you all a Merry Christmas and a prosperous new year!

email mb@biophase.co.uk

Natural Light Growing Centre

Agri-tech innovation centre Crop Health and Protection (CHAP) and its greenhouse innovation partner RIPE Building Services, have officially opened their new high-tech greenhouse facility at the University of Warwick’s Wellesbourne Campus[2].

The structure, named the Natural Light Growing (NLG) Centre, has been designed and built by RIPE Building Services, partnered by CHAP with £500,000 funding from Innovate UK.

The NLG Centre is the first of its kind and will act as a demonstration facility and experimental hub for horticulture to investigate the effect of full spectrum growing conditions on crops in a protected environment. The facility will host projects looking in detail at yield and speed of growth as well as traits like taste, health and vigour.

Rather than being constructed from glass, the NLG Centre uses a new type of ETPE film, which transmits the full spectrum of UV light. The film is inserted into the light-weight frame design and tensioned using patented heat technology. The construction also uses a unique ground anchoring system that allows the structure to be built quickly and efficiently, without the need for traditional concrete foundations, in all weather conditions.

Portion size guide

The research and training charity IGD has published a new guide for food businesses to help them review and set portion sizes[3]. The guide identifies opportunities to reduce portions where appropriate and to help consumers reduce their calorie intake; it aims to help companies reduce portion sizes without compromising on shopper satisfaction.

The guide has been developed following extensive consultation with industry and is based on qualitative consumer research on eating out, on the go and in the home. Using three different scenarios, the guidance offers step-by-step support for companies looking to:

- Downsize an existing product
- Set the portion size for a new product
- Review portion information on labels of multi-serve products

IGD’s research shows that 88% of shoppers want to improve their diet in some way, and that one in five of those looking to eat more healthily are trying to eat smaller portions. Many consumers were found to remain unaware that portion information is available on pack, while those who are aware often struggle to interpret the information correctly. Portion size can often be an emotive issue for consumers, but many are open to the idea of reducing portion sizes. All products and categories were considered, but the research focused on six key categories which are used by government to set public health targets.

While many food and drink businesses are already taking significant steps to make their products healthier, through reformulation, labelling and innovation, identifying opportunities to reduce portion size can be complicated. The guidance is intended as another tool to support companies’ strategies to meet national public health targets and reduce calorie intake.
September 2019 saw the launch of a £142.9m investment programme in green projects by the Department for Business, Energy and Industrial Strategy, part of the second wave of the Government’s Strategic Priority Fund (SPF). Five projects are benefiting from the significant cash injection, including two addressing the food system:

- **Cleaner food systems for healthy people and a healthy planet (£47m)** – this is focused on transforming UK diets to be healthier and more sustainable through changes in production, manufacturing, retail and consumption. It aims to deliver coherent evidence to enable concerted action from policy, business and civil society to help the UK meet its targets on obesity and greenhouse gas emissions.

- **Reusing and recycling materials in innovative ways (£30m)** – this programme aims to drive forward new research to support opportunities to re-use and recycle materials across sectors such as food, water, textiles and electronics – as well accelerating new, greener manufacturing technologies.

UK Research and Innovation (UKRI) has already embarked on a £25m call for research to fundamentally transform the UK food system, which is being administered by BBSRC, in partnership with ESRC, MRC, NERC, Defra, DHSC, PHE, Innovate UK and FSA. Assessment of outline projects is currently underway.

The Food Systems SPF is an interdisciplinary programme of research that aims to help transform the UK food system by placing healthy people and a healthy natural environment at its centre. It will address questions around what we should eat, produce and manufacture in the UK and what we should import. It will consider the complex interactions between health, environment and behavioural factors, while taking into account wider needs for different groups in society. The programme aims to address health, environmental and social challenges simultaneously, bringing together researchers, policymakers, business and civil society to develop evidence for multi-pronged and simultaneous action across the food system.

Many studies suggest that our diets lack oily fish, fibre from wholegrains, fruit, vegetables, nuts and seeds and we often consume more meat than recommended. If diets continue along the current trajectory, it will increase pressure on our health and social care systems and the environment, leading to economic and social instability.

The SPF argues that although much effort has been made to address the impacts of agricultural practices and promote sustainable production in the UK there is still significant scope, and an urgent need, for change, particularly when combined with transformation of diets for health. It is clear, however, that agricultural production can no longer be addressed in isolation; we also need to consider the role of changing patterns of demand in driving our production systems, especially in terms of how much food and what types of food we need to produce, manufacture and import in the future, and which foods we should prioritise to improve health and sustainability. It is increasingly recognised that we need to move away from a ‘calories per hectare’ approach to one that considers the ‘number of people fed healthily and sustainably per hectare’.

The SPF is aiming to develop evidence to enable food system transformation, linking healthy and accessible diets with sustainable food production and supply. This will require a food systems approach and collaboration across multiple disciplines, for example agri-food, environmental, public health, nutritional and social sciences (including expertise in soil science, crop and animal production, aquaculture, biodiversity and ecosystem services, systems engineers, data science, agricultural economics, food science, food manufacturing and processing, food markets, nutrition, biomedical and clinical science, epidemiology, economics, behavioural, social and political science).

UKRI has also launched a £22.5m programme to support up to five Circular Economy Centres for up to four years from 1 October 2020. The centres will conduct interdisciplinary research to accelerate understanding and solutions to enable circularity of a resource flow (materials, material systems, products and/or services), including consideration of (multi-) sector contexts.

The aim is to transition to a more circular economy, where resources are processed with sustainability, waste minimisation and efficiency in mind, and where product lifecycles are optimised to generate more economic and social value before recycling and/or reuse.
Cutting sugar

Public Health England (PHE) has published its second-year report on progress made by the food industry to voluntarily reduce sugar in everyday foods.[6]

The report shows the sugar reduction achieved by retailers and manufacturers in the home sector and the out of home sector (including restaurants, pubs and cafes) in foods contributing the most sugar to children’s diets, such as cakes, breakfast cereals and sweets. It shows:

- for retailers and manufacturers, there is an overall 2.9% reduction (sales weighted average sugar per 100g) since 2015
- for the out of home sector, based on more limited data, there is a 4.9% reduction (simple average sugar per 100g).

Some food categories have demonstrated greater progress than others. Retailer own brand and manufacturer branded yogurts and fromage frais, and breakfast cereals have reduced sugar by 10.3% and 8.5% respectively.

The report also looked at progress made under the Soft Drinks Industry Levy (SDIL) and found that:

- a 28.8% sugar reduction per 100ml in retailer own brand and manufacturer branded products and a 27.2% reduction per 100ml for drinks consumed out of home
- there was a consumer shift towards zero or lower sugar products, with sugar purchased from soft drinks decreasing in all socio-economic groups
- 30,133 tonnes of sugar were removed without reducing soft drink sales, resulting in around 37.5bn fewer kilocalories sold in sugary drinks each year.

Plastic reduction

Unilever has announced new plans to commit to an absolute plastics reduction across its portfolio[7]. The company reports that it is already on track to achieve existing commitments to ensure all of its plastic packaging is reusable, recyclable or compostable by 2025, and to use at least 25% recycled plastic in its packaging, also by 2025. It has recently made two new commitments:

1 Reduce virgin plastic packaging by 50% by 2025, with one third (more than 100,000 tonnes) coming from an absolute plastic reduction

More than 100,000 tonnes will come from an absolute reduction as the business invests in multiple use packs (reusable and/or refillable), ‘no plastic’ solutions (alternative packaging materials or naked products) and reduces the amount of plastic in existing packs (concentration). Replacing non-recycled plastic packaging with recycled plastics will account for the remaining reduction. Unilever will measure the total tonnes of virgin plastic packaging used each year vs the total tonnes of virgin plastic packaging used in 2018. As a result of this commitment, Unilever is committing to have a virgin plastic packaging footprint of no more than 350,000 tonnes by 2025.

2 Help collect and process more plastic packaging than the company sells by 2025

This will require the business to help collect and process around 600,000 tonnes of plastic annually by 2025. This is less than its current 700,000 tonnes plastic packaging footprint because it reflects the 100,000 tonnes absolute reduction that it has committed to above. This commitment will be delivered by investing and partnering in waste collection and processing, purchasing and using recycled plastics in its packaging, and participating in extended producer responsibility schemes where Unilever directly pays for the collection of its packaging.

The company will measure the total tonnes of plastic packaging it has helped collect and process in a year vs how much plastic packaging it has used. It claims to be the first major global consumer goods company to commit to an absolute plastics reduction across its portfolio.
In August this year, Defra opened its call for evidence which was the first step in a review process that is expected to lead to a National Food Strategy – the first, Defra says, for 75 years.

Excuse the pun, but this is intended to be a roots and branches review, which will result in the creation of an overarching strategy for government, designed to ensure that our food system delivers ‘safe, healthy, affordable food, regardless of where people live or how much they earn.’

IFST, of course, submitted its response based on input from and review by many IFST members – you can read our submission on the IFST website. The call for evidence was limited to just 1000 words and, given the breadth of the topics covered, this was quite challenging.

Interestingly, however, Defra’s call for evidence was open to individuals and any organisations who wished to make a submission. So, our carefully considered, scientifically evidence-based and peer reviewed submission is likely to sit alongside the individual views of members of the public and those of lobby groups. We can but trust that those in Defra responsible for synthesising all the submissions take note of this difference.

As IFST continues to grow in influence and resource, we have been pleased to be able to foster closer relationships with government departments and agencies and so, fortunately, we now also have other, more direct ways of engaging with governments and their officials. As a responsible and active professional body, it is important that we can make available our independent scientific information and positions not only to professionals working in the sector but also to governments and other key stakeholders.

With this focus, we have chosen to loosely structure our Spring Conference next April (1st) on some of the main themes within Defra’s planned strategy. The title of our conference is: ‘The appliance of Food Science’ and will consist of four main conference themes: Safe and authentic; Nutritious; Sustainable and; Looks Good, Tastes Good. This last theme, of course, goes beyond Defra’s interests but is obviously a critical consideration for all food producers and consumers!

Our Spring Conference is, of course, still a few months off and I am sure many of you are currently more focused on the immediate challenges of ensuring you can deliver safe, nutritious and tasty food over the Christmas period! So, I will conclude by wishing you all an enjoyable and successful Christmas.

In June this year, Defra’s Secretary of State invited Henry Dimbleby to lead an independent review to inform a National Food Strategy. This will cover the entire food chain, from field to fork: the production, marketing, processing, sale and purchase of food (for consumption in the home and out of it), and the consumer practices, resources and institutions involved in these processes.

As part of this review, Henry launched a call for evidence this summer consulting stakeholders and his independent review will be published in summer 2020. The Government will then develop a National Food Strategy white paper informed by this independent review, among other things, six months after its publication.

IFST has developed its response to this Defra consultation on a National Food Strategy with a range of points and the content can be found here: ifst.org/science-policy/formal-responses

Rachel Ward, Scientific Policy Director, IFST
Critical priorities for sustainability in the agri-food system

Sustainability is a highly complex area where the outputs from multiple scientific disciplines need to engage with the practical realities of the agri-food system. Our newly reconvened IFST Sustainability Steering Group will be providing a platform for discussion and knowledge sharing to translate the issues in this complex area, share updates on developments and link outputs to the UN Sustainable Development Goals. Defra has asked for an IFST view from our Sustainability Steering Group as to the critical priorities around sustainability for the UK/wider food system to inform and advise their research priorities and programme of works for 2020 onwards.

A short set of recommendations as to the critical priorities which should be considered and addressed have been developed and were sent to Defra in October 2019. These included in no particular order:

- **Strengthening food system resilience** to ensure the UK food system capability to supply safe food to the UK population is protected and assured in the face of future predicted system stresses, such as greater climate change disruption, insect population decline and trade disruption through socio-political change.
- **Sustainable and efficient management of resources** to ensure sustainable access to sufficient supply of safe nutritious and affordable food. This relies on availability of a range of different types of resources, not only volumes of staple foodstuff supply, and includes soil, water, energy, waste, sufficient skilled human resources, fit for purpose packaging, accessible nutrients.
- **Optimal reformulation approaches** to prevent unintended consequences and achieve the goal of providing access to truly sustainable nutrition. This will need relevant evidence-based metrics to determine impacts of reformulation and a good level of understanding across food system stakeholders, including product developers and policy makers, to effectively achieve sustainable nutrition without unintended consequences impacting accessibility, cost, consumer trust and public health protection.
- **Data quality and applicability** across the whole agri-food system will need specific contextual guidance to ensure sensible and positive choices are being made that support sustainable food security. Not everyone across the agri-food system is an expert in this complex and evolving technical area. Connected data and robust datasets that are accessible and understood by consumers are paramount to transparency of such metrics.

Our overarching request is to encourage Defra to consolidate the work being done on sustainability and food system resilience across various UK scientific research programmes, government departments and agencies and to provide an overview of the critical priorities around sustainability and food system resilience can be created. For the full content of our recommendations please see: ifst.org/science-policy/sustainable-food-system.

Rachel Ward, Scientific Policy Director, IFST

**IFST Microbiological Criteria Update 2020**

It is time to update your well-worn copies of our leading IFST book Development and Use of Microbiological Criteria for Foods. Published back in 1997, and revised in 1999. This little book has been a go-to reference guide for students, new professionals and technical teams across the agri-food sector. Our expert member Working Group has revised and updated the content to include the latest scientific findings, the up-to-date statutory criteria and a greater number of look-up tables for different food categories, as well as providing background details on specific microorganisms and advice around sampling and testing. IFST is committed to providing science and evidence-based knowledge and is very grateful for the time, commitment, care and expertise provided by our expert group to create this revised handbook of microbiological criteria.

We are confident that it will continue to be a practical and relevant tool to support food safety. The new edition will be available early in 2020. Details on purchasing your copy of our new Handbook of Microbiological Criteria can be obtained from our website ifst.org/our-resources/publications.

Rachel Ward, Scientific Policy Director, IFST
The shiga toxin-producing *Escherichia coli* (STEC) is an important and occasionally lethal foodborne pathogen. Initially nicknamed the ‘hamburger bug’, it is now known that a diverse range of foods can act as vehicles for the transmission of STEC infections, even wheat flour.

The STEC comprise many serotypes and can possess a variety of pathogenicity determinants and this complicates their detection in foods, although the O157 serogroup predominates.

This information statement is an update providing refreshed coverage of the clinical picture and epidemiology of STEC infections and outbreaks as well as control of STEC in the food industry and testing methods.

IFST’s Information Statements summarise the authoritative and impartial science behind key food science issues and they are peer-reviewed by IFST’s Scientific Committee.

For more information, please visit ifst.org/resources/information-statements/shiga-toxin-producing-escherichia-coli-stec-food-poisoning-and-its

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IFST EVENTS

12 December 2019
NOEL, NARRATIVE & NUMBERS
IFST Sensory Science Group event

31 March 2020
ANNUAL GENERAL MEETING (AGM)
We look forward to seeing you there

31 March 2020
EDUCATION, CAREERS AND PROFESSIONAL DEVELOPMENT FORUM
We look forward to welcoming members and stakeholders to our Forum in March. Our aim is to explore ‘routes of entry into the profession: getting good quality information about food science and technology careers to the right people at the right time.’ Representatives of SMEs or larger firms who would like to contribute to the Forum by sharing their experiences of recruitment and retention in the sector are invited to get in touch.

Andrew Gardner, Operations Director, IFST
A.Gardner@ifst.org

1 April 2020
SPRING CONFERENCE 2020
SC2020 is entitled: ‘The Appliance of Food Science’ and will consist of four main conference themes: Safe and authentic; Nutritious; Sustainable and; Looks Good, Tastes Good. We look forward to seeing you there.

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IFST Information Statement update on Shiga Toxin-Producing *Escherichia coli* (STEC) Food Poisoning and its Prevention

In October and November, our team held six successful launchpads at the Scottish Schools Education Research Centre (SSERC), Leatherhead Food Research, University of Reading, AFBI Hillsborough (Northern Ireland), Sheffield Hallam University and Campden BRI.

Our LaunchPads are designed to provide students with advice and help to give valuable insights into possible career paths in all aspects of the food chain.

Over 400 Students from more than 20 universities had the opportunity to meet food sector professionals and learn from their valuable experiences.

A student who attended one of our LaunchPads commented that ‘bringing in graduates who recently started work in the industry to share experiences was great.’

We would like to thank all the food sector mentors who have participated in our LaunchPad events this year.

To see highlights from the launchpads, head to our Twitter @IFSTnews and our Instagram @institute_of_food_science, where we have saved snippets from the six LaunchPads.
IFST Food Safety Special Interest Group (SIG)

The IFST Food Safety SIG provides members interested in food safety with an opportunity to engage and share knowledge with others and hosts regular discussion workshops open to all. It has a broad scope, covering all areas related to food safety, including chemical, microbiological and physical contaminants, as well as allergens. It also considers topics such as analytical techniques, food safety culture and food fraud prevention and contributes to relevant publications.

Meet the Committee
This is made up of volunteers, who meet both virtually and face to face, and who are fully supported by the IFST central team. They also actively communicate via an IFST Food Safety Forum.

Chair
Sterling Crew FIFST

Vice Chair
Andy Kerridge FIFST

Events
Denis Treacy FIFST

Secretary
Cristina Gutierrez-Solano MIFST

Other members
Titilola Adejugibe MIFST, Sonia Andre FIFST, Alison Friel MIFST, John Globe FIFST, Kaarin Goodburn FIFST, Sarah Howarth FIFST, Sue Howlett MIFST, Alex Kent FIFST, Velimir Kirov, Peter Littleton MIFST, Peter McClure MIFST, Jude Mason FIFST, Clare Menezes FIFST, Bárbara Serra, Tom Sheehan, Dave Sherring MIFST, Susan Smith, Frances Strain, Liz Ward MIFST, Rachel Ward FIFST.

Recent highlights
• Delivering a positive food safety culture - a practical approach. This workshop-based event featured speakers from Shield Safety Group, Kitchen Conversation and Culture Compass, and received positive press coverage;
• Social media activities during the build up to World Food Safety Day (7 June), including interviews with experts and useful quotes;
• Collaborative workshop on allergens and Listeria was an innovative, interactive learning workshop, which addressed indicators that signpost threats. The group defined plans for preventive risk management that they could take back to their workplaces to implement. It also provided the opportunity to visit i2 FAST UK – a leading laboratory facility.

Outputs from the group’s events are available on IFST’s website. The group actively encourages input from new members and the programme for 2020 is currently being finalised.

Comments from Sterling Crew, SIG Chair
“We are very fortunate to have a network of active, knowledgeable, food safety professionals, who can support the work of the IFST and its membership. They help with horizon scanning, emerging food safety issues, and providing advice on dealing with the hot topics of the day.

‘The approach of the group is to give practical solutions to the real-life, everyday food safety challenges that our members face’. He adds ‘the group’s strength is not only the depth of knowledge of its membership but also its breadth, covering all areas of food science and technology and all sectors of our industry. We are looking to extend the group’s remit to include food fraud. There currently is not a SIG specifically looking at the challenges of trust in authenticity and preventing fraud. Incorporating it into the group’s work is a natural step as there are some obvious overlaps with the work the Food Safety Group undertakes’.

‘Also, keep an eye out for our upcoming series of podcasts, as we seek to build on ways of engaging with the membership and the wider public. I would encourage members to join the group as we are always looking for fresh ideas and new approaches. It presents a fabulous opportunity to meet and mix with fellow food safety professionals’.

Food Safety Register
IFST’s Register of Food Safety Professionals (RFSP) recognises those working at all levels within food safety throughout the sector and helps build a unified platform for food safety compliance across the food industry and the safety auditing process. The Register offers a three-tiered formal framework that provides an assurance of each registrant’s experience, excellence and professionalism in food safety and integrity. The independent, peer-reviewed application process is rigorous but flexible, taking account of each applicant’s technical qualifications and practical career experience.

