2014 | Issue 1

Institute for Manufacturing REVIEW

3D printing

The future of manufacturing

Ultra precision manufacturing

Twenty-first century supply chains

IfM MANAGEMENT TECHNOLOGY POLICY

UNIVERSITY OF CAMBRIDGE

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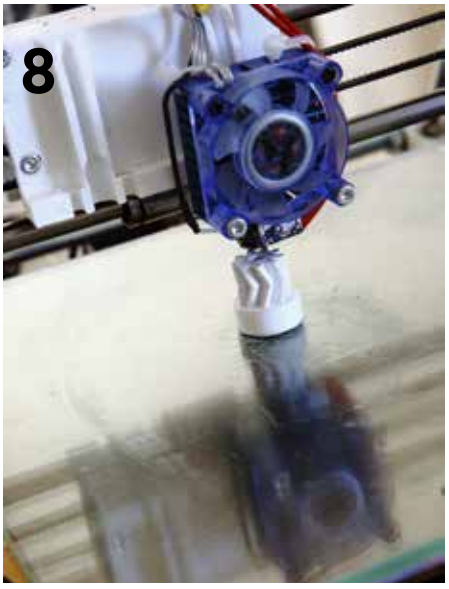

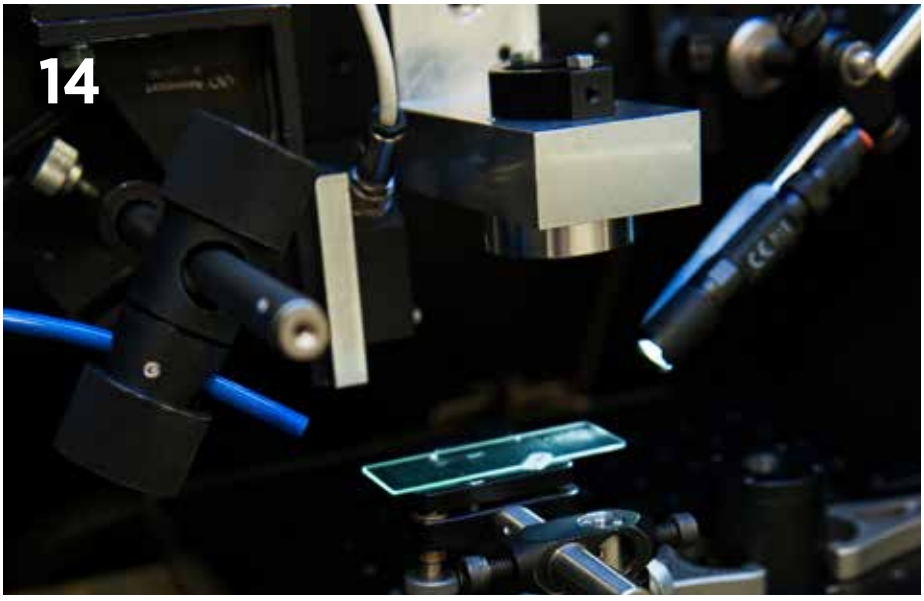

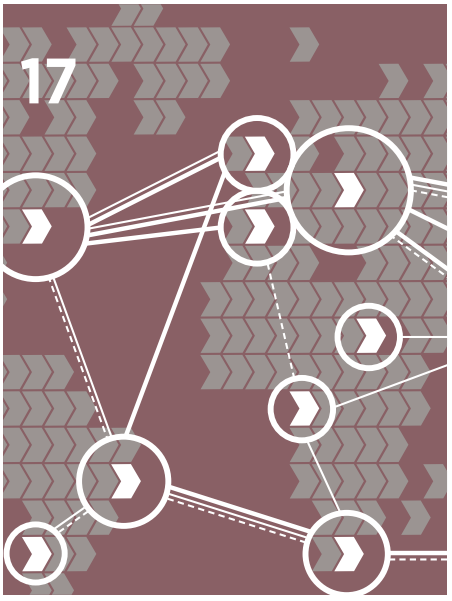

Cover image Dr Ronan Daly, Inkjet Research Centre: *AKD deposited on paper*. This scanning electron microscopy image shows the different micron-scale structures formed by alkyl ketene dimer (AKD) when deposited on paper fibres. AKD is commonly used in the paper industry for reducing water absorbance.

