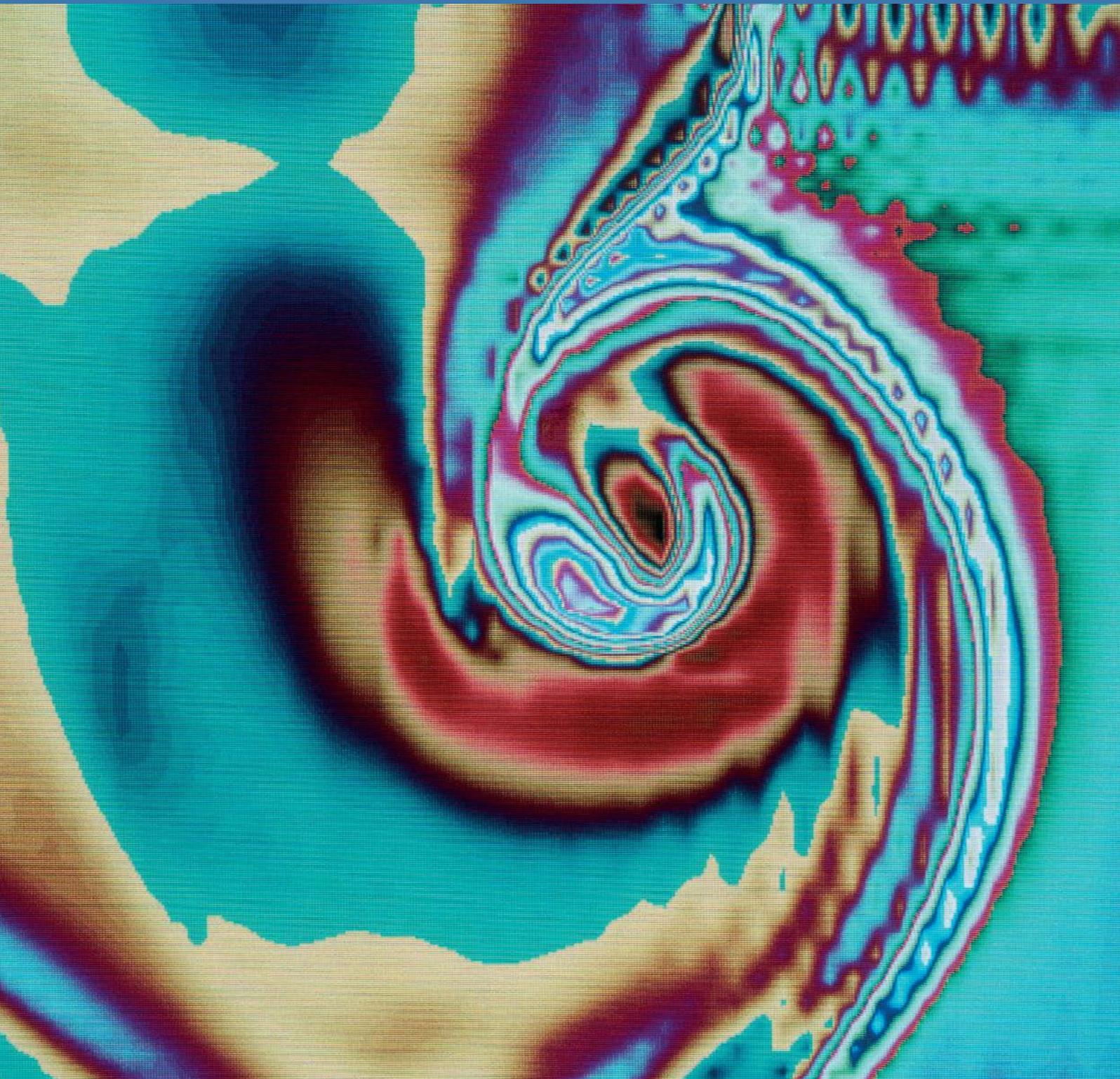


# The Health of Physics in UK Food Manufacturing

How physics plays a vital role in the food manufacturing industry – and how it can be harnessed to make the sector a world leader



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We have a worldwide membership of more than 50,000, from enthusiastic amateurs to those at the top of their fields in academia, business, education and government.

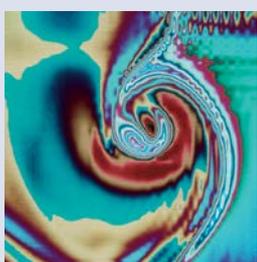
Our purpose is to gather, inspire, guide, represent and celebrate all who share a passion for physics. And, in our role as a charity, we're here to ensure that physics delivers on its exceptional potential to benefit society.

Alongside professional support for our members, we engage with policymakers and the public to increase awareness and understanding of the value that physics holds for all of us.

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**Cover image:** Computer simulation of a vortex. Vorticity in a fluid such as a liquid or a gas is generated by internal friction or viscosity between adjacent particles or layers. The colour coding indicates the gradient of the velocity, which expresses a variation of the magnitude of the velocity: the closer the different coloured bands, the steeper the velocity changes. Fluid mechanics and modelling were both among the areas of physics identified as important to food manufacturing by the IOP's research. Credit: Dr Fred Espenak/Science Photo Library.

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## Foreword

In uncertain economic times, and especially as the UK develops a new relationship with the EU, the country would do well to focus on the areas in which it excels – those fields in which it is, or can become, a world leader.

Food and drink manufacturing is one of those areas. It is already the single biggest manufacturing sector in the UK. It supports more than three million jobs, and doubled its exports over 10 years. And it continues to become much more high-tech than most people realise, with physics playing a central role.

This is a report on the health of physics in food manufacturing, looking at the role of physics in enabling global competitiveness and productivity within the sector.

It is part of an ongoing collaboration with partners, driven by industry and led by the community. It gives insights into the sector's strengths and opportunities, and makes recommendations to support growth and job creation in the food manufacturing sector by promoting the role of physics as an important, but perhaps undervalued, enabler.

Chief among those recommendations is the formation of a national industrial strategy for food manufacturing, which would enable the industry to live up to its full potential – making a strong sector even stronger.

- **Professor Roy Sambles** FRS CPhys FInstP, President, Institute of Physics

Working in the food manufacturing sector, we know how important physics is. Much of the technology used, and many of the innovations that make the sector competitive, are underpinned by physics. It's central to improvements in products themselves. And physics-based skills are applicable throughout the industry, from breaking problems down to first principles, through generating testable hypotheses and working with complex maths, to creating simulations to make predictions as to how food will behave.

But there's a general lack of awareness of this elsewhere. That crucial role of physics in the food sector needs to be fully recognised – and taken full advantage of. If we create the conditions in which food manufacturing can flourish, the sector will create benefits for us all. Fail to do so and we risk losing it to overseas competitors.

Our intention with this report is to galvanise a voice for the food sector – to represent the industry's views on the extent to which future innovations, productivity and competitiveness depend on physics, and to get to a point where we're much better able to apply physics research to the sector's challenges.

Working with the IOP, as the representative body for physicists, puts us in a much stronger position to speak as a coherent, unified body, to exploit academic research much more effectively, and to put the food sector at the forefront of a knowledge-led economy for the UK.

- **John Bows** CPhys FInstP, Senior Principal Scientist, PepsiCo R&D Global Snacks
- **Professor Roger Eccleston** CPhys FInstP, Pro Vice-Chancellor for Global Engagement and Dean of the Faculty of Arts, Computing, Engineering and Sciences, Sheffield Hallam University
- **Dr Robert Farr** Expertise Team Leader for Creation and Manipulation of Microstructures, Unilever
- **Dr John Melrose** Strategic Process and Technology Manager, Jacobs Douwe Egberts

# Introduction

## The IOP's position

In its role as a learned society, the Institute is the representative body for more than 50,000 physicists, many of whom work in industry, applying their skills and knowledge to create the innovations that improve our lives.

The IOP's mission includes a remit to advance physics to further the understanding of the physical world and its application for economic and social benefit. To achieve that, the Institute's five-year strategy includes a goal to position businesses to actively exploit new physics-based research while strengthening the core discipline and breaking down traditional boundaries. Along with our fellows and partner organisations, we've found an opportunity to do that in the largest manufacturing sector in the UK – food.

The Institute was approached by two of its fellows – one from industry, one from academia – who saw a need for physics within food manufacturing to grow. They identified an opportunity for physics to enable growth within the sector by using physics-based research to solve its pre-competitive challenges, and also spotted a chance for the industry to play a central role in solving some genuine fundamental physics problems.

Taking on the challenge, the IOP has created a pilot programme of open innovation in food manufacturing. This report is part of that programme, and conveys the food industry's views on the place of physics in their sector.

The food sector is a particularly fertile area for this type of work. R&D is underfunded relative to its size and scope. It can readily leverage academic capabilities to create new commercial possibilities. Technological innovation is behind productivity and competitive advantage at every stage of the food system. And yet, until now, there has been a general lack of awareness of the extent to which the food industry benefits from physics.

## Methodology

The IOP has developed its understanding of the role of physics in food manufacturing through knowledge exchange between leaders in industry and academia, analysis of current data and ongoing consultation with partners.

This involved:

- Consultation with partner organisations, leaders in industry, experts in physics and research councils
- Analysis of knowledge-exchange and knowledge-capture exercises involving leaders in academia and industry, mapping physics research to pre-competitive industry needs
- Background analysis of the position of food manufacturing in the UK economy, the current position of R&D within this sector, comparisons to other sectors and current funding of physics in food manufacturing
- Ongoing collaboration with partners to share findings and put forward collective recommendations that support growth and job creation

## Why food?

Food and drink make up the biggest manufacturing sector in the UK.

It's a sector that accounts for 19% of manufacturing turnover – more than automotive and aerospace combined. It directly contributes £28 bn of gross value added to the economy, and when food retail and services are taken into account, it's more than £100 bn.

Food and drink manufacturing itself employs almost 400,000 people and, across the whole chain, the sector supports 3.3 million jobs. But another 100,000 recruits are needed by 2020 if the industry is to meet its needs.