How to get involved
For more information on how to get involved with this or any of the IFST Special Interest Groups, please contact Natasha Medhurst FIFST, Scientific Affairs Manager (n.medhurst@ifst.org)

Full details about the group are available on our website
ifst.org/career-development/networks-and-communities/special-interest-groups/food-safety-group
Consumer attitudes towards 3D printed foods
Little research currently exists on consumer perceptions of 3D printed foods. In this study responses from two focus groups (n = 8 and 12) were used to create an online survey investigating consumer attitudes towards 3D printed foods in comparison with conventional foods, as well as consumer beliefs about 3D food printing.

Based on the results of the survey, three clusters were identified: the markedly interested cluster (n = 140), moderately interested cluster (n = 98) and the not interested cluster (n = 91). The markedly interested cluster wanted to know more about 3D printed food, and believed it could reduce the cost of food and benefit people in the future. The moderately interested cluster was excited to try printed food. Conversely, the third cluster believed 3D printed foods were unacceptable and not safe to consume.

Manstan and McSweeney, 2019, https://doi.org/10.1111/ijfs.14292

Safety of horsemeat consumption
In some countries, use of horsemeat as a food is inhibited by ethical and cultural concerns. However, horsemeat has potential health benefits, such as low fat and high unsaturated fatty acid content compared with other meats, as well as attractive sensory properties.

In this study, we summarise existing knowledge on horsemeat quality and effects on human health. Our conclusion is that horsemeat may be consumed as a healthy alternative to other types of meat, provided that risks associated with microbial contamination during storage and possible presence of contaminants in horsemeat are taken into consideration.

Balji et al., 2019, https://doi.org/10.1111/ijfs.14390

Shining light on meat
Near infrared (NIR) spectroscopy has been used to analyse a wide range of properties associated with meat quality in live animals or during carcass evaluation, as infrared (IR) light has the capability to propagate through several layers of tissue.

Recent reports have also shown that methods based on the application of short wavelengths (e.g. 700–1100nm) in the NIR region of the electromagnetic spectrum can measure properties related to meat quality non-destructively and non-invasively in live animals. In addition, this methodology was able to segregate tissues (e.g. lean and fat) assessed through the skin.

This review describes the recent applications of NIR spectroscopy to predict traits (e.g. protein, fat, fatty acids and shear force) associated with meat quality in both live animals and carcass samples.

Chapman et al., 2019, https://doi.org/10.1111/ijfs.14367

Application of electrolysed water and ultrasound to improve the sanitation of knives in the meat industry
This study investigated the effect of combining basic electrolysed water (BEW) and slightly acid electrolysed water (SAEW) with ultrasound (US) for cleaning and sanitation of knives used in slaughtering processes.

The knives were sonicated in a US bath using two modes of operation (normal and sweep) in two steps: (i) 5 min with BEW and (ii) 10 min with SAEW at 35°C. The microbiological counts and the possible changes in the physical structure of the knives were evaluated. The combination of BEW + SAEW + US provided lower mesophilic, enterobacterial, Staphylococcus aureus and yeast counts when compared to the values recommended by the international legislation.

In addition, these conditions removed all organic residues from the knife blades and promoted the highest migration rate of the residues to the US water bath (12.35 mg/L·min), without modifications in the knife blades.

Thus, cleaning and sanitation of knives was feasible with the association of BEW + SAEW + US, which could be a useful alternative for the meat industry.

Members

- Donna Mavor MIFST, Director – DM Training Consultants Ltd
- Dr Julien Lonchamp MIFST, Lecturer in Food Science – Queen Margaret University
- Sook Sean Chang MIFST
- Jignesh Parekh MIFST, Technical Manager – The Food and Drink Forum Ltd
- Dr Amie Adkin MIFST, Head of Risk Assessment – Food Standards Agency
- Steve Rogers MIFST, Site Technical Manager – Finsbury Food Group
- Will Micklefield MIFST, Produce Technologist – Tesco Stores Ltd
- Michael Heigway MIFST, Technical Manager – Green Gourmet Ltd
- Dr Krysztof Zacharski MIFST, Research Engineer
- Nahum Kidan MIFST, Higher Scientific Officer, Food Science – Defra
- Heather Alford MIFST, Higher Scientific Officer – Defra
- Stuart Howe MIFST, Brewing Consultant
- Peter Illman MIFST, Technical Manager – Tesco Stores Ltd
- Phil Sedgwick MIFST, Technical Manager – Tesco Stores Ltd
- Bethan Sutton MIFST, Technical Manager – Tesco Stores Ltd
- Samuel Richardson MIFST, Technical Manager – Tesco Stores Ltd
- Helen Palmer MIFST, Technical Account Manager – Hovis
- Dr Susan Doherty MIFST, Senior Lecturer in Education – Queen’s University Belfast
- Joseph Oladunjoye MIFST, Quality Manager – Avara Foods
- Dr Saravana Sivagnanam MIFST, Post-Doctoral Researcher – Teagasc Food Research Centre
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- Sarah Pitts MIFST, Senior Technical Manager – Vitacress
- Jenny Khan MIFST, Technical Manager, Grocery – Tesco Stores Ltd
- Laura Durrant MIFST, Technical Manager Frozen Fish, Seafood & Meat Free – Tesco Stores Ltd
- Jude Walker MIFST, Food Safety Manager – FSC International
- Rob Seall MIFST, Quality Manager – Tracklements
- Amy Salt MIFST, Technical Manager – Tesco Stores Ltd
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- Daniel Vela MIFST, Meat Technologist, Fresh Pork and Gammon – Tesco Stores Ltd
- Paola Leather MIFST, Production Brewery Manager – S.A. Brain & Co Ltd
- Thibari Kariyawasam Indipolage MIFST, QA Team Manager – Sainsbury’s Supermarkets Ltd
- Christina Anthony MIFST, Lead Incidents Officer/Scientific Advisor – Food Standards Scotland
- Shubnum Raaz MIFST, Technical Manager, Export and Channel Development – Tesco Stores Ltd
- Rebecca Schofield MIFST, Technical Manager, Stone Fruit & Project Atlas – Tesco Stores Ltd
- Ukamaka Olisa MIFST, Quality Control/Assurance Technician – Tuticip, S.A, Leng-d’or Group

Fellows

- Philip Downes FIFST, Consultant
- Sonia Andre FIFST, Director – Ask Sonia Ltd
- James Cackett FIFST, Technical Manager – Tesco Stores Ltd
- Dr Gavin Milligan FIFST, ESG Director – William Jackson Food Group
- Helen Fawehinmi FIFST, Director – Hft
- Barbara Bray MBE FIFST, Technical Consultant – Alo Solutions Ltd
- Susan Alexander FIFST, Principal trainer and HACCP consultant – Aaron Scott And Black
- Prof Mark Swainson FIFST, Deputy Head, National Centre for Food Manufacturing - Lead for Research Higher Education – University of Lincoln
- Jacqueline Healing FIFST, Director Consulting and Technical Services – NSF International
- Kay Legge FIFST, Technical Manager, Continental Cheese – Tesco Stores Ltd
- Laura Farrell FIFST, Nutrition & Health Manager – Tesco Stores Ltd
- Della K Hickson FIFST, Microbiology Operations Manager – INTERTEK Food and Agri
- Paramvir Singh Deol FIFST, Director – RTNTS
- Shankaralingam Pitchia FIFST, Quality Assurance Manager/Food Technologist – Foodland Supermarkets
- Clare Rapa-Marley FIFST, Head of Technical Standards and Audit – Tesco Stores Ltd
- Durran Eden FIFST, EPP & Innovation Manager – Raynor Foods Ltd
- Dr Nazanin Zand FIFST, Senior Lecturer Food Science and Nutrition – University of Greenwich at Medway - Natural Resources Institute
- Duncan Perry FIFST, Auditor, Trainer, Advisor – Outsource Solution
- Manjit Sahota FIFST, Technical Manager – Tesco Stores Ltd
- Kay Davies FIFST, Technical Manager – Country Products
- Sarah Anne de Wit FIFST, Director – Manor House Consultancy Ltd
- Martin Johns FIFST, Innovation Chef – Kenwood / Delonghi
- Marcia Henshaw FIFST, Technical Director/ Company Partner – Henshaw Safety & Training Solutions Limited
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- Robert Cradock FIFST, Senior Lecturer in Food Technology – Nottingham Trent University
- Dr Anne Churchill FIFST, Research Fellow – Givaudan UK Ltd
- Nikolay Ermakov FIFST, Vice President Research and Development EMEA – McCormick (UK) Ltd
- Orla McFadden FIS, Chartered Scientists
- Lesley Fairhurst CSci, Senior Technical Manager – Pret A Manger
- Dr Hasan Iessa CSci, Technical Analyst – Four04 Packaging Ltd
- Christina Anthony CSci, Lead Incidents Officer/Scientific Advisor – Food Standards Scotland

Registered Food Safety Managers

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- Jignesh Parekh RFoodSM, Technical Manager – The Food and Drink Forum Ltd
- Steven Bale RFoodSM, – SBTC (2013) Ltd
- Paramvir Singh Deol RFoodSM, Director – RTNTS
- Stuart Howe RFoodSM, Brewing Consultant
- Joseph Otradunjoye RFoodSM, Quality Manager – Avara Foods
- Zoe Shuttlewood RFoodSM, EMEA Food Safety & Quality Systems Lead – McCormick (UK) Ltd
- Paola Leather RFoodSM, Production Brewery Manager – S.A. Brain & Co Ltd
- Charlotte Riley RFoodSM, - Yorkshire Food Technology Services

Registered Food Safety Practitioners

- Craig Mcsorley RFoodSPrac, Supervisory Meat Hygiene Inspector – Food Standards Scotland
- Darren Stadames RFoodSPrac, Veterinary Manager – Food Standards Scotland
- Elena Gafenco RFoodSPrac, Meat Hygiene Inspector – Food Standards Scotland
- George Christie RFoodSPrac, Supervisory Meat Hygiene Inspector – Food Standards Scotland
- Andrew Kirkcaldy RFoodSPrac, Mobile Meat Hygiene Inspector – Food Standards Scotland
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I realise that the prospect of another article on Brexit is likely at best to produce a yawn - but more probably a groan! Surprising as it may seem, given the drawn out nature of the negotiations, we do now have an agreement between Boris Johnson's government on the one hand and the twenty seven countries of the EU on the other. Moreover in the run-up to the December election – in advance of which this article was written – we have a pretty good idea of what the other two main British political parties would do should they come to power. So perhaps a picture begins to emerge of what Brexit will actually mean in practice for the food sector and that is what I shall try and describe here – but be warned there are still a lot of unknowns.

The first point is that it is not now likely that there will be a ‘hard Brexit’ or indeed any very perceptible change before end December 2020. The Johnson deal, which is supported by the EU, allows specifically for an implementation period through to 31 December 2020. During the implementation period there will be no perceptible change for businesses: the UK will for all intents and purposes continue to follow EU law as if we were still a member state.

The leader of the opposition has committed a future Labour government to a three month further negotiation with the EU followed by a referendum with the choice of either its new agreement or remaining in the EU – either way a good year’s worth of process I would have thought. Most straightforward of all, the Liberal Democrats intend simply to reverse the UK’s withdrawal – so if they win the election there is no need to read on!

All that said, leaving the EU system by 1 January 2021 still seems the most likely option if the opinion polls are to be believed and this will have major implications for the food sector. Our whole system of food safety forms part of the wider one managed by the European Commission and the UK will have to take back key functions of risk analysis and risk management, which up until now have been resolved in Brussels rather than here.

On risk analysis, the UK is already disconnected from the European Food Safety Authority and will no longer be participating in its risk assessment work. This is a loss all round, as UK experts have made a major contribution to this system and as a country we have benefited from the Agency’s advice. Instead, the Food Standards Agency is already preparing for this function and there seems little enthusiasm for trying to re-establish the connection after Brexit.

Additionally the UK will leave the EU regulatory and risk management system, which will bring with it, in my view, a mixture of advantages and disadvantages. The potential advantages would include the possibility of the UK setting up its own effective border-inspection system and adopting a more effective and cost-effective system of standards and controls. I am afraid from my own experience both at FSA and EFSA, I have always taken with a pinch of salt the European Commission’s boasts as to the excellence of their system. Firstly, a UK system of border controls on imported food would make it possible, for example, to reject sub-standard produce without the fear that it would simply be reimported into the UK via another EU country. Secondly, leaving the EU system of controls would provide opportunities to attain the same standards of food hygiene by more cost-effective means.

For example there certainly is scope for some veterinary functions in relation to meat inspection to have a less heavy reliance on a veterinary presence than is currently the case, with the UK having to rely on veterinarians imported from the Mediterranean countries given the understandable reluctance of British veterinarians to perform such functions. On the downside, the UK will presumably no longer be able to rely on EU veterinary inspections of meat production.

Geoffrey Podger assesses the various Brexit scenarios still on the table and considers their potential impacts on the UK food industry.
Arguably the greatest unresolved problem deriving from Brexit may actually lie in the new immigration rules as regards casual labourers. Already there are reports of Brexit deterring the large casual EU labour force on which UK agriculture relies with the NFU, for instance, claiming that numbers were down by 17.6% in August alone with massive wastage of crops that cannot be harvested.

Defra has announced a pilot scheme for the admission of non-EU nationals but it remains to be demonstrated that this will fill the gap given that many overseas workers are put off by the low value of the pound relative to their home currencies (which is itself Brexit related) and the further restrictions that may follow from Brexit. Limiting immigration after Brexit to the highly skilled will do nothing to remedy this problem.

The above may seem to paint a rather bleak picture for the food industry albeit with a few ‘silver linings’. The truth, however, is that over three years after the EU referendum the future from 2021 remains unclear. Assuming that the ‘Johnson deal’ does represent the final withdrawal agreement, the accompanying political declaration, whilst emphasising the need for future UK and EU co-operation, leaves open the key question as to the extent to which the UK may choose to buy more food on the open global market where there is price benefit and, by the same token, the extent to which it may diversify the market for its own food products – all to play for in the free trade negotiations.

Conversely the Labour party’s preference for the UK remaining in a customs union (or indeed to ultimately vote to remain in the EU entirely) would mean the UK signing up to the common EU tariff on imported goods and would thus effectively prevent a significant change in the UK’s food trading.

So whatever happens in the December election, we are certainly not at the ‘beginning of the end’ in determining how Brexit will impact the food industry. The more pertinent question is perhaps whether, to continue Churchill’s metaphor, we have even reached the ‘end of the beginning’?

Geoffrey Podger

Geoffrey Podger was the first Chief Executive of the UK Food Standards Agency and the first Executive Director of the European Food Safety Authority. His subsequent regulatory career was as Chief Executive of the Health and Safety Executive and of its New Zealand equivalent during its set-up stage. He currently holds a number of non-executive posts and is Senior Visiting Fellow at the Centre for Risk Management at King’s College London.

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in third countries and will have to consider what alternative evidence bases it can use.

The fact that the UK will no longer be obliged to follow EU standards is not necessarily going to prove a problem. The reality is that products exported to the EU from 2021 will need either to follow EU standards or be accepted by the EU as having ‘equivalence’ in whatever free trade deal is signed. For these products, the UK is likely to see little benefit in departing from EU standards. Conversely for either imports or exports which are not EU centric in origin or destination, the opportunity will arise to diverge if there is a good reason for doing so. Although there are those who argue that any such process could potentially lower safety standards, the fact is that the ministers/ agencies making such decisions would be under the same legal requirements to protect consumers as now.

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The shortage of new talent to fill skilled roles in the food sector is a critical issue. A key focus for the Institute is therefore encouraging and supporting the future generation of food scientists and technologists. We have developed, often in collaboration with others, a wide range of activities and events.
It may be odd to state that food is important because it should be obvious, but I do not think many people consider it in that way. It is such an integral part of our lives that, at least in the developed world, most people rarely question its availability in some form. A visit to a supermarket for most people is a very functional activity but, being a bit of a geek, I just marvel at the sophistication which brings such a huge variety of food products to me as a consumer. I suspect few people stop to think of the phenomenal achievement of organisation this represents.

This is the work of the market. I suspect the market reaches its apotheosis in our food stores. But let us not confuse efficiency of delivering what the consumer wants with ecological efficiency or resource efficiency. I suggest we need rapid convergence between these concepts.

The Government has stated its intention to produce a food strategy. This sits among many other strategies including those about Clean Air, Resources and Waste, Clean Growth, farming and a long-term plan for the environment. As a set, and when combined with a food strategy, they represent a systems approach to managing some of the most important responsibilities of government – to assure sufficient quality of food to eat, water to drink and air...
to breathe. These are the basics of life.

It is pleasing to see the Government acknowledge its position of leadership in assuring these public goods are delivered. Let us hope they are delivered. But some imaginative policy development is needed and the way we produce our food is right at the heart of this thinking.

In a recent blog[1], I set out nine synoptic trends to which we need to respond. I had originally circulated within Defra towards the end of my tenure as Chief Scientific Adviser (CSA) on food and environment. One of the roles of a CSA is to challenge normative thinking and to inject some originality into policy-making. I had done this with air quality, waste and resources and several other strategic policy areas. My paper on food, provocatively titled Securing the Food of the Future was an attempt to develop a vision for how the UK could move forward.

The paper used the methods which are now standard within foresight analysis – the analysis of current trends, assessment of how these might project into the future followed by matching of the projections to policy options. They are not predictions but they are an assessment of what the future might bring and they are certainly an improvement on assuming that the future is going to be somewhat like the present or the recent past, which is the default assumption in policy making.

In broad terms, the conclusions were that global food productivity has largely expanded to meet demand over the past 30 years by an increasingly efficient global food system, mainly involving the opening up of new land in developing countries and by focusing the production of commodities in those regions of the world where climate, soils and politics mix to produce stable, high quality outputs. These outputs are then traded internationally.

The UK has bought into this in a big way. Its food processing and supply sector is worth nearly ten times its food production sector and is almost 15% of the UK economy. The added value that the UK gets from food is large and under-appreciated, at least within the higher echelons of government.

Government often looks to high tech industries, like finance, communications, aerospace and automotive, for the next big step in economic development and growth. But food is just as sophisticated and my analysis suggests we are going to have to get much smarter about how we formulate the food of the future.

It is our demand for food that is the main driver behind many of the current major environmental problems and if we do not recognise this then those problems will only get worse. Biodiversity loss (highlighted by the Extinction Rebellion protests) is largely driven by the hunger for land to grow more food, or crops for biofuels. Although vehicle fumes are a major factor in creating poor air quality, agriculture is also a significant and increasing cause while vehicle sources are in decline. Added to this, food production is a major user of fossil fuels and a producer of greenhouse gases. In the context of the UK, the agricultural and fisheries sectors are two to three times less resource efficient than the nearest least resource efficient sector of the economy, and at least five times less resource efficient than the most productive sectors of the economy. These are not small margins of difference but reflect the fact that, unlike many other sectors of the economy, we have not seen significant technological revolutions in food production since the mechanisation of agriculture. The ‘green revolution’ of post WWII made a difference but many of those technologies are now being challenged as being unsustainable.

These drastic statistics represent a problem we need to solve. Moreover, what is very clear from the trends over the past 30 years is that research in food production is not keeping pace with the overall need to develop better production systems. Even a very superficial analysis of how we produce food leads one to the conclusion that food is produced very inefficiently. It is likely that each calorie of food we eat uses 5-10 calories of fossil fuel and this ratio is probably rising rather than declining. This is obviously an unsustainable situation. I have suggested that the efficiency of food production could be as low as 1-2 parts in 10,000.