It's also a diverse sector. It encompasses a variety of enterprises from farms to high-tech manufacturers. And it involves smaller companies as well as global giants – 96% of the 6,600 or so businesses in the sector range from micro- to medium-sized.

In the 10 years leading up to 2014, the value of food and drink exports more than doubled to £12.8 bn – despite a decline in overall exports.

Beyond purely economic concerns, the sector is also central to tackling some of the big challenges facing society – an improved diet can reduce the risk of many health problems, and using fewer plant and animal resources is increasingly necessary in the context of climate change. The sector has cut its carbon dioxide

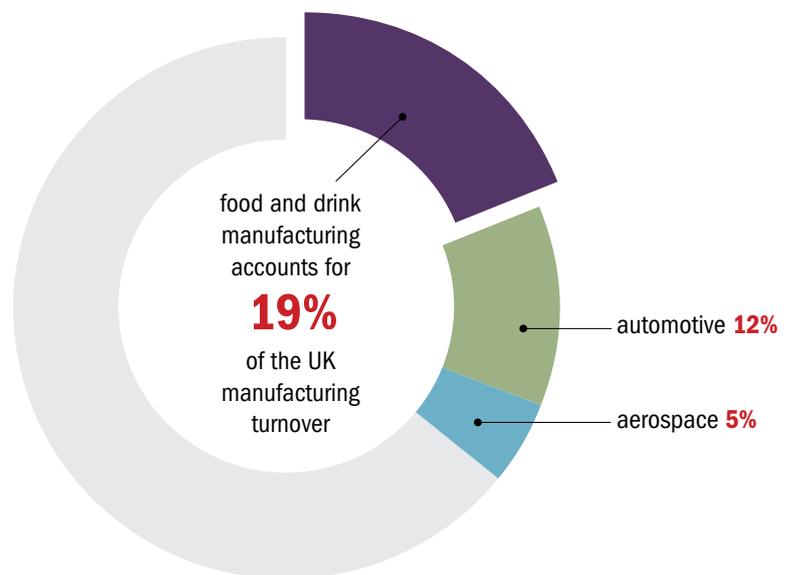
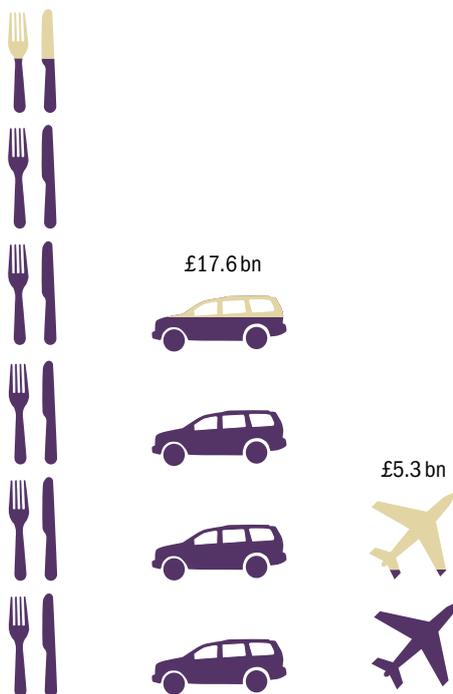
emissions by more than a third since 1990 and all but eliminated artificial trans fats. Manufacturers that are members of the Food and

Drink Federation (from which these figures come) have reduced salt in their products by 8% since agreeing a responsibility deal in 2012.

Gross value added by food, automotive and aerospace sectors in 2014.  
Source: Office for National Statistics

Percentage of total UK manufacturing turnover generated by food, automotive and aerospace sectors. Source: Office for National Statistics

£27.9 bn



The case for urgent action in the global food system is now compelling. We are at a unique moment in history as diverse factors converge to affect the demand, production and distribution of food over the next 20–40 years. The needs of a growing world population will need to be satisfied as critical resources such as water, energy and land become increasingly scarce. The food system must become sustainable, while adapting to climate change and substantially contributing to climate change mitigation. There is also a need to redouble efforts to address hunger, which continues to affect so many. Deciding how to balance the competing pressures and demands on the global food system is a major task facing policymakers.

**Professor Sir John Beddington CMG FRS, former government chief scientific adviser and head of the Government Office for Science**



As well as the challenges to primary production, our food chain faces other issues. The developed world is already seeing a serious growth in obesity, so that as many people are overweight as those that are undernourished. This will worsen as the developing world urbanises, and convenient process foods become increasingly in demand.

The manufacturing industry has focused on secure, safe and low-cost food, but the new challenge is matching health with diets. This will mean the use of new materials for the reduction in calories and increased micronutrient content, while maintaining pleasurable eating sensations – and all without losses in efficiency, meaning that reformulation and design of food structures must be better controlled. This cannot be planned without knowledge of the basics of process and material interactions, in the manufacturing process line, the human mouth and the digestive tract. We need the new physics of food.”

**Professor Peter Lillford CBE, former chief scientist of Unilever, chairman of Technology Foresight Panel, Food and Drinks**

## The economic context

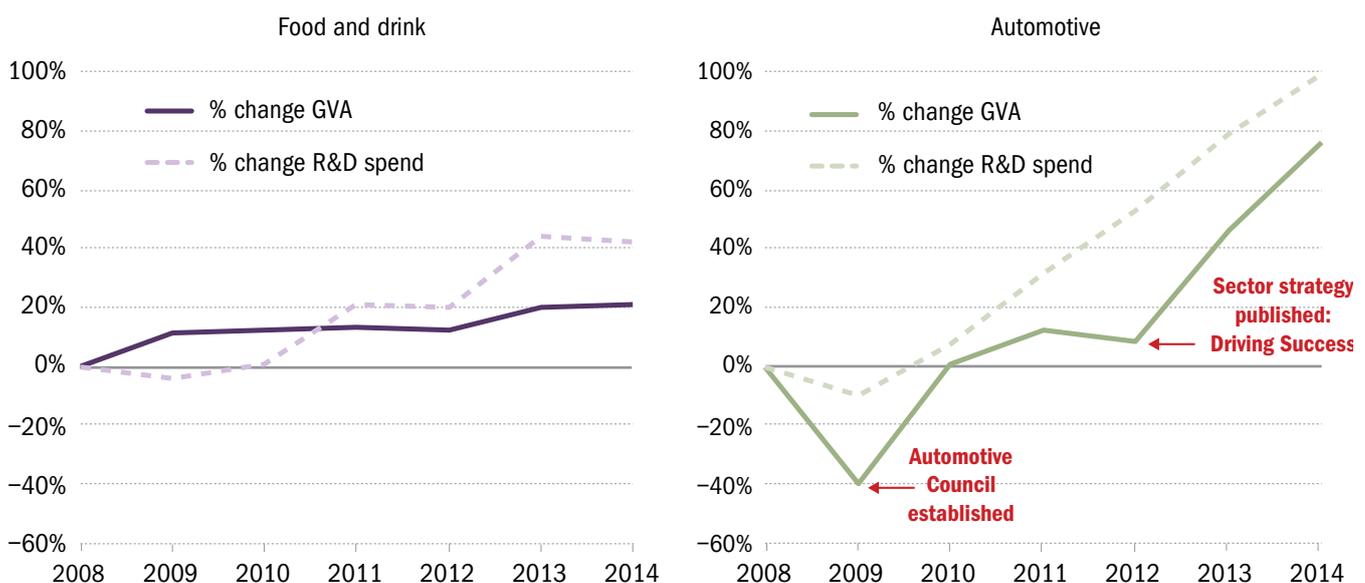
There is increasing evidence that investment in science drives economic growth and productivity.

Research by the UK Innovation Research Centre suggests that for every £1 invested in R&D by the UK government, private sector R&D outputs rise by 20 pence per year in perpetuity. This effect exists at

both national and sector levels. Although food and drink is currently the UK's largest manufacturing sector, it isn't growing as fast as, for example, the automotive industry. The fast growth within automotive correlates with an increase in that sector's R&D spending since 2008 – an increase not seen in the food industry.

Percentage change in GVA compared to R&D investment in food and drink manufacturing and in automotive, 2008–14.

Source: Office for National Statistics

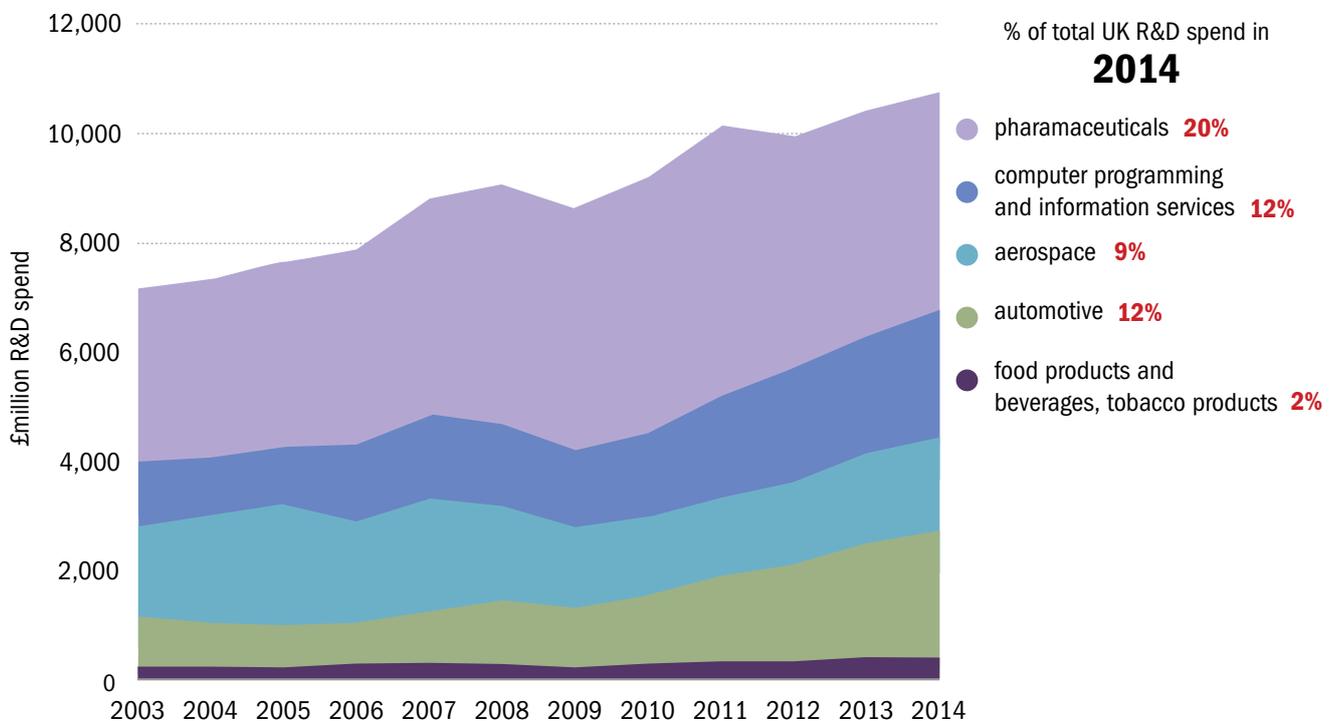


Notably, 2008 also saw the formation of the Automotive Council, which published its sector strategy in 2012. The food sector already has great potential and would likely benefit from similar coordination.

The relatively low level of R&D funding is a particular problem in the food and drinks

sector. In 2014 it accounted for less than 2% of the total R&D spend in the UK. Where other sectors see increasing R&D spending, that in food has remained at around the same level for a long time. This low level of R&D has meant that the sector risks losing out to international competitors.

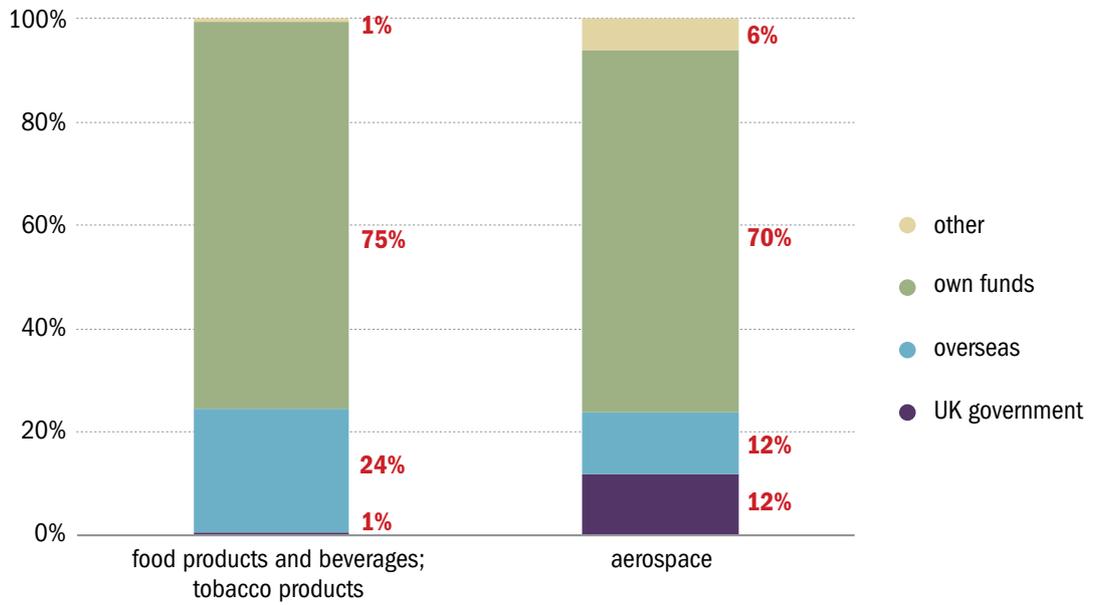
R&D spend by sector. Source: Office for National Statistics



Research has shown that public spending also crowds in private investment. That £1 of government spending mentioned above also leads to another £1.36 of private investment in

R&D, plus another £0.29 from higher education institutions. The higher levels of R&D and sector growth of aerospace correlate with increased public investment in the sector.

Sources of R&D funding in food manufacturing and in aerospace. Source: Office for National Statistics



The food manufacturing sector receives little public R&D funding. Even a small increase in public investment would have a significant effect on

the overall levels of R&D in the sector, and so on growth in the sector.

# The role of physics

## Why physics?

The food and drink manufacturing sector is facing a number of significant challenges: population growth, globalisation, improving food security, minimising environmental impact, and health and nutrition concerns.

A multidisciplinary approach is necessary to tackle these, and physics has a critical role to play. There are many notable instances of physics driving innovation in the industry.

Soft condensed-matter physics has added considerable insight into the behaviour of ingredients in products and during processing, resulting in the development of novel ingredients, improved products, reduced waste and improved processes. Research in this area has, for example, been used to develop membrane emulsification as a novel low-energy emulsification process, and to determine the self-assembly of proteins in solutions and at interfaces.

Modelling can provide valuable insights into ways to improve the manufacturing process and increase efficiencies or optimise food-processing systems, thereby reducing waste.

The structure of food is a critical consideration from both the perspective of the manufacturing

process and that of consumer experience.

Materials characterisation techniques can be used to study the impact of microstructures on the mechanics of the end product, to characterise ingredients and intermediates in the manufacturing process, and also to verify ingredients and products.

Advanced instrumentation techniques can be used to enhance the accuracy with which manufacturing processes can be monitored and controlled, thereby improving the efficiency, minimising waste and the consumption of energy and water, and contributing to increasing the quality and consistency of the final product.

And finally, nanoscale materials and novel coatings can lead to innovative packaging solutions that prolong shelf-life, reduce waste and decrease environmental impact.

These are just some of the examples of the impact that physics sub-disciplines have on food manufacturing. The challenges facing food manufacturers require problem-solvers with keen analytical skills – an attribute of trained physicists, for whom food manufacturing can provide many interesting challenges.

**Professor Roger Eccleston**

**Professor Roger Eccleston** has been pro vice-chancellor and dean of Sheffield Hallam University's Faculty of Arts, Computing, Engineering and Sciences since 2012, where he leads a broad range of disciplines.

Prior to this, he spent three years as dean of the School of Science and Technology at Nottingham Trent University. Other previous roles include that at the Science and Technology Facilities Council, where he was the



director of technology from 2007–9, preceded by a first stint at Sheffield Hallam as the director of the Materials and Engineering Research Institute from 2004–7.

His research focus is on quantum magnetism using large-scale facilities, such as neutron sources.

Eccleston is an alumnus of Sheffield Hallam, having completed a BSc in applied science at Sheffield City Polytechnic; he also holds a PhD in physics from the University of Warwick.

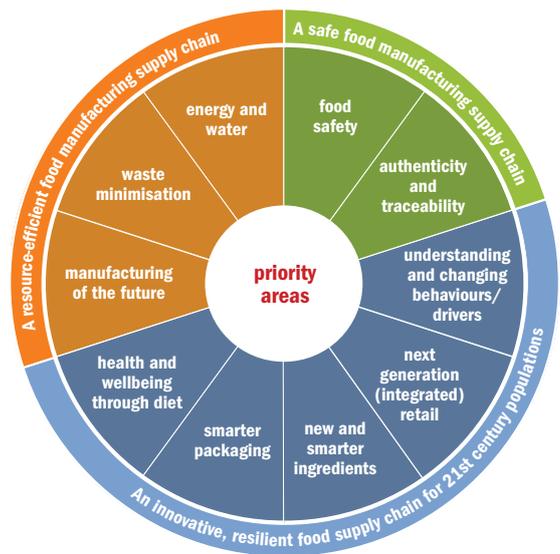
## Consultation with leaders in industry and in physics research

In December 2013, the Knowledge Transfer Network (KTN), Technology Strategy Board, and the Food and Drink Federation published their report A Pre-Competitive Vision for the UK's Food and Drink Industries. Based on a six-month consultation that took input from across the sector, it divided the food industry's needs into 10 themes across three grand-challenge areas, as shown in this wheel illustration taken from that report.

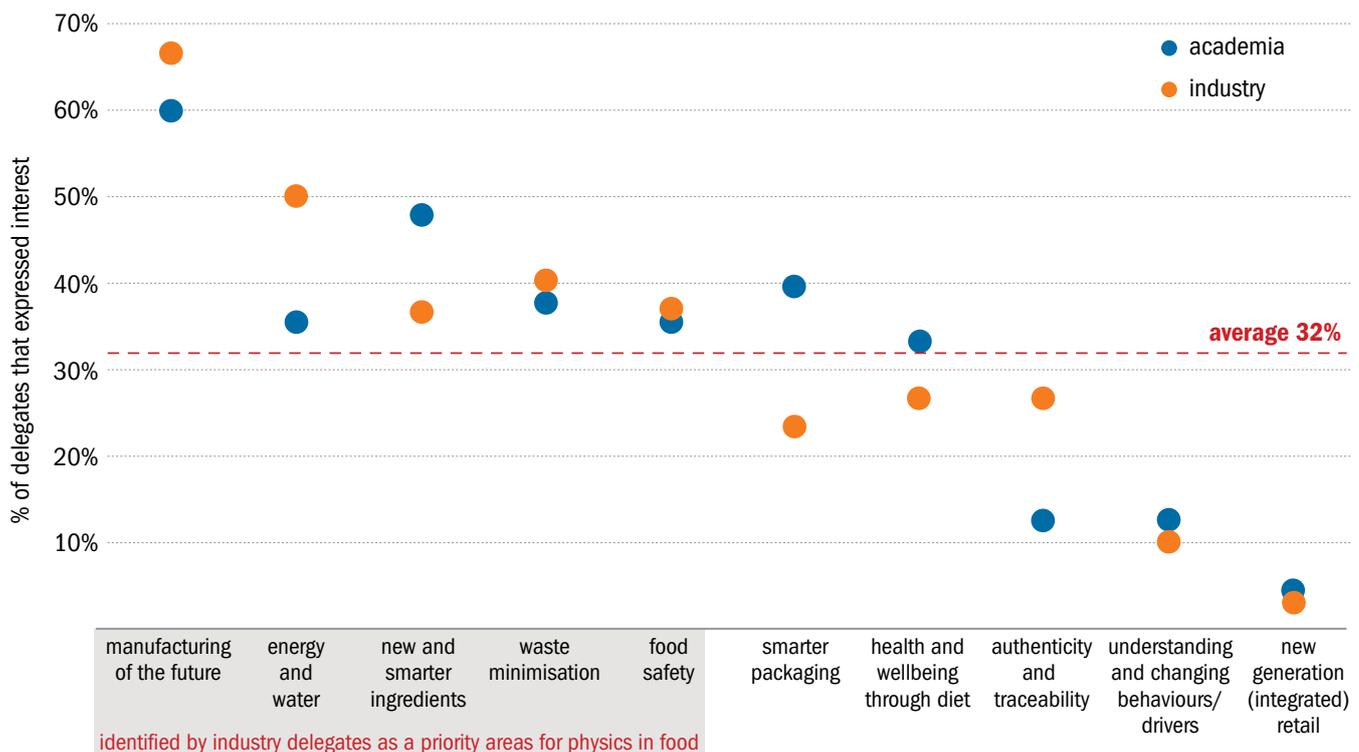
In April 2016, the IOP and partners brought together academics and industrialists for a summit on physics in food manufacturing, part of which included an exercise to map physics interests and capabilities to the sector's needs.