The plus side of this calculation is, however, that there is potential for rapid progress in the efficiency of food production and, for those who crack this problem, there is money to be made. Food is something we all need and anybody who can produce food even slightly more efficiently than at present, and presumably therefore at lower cost, could make a lot of money.

In future, we need to obtain a lot more food out of each unit of land we use for growing it. I suggest that by 2050 this needs to be between five and ten times what we achieve today. The cost of not meeting this kind of target is going to be that we keep

The UK’s food processing and supply sector is worth nearly ten times its food production sector and is almost 15% of the UK economy.
travelling along the current track towards an increasingly degraded environment, to the extent that this will eventually adversely affect the quality and quantity of food we are able to produce.

My proposal is that we need a rapid conceptual shift from food production by farming to food production by manufacturing. This is about building on and extending our excellent food processing technology to, at the supply end, develop methods to manufacture basic input materials and then, at the demand end of the chain, to deliver food formulated in ways which are both attractive for people to eat and nutritious.

The crisis in non-communicable disease which most developed countries face over the next 30 years is partly because of the ways we formulate food. I think we can do a lot to improve on this. Our understanding of what people need in terms of nutrition, including micronutrients, allows us to formulate very health food. The kind of technologies being considered to develop more efficient food production methods, are either with us in nascent form or include the use of basic energy to manufacture raw materials. However, the technologies are also about considering how these foods might come from different production processes, like marine algae in parts of the world where there are abundant solar resources and a lot of low value coastal land to use for production.

Controlled system (‘vertical’) farming of various types is already in the process of being scaled up but can this kind of production system also be used to produce commodities? The progress which has been made in the intensification of tomato production, for example, has turned them into a commodity crop and much the same is happening with strawberries. The production intensity of these crops is at least an order of magnitude greater than extensive production systems for soy and grains. Although still largely consumed for their own sake, could tomatoes and strawberries be used as the sources of primary inputs for food production?

This is not a brave new world because it is needed, but it requires three main technologies to be brought together – process engineering, synthetic biology and robotics – in a systems evolution. The major question for government and big players in the food industry is how can they come together in a pre-competitive alliance to merge these components to achieve a step change in production efficiencies. Those who say that the market can deliver this fail to understand the speed with which this change needs to happen.

Some objections I have heard suggest this vision is too reductionist, or people will choose not to eat processed food – one has to give people what they demand and this cannot be pre-designed. My response to this is that most people already eat highly processed foods, we know how to make food that people want to eat, and that eventually price will dictate what people will or will not eat, so long as it is safe. The reductionism is necessary because we need to find ways of accounting for the calories we use and the waste in producing our food. It is mainly the wasted calories that add to climate change and environmental degradation.

One of the biggest challenges to this vision is going to be the availability of energy. In the end everything boils down to energy availability. Food needs to be seen to be much more important than it is today because at present it loses out in the competition for energy and, in the world of the future, energy will be at a premium in spite of what some leading economists think. I have already mentioned biofuels but when land is used in future to capture solar energy, as it inevitably will be, it is going to be important to channel a significant proportion of this energy towards food production.

Financial returns from producing food are going to have to be competitive with those other sectors of the economy that seek to tap the same energy sources. This makes it imperative that we ramp up efficiency of food production at a systemic level. Arguably, the UK, with its highly developed food technology sector, can lead the world in making this happen and this needs government support to help it lead a systems transition in how food is produced and formulated.

Although still largely consumed for their own sake, could tomatoes and strawberries be used as the sources of primary inputs for food production?
Sensors support machine learning

Nik Watson of the University of Nottingham discusses whether online sensors and machine learning can deliver industry 4.0 to the food and drink manufacturing sector.

Manufacturing is experiencing the 4th industrial revolution, which is the use of Industrial Digital Technologies (IDTs) to produce new and existing products. Industrial digital technologies include sensors, robotics, the industrial internet of things (IoT), additive manufacturing, artificial intelligence, virtual and augmented reality, digital twins and cloud computing. At the heart of Industry 4.0 is the enhanced collection and use of data. Industry 4.0 is predicted to have a positive impact of over £450bn to UK manufacturing over the next ten years[1], with benefits such as increased productivity and reduced costs and environmental impacts. But what does this mean for the UK’s largest manufacturing sector, food and drink?

The food and drink sector is characterised by producing high volumes of low value products and faces constant challenges in terms of productivity, environmental sustainability, safety and labour availability. Food and drink is different to many other manufacturing sectors as it is dominated by small and medium enterprises which do not always have the necessary resources and expertise to adopt new technologies. Online sensors are one of the main types of IDT forecast to see greater use within the food and drink sector as their cost is generally less than other IDTs, and they can often be easily integrated with legacy processing equipment.

Online sensors

Online sensors are devices capable of performing in-line measurements during manufacturing processes. There are a variety of different sensor technologies ranging from simple thermocouples to advanced methods, such as X-ray. Sensors collect data which can be used by manufacturers to make evidence-based decisions on their products and processes and are an essential component of autonomous processes. Sensors are usually characterised by their sensing modality (e.g. electromagnetic) and mode of operation (e.g. spectroscopic). To operate effectively in a food and drink manufacturing environment, sensors must be able to operate non-invasively in real-time. Although a vast range of different sensing technologies have been used in the food and drink manufacturing sector, the techniques that have seen the most widespread use are visible and near-infrared optical methods[2]. Recently, hyperspectral imaging has been experiencing greater use due to its high level of spatial and spectral resolution. Different sensors have been used within the sector for a range of applications including food quality inspection[2], detection of contaminants[3] and optimisation of processes such as cleaning[4]. Online sensors have the potential to deliver significant benefits to the food and drink sector but several challenges remain, which need to be addressed by the academic and industrial communities:

• The cost of the sensors is often too large to justify the benefits they deliver, especially for SME manufacturers.
• Sensor technologies can often require specific expertise to operate and interpret the data they collect.
• Food ingredients are inherently variable and food products are often complex multi-component systems requiring advanced signal and data analysis methods to interpret the sensor measurements.
• Food and drink manufacturing facilities are challenging environments in which to perform reliable measurements. Ultrasonic techniques utilise high frequency mechanical waves...
Supervised machine learning methods, such as Artificial Neural Networks (ANN), Support Vector Machines (SVM) and Random Forests (RF), use input data to train the algorithms\(^6\). Input data can come from a variety of sources including features extracted from sensor measurements and other parameters, such as the measurement environment (e.g. temperature, humidity and light levels). Advantages of machine learning techniques include the volume and variety of data they can process and their ability to improve as more or better data becomes available. In addition, they do not require the development of inversion models, accounting for complexities, such as material motion and variable temperature, and can process data quickly once the initial training stage has been completed. Machine learning methods require large data sets, which makes them ideally suited to numerous applications in the food and drink sector, especially manufacturers producing large volumes of identical or similar products on a daily basis.

Machine learning methods require large data sets, which makes them ideally suited to numerous applications in the food and drink sector, especially manufacturers producing large volumes of identical or similar products on a daily basis.

Machine learning methods are an attractive sensing technology due to their low cost and ability to monitor opaque materials non-destructively. Ultrasonic sensors have been used for a variety of applications within food and drink manufacturing, such as monitoring food texture and emulsion stability\(^5\). As with other sensor technologies, ultrasonic methods require the development of new data analysis methods to relate the ultrasonic measurements to the material or process being monitored in the industrial environment.

Machine learning

Machine learning is a type of artificial intelligence that utilises predictive algorithms for classification or regression problems. Supervised machine learning methods are an ‘out of the box’ autonomous technology. They require skilled users to train, validate and test the models. They also require expert users to determine when models need retraining, for example when a food product undergoes a formulation change. Machine learning methods are often termed ‘black box’ models. This means they can utilise sensor data to predict if a product is of acceptable quality or not. However they do not deliver information on why a product was deemed unacceptable, which is often necessary to enable changes in the production conditions. This issue is also true when selecting the most suitable machine learning method to utilise. Users often try a range of different methods and report their prediction accuracy without any understanding of why different algorithms perform better for specific applications. Supervised machine learning methods also require labelled data for training, which can often be more problematic or costly to collect than the sensor data. If we think of the quality assessment problem, it would not be difficult for a particular sensor to autonomously perform quality assessment measurements on 10,000 products (e.g. biscuits or chicken fillets). However each of the 10,000 products would need to be assigned a label relating to its quality, which is a resource intensive human task. For large problems, such as this, semi-supervised methods should be investigated. When using sensors and machine learning to make predictions in food and drink manufacturing environments, the prediction needs to be considered within the context of the specific application. For example, a prediction accuracy of 95% for determining the quality of biscuits may be acceptable and better than current industry standard methods (operator assessment). However is 95% prediction accuracy acceptable when trying to detect the
presence of food allergens or foreign bodies in products?

The final considerations users of machine learning need to be aware of are overfitting and generalisation. These issues relate to the predictions matching the training data too closely and the model's ability to make predictions on unseen data.

**Case studies**

Below are several case studies demonstrating the use of different sensors and machine learning methods within food and drink manufacturing. These aim to show the potential of the technologies and highlight some of the challenges discussed above.

**BREWNET**

The University of Nottingham is collaborating with the University of Leeds and Totally Brewed (SME craft brewer) to demonstrate how low cost ultrasonic sensors and machine learning can be used to monitor craft beer fermentation processes.

Real-time sensor measurements would enable brewers to predict the optimal time to end the fermentation in addition to identifying any problems occurring during the process. The ABV % prediction from the ultrasonic sensor and machine learning models can be seen in Figure 1.

The results on the left show predictions from an ANN and a linear regression model. Both methods compare well to the actual ABV % value (recorded via typical sampling methods) but the ANN delivers more accurate predictions.

Collecting a representative data set is challenging for some industrial applications. In craft brewing a particular beer may only be brewed once or twice a month. Although numerous ultrasonic measurements can be made from a single batch, data from numerous batches is desirable to create a data set more representative of the system.

Figure 1 demonstrates this by showing how the error in the predicted values reduces as data collected from more batches is used to train the models.

**IoT enhanced factory cleaning**

The University of Nottingham is working on several projects investigating the use of sensors, data and robotics to transform cleaning and allergen detection within food factories. As part of this work researchers have been investigating the use of small and low cost Near-Infrared (NIR) sensors and supervised machine learning to identify different powdered foods containing known allergens. NIR spectra were recorded...
from over 50 different powdered foods and different machine learning algorithms were tested to determine their capabilities. The K-nearest neighbour (KNN) method was found to have the best classification accuracy with results over 98%. This may seem like a suitable method but detecting allergen-containing foods within production environments is a safety critical process and the responsible use of predictive algorithms needs to be considered in detail. Figure 2 displays principle components calculated from the recorded NIR spectra. Principle component analysis is a method for feature extraction from data and can be used to effectively visualise key data features.

**Clean-in-place optimisation**

Cleaning of processing equipment is a critical operation within food and drink manufacturing but comes with a significant economic and environmental cost.

The University of Nottingham has been working with Loughborough University and several industrial partners, funded through Innovate UK projects, to develop an intelligent multi-sensor technology to monitor the removal of surface fouling during cleaning of processing equipment[4, 7].

Trials have been performed at laboratory, pilot and full production scale to determine the most suitable sensor configurations and machine learning methods.

In this project, several different machine learning methods were studied to determine their performance for predicting the presence of fouling using measurements detected by ultrasonic sensors. A test section with transparent sides was built so images could also be recorded during cleaning to help train and test the models.

The results from the images (target data set) and predictions from the different machine learning models (K-nearest neighbour, support vector classifier, random forest, adaboost) can be seen in Figure 3. The results show that all machine learning methods give acceptable predictions (>99%) except the support vector classifier. Although the results have enabled the research team to determine the most suitable machine learning methods, this was only achieved via a trial and error approach, which is often the case when using machine learning.

**Olive Oil Quality Assessment**

Olive oil has been produced for at least 8000 years and plays an important role in diet and health. Extra virgin olive oil is a high-value and vulnerable food product, which regularly tops the list of foods most at risk of fraud in the EU[1].

In the UK, government testing recently found that one third of olive oils sold in Britain are adulterated or breach quality standards[9].

Optical spectroscopy is embedded in the EU regulations for olive oil quality, with ultraviolet absorbance measurements indicating the level of oxidation in the sample[10]. Additionally, fluorescence excitation-emission matrices (Figure 4) show significant differences between extra virgin and refined olive oil.

With funding from Innovate UK and EU H2020, Liquid Vision Innovation has developed an optical sensor that directly reports both the level of secondary oxidation and key fluorescence properties of olive oil samples.

Their approach is direct (chemical-free), thus enabling on-site monitoring of key quality parameters of olive oil, creating opportunities for process optimisation at the mill and increased sampling frequency through the supply chain.

**Summary**

There is no doubt that food and drink manufacturing will experience an increased use of online sensors and machine learning methods in the future. However, for an effective uptake of this technology, there is a need for more affordable and easy to use sensors capable of measuring key quality parameters in ingredients and final products.

Machine learning has great potential within the food and drink sector but there are many current limitations of the techniques which must always be considered for any new application.
Artificial intelligence (AI) has rapidly increased in prominence in every area of our lives over the past few years. Driverless cars are hitting the headlines, Amazon’s Alexa is a feature in households across the globe and AI is even being considered in the prevention and control of diseases. A 2017 study by PricewaterhouseCoopers found that by 2030, global GDP will be 14% higher as a result of AI adoption, contributing an additional $15.6 trillion to the global economy, so it is clear that the potential to transform every area of our lives is huge.

Defined as ‘the capability of a machine to imitate intelligent human behaviour’ (Merriam-Webster), AI is now beginning to make its mark on the food industry, allowing food manufacturers to streamline processes, improve operational accuracy and boost productivity. AI can be applied in almost every area of the food industry where routine tasks are integral to operations and it is particularly valuable in label and date code verification, as it can carry out this function with a higher degree of accuracy than a person, protecting manufacturers from product recalls and helping to combat the problem of food waste. But how does this work?

Transforming the traditional vision system

AI is poised and ready to transform label and date code verification. Historically, manufacturers have relied on pen and paper checks performed by operators on the packaging line, which brings its own challenges due to the time-consuming nature of the checks, the risk of inaccurate data and the problems of storage of the paperwork.

Traditional vision systems, while in theory a great addition to the packaging line to perform this function, have not been widely used in this area of the food industry as they are better suited to optical character recognition (OCR), which is not commonly used in the food industry. Inkjet and thermal printers are more typical as these formats allow brands to have more flexibility in their packaging designs, yet they frequently result in varying fonts and sizes, as well as occasionally blurred date codes or misplaced printing. Vision systems usually struggle to read these formats as the image is not clear or uniform enough for the system to accurately process the dates (Figure 1).

Add high temperatures that can distort the images or the presence of smears or water, and all in all, vision systems are generally not well-equipped to deal with the variables of a food facility. However, incorporating AI can transform vision systems,
allowing them to read any label that is legible to the naked eye, no matter what the conditions or the print type.

**Incorporating AI**

AI at its core uses technology to do what humans do at increased speeds and with greater levels of accuracy. So when it comes to checking date codes on a packaging line, AI enables systems to check these labels more quickly and accurately than a human operator ever could. At its most basic level, AI aims to replicate a human brain; where a brain uses neurons to pass sensory messages around the body, AI does the same with its neural network.

A neural network is a set of algorithms that is used to deal with complex problems with an element of variability. For example, humans can identify images that they have never seen before, based on their experience of seeing similar things and getting feedback as to whether they are right. For example, if you have seen a cat sitting next to a fire, you would also be able to recognise that the animal leaping onto a sofa is also a cat (Figure 2). An untrained neural network does not have this ‘experience’ so it must be trained to understand a dataset of images and assign them to the correct classification. Labelled data is needed to train a neural network, for example a ‘good date’ or a ‘bad date’, so that over time, it can start to recognise where new images should be classified. As more and more neural networks are added, they build to create a further level of AI named ‘deep learning’.

**Neural networks achieve deep learning**

Deep learning uses these artificial neural networks to simulate the cognitive processes of a human brain when it comes to decision-making and recognition, using upwards of ten layers of processes and millions of these networks. In this way, deep learning is good at identifying objects or features and classifying these into specific
sets. This works especially well when recognising errors or missing items that are unknown in advance, as can be common on a packaging line. It is an extremely effective way to solve complex classification problems where there is a high degree of variability – for example reading back the date code on food products where different fonts, positions and artwork are in use on a regular basis, as well as varying printing technologies (e.g. inkjet, thermal, laser etc.). Deep learning models can identify any unacceptable reads, such as an illegible date code, while also tolerating natural variations in complex patterns, for example a date code printed higher on one packet than those on the rest of the line.

The most common neural network used in machine vision applications is the Convolutional Neural Network (CNN). These are extremely complex, however, essentially they work like an algorithm to extract model data based on large training sets. Once the system has been trained, it can even recognise images it has never seen before as it uses features already learned to analyse new image data and classify the new image based on the probability that it belongs to a given category.

With deep learning, adding more training images improves the accuracy of classification as it has a greater level of ‘experience’ to draw upon when meeting certain features for the first time, which makes it more resilient to changes over time.

**Machine learning**
Machine learning is a term that can encompass both neural networks and deep learning. It allows systems to automatically learn and improve from experience without the need for explicit programming as they can access data and use it to learn for themselves.

A key feature of machine learning is that it can be used to segment and classify data based on examples it has already seen, which the algorithms can predict. It relies on huge datasets and vast amounts of human effort to train up the systems to make decisions, but once it is programmed it is an extremely useful way of automating routine and unsafe tasks, or those prone to human error, to improve productivity and remove operators from dangerous or mind-numbing tasks.

In a repetitive process, such as a packaging line, AI with machine learning can really come into its element. It is designed to spot patterns, and an incorrect date would be flagged as an anomaly to the pattern. The accuracy levels would be greater than a human reading the packages who could be inclined to miss the misprinted or illegible date code due to the monotonous and repetitive nature of the task.

**Product recalls**
A major study by Brunel University, London, and Ghent University reviewed the production processes at 47 food manufacturers in Belgium and found that human error is a major cause of food waste, accounting for 10.9% [1]. It is also the primary cause of product recalls, which contribute to the food waste caused by manufacturers. With hundreds of packages flying past for hours at a time, it can be very difficult to spot a wrong date before it is shipped out to supermarkets across the UK, only then to be recalled to protect consumer safety.

Humans can grow tired and misread date codes on the packaging line, but a machine will be able to continue for hours and scan each one as if it were the first, reducing the risk of these recalls.

The costs associated with a product recall can be quite staggering and in the realm of £330,000. This includes direct costs, such as removing the
product from the market and investigating the cause, but also indirect costs such as fines, lost sales and industry impact.

But it is not just the cost that can have a devastating impact. A product recall can ruin a business’s reputation and can result in a loss of orders from customers. Furthermore, a recall could have devastating effects on individuals, particularly if the product due to be recalled has resulted in food poisoning or even a fatality.

The waste that is generated both in terms of the ingredients, the final product, the packaging and sometimes the fuel used to transport the products also takes their toll on the environment and this is an issue that many retailers are looking to tackle.

Preventing food waste
It is estimated that at least one third of food produced worldwide ends up as waste[2]. The Courtauld 2025 commitment[3] is a UK programme managed by the Waste Resources Action Programme (WRAP) to identify priorities, develop solutions and implement changes to cut the carbon, water and waste associated with food and drink by at least one-fifth by 2025.

With a view to tackling the food waste problem, and in particular product recalls and how preventing them could reduce wastage, a large retailer approached its food manufacturing suppliers in 2017. Two of the retailer’s suppliers, both leading global food manufacturers, asked OAL to work with them to meet the retailer’s brief and combat the issue of incorrect date codes entering the supply chain and contributing to the problem of waste.

OAL understood the potential of AI to address this challenge and was awarded an Innovate UK Grant of circa £1m to develop the solution in partnership with the University of Lincoln.

The University put together a team of global experts, including the founding professor of machine learning, Stefanos Kolias, who had produced world-leading research activity in the fields of machine learning and intelligent systems, and Professor Xujiong Ye, who leads the Computational Vision research group.

By combining machine learning and AI, APRIL Eye takes the human away from the boring and repetitive tasks and reduces the risk of errors while safeguarding the packaging line, the manufacturer’s bottom line and the brand itself.

November 2017 and since then has gone through many trials and optimisations following industry feedback. As the team’s knowledge developed, the scope of the project grew, and the launch of APRIL™ Eye as the world’s first AI-based vision system has proved to be instrumental in preventing recalls and combatting food waste across the industry (Figure 3).

How it works
A label and date code verification system like APRIL Eye works by reading the date code as a human would and ensuring it is correct. By combining machine learning and AI, APRIL Eye takes the human away from the boring and repetitive tasks and reduces the risk of errors while safeguarding the packaging line, the manufacturer’s bottom line and the brand itself.

To be able to read the date codes, APRIL Eye has been trained up using half a million pictures of date codes with various fonts and printing formats (whether inkjet, OCR, thermal etc.) to ‘teach’ the system to recognise numbers and letters, whatever they look like as long as they are legible to the naked eye. In this way, the technology can be incorporated into the packaging line and end users need not undertake any taxing training.

Upon scanning packaging, APRIL Eye takes a picture of the date code and uses its database of date codes to ensure that what it is reading matches the pre-programmed date. Once a decision is made, the system confirms and moves on to the next package. If the package is labelled with an incorrect date code, the packaging line is stopped. APRIL Eye is able to scan over 1,000 packs a minute, offering a fully automated, fool proof system to prevent incorrect packaging from entering the supply chain, helping to reduce waste (Figure 4).

Protecting the packaging line
AI has proved to be invaluable in the packaging line, protecting not only food packages from being recalled, but also in protecting consumer health and helping to reduce waste.

The goal of AI is to ultimately create systems that function independently and intelligently, and there have been great steps forward in improving processes and reducing wastage.

References and article available online at fstjournal.org/features/33-4/date-code-verification

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Factories get smarter
Industrial automation has traditionally provided the food industry with faster, more reliable and cleaner production capacity - however, with the advent of the smart factory and commercial Artificial Intelligence (AI), the factory of the very near future is starting to make production efficiency improvement decisions itself.

The first stage of becoming a smart factory is digital network communication; having the right data infrastructure allows companies to create, move and use that data efficiently. With the swift movement and processing of data comes homogeneous control and fast responsive manufacturing, which in-turn justifies investment in the latest automation technology.

Getting the most from a smart factory is then a case of being aware of the possibilities. This is where using state-of-the-art technology, such as AI, can already improve the performance and efficiency of factory assets and human resources.

**The role of the Industrial Internet of Things (IIoT)**

The role of the IIoT in today’s factory is to connect customer demand to a fast and flexible production facility. Once a purchase decision is made then any increase in the speed of response from the manufacturer is a competitive advantage. If the IIoT offers us one thing, then it is the ability to define customer demand instantly and adapt production to suit.

Companies that can be flexible enough to move away from large batch production can also avoid the cost of large stock holding, both at the manufacturer and throughout the distribution chain. Customisation is already a unique selling point for a large number of consumer goods. The food industry is following suit with individual printing and marking options being designed into many new products. Customisation equals profitability in both cases. The transfer of data from a sales operation to a manufacturing site, out to the suppliers and then simultaneously back to the distribution and retail network is the key to responsive, flexible manufacturing. To achieve ‘batch size one’ profitability and efficiency we must have the connectivity that the IIoT offers.

The ability to generate, record, transfer and process a large amount of data reliably and efficiently has other benefits. It enables a higher degree of traceability, for example, serialisation is already essential for many food, pharmaceutical and consumer products. Better information also allows for continuous improvement and process optimisations at a micro and macro level, generating multiple opportunities for increased efficiency and cost reduction.

**Artificial intelligence in context**

AI is still at the beginning of its journey but we can expect it to have a substantial impact on the industrial environment over the next few years. It is a perfect fit for manufacturing and leading companies are now integrating various AI functions into industrial automation equipment. Advanced Analytics (AA) and AI technologies are extending traditional machine control architectures with more advanced
data processing, learning and decision-making capacity. The objective is to deliver increased productivity, efficiency, reliability and accuracy, as well as opening up new possibilities for machine control.

AI can, for example, be a driver for increased productivity. Today, most machines are still built to work within defined margins of capability – perhaps to allow for different loads or speeds or safety ranges. AI technology using deep learning algorithms within the control system enables machines to be driven right up to and even beyond today’s margins, significantly boosting productivity without compromising reliability and quality.

Applying AI principles to individual machine processes can already help to reduce auto-adjustment times, synchronise increasingly complex systems and offer helpful suggestions to operators. It can even enable autonomous decisions to be made based on measured data in real-time, further optimising the process.

Making reliable predictions based on experience, evidence and guidelines is a fundamental function of human intelligence. AI is no different in this respect; it can contribute towards more effective predictive maintenance by monitoring the condition of components to enable replacement before damage occurs, so preventing unplanned downtime.

This approach is already in use but deep learning algorithms are pushing the boundaries further, calculating with more accuracy how long a component can run before replacement. It may even be possible to compensate for delivery times on replacement parts by slowing the machine down slightly to increase longevity rather than stopping the production line completely.

Similarly, the combination of AA and AI can be a driver for increased efficiencies right across the production environment and here we get into the realm of Big Data Analysis. AA and AI edge computing technologies enable different machine states to be recorded and analysed in real-time, further optimising the process.

Today, the latest robots, such as the new MELFA FR robot series from Mitsubishi Electric, are available with AI functions and can increase the yield in industries such as food and life sciences. Source: Mitsubishi Electric Europe B.V.

Reaping the maximum benefit from this development will depend on control systems that not only embed these technologies but also provide higher levels of connectivity. If the full spectrum of data sources on the plant floor can be connected to edge computing platforms for efficient processing and on to Manufacturing Execution/Information Systems (MES/MIS) and Enterprise Resource Planning (ERP) systems, then the full benefits of AA and AI are realised. This level of integration enables a far greater range of key performance indicators (KPIs) to be analysed and so can be used to drive improvements in overall equipment effectiveness (OEE).

Control systems built around AA and AI technologies are machines that are self-learning and self-optimising. The importance of AI to the machine control market cannot be overstated. In addition to developing products that incorporate a connection to cloud based AI as a service, IBM’s Watson for example, Mitsubishi Electric for one supports many standard analytic AI algorithms and services and is positioning its developments in AI technologies under its own brand to reflect its growing importance.

Processing at the edge
Managing the crossover between Information Technology (IT) and Operational Technology (OT) is the next major challenge. The successful merge of these worlds needs to address the skills gap that has traditionally existed between automation experts and IT departments. Historically the OT layer is managed by automation engineers, who do not necessarily have extensive IT skills, while programmers and IT system architects may not completely understand the automation world.

The most recent technology developments are based on edge computing, which provides the answer by bridging the gap between IT systems and plant level automation. Edge devices can collect and analyse data from neighbouring automation systems and make decisions in real time to influence the production process.
computing technology (described earlier) is being used to leverage the value of manufacturers’ data using advanced analytic algorithms executed on the edge of the shop floor.

Another important category of process data is that used for traceability and consumer information, especially in the food sector. This can be employed, for example, to prove compliance with the cold chain or to attach origin information to food packaging that can be called up via a QR code. Data collected from programmable logic controllers (PLCs), controls and drives centrally and processed locally using edge computing reduces the bill for storage space in the cloud in addition to delivering many other advantages for faster production control and monitoring.

**Predicting the future**

AI is certainly playing a key role in manufacturing, moving from vision recognition to skill learning and predictive maintenance for failure prevention, however it has further scope for providing operational benefits and efficiencies. When detecting impending faults and informing operators how to fix problems, for example, AI again comes to the fore.

AI is being used to increase the effectiveness of predictive maintenance for plant automation assets. Cloud-based solutions using AI platforms analyse operational data and can optimise maintenance regimes based on actual usage and wear characteristics. Predictive maintenance for plant automation assets can of course reduce operational costs, increase asset productivity and improve process efficiency.

**Looking after your assets**

Against the backdrop of a desire to increase OEE by means of digitalisation, there is a high demand for analysis of extracted data (data mining) from production. The condition and operating profile of plant automation devices and machines can be recorded. This provides valuable information for predictive maintenance.

The resulting database information then enables predictive maintenance strategies with a significant saving potential in maintenance costs. To improve these strategies further, edge computing systems and make decisions in real time to influence the production process.

Using this technology effectively can provide a huge competitive advantage. It also creates new challenges: from system compatibility to data security. On the other hand, edge computing systems can be easily interconnected with cloud services to provide scalable data storage and management solutions. In this way users have all the benefits of IT systems, without storage issues or being influenced by potential threats.

**Edge computing solutions bridge the gap between IT systems and plant automation equipment**

Source: Mitsubishi Electric Europe B.V.

**Recording the condition and operating profile of automation devices provides valuable information for predictive maintenance.**

Source: Mitsubishi Electric Europe B.V.
There are daily reminders that the world is in the midst of a new technological revolution. The digital age is affecting all areas of our lives, and in particular, this growing revolution is transforming the entire agri-food sector, from farmers through to food manufacturing businesses, supermarkets and consumers in their own homes.

Digital technology enables transactions and planning to be undertaken more quickly, more accurately and with greater confidence. New technologies, such as the Internet of Things (IoT) and artificial intelligence (AI), enable new levels of efficiency with machines talking directly to machines. These developments help tackle the challenges in the food production supply chain, by providing new technologies to drive immutable traceability, sustainability, reduce waste and underpin food security.

**Launch of IoFT**

A new project is driving the digital food technology agenda forward. The EPSRC-funded Internet of Food Things (IoFT) Network Plus – or IoFT for short – launched last year and brings together data and computer scientists, engineers, the food industry, chemists and economists to drive digitalisation into the UK food supply chain. The IoFT Network is led by the University of Lincoln in partnership with the universities of Southampton, Exeter, East Anglia, and the Open University. The Network acts as a national focal point, funds pilot studies, carries out reviews, conducts workshops and holds conferences to discuss, address and catalyse the digitalisation of the food industry. Alongside academic expertise, the project involves industry specialists from a range of areas, such as global engineering company Siemens, IoT and machine management solutions’ firm IMS Evolve, supermarket chain Tesco, the rural agricultural consultancy Collison and Associates, as well as the high value manufacturing and digital catapults.

The motivation for the IoFT was born of a realisation that an interdisciplinary approach encompassing a whole range of new technologies was required to tackle the core challenges facing the food production supply chain. Furthermore, the challenges are inherently broad and multi-faceted. Whilst climate change overarches everything, other challenges from public health issues, such as obesity and diabetes, food waste, food fraud, tampering and tackling...
food-borne diseases are a growing cause for concern. Digital technologies, including the IoT, have much to offer. However implementing effective solutions will require an aggregation of technologies and therefore the promotion of interdisciplinary research teams collaborating across traditional research boundaries. The Network will be promoting this through suitably-targeted project funding, talks and workshops.

**Traceability and trust**

One of the key practical challenges facing the digitalisation of the food system is the complex issue of traceability. Consumers are increasingly aware of the importance of food provenance and the role that this plays in food safety and ultimately, security. For consumers, knowing something about where a particular food originated from offers at least some form of awareness of the geopolitical issues facing its sustainability or knowing something about the journey that a food product has taken offers some reassurance of its relative safety, more than their traditional trust in brand value alone.

Delivering all of the above in practice requires another key attribute: building and demonstrating an effective trust or assurance that the information encapsulated in the new technology-based system is what it claims to be. The manifestation of a digital system that represents a real-world counterpart is referred to as a digital twin, a concept often used when simulating the complexities of the IoT and other new technologies in a range of industries. Whilst it is relatively clear that computer based systems are aligned to a co-located factory, it is much more challenging to demonstrate the trustworthiness of a digital simulation of a physical food supply chain that stretches halfway around the world.

**The digital food system**

In order to help build a foundation for further investigations into the use of shared data to support digital collaboration, the IoFT has recently published a report examining different models of collaboration in the food and beverage sector. The aim of the work was to survey the landscape to identify different practices and understand better how they currently take advantage of data to enhance their collaborative potential.

Digital technologies, including the IoT, have much to offer. However implementing effective solutions will require an aggregation of technologies and therefore the promotion of interdisciplinary research teams collaborating across traditional research boundaries.
The report, which can be found on the IoFT website, traces how digital technologies are enabling a new suite of food system business models. The dominant model is still the connected supply chain from farmer through food manufacturers to large scale High Street retailers. However, digital technology is driving the penetration of new market entrants enabled by large scale digital platforms that secure rapid payment, connect to the supply chain and enable rapid delivery of food straight to the home.

The ubiquitous nature of digital platforms along with the adoption of digital service models is removing barriers to entry; digital companies are now well anchored in the food system. The report illustrates how data sharing and collaboration across the system could have positive economic and social impacts. However, sharing is sporadic and only well established in closed and tightly controlled supply chain systems. It appears that the lack of collaboration reflects commercial constraints, legal barriers, cultural issues, no common technical or data standards and issues with trust.

The IoFT is now starting to unpick the barriers to collaboration. This includes key studies to explore the notion of a ‘Data Trust’ for the food system. The ‘Data Trust’ concept has been championed by the AI community, who recognise that formal governance structures are required to underpin confidence in data, enable sharing, provide a safe legal framework for co-operation and clarify ownership of data. The Network will consult with industry and government over the next six months to consider the role and establishment of a ‘food data trust’.

This is seen as a foundational step that can realise the full potential of the digital food system. It will include a full stack of transformational digital technologies operating across the whole supply chain with wide scale use of:

- distributed ledger technology that can immutably track and trace food and financial flows,
- AI to optimise supply chain inventory in real time to reduce food and financial waste
- the IoT to record meta data (temperature, supply chain routes and durations) on foods
- novel enterprise resource planning (ERP) systems that optimise factory productivity and connect to the digital stack
- machine learning and analytics to measure foods in real time
- service robotics to automate the factory and delivery space.

Societal, environmental and economic benefits from a digitised food system are significant. The Government’s Made Smarter Review showed that when applied in food manufacturing alone, digitisation could generate £56bn of value to the UK economy over the next 10 years. These benefits reflect not only the scale of the food system but also the transformational power of digital technologies.

**Our pilot projects**

In addition to addressing key focus areas, since its launch in the spring of 2018, a total of £150,000 has been awarded to fund three pilot projects at the University of Aberdeen, the University of Stirling and the University of Nottingham. The second wave of exploratory pilot projects will be announced shortly and there will be further opportunities in the future. The initial three projects demonstrate a range of opportunities for new technologies to benefit the agri-food production chain.

**Provenance of Food Delivery through IoT**

The University of Aberdeen’s project, PROoFD IT!: Provenance of Food Delivery through IoT, is exploring the potential of novel IoT devices to enhance food safety in business-to-business and business-to-customer (B2B and B2C) food delivery. PROoFD IT! deploys low cost technology to track the food delivery process and monitor critical environmental data (such as temperature) through a connected supply chain. The team is working with local partners to understand the last-mile food delivery process in the context of both B2B and B2C deliveries. Observational studies to date have focused on temperature measurement as well as food safety processes. As a result of this foundational work,
The internal cleaning of processing equipment has become a fully automated process known as Clean-in-Place (CIP) and is beginning to take advantage of novel technologies, such as in-line sensors, IoT and machine learning.

IoT technologies can be used to automatically detect the presence of allergens and enhance the cleaning of food factories. The project addresses a key societal challenge of providing safer food and free from allergens.

The emergent findings of the project are that low cost near-infrared sensors can be combined with machine learning techniques to identify different powdered foods containing known allergens.

However, further work is required to determine the most suitable signal and data pre-processing techniques and machine learning algorithms. The results from the site visits and interviews highlighted key issues, such as the need for real-time sensor technologies that are easy to use within factory environments, and concerns around data trust and ownership.

In food and drink manufacturing up to a third of working time can be spent cleaning, significantly affecting productivity and efficiency. The internal cleaning of processing equipment has become a fully automated process known as Clean-in-Place (CIP) and is beginning to take advantage of novel technologies, such as in-line sensors, IoT and machine learning.

However, cleaning of the factory floor is still primarily completed by human workers following guidelines specified by the British Retail Consortium. One of the biggest challenges facing manufacturers is the cross contamination of allergens within the manufacturing environment, and cleaning is a critical step in preventing this. This challenge is growing as manufacturers strive to provide more variety and alternative food options.

The IoFT is asking the question: ‘What type of governance systems are needed to enact these relationships?’ Real world case studies will be evaluated in order to support the development of enquiry in these areas. Researchers with particular interests in this area will continue to be encouraged to apply for pilot funding, make contact and participate in future workshops.

The team has been developing a new system using IoT sensors and location beacons that provide intelligent compliance reports of whether food is maintained at an appropriate temperature at various stages of the delivery process.

The data generated will be persistently stored and shared via a private blockchain network, and the compliance reports will be available to delivery recipients via a mobile app interface, which also provides connectivity for data upload. As a result of these achievements, the team will shortly be testing the prototype system with external partners in the context of real deliveries. The new system will record provenance-based semantic descriptions of compliance monitoring during food deliveries and will also provide valuable information for business, customers and regulators.

Efficient and sustainable pig farming

The University of Stirling is identifying how data can be used to enhance efficient and sustainable pig farming. A team of computer scientists and mathematicians is applying statistical and machine learning methods to sensor data collected by a partnering pig farm.

The key focus is on the development of a novel digital platform that collates data and provides insight across the whole pig production system; this includes critical data on environmental parameters, farm and abattoir animal measurements, feed rates and meat quality. In addition, a team of computer scientists and mathematicians are applying statistical and machine learning methods to the sensor data, such as state-of-the-art 3D cameras, which estimate pig weight, to handwritten bits of paper, which record the average batch weights at two points in their growth cycle.

IoT Enhanced Factory Cleaning

The IoT Enhanced Factory Cleaning project at The University of Nottingham is investigating how data, novel sensors and
A taste for space

was by foot or maybe assisted by a domesticated animal to carry supplies. These initial expeditions were confined to relatively short distances by the limited availability of food but, when cooking became a routine activity, it was possible to carry a greater supply of food and explore further afield. History tells us that the fascination of humans with the stars led to a realisation that their positions and patterns could be used to navigate more precisely across land and sea, rather than just following the coast line. Necessity is a great driver of innovation and Napoleon’s military expeditions in the late 1700s convinced him that food was essential to a successful campaign. Depending

### Background

In 2017, President Trump signed a bill proposed by Senators Cruz and Nelson to add exploration of Mars to the remit of the American National Aeronautics and Space Administration (NASA). The programme involves unmanned flights to assess conditions on Mars, with the long-term aim of a crewed mission to the planet. Exploring Mars represents another example of the great expeditions that have taken place on Earth over many thousands of years. Like all expeditions, success depends on a wide variety of factors. Key amongst them are transport, navigation and food supply. When primitive humans made their first expeditions, transport
on recently-conquered towns and villages to supply food was not a reliable way to keep the soldiers healthy and ready to fight, so the French Government set up a prize which led Nicolas Appert to invent the first thermal processing of food in containers, the forerunner of the present canning industry. Naval expeditions in the 1700s also had a food problem; most voyages were severely compromised by the frequent occurrence of scurvy in crew members with mortality rates of 50 to 80% being a common occurrence. Realising the importance of healthy crews, the British Navy appointed a physician (Dr Lind) to investigate. Working on the hypothesis that scurvy was caused by poor diet, his work significantly decreased the incidence of scurvy and was a key factor in allowing Captain Cook to voyage from the UK through the Pacific Ocean and on to Australia. Lind’s work also established nutrition as an essential scientific discipline. In contrast, a failure in food supply led to the disaster of the Franklin expedition to the Arctic in 1845 when the whole party of 129 people perished in distressing circumstances.