Participating delegates considered the major challenges of food and drink manufacturing, and provided information about their physics research strengths, facilities and application interests, and considered where those things map to the wheel.

Pre-competitive research priorities in the food manufacturing sector. Source: Knowledge Transfer Network



Academic and industrial interest in the food sector's priority areas. Source: Physics in Food Manufacturing Summit 2016



They then collectively shared their observations on:

- The priority areas that people are most interested in
- Which physics disciplines seem to be the principal enablers for those areas
- Which new capabilities might be most relevant to food and drink manufacturing
- Whether there are any priority areas for research where physics doesn't appear to have a role to play

Industry delegates highlighted five areas in particular where physics can tackle the food industry's pre-competitive challenges:

- Manufacturing for the future
- Waste minimisation
- Energy and water
- New and smarter ingredients
- Food safety

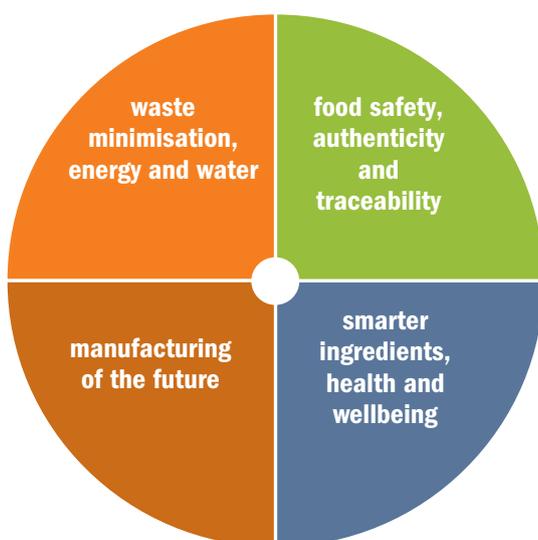
The priority pre-competitive research areas fall into natural groupings based on the expected

Comparing the levels of interest from academia and industry in the various sector challenges showed a strong correlation in general. However, there are some apparent gaps, indicating an ongoing need for knowledge exchange between industry and academia, and greater coordination between them to apply the right knowledge to the right problems in a more strategic way.

outcomes and challenges involved. In particular, waste minimisation is closely linked to energy and water, food safety is linked to authenticity and traceability, and health and wellbeing are linked to smarter ingredients.

Taking into account these groupings, as well as the industry priority demonstrated in the previous graph, the KTN challenges can be refocused from a physics perspective. This gives us a view of research challenges in food manufacturing through the lens of physics.

Research challenges in food manufacturing refocused through the lens of physics. Source: Physics in Food Manufacturing Summit 2016



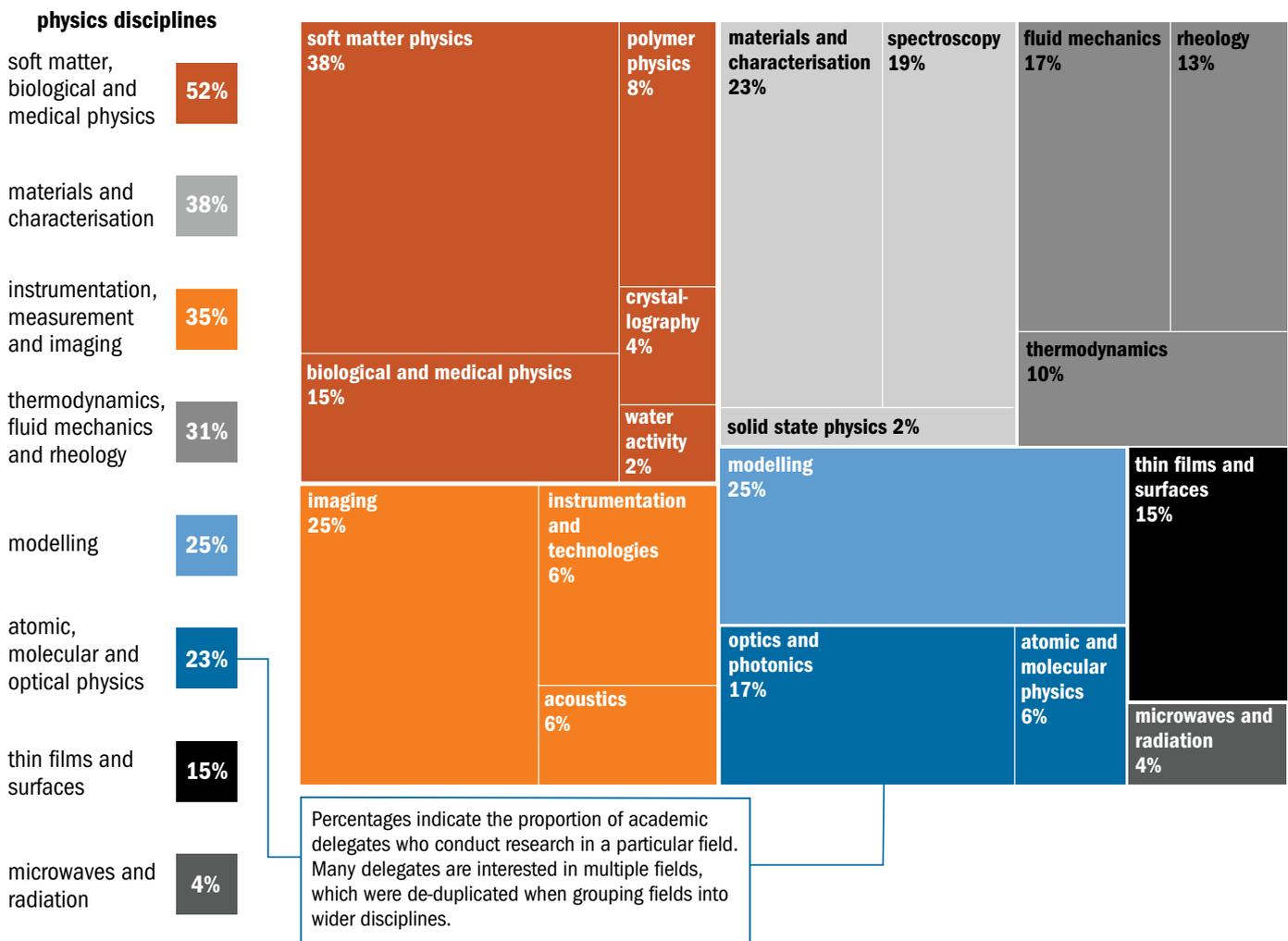
# The role of physics

## Mapping physics research to industry challenges

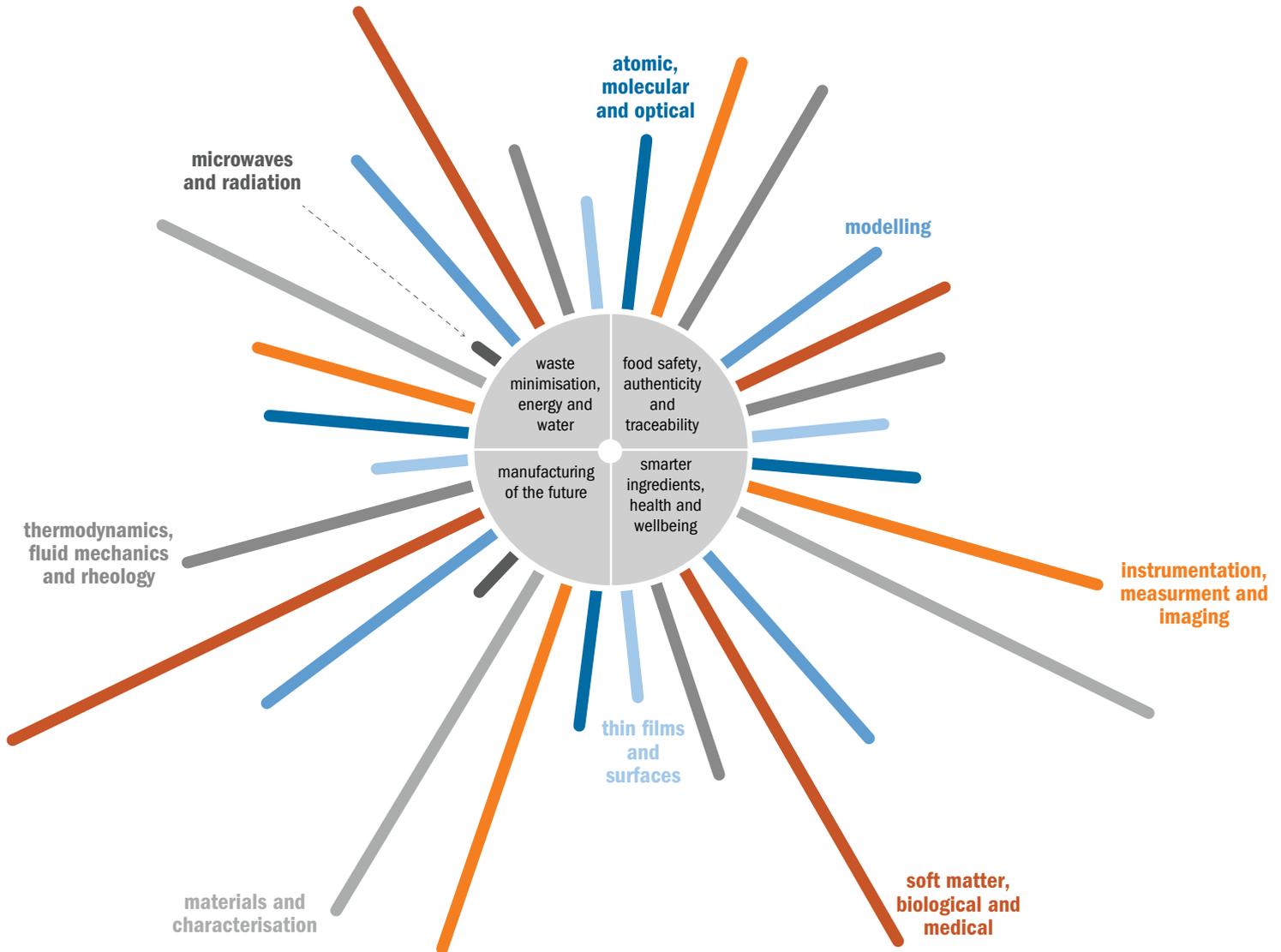
Canvassing the physics community at the IOP summit revealed 21 physics building blocks that