Now we are considering extra-terrestrial expeditions, the same fundamental issues remain but are more complex due to the vast distances and times needed to travel to Mars as well as the many unknown factors relating to the conditions far away from Earth. For example, some of the Polar expeditions established food dumps along the route in advance of the actual expedition to reduce the weight carried on the sledges. Setting up food dumps on the way to Mars over a distance in excess of 4.5 x 108 kilometres is in itself a mammoth task and raises questions of food shelf-life, the cost of sending the supplies to the desired location and the consequences of missing or losing a food dump.

Our main source of knowledge about space flight comes from the International Space Station (ISS). This huge structure (about 100m x 30m and weighing 408 tonnes) has been orbiting the Earth 15.5 times per day for over 20 years at 27,580 km/h and at a height of 400km. In that time, it has hosted several hundred astronauts who have not only built and maintained the ISS but have also carried out research on space-relevant topics. The ISS is a collaboration between the USA, Russia, Europe, Japan and Canada. Each partner supports the ISS financially as well as supplying equipment and consumables. Despite the political tensions on Earth, the ISS project has survived and, at any one time, there will be a mixture of American astronauts and Russian cosmonauts on board the ISS with visitors from the other participating countries. Tim Peake was the UK participant when he launched into space on December 2015 for a six-month visit to the ISS.

**ESA study on under-consumption of food in space**

The European Space Agency (ESA) is supporting NASA in the Mars project and one issue they have highlighted is the decreased consumption of food during space flight. Nutritional studies of astronauts have shown that in the vast majority of missions, only around 80% of their recommended daily calorie intake is consumed. The flavour team members were selected to ensure the TT had the necessary skills to evaluate the role of flavour in space food. The TT contains academic and commercial members with expertise in areas such as physiology, nutrition, taste and smell receptors, flavour chemistry, product development, shelf life, sensory analysis and the psychology of multimodal perception. Since the remit of the project is to evaluate the information available and propose a future research plan, the team funding is for two face-to-face meetings during the two-year project duration with all team members working

**The food rehydration station adds hot water to the dehydrated food packages; food is eaten directly out the packets to save the weight of plates and bowls**

Nutritional studies of astronauts have shown that in the vast majority of missions, only around 80% of their recommended daily calorie intake is consumed.

**Mission. ESA has set up two Topical Teams (TT) that are looking at the fundamental science behind this under-consumption. One TT is focused on nutrition and is evaluating the effect of under-consumption of the macronutrients (protein, carbohydrates and fats) on micronutrient (vitamins and minerals) intake, as well as considering the potential long-term effects of three years under-nourishment. The other TT is focusing on whether the flavour of space food is a potential reason for decreased food intake because flavour quality and food intake are related, as described in the following paragraphs. The objective of the team is to consider what factors might affect flavour and food intake during space flight and propose experiments that could provide evidence to support these hypotheses.**

The flavour team members were selected to ensure the TT had the necessary skills to evaluate the role of flavour in space food. The TT contains academic and commercial members with expertise in areas such as physiology, nutrition, taste and smell receptors, flavour chemistry, product development, shelf life, sensory analysis and the psychology of multimodal perception. Since the remit of the project is to evaluate the information available and propose a future research plan, the team funding is for two face-to-face meetings during the two-year project duration with all team members working
We know that the human body have been well-documented that affect satiety and appetite the body’s control mechanisms regarding food intake and affects food consumption. The science behind food intake and the body’s control mechanisms that affect satiety and appetite have been well-documented. We know that the human body strives to maintain food intake so it meets the body’s needs for energy, repair, growth etc. It is now apparent that taste and smell receptors are part of this regulatory process, not just when we eat food and interpret the receptors’ signals as ‘flavour’ in our brains but the receptors are also involved in controlling the uptake of nutrients in the gut. Because of the multiple roles of these receptors, they are often referred to as chemosensory receptors. If food does not taste good it is rejected, presumably to avoid toxic compounds or spoilt foods that may contain food poisoning organisms, but the current thinking is that the chemosensory receptors that identify the taste of our food also screen the incoming food for its nutrient value. An attempt to translate between the taste function and the screening function of the chemosensory receptors is shown in Table 1. The role of chemosensory receptors in the mechanisms governing food intake (what is allowed to pass through the mouth) and food uptake (what is absorbed in the gut) is a fairly recent discovery and has led to much research on the ‘mouth-gut-brain axis’ i.e. how the receptors, the hormones and the brain control our food intake[5]. The food intake control is undoubtedly complex and not fully understood but the key factor is that chemosensory receptors (and probably odour receptors too) are an important part of that control mechanism[4]. A recent study[5] proposed that there is another food intake mechanism that allows humans to overeat if the taste receptors indicate that the food is nutritionally beneficial. This is thought to be part of our ancient survival mechanism, which means we can overeat one day so we can store energy as fat in order to survive if there is no food available for the next few days. Now that many parts of the world enjoy regular and nutritious food supplies, it has been postulated that this ‘overriding’ mechanism may be the factor that causes some people to over-eat and become obese. If we turn this hypothesis around, then it is possible to postulate that poor-tasting food may decrease food intake and this may be a factor in the decreased food intake during space flight. If we take this as our first learning, then the scientific questions that arise are along the lines of ‘What factors can interfere with the chemosensory receptors and could be responsible for decreased food intake during space flight?’. The team has spent some time looking at the various possibilities and has rejected some ideas while homing in on other specific areas. One area that was considered and rejected was the information about flavour perception in commercial aircraft flights, where poor flavour of airline meals is a recurring theme. However, the ISS living space is pressurised to 1 bar, the same as on Earth, unlike commercial aircraft that are pressurised to around 0.75 bar. Therefore, the conditions are similar but not the same and it is not valid to translate the flavour perception results from commercial flights to the ISS situation.

**Conditions on board**

Our focus areas have been chosen after consideration of the conditions on board the ISS. The first is the quality of the recycled air which contains not only the usual volatile organic compounds (VOCs) but also, a high level of carbon dioxide (2-4%), which is way above earth levels (0.04%). It is known that carbon dioxide in fizzy drinks is converted to carbonic acid by the enzyme carbonic anhydrase and that this compound activates the sour taste receptor and may activate some of the trigeminal receptors as well. The first question from this observation is ‘What effect might constant stimulation of the sour/trigeminal receptor have on overall flavour perception? Is it like a background signal that interferes with the other flavour sensations and diminishes the overall taste quality of food or do the receptors/brain react to filter out the signal?’. The second question is ‘How could we test these hypotheses in Earth-based studies to determine if this is a significant effect, worthy of further investigation?’.

### Table 1 Translating taste function into the food screening functions proposed in the text

<table>
<thead>
<tr>
<th>RECEPTOR</th>
<th>SCREENING FOR...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt</td>
<td>Micronutrient content – minerals</td>
</tr>
<tr>
<td>Sour</td>
<td>Spoilt food detector</td>
</tr>
<tr>
<td>Bitter</td>
<td>Potential toxic compounds</td>
</tr>
<tr>
<td>Sweet</td>
<td>Carbohydrate</td>
</tr>
<tr>
<td>Umami</td>
<td>Protein</td>
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<tr>
<td>Fat</td>
<td>Fat</td>
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</table>
Another relevant area is the quality of the recycled water on the ISS. Currently, urine, washing water and water vapour (e.g. sweat) from the air within the ISS are collected and cleaned by passing them through two massive (500 kg) filters. Studies by NASA have identified potential toxic contaminants in the recycled water and limits, referred to as Spacecraft Water Exposure Guidelines or SWEGs, have been set to ensure the safety of astronauts. Closer inspection of the NASA data reveals that some compounds are marked RWC, which stands for Reduced Water Consumption i.e. these compounds are flavour-active at the levels found in recycled water and decrease the amount of water an astronaut will drink. Anecdotal evidence from interviews with astronauts is that very few, if any, drink water on its own; they add fruit cordial or squash, presumably to mask the taste of the recycled water. Some of the compounds found in recycled water are reported to have bitter flavours and are present at 10 to 100 times the taste threshold for these compounds. This means that recycled water is safe to drink but not very palatable. However, much of the food on the ISS is dehydrated to save weight and therefore recycled water could affect the perceived flavour of much of the food supply, not just drinks.

**Bitter compounds**
The information that water may impart a bitter note to food on the ISS, then led to the question 'What evidence is there that bitter compounds actually affect food intake?' After all, we like bitter tastes, such as quinine in tonic water or hops in beer. A scan of the scientific literature showed that some publications report a negative effect of bitter taste on food consumption, others report no effect. A deeper dive into the literature shows that there are 25 different bitter receptors in humans, which are activated by different bitter compounds, but it is not known if all the bitter receptors are involved in the food intake mechanism or just a subset. If the latter is the case, then it could
explain why some compounds affect food intake while others do not. As ever in scientific research, one question typically results in another set of questions to which there are no answers! To resolve this question, further experimentation is needed. As a way to break through the unknowns, one idea is to run sensory experiments to determine if the contaminants affect the flavour of some selected foods. However, the astute reader will realise that the compounds in question are toxic and it will be difficult to design a sensory study that delivers clear results and meets ethical guidelines.

Noise
A slightly simpler factor to investigate is the effect of noise on food intake. Although there is no sound in space (due to the lack of air to transport sound), inside the ISS there is a constant drone of life-support equipment. Sampling the ISS noise is easy as it only requires a recording from a drone of life-support equipment. Inside the ISS there is a constant lack of air to transport sound), so dehydrated foods available on the ISS. Weight and space are crucial as the launch site for the Mars mission. With reduced gravity on the Moon, a launch to Mars would require less rocket power. Sending more robots to scout the Martian surface is also planned. Whoever crews the Mars mission, will need exceptional skills, backed up by all the knowledge available. Our tiny team is proud to be involved in that endeavour.

References and article available online at fsjournal.org/features/33-4/food-in-space

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Andy Taylor’s career involved flavour research at the University of Nottingham and then at Mars Petcare. The academic research led to the formation of a spin out company, Flavometrix, to apply the fundamental ideas of flavour release to commercial products and still provides consultancy services to small and large companies. Andy also is the Chief Assessor for the annual GIRACT awards (www.giract.com) which are sponsored by food and flavour companies to encourage students to consider flavour research as their PhD choice.

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Gene editing offers dietary benefits

Plant breeders have an occupation that requires deep reserves of patience and for good reason. Using standard breeding methods, it can take decades or longer to create new traits with the characteristics they have targeted.

Food scientists do not have that kind of time. Working under tight deadline constraints for the production of new food products, they have typically looked to new processing methods or new chemical solutions as a way to achieve their goals.

Gene editing technology has changed all that. It is now possible for a laboratory scientist to remove undesirable characteristics at the molecular level, without affecting the rest of the plant’s composition. This technology allows food scientists to rapidly do what farmers have done for hundreds of years: choose the best crops and breed them to make better, stronger, higher yielding plants.

Food scientists around the world are concerned about the rise of food-related illnesses and consumers are paying more attention to what is in their food and where it comes from. That is why it has become critical to have a fast and effective way to improve the health and nutrition profile of the plants we eat every day.

Dan Voytas of Calyxt explains how the company has used gene editing to develop a healthier cooking oil.

A gene-edited solution
On March 1, 2019, Calyxt became the first company to introduce a gene-edited food to the US market. The product, Calyno®, is a high oleic soybean oil that contains approximately 80% oleic acid and 20% less saturated fatty acids – far less than commodity soybean oils. With zero grams of trans fat per serving and reduced saturated fat content, Calyno is a premium food ingredient that is similar in oleic content to olive, sunflower and safflower oils.

The product was developed using Calyxt’s advanced plant selection process that allows the team to work with the unique characteristics that naturally exist in each plant. This technology is much more straightforward than those used by the previous generation of biotech agri products, which were mostly introduced by big companies like Monsanto, Syngenta or Bayer.

Gene editing technology offers an opportunity for smaller companies to bring new, healthier products to the marketplace. Calyxt has the exclusive license to use the TALEN technology in plants, which allows it to move quickly through the development pipeline. The company was originally formed in 2010 as a subsidiary of Cellectis, a clinical-stage biopharmaceutical company that harnesses the immune system to target and

Transcription Activator-Like Effector Nucleases (TALEN) – the gene editing method co-invented by Dan Voytas in 2009 in his plant genetics laboratory at the University of Minnesota. Using TALEN, DNA fragments of the enzyme that transforms ‘good’ oleic acid into a ‘bad’ fatty acid are deleted, without adding anything to the plant genome.

There is a high fidelity on the edit that allows scientists to make precise edits, overcoming some of the challenges that existed in the technology previously and making the technology easier to use.

The TALEN technology can ‘dial down’ unhealthy aspects of the plant and ‘dial up’ the nutritional benefits that already exist. The soybeans are not genetically modified, because, unlike crops created through transgenesis (GMO), no foreign material is added. Instead, gene editing allows the team to work with the unique characteristics that naturally exist in each plant.

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How Calyno is made
Calyxt’s scientists use
eradicate cancer cells, and Calyxt went public in July of 2017.

**Sustainable and traceable**

The story of Calyxo’s development, growth and production resonates with consumers who are eager to learn the specifics of where their food comes from. Unlike many olive or sunflower oils, Calyxo oil is grown entirely in the United States. The soybeans are grown by more than 100 midwestern growers on more than 34,000 acres of farmland. The value proposition for growers is compelling, since these soybeans provide them with an alternative crop and a new source of income generation. Farmers growing the soybeans used for Calyxo oil receive a premium for their crops that is higher than the price on the Chicago Board of Trade, and Calyxt buys back all of the crop from them.

In a time when everyone wants to be reassured about where their food is coming from, Calyxo offers transparency. Products are tracked using a closed-loop system to ensure they meet safety and quality standards. Through the Calyxt Identity Preserved Program, a unique supply chain model that tracks each ingredient from seed all the way to final product, each batch of oil is traceable to the county in which the soybeans were grown.

**In the kitchen**

Calyxo oil is similar to other healthy oils, like olive, sunflower and safflower oils, and it can easily be incorporated into foods and recipes without affecting taste.

It has a better nutrition profile than many other oils on the market and it also has significant culinary advantages. Its neutral, clean taste makes it a good choice for a variety of applications, including salad dressings, sauces, frying and baking. Foods prepared with Calyxo do not carry the taste of oil into the finished dish, and chefs who use it find that essential flavours are no longer masked by heavy or bitter oil flavours.

In addition, the oil offers improved shelf stability and less waste. It stays fresh much longer than conventional oil does and conveys less oil into the final product, so it has lower overall oil absorption rates. Because less oil needs to be used when working with Calyxo — with 2-3 times increased fry life — less of it is wasted during the food production process.

**What is next?**

High oleic oil is the first product to come from the Calyxt product development pipeline, but many more possibilities are in the research and development stage. Calyxt is working on wheat that has been gene edited to provide up to three times more dietary fiber than standard white flour, enough so that one serving will provide the recommended daily allowance of dietary fiber. This is significant in an era when 50% of Americans do not meet their daily fiber requirement. (Total dietary fiber intake should be 25 to 30 grams a day, but current dietary fiber intake among US adults is about 15 grams a day, on average).

Work is moving forward on a gene-edited alfalfa plant that is more digestible as animal feed, allowing the production of meat with less feed, less waste and less methane creation. Another product in the pipeline is gene-edited potatoes that can be put in cold storage without creating sugars that can form cancer-causing chemicals when cooked at high temperatures. Long-term R&D efforts also are exploring the possibility of developing allergen-free peanuts, among other projects.

**Food industry implications**

The food industry is on the verge of a major transformation that comes with greater care and concern for our planet, our farmers and our health. Gene editing of food crops may be the best and fastest solution to improve food quality and to begin combating diet-related conditions like heart disease, Type 2 diabetes, obesity and food allergies.

Although the EU has currently ruled that gene-editing technologies should be subject to the same stringent regulations as conventional genetically modified (GM) organisms, a number of EU countries are calling on the European Commission to update EU GMO laws with regard to so-called new plant breeding techniques (NPBTs).

In the future, there is likely to be an increasing focus on healthier foods, wellness, plant-based proteins and sustainability that will align with current and future consumer demand.

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**References and article available online at**

[fstjournal.org/features/33/4/gene-editing](http://fstjournal.org/features/33/4/gene-editing)

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Food ethics: the moral maze

Introduction
Is it wrong to sacrifice pristine tropical rainforest for the production of cheap beef, soya and palm oil? Should the marketing of HFSS (high fat, sugar and salt) snack foods and sugary carbonated beverages to children be more tightly controlled? Does the food industry put profit before planet with single-use plastic food packaging? Why should farmers and the food industry be concerned about animal welfare and environmental sustainability? These questions are typical of those analysed within the field of food ethics. They are normative ethical questions, which means they are concerned not with how the food industry actually behaves (although that is of interest), but with how the industry ought to behave in relation to sound moral principles. They relate to the rightness or wrongness of food industry standards of action, which can be appraised by means of ethical analysis as a decision-making tool, thereby helping to calibrate a food business’s moral compass.

In the first of a two-part article, Ralph Early, formerly Professor of Food Industry and Head of the Food Department at Harper Adams University, discusses the role of food ethics in decision-making and its importance to the food industry.

Some food companies are prepared to risk the manufacture and sale of products which are unsafe to eat.
the food industry and the global food system, issues that have the potential to raise serious ethical questions will always be found. Perhaps this is inevitable given human nature and the present-day construction of an industrially anthropogenic, neoliberal age, where profit and the power of those who pursue it most aggressively frequently outweigh the common good of people and the planet. Troubling as this may be, it does reinforce the justification for food ethics as a specialised field of inquiry. Certainly, the conduct of some unscrupulous as well as some apparently scrupulous food businesses would seem to confirm this.

Food ethics then is a topic that ought to be of interest to all food industry professionals, especially to food company CEOs, directors and senior managers and not just university academics. The purpose of this two-part article is to introduce the concept of food ethics and to illustrate ethical analysis in relation to selected food ethics issues.

Why food ethics?

History reveals that for some 2,500 years, ethical concerns about food have been influenced by notions of temperance and the acceptance or rejection of specific food materials according to religious laws prescribed by divine-command ethics or supernaturalism.

Over many centuries, food-related ethics and human relationships with food have revolved around notions of food as a quality that gives life, as a bounty provided by nature and/or the gods, and as a social good in which all should be able to partake, fairly and with good grace.

It is not surprising therefore that gluttony is listed as one of the seven deadly sins, or cardinal vices, of Christian theology. For instance, in times when the security of food supply was...
uncertain, e.g. due to failed harvests caused by disease, extreme weather conditions or political unrest, taking more than one’s fair share of food would have been regarded as morally reprehensible. But regard for food as a component of human life and mankind’s ethical relationship with food began to change as methods of food production became more technological and scientifically prescribed, and as understanding of the role of nutrition in human health developed[4].

Gradually, over the last 300 years or so, our focus on food has shifted from one in which food as a material underpinning social structure and order was central, to one in which the way food is produced is of particular importance, as judged by our evolving ethical lens.

Today, as citizens transformed into consumers by the marketplace, we increasingly express concerns about what food is and, for instance, whether or not it is ethical and sustainable. Our concerns are frequently mediated through the process of food choice, which means that the selection and purchase of food may be an explicitly ethical act. It may also constitute a political act.

For example, those who choose fair trade products (Figure 1) may be troubled by primary producers not receiving a fair return for their efforts (ethical) and they may also be disturbed by the imbalance of power between multi-national corporations and small-scale producers (ethical and political). Similarly, those who choose organic produce (Figure 2) because of unease about the effects of intensive farming on the environment and biodiversity (ethical) may also be disconcerted by the fact that a small number of global biotechnology corporations now dominate the global seed industry (ethical and political), especially with respect to GM crops (ethical and political).

The food system that feeds us daily has changed dramatically over the last half century and as we have become increasingly dependent on the food industry for our daily fare, we have realigned our ethical concerns. Those that relate to human relationships with food were historically of central importance, but are now less so. They have been subordinated by our increased focus on the ways in which the farming, fishing and food industries keep us fed, as well as the effects of food on our health, well-being and longevity understood in scientific terms. This shift in perspective, accompanied by a general trend in society expressing moral concerns about the world in which we live, has led to the development of food ethics as a discrete field of moral philosophy.

The territory of food ethics

The food system is the territory of food ethics. The multiplicity of agriculture, fishery, primary food processing, food manufacturing, food service and food retailing businesses etc. that constitute the system define the environment in which food ethicists commonly operate. But we must also recognise that the relationships between people and their food, particularly the lack of it causing hunger and malnutrition, also constitute an important ground for food ethics’ concerns.

The term ‘food ethicist’ has increasingly entered common usage since 1996 when, judging by the literature, the term ‘food ethics’ was introduced to the academic lexicon by Mepham[5]. Food ethicists may themselves be professional philosophers with an exacting interest in the moral values and ethical conduct of food businesses, but some food industry directors and managers also fulfil functions which require appeal to ethical theory in order to define and control business operations.

Table 1 The scope of food policy as an element of public policy

<table>
<thead>
<tr>
<th>Food Policy Domain</th>
<th>Food Policy Objectives</th>
</tr>
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<tbody>
<tr>
<td>Food entitlements</td>
<td>Elimination of national food poverty</td>
</tr>
<tr>
<td>Food security</td>
<td>Ensuring an adequate food supply</td>
</tr>
<tr>
<td>Food and health (Nutrition)</td>
<td>Food underpinning of good nutrition</td>
</tr>
<tr>
<td>Food and health (Food safety)</td>
<td>Ensuring a safe food supply</td>
</tr>
<tr>
<td>Food labelling</td>
<td>Enabling autonomous food choice</td>
</tr>
<tr>
<td>Food additives</td>
<td>Ensuring the necessity and safety of materials added to food for technical reasons</td>
</tr>
<tr>
<td>Sustainable food production</td>
<td>Ensuring environmentally sensitive and sustainable methods of food production</td>
</tr>
<tr>
<td>Food subsidies</td>
<td>Supporting agri-food businesses and society e.g. school meals</td>
</tr>
<tr>
<td>New food products and processes</td>
<td>Ensuring the necessity and safety of new and novel foodstuffs</td>
</tr>
<tr>
<td>Food biotechnology</td>
<td>Protecting the environment and consumers with respect to e.g. genetically engineered and gene edited foodstuffs</td>
</tr>
</tbody>
</table>
Food ethics and food policy interact, or ought to if food policy is to function effectively in the refinement and execution of public policy making. Critically, this should be in linkage with public health and environmental protection, although governments do not always understand this.

**Tools of food ethics**

Unlike many aspects of food science and technology which deal in hard facts supported by empirical evidence – the black and white – ethics is a topic which attempts to establish the black and white, but often navigates in the grey. Also, when determining an appropriate course of action in response to a particular issue, food ethics analysis can be complicated by the different ethical theories to which one may appeal for guidance. In addition, food ethics itself overlaps with other ethics fields (Figure 4) which is a mark of its distinct utility.

At first sight, moral philosophy can appear complicated: not least because of the panoply of philosophers from the Greeks, namely Socrates (died 399 BCE), Plato (born 429 BCE) and Aristotle (384-322 BCE), who underpin western philosophical thinking, to the numerous scholars who, from the 18th century’s Age of Enlightenment onwards, have made important contributions to ethical theory.

Of the many theories to which one may appeal (too many to consider here) when analysing a given issue, the most useful is deontology[7,8], which is concerned with the rightness or wrongness of an act; utilitarianism[9], which holds that an act is right if it yields the greatest good (or happiness) for the greatest number; and virtue ethics[10], which emphasises the virtues of the person judged in terms of intellect and character.

In addition to the ethical theories to which the food ethicist may appeal, the ethical principles of (1) beneficence (one should do good), (2) non-maleficence (do no harm), (3) respect for autonomy (self-governance) and (4) justice as fairness, have practical value (as we will see in part two).

Clear thinking, disinterestedly logical reasoning, ethical theory and ethical principles are the tools of the food ethicist, and they must be used carefully in conjunction with knowledge and facts. When considering food systems issues, ethical positions, such as emotivism and ethical egoism, may be apparent and although both may influence perceptions of ethical issues or dilemmas, they are incapable of contributing to sound ethical judgement. Ethical analysis and subsequent judgement require a structured approach with appeal to sound ethical theory and while different analytical methods have value, e.g. the Ethical Matrix[11], a relatively straightforward approach is to evaluate:

1. The act itself. Is the act morally good or bad, right or wrong?
2. The outcomes of the act. Who or what benefits and who or what is harmed?
3. The character of the moral agent. Is the act undertaken by a person of good moral virtue or otherwise?
4. The motive of the moral agent. Does the person who commits the act do so with morally sound intent?

Analysis of a food ethics issue using this approach can deliver a confident understanding of an issue, as well as pointing to and justifying appropriate and ethically defensible courses of action.

Part two of this article will explore how food ethics can work in relation to real-world food industry issues and how it can offer insight to ethical dilemmas for food industry professionals who deal with morally challenging problems, day-to-day.

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**References and article available online at**

fstjournal.org/features/33-4/food-ethics

**Ralph Early, Independent Food Scientist and Food Ethicist**

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Ralph Early, formerly Professor of Food Industry and head of the food department in Harper Adams, retired in December 2018 after 23 years at the university working to prepare graduates for careers in the food industry. Before transferring to academia in 1993 he spent 18 years in the food industry, including the positions as Quality Standards Manager and Head of Industrial Products Development with Dairy Crest.
Gael Delamare and Craig Leadley of Campden BRI explain the potential benefits and limitations of 3D food printing. They review printing methods and consider the importance of food rheological properties, consumer attitudes and the challenges of late customisation or personalisation of foods.

In recent years, the food industry has shown an increased interest in the technology for food applications due to its potential for the creation of unique shapes and the late customisation of food.
continuous stream of food paste for each layer. The difference between them is that fused deposition modelling relies on the self-supporting properties of the paste on a print bed while hydrogel-forming extrusion requires the deposition of a paste containing hydrocolloids into a gel setting bath. FDM is probably the most widely used method for food printing. A broad range of materials can be printed using this technique – see Figure 1 for examples printed by Campden BRI.

**The importance of rheology**

The rheological properties of a food are critical parameters that need to be understood in order to successfully print using FDM. There is frequently a balance to be struck: the food product needs to flow smoothly when extruded from the print head (without blocking or trailing) but also needs to have sufficient structure, post deposition, to support the subsequent layers of deposited material. The addition of functional ingredients, such as starches and gums, can help or hinder the quality of print. Figure 2 shows, as an example, the impact of starch addition on the print quality of a carrot puree. In this example a carrot puree containing 3% starch produced a better quality of printed product compared with the other formulations.

By modelling the shear rates that occurred during extrusion and measuring the rheological properties of the material at these shear rates, it was possible to predict the print quality of the carrot puree. Print quality could be predicted as a function of printer settings (extrusion rate and printing speed) and rheological properties (consistency index, flow index and yield stress).

**Personalised nutrition**

The ability to manufacture personalised and late customised products using 3D printing is an attractive proposition. In theory, an end user could order a specific nutritional profile that could be printed on demand e.g. ‘I want a high fibre, high protein product fortified with a specific vitamin’.

While attractive in principle, our recent work has demonstrated that this might be more challenging in practice. For instance, we attempted to print and bake a high protein, high fibre biscuit by customising the recipe with varying levels of pea protein and pea fibre. The fortifying ingredients impacted on the rheological properties of the dough, which affected print quality (Figure 3, page 50). As fibre content increased, print quality reduced. High protein formulations resulted in darker biscuits (baking times and temperatures were standardised in our experiments). None of these issues are insurmountable but this simple experiment demonstrates that formulation modification impacts on rheology and consequently print quality. Downstream processing (i.e. operations post printing, such as baking and frying) is also impacted by formulation. The ‘click and print’ dream is not as simple as it might first appear. As the technology develops, it may be that methods, such as...
artificial intelligence (AI), could be used to modify print settings and downstream processing ‘on the fly’ to deal with this product/process interaction.

**Consumer attitudes towards 3D printed food**

Providing that 3D food printing is technically possible and commercially viable, consumer acceptance of 3D printed food is critical if it is ever to see widespread commercial implementation. If consumers reject the technology, then technical feasibility is irrelevant. A panel of 215 consumers was recruited to assess consumer awareness of the technology, their willingness to consume and buy 3D printed food and interest in printing 3D food at home. Only a third of the respondents (36%) had heard about 3D printed foods, but a third of the respondents who were aware of 3D printed foods (33%) felt they could not explain what they are. These results highlight a lack of communication to consumers that would need to be mitigated to increase the potential future sales of 3D printed foods. After being shown a definition and pictures of 3D printed foods, most respondents (83%) would consider eating them. The principal reason mentioned by respondents considering eating 3D printed foods was their novelty (75%). The new sensory experience (51%), appealing/creative shapes (47%), late customisation (44%) and food waste reduction potential (43%) were other reasons chosen by around half of the respondents. In contrast, the principal reason cited by the respondents rejecting 3D printed foods was the perception that the product would have undergone a high level of processing (67%). Additional concerns included the likely presence of artificial ingredients (50%), poor texture (50%), bland taste (47%) and safety concerns (42%). The 3D printed foods that receptive respondents were most likely to consider eating were sweet products (78%) including biscuits, chocolate, sweets, cake decorations and cakes, while they showed less interest for 3D printed ready meals and meat products (56% and 53% respectively). When asked about buying 3D printed foods, the majority of respondents (59%) found the idea either somewhat (44%) or very (15%) appealing.

Attitudinal differences were investigated between genders and age groups based on the respondents’ answers and characteristics. Males showed a more positive attitude towards 3D printed food than females, as a higher proportion of males would consider eating 3D printed foods (92% for males vs 80% for females). Interestingly, male respondents were more likely to buy 3D printed meat products than females, whereas more female respondents found the idea of buying 3D printed cake decorations appealing. In terms of opinions by age, two groups were evaluated: younger respondents (18-39 years old) and older respondents (40-69 years old). A significantly higher proportion of younger respondents found the ideas of buying 3D printed food and printing food at home appealing (69% and 74% respectively) compared with the older respondents (52% and 58% respectively).

**Conclusions and future perspectives**

3D printing of foods is already in commercial use. Generally speaking it is being used for relatively low volume, novelty applications like customised chocolate, cake decorations or for use in high end restaurants to create a unique dining experience. It is without question the case that intricate and impressive designs can be printed that would be difficult to reproduce with conventional technologies. A major limitation of current approaches is speed of printing, which can be of the order of 5-15 minutes depending on the complexity of the design. Some form of multi-head or serial printing designs are needed before high-speed, industrial 3D food printing looks feasible from the perspective of throughput and cost.

Existing printers are, generally, adaptations from non-food designs rather than being created with food printing in mind. There are, therefore, hygienic design and materials of construction issues that need to be overcome. Collaborative work between food industry end users and equipment suppliers is needed in order to address this. The principle of late customisation is very attractive but as demonstrated previously, it is not simply a matter of ‘click and print’ because flow behaviour and downstream processing after printing are impacted by formulation. While it may seem to be entering the realms of science fiction, as Industry 4.0 is adopted in the food industry, it is not inconceivable that on-line, customised orders could be received and printed in real time. For the potential of this late customisation approach to be realised however, process lines that can ‘adapt’ to changing formulation need to be available. Technologies like AI will be a key enabler for this approach. Clearly there will be practical limitations – taking the biscuit example discussed previously, whilst it may be possible to adjust printer settings ‘on the fly’ to account for changes in flow behaviour due to formulation, it would not be feasible to change baking temperature and time on a per biscuit basis!

Consumer acceptance of the technology does not appear to be a barrier to adoption though it is fair to say that consumer awareness of the approach appears to be quite low. Aside from industrial high-volume manufacturing or food-service applications, it may be that 3D food printing finds a niche for in-the-home applications where the current speed of printing may not be so problematic.
Microscopy tools for product innovation

Mark Auty of RSSL explains the different types of microscopy used to study food ingredients and products and assesses their performance in different applications.

Over the past 20 years, food microstructure has been increasingly recognised as important in food science and now there are a wide range of imaging tools and methodologies being applied to food research.

Mark Auty of RSSL explains the different types of microscopy used to study food ingredients and products and assesses their performance in different applications.
A polarised light microscope consists of two polarising plates arranged perpendicularly, one below the condenser (the polariser) and a second above the objective (the analyser). If the sample is isotropic, incident polarised light is not rotated, and no light is transmitted. If the polarised light passes through an anisotropic substance, such as a lactose crystal, part of the light is rotated and passes through an analyser appearing bright (birefringence). Polarised light microscopy is very useful for characterising starch gelatinisation or crystallisation, such as lactose crystallisation in spray dried milk powders (Figure 2).

**Phase contrast**

This technique has traditionally been used to study transparent materials and can be useful for characterising food emulsions or bacteria in yoghurt. **Differential interference contrast**

This technique requires the addition of specialised optical elements to a basic light microscope setup but gives excellent results and has superseded phase contrast for studying transparent materials. A polariser and prism are located one below the condenser (the polariser) and a second above the analyser (the analyser). If the sample is isotropic, incident polarised light is not rotated, and no light is transmitted. If the polarised light passes through an anisotropic substance, such as a lactose crystal, part of the light is rotated and passes through an analyser appearing bright (birefringence). Polarised light microscopy is very useful for characterising starch gelatinisation or crystallisation, such as lactose crystallisation in spray dried milk powders (Figure 2)

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**Conventional optical microscopy**

There are several optical microscopy approaches that can be used for studying different types of food materials with different characteristics and properties:

**Bright field**

Bright field illumination employs an axial cone of light from the condenser, which is transmitted through the specimen and is commonly based on Kohler illumination. This technique is useful for high contrast specimens, for example in coloured food particles. Stains or dyes may be used to impart colour to the specimen. Typical food stains for food products include iodine/potassium iodide to stain starch, toluidine blue to stain proteins and polysaccharides and Sudan Red to stain lipids.

**Polarised light**

A polarised light microscope employs ‘wide field’ illumination where the volume of sample above and below the plane of focus is uniformly and simultaneously illuminated. The key feature of confocal imaging is that both illumination and detection systems are focused simultaneously on a single volume element in the specimen, achieved by positioning a pinhole close to the detection source. This requires thin, relatively transparent, samples but results in out-of-focus blur that reduces resolution and specimen contrast. CSLM employs a diffraction-limited spot, which is detected by the pinhole placed in front of the emitted light detector greatly reducing out-of-focus blur and increasing resolution.

**Confocal Scanning Laser Microscopy**

Confocal scanning laser microscopy (CSLM) is a form of epi-fluorescence microscopy. Conventional fluorescence microscopy employs ’wide field’ illumination where the volume of sample above and below the plane of focus is uniformly and simultaneously illuminated. The key feature of confocal imaging is that both illumination and detection systems are focused simultaneously on a single volume element in the specimen, achieved by positioning a pinhole close to the detection source. This requires thin, relatively transparent, samples but results in out-of-focus blur that reduces resolution and specimen contrast. CSLM employs a diffraction-limited spot, which is detected by the pinhole placed in front of the emitted light detector greatly reducing out-of-focus blur and increasing resolution.

**Microscopy for Food Analysis**

**Figure 1 Diagram showing inter-relationships between microstructure and functionality of food products**

<table>
<thead>
<tr>
<th>Technique</th>
<th>Radiation type</th>
<th>Approximate resolution</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stereo-microscopy</td>
<td>Photons</td>
<td>5μm</td>
<td>Overview of micro-structure, large pores</td>
</tr>
<tr>
<td>Light microscopy</td>
<td>Photons</td>
<td>200nm</td>
<td>Ingredient localisation, crystallisation, particle shape &amp; size</td>
</tr>
<tr>
<td>Confocal microscopy</td>
<td>Photons</td>
<td>200nm</td>
<td>Ingredient localisation, 3D information</td>
</tr>
<tr>
<td>Scanning electron microscopy</td>
<td>Electrons</td>
<td>4nm</td>
<td>Large depth of field – simulated 3D view, high resolution (nano-scale)</td>
</tr>
<tr>
<td>Transmission electron microscopy</td>
<td>Electrons</td>
<td>1nm</td>
<td>Fine structural detail, macromolecular interactions</td>
</tr>
<tr>
<td>Atomic force microscopy</td>
<td>N/A (physical cantilever)</td>
<td>&lt;1nm</td>
<td>Surface toplogy, nano-mechanical behaviour</td>
</tr>
<tr>
<td>X-ray Microtomography</td>
<td>X-rays</td>
<td>&lt;1-10μm</td>
<td>Non-destructive 3D structure based on atomic contrast</td>
</tr>
</tbody>
</table>

**Table 1 Main techniques used in food microscopy**
Insight into its true three-dimensional arrangement and allows for simple differential fluorescent labelling of specific components such as fats or proteins (Figure 3 for examples).

**Electron microscopy (EM)**

Electron microscopes comprise an electron emitter encased in a vacuum. Accelerated electron beams have a much shorter wavelength and consequently greatly increase resolution compared to light radiation. The electron beam is focused by electromagnets and an image is produced either by passing the beam through a thin section of material as in transmission electron microscopy (TEM), or by electrons striking the surface of a bulk sample and emitting electrons as in scanning electron microscopy (SEM). SEM has been used extensively in the study of food ingredients and products. Traditionally, chemical fixation and dehydration protocols were necessary to preserve biological specimens from the harsh environment of electron microscopes. Interpretation of EM images requires a thorough understanding of the effects of sample processing on the integrity of microstructural elements and the possible generation of artefacts.

TEM involves passing a narrow beam of electrons through a thin specimen prepared either as a negatively stained dispersion or in the form of a thin section or a metallic replica. For resin-embedded thin sections, sample preparation can be extensive and usually involves chemical fixation, solvent dehydration and embedding in a polymer-based resin. Ultrathin sections ~90–150nm thick are cut using a glass or diamond knife with an ultramicrotome. The sections are post-stained to increase contrast and carbon coated to prevent beam damage.

In SEM, secondary electrons emitted by the sample provide topographic information with a high depth of field. Conventional SEM has been extensively used to characterise the surface morphology of low moisture products including dairy powders (Figure 4) or snack products, such as crackers or confectionery.

Modern SEM instruments may be fitted with field emission electron sources which allow for much lower voltages (0.1–5kV) thereby reducing charging effects. Cryo-SEM is particularly useful.
for food products and involves rapid freezing of small samples, fracturing under vacuum and then transferring to the SEM chamber onto a special cryo-stage, where frozen hydrated bulk samples can be directly imaged under the electron beam. Cryo-SEM has been successfully used to study dairy spreads, mayonnaise and ice cream. Freeze fracturing allows visualisation of internal structures, such as air, protein or and fat distribution in whipped cream, cheese and yoghurt (Figure 5).