relate to the pre-competitive challenges in food manufacturing. These physics research areas can be grouped into eight broader physics disciplines that were shown to feed into R&D in this sector.

Physics building blocks identified as being important to food manufacturing. Source: Physics in Food Manufacturing Summit 2016



Physics disciplines mapped to sector challenges. Source: Physics in Food Manufacturing Summit 2016



Delegates then mapped these physics disciplines to the challenges, showing areas of priority as well as the breadth of disciplines that can be applied to challenges in food manufacturing.

Each industry challenge is met by a wide range of physics disciplines, showing the diverse nature of physics research in food manufacturing, as well as the importance of physics in addressing the pre-competitive challenges.

# The role of physics

Physics disciplines mapped to sector challenges – a different view. Source: Physics in Food Manufacturing Summit 2016

	manufacturing of the future	smarter ingredients, health and wellbeing through diet	waste minimisation, energy and water	food safety, authenticity and traceability
soft matter, biological and medical physics	33%	29%	25%	15%
materials and characterisation	27%	29%	23%	19%
instrumentation, measurement and imaging	27%	23%	15%	19%
thermodynamics, fluid mechanics and rheology	19%	15%	13%	13%
modelling	19%	17%	17%	13%
atomic, molecular and optical physics	10%	10%	13%	13%
thin films and surfaces	6%	8%	8%	8%
microwaves and radiation	4%	0%	2%	0%

That same data can also be viewed as a heatmap, which shows some obvious hot points – for example, a third of delegates linked soft matter, biological and medical physics to manufacturing of the future. These hot points show the physics

disciplines that can clearly play an important role in food research. However, each challenge has a broad range of physics disciplines to draw on. Note, for example, the link between modelling and waste minimisation, energy and water.

The physics disciplines	
Soft matter, biological and medical physics	Understanding the structure and kinetics of complex fluids and soft solids such as colloids, polymers, gels, liquid crystals and granular matter. Physical modelling and experiments (eg, optical tweezers, microscopy and spectroscopy) to investigate biological systems such as bacterial motility, biopolymer kinetics and molecular motors. Imaging instruments and signals for monitoring and diagnostic purposes.
Materials and characterisation	Understanding, modelling and processing of theoretical and practical aspects of the structure and behaviour of materials.
Instrumentation, measurement and imaging	Development and use of instruments and equipment to measure, monitor and/or record physical phenomena.
Thermodynamics, fluid mechanics and rheology	Thermodynamics: developing models for thermal systems where heat is the main energy-transfer mode. Fluid mechanics: the study of forces and flow within fluids. Rheology: the science of flow and deformation of matter, describing the interrelation between force, deformation and time.
Modelling	Using physical and mathematical representations of a system or process as a basis for simulations to understand how it will behave without actually testing it.
Atomic, molecular and optical physics	The study of the behaviour of atoms and molecules, modelling and imaging of molecules, and the interaction between light and matter.
Thin films and surfaces	The study of chemical and physical processes that occur at surfaces and interfaces, leading to application in fields including heterogeneous catalysis, chemical sensors, electrical and magnetic devices, as well as material coatings.
Microwaves and radiation	The use of electromagnetic waves or subatomic particles for processes such as heating, thickness control and food preservation.

# The role of physics

Soft matter, biological and medical physics supports manufacturing of the future. Source: Physics in Food Manufacturing Summit 2016

Use of membrane emulsification as a novel low-energy emulsification process

Illuminating the fundamental processes underlying the self-assembly of proteins in solution and at interfaces

Forming materials using extrusion, tape casting, isostatic compaction, and low-pressure injection moulding

Formation and behaviour of non-equilibrium systems such as glasses, gels or jammed states in molecular, colloidal or supramolecular systems



Modelling supports energy, water and waste minimisation. Source: Physics in Food Manufacturing Summit 2016

Modelling the cutting process of wafers on the assembly line with the aim of improving the manufacturing process and increasing efficiency

Using computational fluid dynamics to meet the theoretical challenge of modelling a variety of phenomena, leading to significant efficiency savings in the manufacturing process

Mathematical modelling, simulation and optimisation of food processing systems to increase efficiency and reduce waste

Using thermodynamics to assess energy efficiency through analysis of resources used in food manufacturing processes



# The role of physics

Materials and characterisation supports smarter ingredients, health and wellbeing. Source: Physics in Food Manufacturing Summit 2016

Characterisation of powders using various techniques including differential scanning calorimetry, thermogravimetric analysis, electron microscopy and X-ray powder diffraction

Characterising the structure of starches in foods, to understand how starch structure influences digestion and subsequent microbial fermentation

Using mechanical characterisation to investigate how the microstructures of ingredients affect the end product

Applying Raman spectroscopy (molecular-scale fingerprinting) to food products to determine composition and quality



## CASE STUDY: Crisps

Where's the physics in making the humble potato crisp that we all know and love? The manufacturing process is based on a simple kitchen process – take a whole potato, wash, peel, slice, fry for three minutes, and season. But there's much more science involved than at first glance. British consumers eat 10 million packets of Walkers crisps a day, so ensuring that every crisp is the same, great quality – every chip, every bag, every day – is a formidable challenge.

The challenge starts with an inherently bio-variable, natural raw material – the potato. Only specially selected British chipping potatoes are used by Walkers, such as Lady Rosetta, Hermes and Marquees, chosen for their great flavour and appearance, disease resistance and crop yield as well as storage capability – the fresh crop season is only four to five months long, so all-year crisp production requires potatoes that keep in good condition in temperature-, humidity-, CO<sub>2</sub>- and light-controlled long-term storage.

Great flavour requires in-depth understanding of potato biochemistry, such as enzyme inactivation to avoid an unappealing earthy flavour, the role of sugars and Maillard reactions for colour formation, and lipid oxidation in the frying oil. Meanwhile, getting the right texture requires deep understanding of the starch transitions during the dehydration process.

Starch in potatoes starts in its native crystalline form and, during dehydration, passes through its rubber melt phase, and finally through a glass transition. If the correct starch

transformation during dehydration is achieved, we get the light, crispy texture that consumers expect. The soft-matter phase of starch (ie, the melt phase) is critical – understanding internal forces of steam-vapour pressure versus starch yield stresses, the sensitive time/temperature glass transition region and oil-uptake kinetics are all required to create the desired texture.

Once we understand the physics of the flavour and texture generation, then the dehydration process can be designed to deliver the correct time-temperature profile, slice agitation in the fryer oil and take-out conditions as the slices leave the oil.

Potato slicing is one of the most critical operations. To reduce stress cracking, which can cause in-bag breakage, considerable computer simulation effort has gone into the slicer blade and slicing process design (eg, the blade bevel angle or the slicer rotation speed). Slicing also impacts surface roughness, which is a factor in oil uptake during frying.

Sophisticated 3D imaging techniques are used, such as high-resolution X-ray CT scanning, to understand where the oil in a fried potato slice is located relative to the potato starch cells (which impacts mouth feel and perception of succulence) and pore-size distribution (which affects the texture).

What the consumer sees in and eats from a packet of Walkers crisps is simply great texture and flavour, every crisp, every bag, every time – but the scientific understanding behind this simple pleasure is anything but simple.

**John Bows, PepsiCo**

After graduating from Exeter University with a BSc (Hons) in physics, **John Bows** joined Campden BRI in 1988, where he set up a microwave product and packaging contract research capability. John was the technical lead on the UK Government's Microwave Working Group, which developed the letter rating system on microwave ovens and ready-meal heating instructions.

In 1991, Bows joined Unilever R&D (Colworth), working on many process and packaging technology innovation projects across food categories, specialising in field physics technologies to provide advantaged process solutions for product innovation. He developed the microwave packaging solution for the successful launch of the world's first raw-rising dough microwave pizza, and developed novel non-



invasive metrology techniques for 3D temperature and structure mapping within food.

In 2005, Bows joined PepsiCo R&D (Leicester), leading various breakthrough technology-innovation projects for PepsiCo's snack business. He currently leads a multimillion-dollar project to develop a breakthrough in great-tasting healthy snacking.

Bows has a publication track record comprising 14 peer-reviewed publications, 12 conference proceedings and 10 granted patents. He was a founding director of AMPERE (Europe microwave heating association) in 1995 and is currently a member of the Microwave Working Group, which organises global microwave conferences. In 2002, Bows was elected as a fellow of the IOP.