A major challenge with conventional EM techniques is preventing damage to non-conductive specimens caused by the high-energy electron beam. Biological materials, being relatively non-conductive, are especially susceptible to beam damage and require coating with a conductive layer of carbon or heavy metal. In addition, the electron beam requires a vacuum to prevent dissipation of electrons in the column. Variable pressure (sometimes termed low vacuum mode) or true ‘environmental’ scanning electron microscopes (ESEMs) overcome both specimen-charging effects due to the electron beam and the need for dehydration by allowing a gas of 1–20 Torr within the imaging chamber. The gas may be inert or water vapour, consequently samples may be observed at saturated water vapour pressure in the case of true ESEMs. Variable pressure SEM employs a weak vacuum that still allows direct observation of samples with moderate moisture contents, such as cheese or meat products.

**Dynamic CSLM techniques – making and breaking food structures**

Food processing is not a steady-state process and many foods undergo several transformations during manufacture, storage and consumption. These processes often include mixing, heating, pH adjustment or complex biochemical transformations, such as fermentation. To understand how unit operations affect microstructure and ultimately behaviour of a food product, microscopy images are taken at key process steps for correlation with bulk physical measurements, such as viscosity or particle size. These ‘snapshots’ along the process line cannot, however, show what is happening during a fast-moving process, such as shearing, product aggregation or breakage, so dynamic imaging techniques are needed. Dynamic CSLM allows direct monitoring of food transformations, such as milk gelation for yoghurt or cheese manufacture (Figure 6). Using this technique, we can follow the particle movement, aggregation and subsequent network formation of casein micelles during real-time acidification at controlled temperature.

Conversely, food is designed to break down during consumption, but little is known of how fracture behaviour is affected by microstructure. Micro-tensile stages are now available for studying deformation of solid food materials at the microscopic scale. An example is shown in Figure 7 where two fat-filled protein gels were fractured to characterise the movement and release of liquid fat during breakage. This type of study highlights the importance of microstructure on the fat release properties of food and how new reduced-fat products can be designed to optimise fat release and sensory properties.

**Emerging microscopy techniques**

There is a need to develop new imaging tools that are relevant to the metastable complexity of dairy products. These new tools face the following constraints:

- **Speed of acquisition:** many dairy products are highly metastable or liquids.
- **Chemical mapping:** particularly for complex organics, such as proteins.
- **High resolution:** spanning the nano-micro length scales.
- **Controlled environment:** for example, temperature or humidity.

![Figure 5 Cryo scanning electron micrographs of various dairy product images at -125°C after freeze fracturing](image)

![Figure 6 Confocal scanning laser micrographs taken from time lapse series of skim milk acidified with glucono-delta lactone at 40°C, protein labelled with Nile Blue (bright areas). Scale bar = 25µm.](image)

![Figure 7 where two fat-filled protein gels were fractured showing the interface between two air bubbles (A) that contains fat droplets (arrow) and milk proteins dispersed in the aqueous phase. b) Cheddar cheese showing fat globule (F), (P) and streptococci-like bacteria at the fat/protein interface (arrow). c) Full-fat yoghurt showing starter bacteria (arrows) and fat droplet partially embedded in the protein matrix. d) Full-fat yoghurt cryo-fractured fracture showing large pores caused by ice crystals forming during freezing (arrows). Scale bar = 1µm.](image)
New developments in microscopy and imaging are beginning to address these issues and are discussed below.

**Atomic force microscopy**
Scanning probe microscopies are a group of techniques originally designed to characterise surfaces at the atomic scale. Atomic force microscopy (AFM) is one such technique which allows imaging of soft composite materials and liquids at molecular scales with a resolution of <1nm. AFM is increasingly being applied to food materials including chocolate and dairy products. A cantilever with a needle-like probe tip is scanned close to or touching the sample surface and deflection monitored by a laser and photodiode and converted to topographical and/or nano-mechanical information. Atomic force microscopy has been used to study polysaccharides, starches and food proteins.

**Chemical mapping – confocal Raman microscopy**
The development of confocal Raman microscopy will become a key tool in the microstructural characterisation of food ingredients and products. Raman imaging is a powerful technique for generating detailed chemical images based on a sample’s Raman fingerprint spectrum. A complete spectrum is acquired at each pixel of the image, which is then processed to generate false colour images based on material composition, phase, crystallinity and strain. This allows for 3D molecular mapping of a material with a spatial resolution of <1µm. Since there is only one Raman photon for every ~10⁷ fluorescence photons, care is needed to avoid natural fluorescence which can swamp the weak Raman signal. For spectral mapping, acquisition and processing times are also much slower than those of traditional confocal microscopes and can take several minutes or hours rather than seconds. Recent developments in technology have reduced the time to acquire a full spectrum down to just under a millisecond.

Despite these limitations, early studies demonstrate the power of the technique for localisation of specific plant biopolymers, phenolic compounds, fat crystallisation and polymorphism.

**Non-destructive 3D imaging – X-ray computed microtomography (XMT)**
XMT is a non-destructive analysis technique used to visualise and characterise objects in three dimensions. It is the process of imaging an object from many directions using penetrating radiation, such as X-rays, then using a computer to determine the interior structure of that object from these projected images.

It has been used to probe the structure of dairy products, such as cream cheeses and yoghurts, in addition to visualising the microstructure of loose-packed and compacted samples of spray-dried skim milk powder and whole milk powder and to quantify the proportion of both interstitial and occluded air voids in each sample. Individual beam scans can be analysed and reconstructed for true volumetric morphological analysis.

**Conclusions**

Microscopy offers a powerful set of tools to help understand the complex relationships between structure and function in food products. There are now a wide variety of microscopy techniques to choose from with new techniques emerging. It is important to know the strengths and weaknesses of each technique and use a correlative approach to ensure correct interpretation of images for each application.

References and article available online at fstjournal.org/features/33/4/microscopy-for-food-analysis

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**Measuring – image analysis**

Microscopy has the advantage that it is a direct technique allowing visualisation of reality rather than an assumed structure derived from bulk physical measurement. Image analysis can be used to measure features of an image and there are several software options available, both open source and commercial packages.

Techniques, such as CSLM and XMT, are particularly suitable for image analysis due to the clear discrimination of the major phases and accurate 3D structure. Particle/droplet size, shape, pore size or linearity, connectedness, clustering etc. are all measurable using basic software. The advent of machine learning and artificial intelligence will allow more complex vision-based analysis from large 3D/4D image datasets.
Sterling Crew reviews the proposed changes to allergen labelling rules and their potential impact on food businesses in the retail and catering sectors.

More than 160 foods have been identified which can cause allergic reactions.

Food allergy is recognised as an important food safety issue, which rightly commands media, regulatory, industry and consumer attention. Sufferers of food allergies or food intolerances must avoid eating problem foods and rely on emergency treatment in case of exposure. The dietary restrictions which follow can become a blight on affected individuals and their families. In some individuals with severe forms of the condition, life threatening reactions can be prompted by even small traces of the trigger foods. An allergic reactions may range from relatively short-lived discomfort to anaphylactic shock and fatality. Recently, widely reported deaths of teenagers with food allergies have highlighted the human impact of the condition and the importance of clear, accurate labelling and effective allergen management.

Food allergic reactions are hyperactive responses of the immune system to generally innocuous substances. They are typically an immunoglobulin E (a type of antibody) reaction caused by the release of histamine but also encompassing non-IgE immune responses. This mechanism causes allergies to typically give an immediate reaction to foods and may involve anaphylaxis. Non-IgE reactions are characterised by an immune mediated response not involving IgE. This may occur some hours after eating the implicated food which can make diagnosis challenging.

Food intolerance is a detrimental reaction, often delayed, to a food or a compound found in foods that produces symptoms in one or more body organs and systems. In practice the term generally refers to reactions other than food allergy. The most common food intolerance in the UK is lactose intolerance. Food intolerances are rarely life threatening but can have a big impact on sufferers’ day-to-day lives.

More than 160 foods have been identified which can cause allergic reactions. The diagnosis of an allergy is usually achieved by reviewing a person’s medical history and finding a positive result for the presence of allergen-specific IgE when conducting a blood or skin test. People who suspect that they suffer from a food allergy should undergo tests to determine if it is a real allergy and what substance is the cause. It is estimated that around 10 to 20 people die from a food allergic reaction in the UK each year. The exact number is not known because some allergy deaths are recorded as asthma-induced. In the developed world it is estimated that around 4-8% of people have at least one food allergy.

In a recent FSA survey, it was found that 79% of respondents reported no food hypersensitivity while 21% reported having an adverse reaction to consuming certain foods. The most common reported reactions were food intolerances (12%) followed by food allergies (5%).

Natasha’s law
A new law protecting allergy sufferers has been introduced following the tragic death of 15-year old Natasha Ednan-
Laperouse. Natasha died of anaphylaxis after collapsing on board a flight to Nice in 2016. She had a severe allergic reaction after eating sesame seeds in an artichoke, olive and tapenade Pret A Manger baguette bought at Heathrow Airport. Natasha and her family were aware she was allergic to sesame and took precautions to avoid contact. The bread contained ground sesame seeds, which were not listed on the label and there was no allergen advice. At the time, there was no legal requirement for Pret A Manger to list allergens because of reduced labelling requirements for food produced on site, called pre-packed for direct sale (PPDS). For these foods it was sufficient for general allergen warnings to be posted around the shop at point of choice, rather than on the packaging, and for specific

<table>
<thead>
<tr>
<th>Prepacked foods vs PPDS</th>
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<tbody>
<tr>
<td><strong>Pre-packed foods</strong> any food put into packaging before being placed on sale. Pre-packed foods must have an ingredients list in descending order of weight and allergenic ingredients must be emphasised every time they appear in the ingredients list. Food is prepacked when it is either fully or partly enclosed by the packaging, cannot be altered without opening or changing the packaging and is ready for sale.</td>
</tr>
<tr>
<td><strong>Food pre-packed for direct sale (PPDS)</strong> Although there is currently no legal definition, PPDS has been exempt from the above requirement if it is made, packed and sold on the same premises. This could include sandwiches, baguettes, salads in boxes etc. It is expected, in these circumstances, that the customer will speak to the person who made or packed the product to ask about ingredients. Currently for these products, allergen information can be provided in the same way as for non-prepacked (loose) foods through signposting at point of choice to encourage customers to ask staff about allergens.</td>
</tr>
</tbody>
</table>

Prepared by: Francesca Raffaelli

The coroner overseeing the inquest into Natasha’s death, criticised Pret A Manger for having inadequate labelling on packaging in terms of visibility and giving insufficient attention to monitoring food allergy. He felt that Natasha was falsely ‘reassured’ by wrappers and store signs. A complaint log for the company from between July 17, 2015 and June 29 2016 showed nine cases of sesame-related allergy incidents.

The coroner added that the tragedy of Natasha’s death ‘should serve as a watershed moment to make meaningful change to save lives’ and wrote to the Environment Secretary asking if big businesses like Pret A Manger should benefit from food labelling exemptions meant for small sandwich shops.

Natasha’s parents began a campaign for ‘Natasha’s Law’ to require all food businesses to...
include full ingredients labelling on PPDS foods giving food allergy sufferers greater confidence in making safe food choices.

Consultation and legislation

Following Natasha’s death and the coroner’s comments, the FSA invited food businesses and allergy sufferers to have their say on four options put forward to improve the way allergy information is provided on PPDS:
- Mandating full ingredient list labelling.
- Mandating allergen-only labelling on food packaging.
- Mandating ‘ask the staff’ labels on all products, with supporting information for consumers available in writing.
- Promoting best practice around communicating allergen information to consumers.

After the consultation, the FSA recommended the ‘Mandating full ingredient list labelling’ option supported by the Environment Secretary.

The legislation was passed on 5th September 2019, with a two year implementation period for businesses to adapt to the change. From 1 October 2021, the way food businesses must provide allergen labelling information for PPDS food will clearly change.

This law currently covers England, but it is anticipated that similar arrangements will follow in the devolved nations. To help food business operators implement the change, the FSA aims to publish A Technical Guidance in December 2019. However, the lack of a legal definition for PPDS is presenting difficulties. The current FSA position on PPDS is that it applies to any foods that have been packed on the same premises from which they are being sold[1-3] whilst the industry has suggested that there should be a distinction between foods selected by the customer without a member of staff helping, and those foods only served from behind a counter. The FSA was due to issue a complete definition with guidance on 1st October 2019, however, after concerns raised by industry, the decision has been deferred until there is full stakeholder engagement. This will allow greater clarity on the types of food covered and how they are made available to the consumer.

The new law states that food businesses will need to include a full ingredient label on PPDS foods and any allergenic ingredients must be emphasised in bold, italics or a different colour. The changes will cover labelling requirements for foods that are prepared and packed on the same premises from which they are sold, for example, a packed sandwich or salad made by staff earlier in the day and placed on the shelf for purchase. In contrast, the current law exempts PPDS food from even coming under the scope of the legislation are micro or small sized enterprises. They may find it too much of a burden to produce a full accurate ingredient label.

After the fall out of the inquest into Natasha’s death, Pret A Manger has responded emphatically to the criticism. All of its freshly made sandwiches, salads, baguettes and soups are now labelled on pack each day with a full list of ingredients including the presence of any of the 14 EU declarable allergens highlighted in bold. This is achieved by using individual recipe cards, which enable employees to prepare food in kitchens on site and print off a bespoke label providing an electronic record of each product that leaves the kitchen. All the company’s 391 stores have had a refit with new equipment and technology to facilitate allergen management and labelling.

This major endeavour by Pret A Manger highlights the nature of the problem. Large restaurant chains have the expertise, resources, technical capability and sophisticated Food Safety Management Systems with robust HACCP programmes to enable them to specify and monitor allergen management and labelling performance. Even so, the packs often still have warnings that the foods are made where allergens are present, there is no guarantee that foods are free of an allergen not listed on the label.

The vast majority of small foodservice outlets do not possess this capability and may simply buy in pre-packed foods instead of preparing them in-house, because the onus of labelling would then rest with the manufacturer. Alternatively they may decide to stop wrapping food which may mean more risk of contamination and cross-contact.

It could be argued that the new labelling requirements might introduce a greater risk and give allergic consumers a false sense of security. There could be an additional hazard of an incorrect ingredients list on the packaging from human error or from cross-packing when the right label is put on the wrong pack. This could have disastrous consequences if an allergen is under-declared. It is also compounded by the additional risk of using an incorrect recipe or the addition of a wrong ingredient.

The FSA regularly reports

Table 1 The 14 allergens that must to be identified if they are used as ingredients[4,5]

<table>
<thead>
<tr>
<th>Number</th>
<th>Allergen</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>celery</td>
</tr>
<tr>
<td>2</td>
<td>cereals containing gluten – including wheat (such as spelt and Khorasan), rye, barley and oats</td>
</tr>
<tr>
<td>3</td>
<td>crustaceans – such as prawns, crabs and lobsters</td>
</tr>
<tr>
<td>4</td>
<td>eggs</td>
</tr>
<tr>
<td>5</td>
<td>fish</td>
</tr>
<tr>
<td>6</td>
<td>lupin</td>
</tr>
<tr>
<td>7</td>
<td>milk</td>
</tr>
<tr>
<td>8</td>
<td>molluscs – such as mussels and oysters</td>
</tr>
<tr>
<td>9</td>
<td>mustard</td>
</tr>
<tr>
<td>10</td>
<td>tree nuts – including almonds, hazelnuts, walnuts, brazil nuts, cashews, pecans, pistachios and macadamia nuts</td>
</tr>
<tr>
<td>11</td>
<td>peanuts</td>
</tr>
<tr>
<td>12</td>
<td>sesame seeds</td>
</tr>
<tr>
<td>13</td>
<td>soybeans</td>
</tr>
<tr>
<td>14</td>
<td>sulphur dioxide and sulphites (if they are at a concentration of more than ten parts per million)</td>
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</tbody>
</table>
product withdrawals due to allergen mislabelling. Indeed allergen issues account for the majority of the published withdrawals[7]. These are often from large retailers and manufacturers who have some of the country’s most sophisticated Food Safety Management Systems and best resourced technical capability. If they struggle with allergen labelling, it demonstrates the nature and scale of the challenge facing small retail and catering businesses.

There is concern that the new labelling requirements might not be an improved alternative to an engaged conversation with shop staff, and in fact may well actually discourage this important dialogue taking place. Although there is an expectation that the customer is still able to speak with the person who made or packed the product to ask about ingredients, they may choose not to do so and simply trust the label. A more effective, safer deliverable approach might be mandating ‘ask the staff’ labels on all products, with supporting information for consumers available in writing. However, some people may feel inhibited about asking staff for information. Although this option was selected, together with a mandatory written information sheet, as the best by industry, consumers supported the provision of more written information on allergens and labelling of all ingredients.

Precautionary allergen labelling

Foodservice businesses have a responsibility to minimise the risks to allergen-susceptible consumers of their products. As part of their allergen communication risk strategy a decision needs to be made on whether precautionary allergen labelling (PAL) is required. It should be based on risk assessment and risk management steps and allergic individuals should be warned about allergens that may be present unintentionally.

It may not be possible in every case to guarantee foods from an outlet are free from allergens due to a significant cross-contamination risk from products, people and the environment. The aim is to enable consumers at risk to make an informed decision to protect themselves and those in their care. Allergic individuals must be informed about which allergens are present as ingredients, but in catering premises they may not be told if they ask about those that could be there in traces, unintentionally from cross-contact or cross-contamination.

The value of allergen labelling other than for intentional ingredients is controversial. In the UK, longstanding industry practice emphasises that the use of advisory ‘may contain’ labelling should be the last resort of a series of assessments. It should not be used as an alternative to good manufacturing and catering practice and relevant controls. In general, the principles referred to for product formulation and avoidance of unintended allergen presence by manufacturers apply equally to foodservice providers.

Such labels do not help allergic consumers cope with their condition and may mean their food choices become ever more restricted. Responsibility applied PAL should be seen as a last resort, following a thorough allergen risk assessment of each product. In response to the problems posed by accidental inclusion of allergens and the lack of resources and confidence to implement appropriate control systems, many more food service operators may adopt PAL in the future and chose a defensive labelling approach.

Enforcement

The introduction of legislation cannot on its own deliver safer food for allergic sufferers; it has to be effectively communicated to business and enforced. The financial position of local authorities will affect the delivery of the new allergen labelling legislation. The economic climate has resulted in a decrease in enforcement visits and food sampling programmes by councils. There needs to be a consistent, resourced approach across the UK. The allergen labelling requirements could become a component of the Food Hygiene Rating Scheme[8] if the officers involved were given training and guidance.

There could be a future facility for approved private sector organisations to carry out allergen management and labelling visits or even rating inspections freeing regulatory authorities to focus on their important enforcement role[9]. There are however obvious local authority operational and political concerns about the ‘privatisation’ of this service. A number of independent third party certification schemes are available which could provide additional assurance.

Conclusions

In light of recent tragedies the food industry should be doing more to keep allergic customers safe. It makes sense for those businesses in food service to review the robustness of their approach to the management and labelling of allergens. Allergen management in most foodservice businesses is demanding as typically sites are handling multiple allergens with frequent changeovers. Consumer demand for free-from, vegetarian, vegan and allergen controlled products increases the complexity. However continuing with the current ‘status quo’ is not a realistic option. Consumers must have the information they need to make the right choice. As management of a food allergy or intolerance requires the strict avoidance of the food linked with the sensitivity, the trustworthiness of both written and oral information is critical.

This will present challenges especially for smaller food companies, where food handlers are often transient and low paid with a low level of education and training. However, all food business operators will have to raise the allergen awareness and training of their staff. It is my opinion that the safety of food can be best assured by encouraging a dialogue between the allergic consumer and the food business, including best practice around communicating allergen information to consumers, underpinned by a positive food safety culture[9] that drives food handler behavioural practice. We do not want to inadvertently create a situation that could potentially be more dangerous than the current position. ■

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Agricultural activity is intensifying to cope with the rising food demand that accompanies consistent population and consumption growth. The process of food manufacturing is currently emission intensive, multifaceted and inefficient, with research suggesting a global loss of approximately 30-40% of all food produced for human consumption every year[1]. The increase in resource consumption combined with inadequate waste management methods has created an agricultural waste problem, generating around 700m tonnes annually in Europe[2].