## CASE STUDY: From ice cream to soups

Foods are frequently complex, with many coexisting phases of matter, and are deliberately created as metastable materials.

To take an extreme example, ice cream has a crystalline ice phase (so in some sense is a high-temperature ceramic) but also a sugar syrup, prevented from freezing by the osmotic pressure of solutes, which undergoes a liquid-liquid phase separation because of the dissolved polymers. There is also a fat phase (which is not only crystalline, but contains liquid oil at warmer temperatures), air phase, and a whole set of two-dimensional phases where proteins and diglycerides compete for space at the interfaces between other components.

Margarines, dressings, soups and sauces present similar complexities.

In all cases, the lowest free energy state is nothing like the product that is sold, so, during processing, one needs to hit a tiny and unstable target in the space of possible structures – and to do this as fast as possible while using a minimum amount of energy. That structure needs to stay intact for perhaps months of storage under conditions similar to when it's eaten, but, when it is finally consumed, the microstructure needs to fall apart just so, to give a nutritious and tasty experience.

All of the steps in this chain involve complex physics that needs to be understood to improve both foods and food processing, and which can be probed through advanced measurement techniques. No single technique is able to cover all of the interesting length scales in evolving food structures, from nanometres (typical of macromolecules) to hundreds of microns; and light scattering, electron and confocal optical microscopy and X-ray tomography are all brought to bear. Magnetic resonance imaging may be needed to follow the breakdown of food during digestion, where the

rapidly changing pH, dilution and hydrolysis of polymers can push food materials into domains of fractal flocculation long beloved of statistical physicists. Imaging is not the only area of concern – structure is primarily important for the effect it has on texture, so it's also necessary to measure the mechanical properties both of the bulk food (rheology) and of the surfaces of air bubbles and fat droplets, since the coarsening of structure is often driven by the free-energy gains from eliminating interfaces.

In recent years, simulation has been playing an ever larger role in the food industry. For example, new processing equipment is often tested *in silico* before being trialled in reality, and computational fluid dynamics can be brought to bear on anything from reducing the energy usage of new freezer cabinets to choosing the best design of teabag to enhance flavour infusion. Despite this, the simulation of complex, evolving microstructures in the large-scale flows typical of processing machinery remains a serious challenge for the industry.

Lastly, it's tempting to imagine that sophisticated measuring equipment and high-powered silicon are the *sine qua non* of modern food research. However, as in so many fields, there is no substitute for good thinking. Even quite pure pencil-and-paper theoretical work can be used to address interesting practical questions in manufacturing. For example, many foods are packed particulate systems, whether emulsion drops in a mayonnaise or salt crystals in a dry bouillon, and recent work on sphere packing has led to a new heuristic for predicting random close-packing fractions of polydisperse particles – an important parameter that determines many mechanical properties of these types of system.

**Dr Robert Farr, Unilever**

**Dr Robert Farr** is a physicist at Unilever R&D. He is currently based at Colworth Science Park near Bedford, but has also worked at labs and development centres in the Netherlands, the US and Germany. For the past 18 years Farr has been helping to solve problems in materials science and heat- and mass-transfer for a range of projects across Unilever's core categories of foods,



refreshment and home and personal care.

His interests lie in the theory and simulation of the relation between the structure and the mechanical, thermal and diffusive properties of materials. As well as his research role at Unilever, Farr has business start-up experience through an internal business incubator, and is a visiting fellow at the London Institute for Mathematical Sciences.

## CASE STUDY: Coffee

Physicists can apply much of their skillset to food manufacturing: their ability to analyse problems, bringing clarity to a problem statement, establishing the basic principles and governing equations, and breaking a problem down and estimating what is important. They can focus on pinch-points in a process, involving complex physical transformations. Physicists bring strong equation-based modelling skills, can make rational estimates and, furthermore, are trained to develop and apply new measurement techniques. In particular, physics training brings a broad view, and physicists can adapt models and knowledge developed from seemingly unrelated areas to their current food problem.

As you drink your morning coffee you may wonder what the role of physics is in this beverage product. There is plenty. Much of the roasting of coffee is a mystery. In particular, the evolving physical condition inside the roasting bean sees much myth but little hard evidence. Although some may like to keep it as an art, we as physicists and commercial operations seeking to optimise raw material and energy use, need a deeper understanding. A collaboration with the University of Oxford led us to new models of moisture and pressure conditions inside a roasting bean – models inspired by ones developed for baking bread.

Coffee is brewed by flowing through a packed bed of particles – the complex physics of flow through such beds, the permeability of the bed and the packing of grains are rich areas of intriguing micron-scale physics. The coffee bed is

not in a steady state – on the timescale of brewing, it evolves. The flow passing through it is multi-phase, the beverage liquid but also gas; coffee grains are 50% air, which is released into the flow when they are wetted. At Jacobs Douwe Egberts, we've developed controlled experiments on measuring the evolution of the flow resistance of the bed, and novel theory on the packing of the grains. We've found new insights into the effects of fining agents on particle packing and dynamic bed permeability. We've used nuclear magnetic resonance at the University of Cambridge to image flows through beds. The work is relevant to the individual brewing we all do at home in modern, on-demand coffee systems but also the industrial-scale processing of instant coffee. In the latter case, there are intriguing questions of the resulting granule structure on drying the extract, how its interconnected pore space promotes the fast dissolution of the granule. This was the goal of a recent collaboration with the University of Birmingham funded by Innovate UK.

While this is all developed for coffee, we've exploited developments in physics from other areas, particularly those in which flow through porous beds is central, such as the oil and gas industry. We hope in turn that, when published, some of our new ideas may be useful elsewhere. Beyond these examples, coffee beverage manufacturing is replete with problems on the flow of powders, the creation of metastable states, and the evolution of foams and colloid structures.

**Dr John Melrose, Jacobs Douwe Egberts**

**Dr John Melrose** studied for a BSc in physics and computational maths at the University of Illinois and then for a PhD in physics at Cardiff University, completing the latter in 1983. His thesis area was real-space renormalisation techniques in statistical physics.

Melrose spent many years as a postdoc in physics and chemistry departments, working on diverse areas such as the modelling of transport in semiconductors, quantum Monte Carlo techniques, statistical physics, electro-rheology and fractal pattern formation in electro-deposition. He was often funded by, and in collaboration with, industry.

In 1992, he joined Professor Dame Athene Donald's group in the University of Cambridge's Cavendish Laboratory,



running a simulation team developing algorithms for colloid particles, fibre mechanics and flow in porous media. Those algorithms were applied to colloid rheology, aggregation and even hair mechanics.

Melrose has around 80 publications in the physics, chemical engineering and food science literature. In 2000, he joined Unilever Colworth to lead their food-process modelling and later became senior physical scientist and technology scout in their corporate research body. In 2009, Melrose joined Kraft as the chief scientist for their coffee business – while Melrose has stayed in Banbury, the coffee business has moved, first to Mondelez and recently to a joint venture, Jacobs Douwe Egberts.

## The food manufacturing workforce

As we've seen, physicists are important to innovation in food manufacturing. But they're under-represented in the sector.

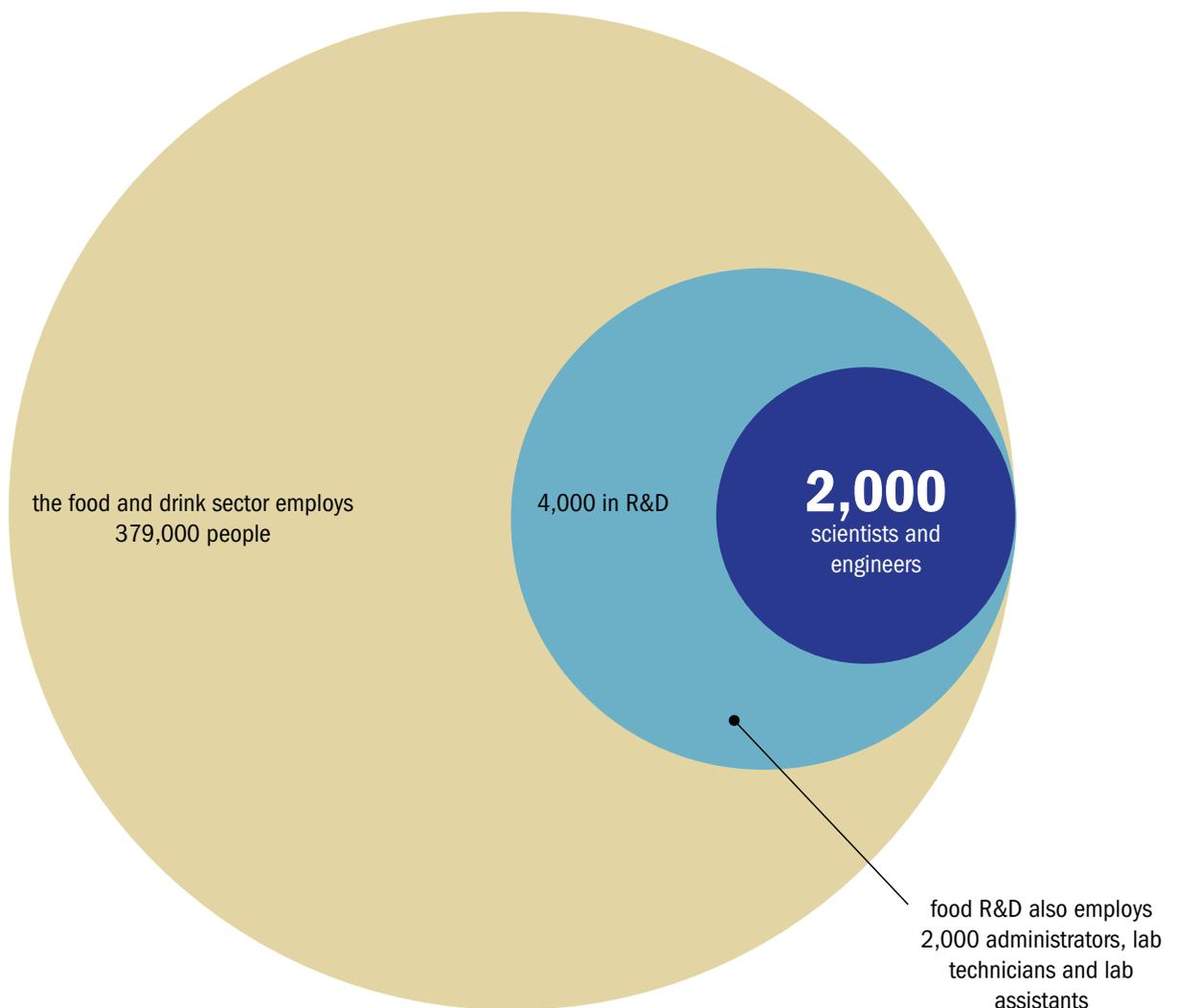
The IOP carries out a great deal of work to encourage more people to study physics, and is now working with partners to encourage students to consider the food sector and to highlight how rewarding careers within the industry can be.