The current, dominant waste management techniques (landfill, incineration and composting) disturb and pollute the surrounding landscape, releasing methane as food waste decomposes[3]. The inefficiency of the waste disposal system results in an unnecessarily high cost for consumers, producers and the public bodies responsible for waste management.

Additionally, the current system fails to identify and utilise the widespread and varied benefits of agricultural waste. In response to this, under the European 2020 growth strategy, Europe has assigned itself the target of shifting from a linear consumption and production model (underlined by the ethos of ‘take – make – consume – dispose’) to one that follows a circular economic strategy.

This is an integral part of the commitment by the European Union to halve food waste at the retail and consumer level (per capita) by 2030 and reduce losses along production and supply chains[4].

A circular economy optimises resource yields by circulating the products and components of biological and technical cycles, reducing the consumption of raw materials. This innovative approach aims to extend the lifespan of agricultural end and by-products through a holistic assessment of all stages of agri-food production and supply chains, including waste valorisation processes. Growing awareness of the potential economic, industrial and environmental benefits derived from waste products has increased the attractiveness of valorisation technology to countries pursuing policies of regeneration and recycling. This offers a valuable research and development opportunity in the agri-food sector – which paved the way for the AgroCycle project.

AgroCycle evaluated the material streams that create products perceived as waste in the agri-food sector, applying circular methods to close loopholes in which material (and value) is lost. The waste then deemed unavoidable can be converted into industrially important chemicals, materials and fuels – either to be fed back into the agricultural production system or sold. The project was
funded by the European Union’s Horizon 2020 Research and Innovation programme and was led by the School of Biosystems and Food Engineering at University College Dublin, including over 26 partners from the EU, China and Hong Kong.

**Agri-food waste valorisation technologies**

Sustainable and circular engineering solutions company, Exergy led the project development of biofuels using two different technologies (Figure 1). The first technology involved the pyrolysis of forestry residues, yielding bio-oils, biochar and biogas and was performed in collaboration with the University of Sheffield. The second technology involved the development of microbial fuel cells (MFCs) to generate electricity and heat, in collaboration with the University of Bath.

### 1 Pyrolysis

Pyrolysis is the thermochemical decomposition of organic material at a high temperature under anaerobic conditions. Lower process temperatures and reduced emission of pollutants make pyrolysis a favourable option over combustion. Three fractions are produced during this process (bio-oils, biochar and biogas), and their separation enables their use as a liquid fuel, soil enhancer and a gaseous energy source respectively. Further value is created by the ability to control the proportion of solid, liquid and gaseous products by adjusting variables, such as temperature or heating rate. The potential value of the materials created is also relatively high; bio-oil can produce electricity or be upgraded as a biofuel, biochar can be burnt as an energy source or blended with fertilisers, and biogas can provide electricity. Biogas can either be recycled to the pyrolysis process or utilised in a biorefinery during biochemical production. The aim of this study was to investigate the effect of biomass particle size and temperature on the pyrolysis yield and distribution of products.

The feedstock used by the University of Sheffield for the pyrolysis trial was based on three different lignocellulosic biomasses relevant to Europe and the UK — spruce, larch and pine. A wide range of agri-food crop residues, such as rice straw, wheat straw, sugarcane bagasse, walnut shells, olive husks and many more, are also potential feedstocks for pyrolysis.

The biomass was heated at three different pyrolysis temperatures: 300°C, 400°C and 500°C, and the particle size adjusted. The results revealed a greater production of gas when reaction temperature was increased, alongside a decrease in total biochar and biol-oil. A pyrolysis temperature of 300°C produced the highest amount of char from pine wood and the highest amount of bio-oil from larch. Biomass particle size was determined to have little influence on the pyrolysis yield of biogas and bio-oil.

The bio-oil fraction (Figure 2) can be used as a transportation fuel and in furnaces; it has also proven promising as an agricultural fertiliser and in pharmaceutical applications. If the bio-oil is used as a transport fuel, it needs to be upgraded to remove certain organic compounds (e.g. acids, ketones, esters, phenols, hydrocarbons), which can make the fuel unstable and corrosive due to its high oxygen content.

Other products were also valorised during the project. For example, the non-condensable (syngas) produced during pyrolysis can be collected and upgraded to produce biofuels or biochemicals, with the hydrogen component of the syngas enhanced in an additional stage to produce synthetic biofuel. The biochar was also valorised as a catalyst in microbial fuel cell processes and tested as an adsorbent in wastewater treatment processes. Using the results from the larch biomass pyrolysis, Exergy developed a virtual simulation of complete pyrolysis, modelling thermochemical processes using simulation software. It includes the optimisation stages, valorisation of biochar for electricity production and incorporates the upgrading stage of the bio-oil where required.

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**Figure 1**

AgroCycle graphic depicting components and products of agricultural waste valorisation [Source: AgroCycle website: agrocycle.eu/](http://agrocycle.eu/)

**Figure 2**

Bio-oil recovery system in the pyrolysis process [Source: AgroCycle deliverable 2.6](http://agrocycle.eu/)
This can aid the decision-making process by determining the volume of each biomass produced under different pyrolysis conditions.

These results demonstrate the potential for producing biofuels and high-value products from the pyrolysis of forestry waste and other agri-food wastes. Although pyrolysis is not a new technology, its use in the agricultural waste industry and the identification of the influence of temperature in the products produced is a new application.

A common concern surrounding existing biofuel production is the dedication of land and crops specifically for fuel as opposed to food; this will remain problematic whilst global food insecurity persists. Pyrolysis of agricultural waste therefore helps to address the ‘food versus fuel’ debate, sourcing new and sustainable ways to generate biofuel.

Pyrolysis in other projects has mainly focused on generating liquid and gas components, however, AgroCycle has also focused on valorising the biochar. Using the biochar as a catalyst in microbial fuel cell applications adds further value to a product previously considered to be waste.

Additionally, current disposal of agricultural waste is environmentally and economically expensive, thus pyrolysis reduces the volume of waste and the cost of disposal, while generating added value. Furthermore, the development of a complete pyrolysis simulation enhances its industrial appeal and potential implementation by enabling the identification of the range of products created under defined conditions and providing a preliminary economic analysis.

2 Microbial fuel cells

Microbial Fuel Cell (MFC) technology is a circular economy energy alternative, directly converting organic biomass into an electric current. Although already a successful technology, its commercialisation and potential for system scale-up has been hindered by the high cost of its construction materials and its low energy efficiency. In collaboration with the University of Bath, Exergy led the investigation into how affordability and efficiency issues could be overcome, and how power output could be scaled-up.

Anaerobic digestion is frequently used to break down food wastes. The by-product of methane-rich biogas is harvested and used as fuel and the end-product is a nutrient-rich slurry (fresh digestate). The fresh digestate can be employed as organic biofertiliser, or alternatively, as a bioenergy source. In AgroCycle, the digestate is used as the feedstock, electrolyte and bacteria source for the MFCs. The MFCs in this investigation utilised a simple design of two graphite felt electrodes: a cathode floating on the digestate surface and a submerged anode (Figure 3). To increase the anode electrode surface area, the graphite underwent two pre-treatment stages. Firstly, ethanol was used to enhance the hydrophillicity of the carbon fibers (stage 1) and secondly, a thermal pre-treatment generated cracks in the graphite (stage 2). Stage 1 decreased the contact angle by 85.7% and enhanced the electroactivity by 4%, while stage 2 increased the electroactivity by a further 9%.

The thermodynamic limitation of a single MFC was overcome by the strategy of arranging multiple units into stacks – a method demonstrated previously. Two arrangements were created: P1, with 2 MFC units and P2 with 10 MFC units connected in parallel. The overall power output of P2 was five times larger than P1 and 10 times larger than a single MFC unit, demonstrating a linear increase in maximum power output per MFC unit connected in parallel.

Valorising agricultural waste to produce digestate (used as the feedstock, electrolyte and bacteria source in the MFCs) and in the production of biogas, biofertilisers and bioplastics, removes the need for additional carbon input, whilst generating its own energy throughout the process. This reduces energy and fossil fuel consumption, leading to a smaller carbon footprint. The process is therefore sustainable and circular, converting low-value waste products into energy and byproducts of economic and industrial value, to be re-used instead of discarded.

Although using anaerobic digestants to generate energy is not a new discovery, AgroCycle is unique in its construction of MFCs without the usual, expensive membrane. This is possible due to the vertical stratification that naturally occurs between different redox zones in the digestate. Additionally, unlike other previous projects, the MFCs of AgroCycle do not require a catalyst at the cathode. This simplified re-design of the MFCs and their manufacturing process significantly reduces the cost of the technology. This is a vital component when bridging the gap between innovation and industry and when considering the viability of system scale-up. Additionally, this increased affordability improves potential access to circular and sustainable technology in a variety of economic environments.

Energy efficiency improvements were achieved by the miniaturisation of the fuel cells and by increasing surface-area-to-volume ratio on which electrochemical reactions can occur. The ‘stacking’ of MFCs also has value in potential system scale-up as it increases power density and ensures that the MFC system is not required to take a one-size-fits-all approach. MFCs can be stacked to suit the energy generation required, with power output showing a linear increase as MFC units are stacked in parallel.

Alternative methods of waste disposal are increasingly being...
incorporated into the food and agricultural policies of cities. Anaerobic digestion and MFC units could provide an exciting alternative for energy generation: electricity generation could be localised, allowing councils to use their city’s waste to generate power, either for local usage or to be sold. Leading by example in Milan, methane produced from the anaerobic digestion of the city’s organic waste powers 25% of the waste collection trucks[10]. The potential to reduce the cost of this process, as shown in the AgroCycle project, could incentivise waste valorisation in this manner and present it as a viable option for cities trying to reinvent their waste and recycling systems. Alternatively, this could potentially be utilised on an even smaller scale, with individual households generating power from their own agri-food waste.

**Education**

A particularly important element of the AgroCycle project is its focus on the education of young people. Ensuring people understand the importance of incorporating sustainable processes in modern society is imperative for the success of circular strategies in the future. Focusing on young people educates the behaviour of current and future consumers, explaining the factors that comprise circular processes and demonstrating that a circular economic strategy is a practical option for the future.

This is in the form of an educational AgroCycle Kids online platform was also created, with resources to read, activities to complete in schools and a ‘Cinema Room’ with videos explaining the circular economy and examples of it in action (Figure 4).

**Conclusions**

AgroCycle’s investigation into waste valorisation in the agri-food sector demonstrates an exciting future for circular technology. Exergy’s focus within AgroCycle addresses two major global issues: the first, reduction of waste and the second, provision of a sustainable source of electricity. Development of these technologies will help propel society towards a more sustainable way of living.

AgroCycle’s unique, simplified design of the microbial fuel cells has reduced manufacturing costs. This, combined with unit ‘stacking’, increases the viability of system scale-up. Together these developments are vital in the progression of the technology towards commercialisation.

The MFC construction demonstrated by AgroCycle is also flexible in both size and power output. This expands its suitability to a variety of socio-economic situations and waste valorisation needs.

AgroCycle demonstrates that the pyrolysis of agri-food waste is a potential option for economies reliant on agriculture, through reducing and/or adding value to an extensive source of waste. When combined with MFC units, pyrolysis could also be a viable alternative for those without access to a mains electricity grid.

Producing biofuels by methods that address the issue of ‘food versus fuel’ is a necessity when increasing the accessibility of this technology and its uptake in countries suffering from food scarcity. The reduced reliance on raw materials also increases resilience to fluctuating and volatile markets. The additional valorisation of biochar and its subsequent use to fuel MFCs means no additional carbon input into the system is required during electricity generation. AgroCycle therefore demonstrates an exciting option for future energy generation and waste valorisation, viable in a greater range of socio-economic and industrial environments. The longevity of these circular waste transitions is supported further by AgroCycle’s unique online education platform, imperative in influencing current and future consumer behaviours.

Although the MFC technology discussed is not yet commercialised, AgroCycle delivers a blueprint for future EU policy on agri-food waste valorisation.

One of the unique aspects of the AgroCycle project is the commitment to develop a circular economy and engage stakeholders throughout the entire value chain of the agricultural industry. This extends to the educating the next generation with the online educational platform.

Dr. Matthew Moss, Exergy Ltd

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Engineering a career path

Midland Group Training Services (MGTS) is a not for profit, educational charity providing apprenticeships and qualifications. It specialises in supporting engineering and machinery reliant industries with a focus on the delivery and development of skills, knowledge and behaviours required by industry to aid technological development and improve production performance. At any one time there can be in the region of 800 apprentices on programme.

The head office, based in Coventry, operates from a 40,000 sq ft facility comprising offices, training rooms and large engineering training workshops. It also has a centre in Redditch and an engineering academy based at Reaseheath College, Nantwich (part of an industrial partnership in the UK Dairy Industry known as the EDEN [European Dairy Education Network] programme).

MGTS is led by a Board of Trustees comprising managing directors and directors from the engineering and engineering associated industries. It acts as a technical translator listening to employers’ current and future needs and aligning these with specialist education, training and assessment programmes. It has worked in partnership for apprentice and engineer development with Britvic, McCain Foods, Heineken, Molson Coors, Arla, Saputo [formerly Dairy Crest], Burton Brewery, Nestle and Princes Foods and many more.

David Bridgens of Midland Group Training Services describes the programmes it has in place to train apprentices in engineering skills for the food industry.

“Organisations of all sizes find it difficult to fill engineering roles.”

By 2024 to feed an expected population of 70m people and meet market demands. A 2017 study found that organisations of all sizes find it difficult to fill engineering roles. Despite this talent shortage, which can be addressed by apprenticeships, less than 1% of the industry workforce is made up of apprentices.

Dairy UK Eden Engineering Training Programme

In 2011 MGTS was asked to submit an expression of interest for the Dairy UK Eden Engineering Training Programme. Dairy UK, representing the UK dairy industry, recognised that despite being one of the most productive industries in Europe, there were opportunities for improvement. Having surveyed all Dairy UK dairy processing businesses in relation to their need for skills, a clear gap between the desired competence of maintenance engineering and the requirements of modern dairy businesses was identified.

As a consequence, the Eden Engineering Programme was
established in conjunction with the National Skills Academy for Food and Drink. The vision of Eden was to introduce world class dairy specific engineering training in the UK to be clearly aligned to the specific requirements of the dairy industry, the priority being to develop the required skills, knowledge and behaviours, not just qualifications, with the proviso that the programme included elements of food safety and food technology. MGTS was awarded preferred provider status and has been delivering engineering maintenance apprenticeships to the dairy industry since 2012 in partnership with Reaseheath College.

**Food and Drink Engineering Maintenance Programme**

In 2016 the Food and Drink Engineering Maintenance trailblazer was approved for delivery with the food industry developing the new standard. Since the inception of the standard, some 330 food and drink engineering maintenance apprentices have joined the programme, which now includes apprentices from Heineken, Morrisons, Glanbia, Ferrero, Bakkavor, Wyke Farm as well as the initial dairy companies.

One of the key barriers to the attractiveness of the sector for apprentices can be the remote location of many manufacturing plants. Operating an apprentice programme for a sector with such a geographic spread and a lack of local training provision necessitated providing secure, safe residential accommodation. The Food and Drink Engineering Maintenance (FDEM) programme, (formerly known as the trailblazer) delivered at Reaseheath with residential provision, has addressed this requirement.

The residential FDEM apprenticeship has been delivered by MGTS for the past seven years, with the largest intake of food and drink apprentices being 60 in October 2018. With a limited capacity factor of 60 students at the MGTS Reaseheath College centre, coupled with the ambition to offer a wider geographical spread for FDEM programme delivery, MGTS has extended its capability at the Redditch centre by refurbishing and equipping an additional 355m² workshop area, which was previously used for storage purposes. The additional workshop space will help the food and drink industry to recruit much needed, highly skilled engineers. To address the residential provision, MGTS has partnered with Pershore College so that apprentices are able to attend the MGTS centre in Redditch.

The official opening of the new workshop took place in July this year and was performed by Rachel Maclean, MP for Redditch. The first cohort of 20 Morrisons apprentices and two Princes Foods apprentices commenced training at the new Food and Drink Engineering Maintenance centre on 30 September 2019.

**References and Article**

Available online at fstjournal.org/features/33-4/careers/engineering-apprenticeships

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Shaping the future

The UK has an evident shortage of readily employable, innovative engineers who are needed across all sectors but especially in the food manufacturing and agri-tech sectors, which is where NMiTE (New Model in Technology and Engineering) comes into its own, as it looks to transform engineering education in Britain. It is chaired by Dame Fiona Kendrick, the former Chief Executive of Nestlé UK & Ireland and President of the Food and Drink Federation (2015-17).

Inaugurated on 19 October 2018, NMiTE was created to help solve the problem of Britain’s estimated annual shortfall of at least 22,000 engineering graduates with a radical new approach and a curriculum that combines the best innovations from leading universities around the world.

As an initiative backed by government, educators and industry, the institution aims to secure university status and bring improvements to their organisation or those who are transitioning (or looking to transition) from the armed forces. This life-long learning approach will ensure that an organisation’s or individual’s skillsets are relevant and in tune with the UK’s needs.

NMiTE has partnered with a variety of businesses in the area to build on its range of CPD courses, and many of these partnerships are already well underway. NMiTE will be working with local and national companies on its lean manufacturing series programme. It will also be working alongside partners to develop CPD that will continually add value to businesses.

Amongst NMiTE’s proposed CPD courses is the institution’s Lean Manufacturing series. Recently launched in partnership with meat processor Avara Foods, the Lean Manufacturing series will give professionals the chance to enhance their skills, productivity and employability. A lean approach to work is about understanding and improving the processes by which products are created and delivered, and empowering people through the fundamental principles of problem solving and coaching. Lean thinking and practice will help organisations to become steadily more competitive, which in turn will lead them to become more efficient and sustainable.

It also teaches that problems should be viewed as opportunities for meaningful learning, rather than errors to be swept under the carpet. The Lean Manufacturing series is currently broken down into one day courses, that can be moulded to suit the needs of an organisation.

The life-long learning experience NMiTE aims to offer has already seen a huge wave of interest, more than enough to run its MEng four times over. By opening the course up to a broad range of ages, from young people through to mature students, and showing their working and portfolio of work that represents the fundamental principles of problem solving and coaching. Lean thinking and practice will help organisations to become steadily more competitive, which in turn will lead them to become more efficient and sustainable.

Shaping the future

Toby Kinnaird of NMiTE describes the philosophy behind its approach to teaching engineering in the food and drink sector.

receive teaching in small project teams over the three years, and work alongside a variety of NMiTE’s industry partners, giving them an overall advantage within their chosen profession.

A key element of NMiTE’s vision is to approach engineering concepts in a much more liberal sense. The UK’s future demands that engineers consider the human, social, ethical and political contexts in which their work exists, and so NMiTE will look to recruit learners who are creative, curious and committed to making the world a better place. Essentially, learners will be expected to know the reasoning behind their engineering and to make sure that they are delivering the best possible solution. Project outcomes will allow future learners to build a portfolio of work that represents and shows their working and learning alongside a variety of NMiTE’s partners, this means that upon graduation NMiTE’s future learners will have a great chance of being work-ready and producing work of a high calibre.

Alongside the proposed MEng will be NMiTE’s upskilling, reskilling and Continuing Professional Development (CPD) courses that have been built to support the continuing development of its graduates, as well as help those looking to

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