The sector not only provides deep intellectual challenges for physicists to sink their teeth into, but also offers career paths towards senior management. This is illustrated in the profile of

John Melrose who first came into the sector to use his technical expertise and now has a senior leadership role.

In the course of the IOP's consultations, it was clearly articulated from industry partners that the future growth of the sector will rely on manufacturers recruiting physicists. One example of good practice in recruiting students is the internship scheme at Jacobs Douwe Egberts. The Institute and partners would encourage the creation of similar programmes elsewhere where they don't currently exist, and greater efforts to take on physics students among existing schemes.

Employees in the food manufacturing sector. Source: Office for National Statistics



## CASE STUDY: The internship scheme at Jacobs Douwe Egberts

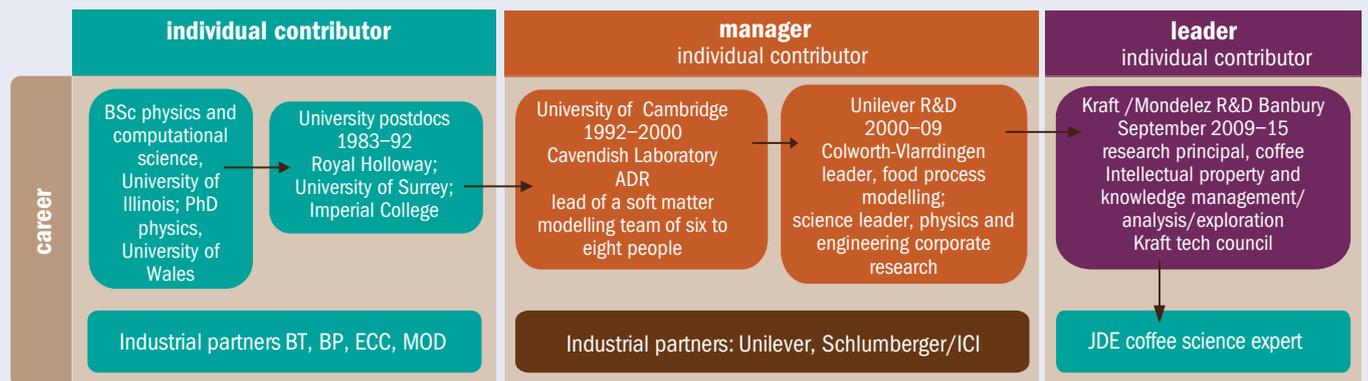
Jacobs Douwe Egberts brings in interns at both of its R&D centres – in Banbury and in Utrecht. In Banbury they take 15–18 interns a year, usually for a one-year period. So far these have been mainly from UK food science and chemical engineering departments – but the company hopes to add a few physics students into the mix.

The students are each given an individual research project, which can be quite stretching. They also receive a range of training on soft-skills, are mentored and, in addition, given a team challenge: to self-organise to create charity events throughout the year.

From Jacobs Douwe Egberts' point of view, R&D gets what is often an energetic, creative, hard-working, fast-learning resource to back up its programmes and to learn and do some fundamentals. In return, interns gain valuable experience of the commercial R&D workplace, a chance to put their skills into practice and recognition that the food industry can offer an exciting career.

Over the years many interns – sometimes as many as six per cohort – have ended up in a permanent role. The company has said that it finds the intern scheme an excellent recruiting route and a great way to inject some exuberance.

### Career journey of Dr John Melrose, Jacobs Douwe Egberts



# Funding for physics in food manufacturing

As we've seen, there is a clear correlation between economic growth and investment in R&D. However, spending on research relevant to the food sector is low. If the sector is to grow, the research councils will need to stimulate research and to fund the pre-competitive research that is applicable to food manufacturing.

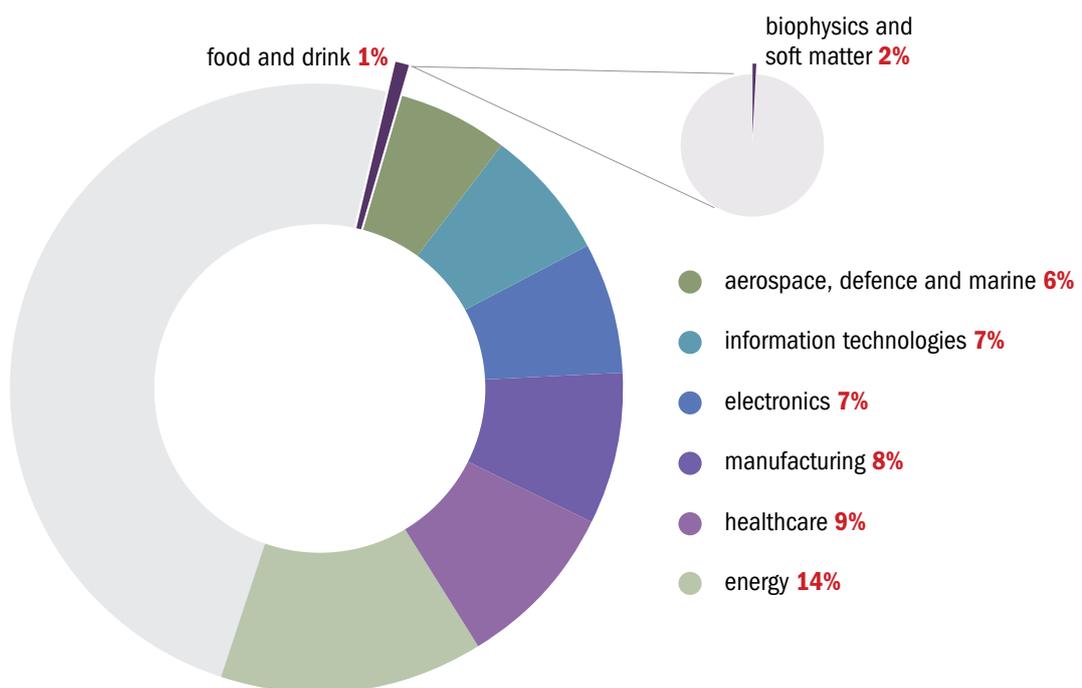
To take one example, breaking down the current portfolio of the Engineering and Physical Sciences Research Council (EPSRC) gives an

indication of the present level of funding of physics relevant to food – and shows that there's room for growth.

The EPSRC currently spends around £84 m on research that it identifies as feeding into the food and drink sector – just 1% of its total portfolio.

Only 2% of this total goes towards biophysical and soft-matter physics – a research area identified by the IOP's consultations as one of the most relevant to food manufacturing.

Breakdown of EPSRC research portfolio. Source: EPSRC



This suggests that the funding landscape is fragmented and doesn't meet the sector's needs – that there is no holistic approach to growth across the supply chain.

Although there is some work across the different research councils on global food

security, and this provides a platform to build on, there is a need for more communication between industry, academia and the funding bodies to evolve a more effective industrial strategy for investment in research to drive competitiveness and productivity.

# Connecting academia and industry

Another area that the IOP's consultations revealed as needing greater engagement is in enabling the food sector and academics – particularly physics researchers – to forge stronger and more strategically aligned connections.

A successful academic–industrial partnership can help businesses underpin their core scientific understanding, innovation pipeline and long-term growth, and can help academic institutions demonstrate impact, upskill their people and attract funding.

Although there are some barriers to collaboration, great opportunities can be created when strong connections are made. The most fundamental requirement for this to happen is that people working with complementary skills and expertise are aware of each other. This can be particularly difficult when not all physicists recognise that working on food-related problems can be so rewarding – which is something that will need to be remedied.

Once each party knows that the other exists, both of them have to get value from the collaboration. Projects that benefit all partners are often based on complex problems that industry can't solve with its own resources and skills, and which are important enough to warrant the longer timeframe of academic research. These projects usually take root in established relationships in which both partners have built understanding of each other's drivers and

motivations. This understanding leads to a clearly articulated project objective and achievable outcomes.

As starting points, many opportunities exist for small projects and consultancy. Although these are unlikely to deliver the intellectual challenges or research outputs of longer projects, they can, if fruitful, be seen as opportunities to build relationships. Industrials and researchers consulted by the IOP shared many of their starting points, including:

- Academics working with material from industry
- Student placements
- Applying innovative techniques to new materials in new sectors
- Providing measurement services and applying analytical methods
- Industrial sabbaticals for academics

The IOP also heard calls for academic scientists to be more proactive in building links with commercial scientists. Researchers felt that industry could do better in communicating the sector's activities and challenges. Ultimately, all sectors need to develop the skills to sell their ideas and approaches to each other.

Connecting academia and industry is an area in which the IOP is particularly well placed to facilitate support through its networks such as special-interest groups, and through its open innovation programmes.

# Conclusions and recommendations

Food manufacturing is a large, diverse sector in which physics plays a crucial role and which can benefit enormously from physics-based innovation.

Physics is a significant lever in food manufacturing – it tackles all of the industry’s main challenges. But if the sector is to reach its full potential, the science base that supports it needs investment – and that investment must be directed appropriately. Furthermore, the correct people will need to connect in the right way to ensure that relevant expertise is directed to the appropriate places.

As with other industries, food manufacturing will continue to need workers with scientific skills, making education and training in the sciences important. Manufacturers themselves will need to take steps to employ more physicists. If the recruitment shortfall is to be reversed, all parties involved will need to commit to showcasing the rewarding careers available to physicists, and to actively encourage physics graduates and postdocs to work in food.

Overall, food manufacturing would benefit considerably from the joined-up thinking of a sector-led strategic approach. The automotive industry began to grow sharply after the formation of the Automotive Council and with an increase in R&D spend, and food can do the same – or better. The IOP has some recommendations (below) in the area of strategic oversight.

For our part, the Institute will also continue to take a role in facilitating innovation. The IOP’s next steps include an international conference on physics in food manufacturing to be held on 9–10 January

2017, publications to highlight the role of physics in the sector, and producing and distributing materials highlighting possible careers for physicists in the food industry. Our special-interest groups already play a part in linking researchers up with industry, and there is the potential to expand this further.

Taken together, these steps can help to ensure the UK’s growth and prosperity through physics – turning an already strong manufacturing sector into a true world-leader.

## Recommendations

We recommend that the government establish an industrial strategy committee for food manufacturing, chaired by a minister in the Department for Business, Energy and Industrial Strategy.

This committee would:

- Provide a coordinated, strategic, raised level of investment in the scientific research that underpins innovation in food manufacturing
- Support collaborations between academia and industry, and leverage knowledge from the research base
- Spread and ensure awareness of the food sector’s reliance on technological innovation
- Inspire physics students – tomorrow’s workforce – to work in food manufacturing

The IOP, as the representative body for physics and physicists, should play a part in this committee to ensure and facilitate the involvement of, and engagement with, physicists in academia and industry.

## IOP activities

The Institute and its partners will explore the possibility of a legacy activity developed from its open innovation programme in food manufacturing.

The IOP currently funds and supports 48 special-interest groups, several of which are industry-focused. One possibility is the establishment of a Food Manufacturing Group, which could help to coordinate relations between academics and industrialists, and feed into the development of industrial strategy for the food sector.

The Institute is also working with partners to signpost the community towards sandpit workshops on funding pre-competitive research, producing resources to distribute to affiliated schools to highlight the career opportunities that the food sector provides, and developing an outreach event to engage the public with the role of physics in food.

# Appendix 1: Bibliography and sources

## **Introduction**

The data on the food manufacturing sector are taken from the Office for National Statistics Annual Business Survey, 2016.

The quote from Professor Sir John Beddington is taken from the Government Office for Science report *The Future of Food and Farming*, published in January 2011.

## **The economic context**

The data comparing the food sector to the automotive sector are taken from the Office for National Statistics Annual Business Survey, 2016.

The data showing the R&D spend as a percentage of GDP are taken from the UNESCO Institute for Statistics report *Science, Technology and Innovation: GERD as a Percentage of GDP*, 2016.

The data comparing sources of R&D funding in food and aerospace are taken from the Office for National Statistics bulletin *Business Enterprise Research and Development*, 2015.

The data comparing R&D funding in different manufacturing sectors are taken from the Office for National Statistics bulletin *Business Enterprise Research and Development*, 2015.

## **The role of physics**

All data in this section are taken from surveys conducted during the summit on physics in food manufacturing organised by the IOP and partners.

## **The food manufacturing workforce**

The data showing the number of employees in food manufacturing are taken from the Office for National Statistics bulletin *Business Enterprise Research and Development*, 2015.

## **Funding for physics in food manufacturing**

The data on the amount of funding that the EPSRC identified as feeding into the food sector are taken from the EPSRC publication *Visualising our Portfolio*.

## **Connecting academia and industry**

This is based on consultation between leaders in academia and industry at the summit on physics in food manufacturing held in April 2016, which was organised by the IOP and partners.

# Appendix 2: Partners in physics in food manufacturing open innovation programme

This report forms part of a programme of open innovation in food manufacturing, which is a collaboration between the organisations below.

## **Engineering and Physical Sciences Research Council**

The Engineering and Physical Sciences Research Council is the main UK government agency for funding research and training in engineering and the physical sciences, investing more than £800 m a year in a broad range of subjects – from mathematics to materials science, and from information technology to structural engineering.

## **Food and Drink Federation**

The Food and Drink Federation is the voice of the UK food and drink industry, the largest manufacturing sector in the country, speaking on behalf of global brands and thriving small businesses.

## **Innovate UK**

Innovate UK is the UK's innovation agency. It is an executive non-departmental public body, sponsored by the Department for Business, Energy and Industrial Strategy. It works with people, companies and partner organisations to find and drive the science and technology innovations that will grow the UK economy.

## **Institute of Physics**

The Institute of Physics is a leading scientific membership society working to advance physics for the benefit of all. It has a worldwide membership of more than 50,000, from enthusiastic amateurs to those at the top of their fields in academia, business, education and government.

Its purpose is to gather, inspire, guide, represent and celebrate all who share a passion for physics. And, in its role as a charity, it's here to ensure that physics delivers on its exceptional potential to benefit society.

## **Jacobs Douwe Egberts**

Jacobs Douwe Egberts is a global coffee and tea company, serving consumers in more than 100 countries through iconic brands, including: Jacobs, Tassimo, Moccona, Senseo, L'OR, Douwe Egberts, Kenco, Pilao and Gevalia.

## **Knowledge Transfer Network**

The Knowledge Transfer Network (KTN) is the UK's innovation network. It connects people to speed up innovation, solve problems and find markets for new ideas.

## **PepsiCo**

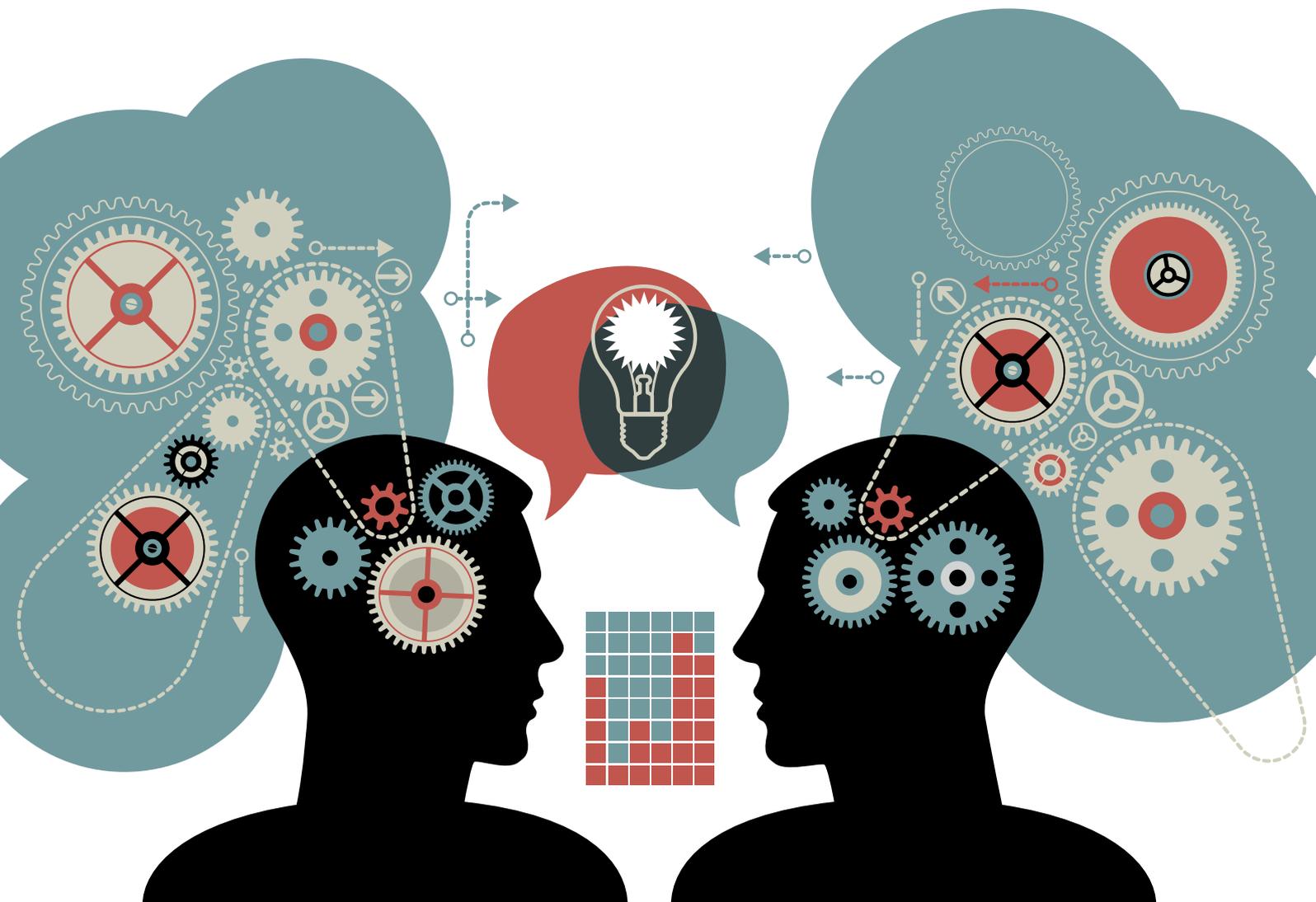
One of the world's leading food and drink companies, PepsiCo is home to market-leading brands and household favourites like Quaker, Walkers, Pepsi Max and Tropicana.

## Sheffield Hallam University

Sheffield Hallam University is home to the National Centre of Excellence for Food Engineering, designed to tackle the food sector's challenges head on. It supports the food and drink industry by developing new and enhanced facilities, processes and equipment, and creating a knowledgeable workforce with experience of leading engineering systems and processes.

## Unilever

Unilever is a British-Dutch consumer goods company that produces food and beverages, cleaning agents and personal-care products. It operates in 190 countries and its products are used in nine out of 10 UK homes.



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