Welcome

We hope you will enjoy this new publication from the IfM which is designed to provide something for everyone – a glimpse of our current activities as well as a deeper look at some of our major lines of research and engagement with industry. We are keen to open another window on the IfM but also to contribute to the rapid growth of interest in manufacturing in the UK and internationally. Those new to the field should find the format and style easily accessible. Those with a deeper technical interest should find things to "get their teeth into".

As many of our friends will know, the IfM takes a very broad view of manufacturing from understanding markets through R&D, design, production, distribution, service and sustainability and we seek to pursue our work through engineering, management and policy. We now have well over 200 colleagues and more than 100 senior undergraduates and Masters' students. This makes for a lively community working in close partnership with industry and government.

It is an important time both for manufacturing locally, nationally and globally and you will find plenty of examples here of exciting new problems, approaches and successes. Do let us know which parts you like best – and if you would like to contribute your news, or indeed, an article we would be delighted to hear from you.

Professor Sir Mike Gregory
Head, Institute for Manufacturing

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www.ifm.eng.cam.ac.uk/ifm-review

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IfM news

Three new lecturers

Dr Ronan Daly has become a University Lecturer in the Science and Technology of Manufacturing. He joined the IfM in 2011, belongs to the Inkjet Research Centre and is an SCR Associate at Churchill College.

Dr Michaël De Volder joined as a University Lecturer in Nanomanufacturing and Engineering Design. He was previously at the University of Leuven, Belgium, where his postdoc research focused on the fabrication of carbon nanotube devices.

Dr Chander Velu, a University Lecturer in Economics of Industrial Systems, has joined from the Judge Business School. He will be involved as a co-investigator on the EPSRC/ESRC funded project led by Tim Minshall, 'Bit by Bit: Capturing the Value from the Digital Fabrication Revolution'.

Child's play

Ex-MET develops toy to teach children how to programme

John Ginger, a recent Manufacturing Engineering Tripos (MET) graduate has, with fellow University of Cambridge alumnus Matt Screeton, developed a robot to help children learn programming and robotics while they play.

They have secured seed funding for 'Robotiky', and already run trials with hundreds of schoolchildren. John, who graduated in 2012, says: "This has been an exciting adventure which has been a great opportunity to use the manufacturing skills learnt at the IfM in practice."

Inkjet-printing eye cells

Researchers from the IfM have used inkjet printing technology to successfully print cells taken from the eye for the very first time.

The breakthrough, detailed in the journal *Biofabrication*, could lead to the production of artificial tissue grafts made from the variety of cells in the human retina and may aid in the search to cure blindness. The results are preliminary and provide proof-of-principle that an inkjet printer can be used to print two types of cells from the retina of adult rats – ganglion cells and glial cells. This is the first time the technology has been used successfully to print mature central nervous system cells and the results showed that printed cells remained healthy and retained their ability to survive and grow in culture.

The research was undertaken by Professor Keith Martin and Dr Barbara Lorber at the John van Geest Centre for Brain Repair, University of Cambridge, in collaboration with Kai Hsiao and Ian Hutchings from the **Inkjet Research Centre**.

Kai said: "In order for a fluid to print well from an inkjet print head, its properties, such as viscosity and surface tension, need to conform to a fairly narrow range of values. Adding cells to the fluid complicates its properties significantly."

Credit: Desirae via Flickr

New policy forum comparing national approaches to manufacturing

The **Centre for Science, Technology & Innovation Policy** (CSTI) has launched a series of International Science, Technology and Industrial Policy Forums which aims to contrast policy approaches and national contexts in key manufacturing countries. The first Forum focused on Japan. 30 participants from government and academia discussed recent changes in Japan's approach to industrial policy, the challenges associated with industrial structures and corporate governance in Japanese manufacturing sectors, and the regional institutions supporting the Ministry of Economy, Trade and Industry in industrial policy implementation.

The countries under the spotlight in forthcoming forums include Singapore, Germany and Korea.

Global value networks

The **Centre for International Manufacturing** (CIM) is publishing a new report, *Capturing value from global networks,* in April. CIM is also research lead in REMEDIES, a £23m UK pharmaceutical supply chain initiative. » see page 19.

Making infrastructure smarter

The Distributed Information and Automation Laboratory (DIAL) is playing a key part in the University's multidisciplinary Centre for Smart Infrastructure (CSIC) which aims to drive the adoption of new sensor and data management technologies in the construction sector.

One of the projects DIAL is involved in is tunnel inspection. Inspecting for damage and degradation is normally performed by a technician entering the tunnel to look at its surface and take detailed notes of its condition. This is time-consuming and labour intensive, and exposes operators to health and safety hazards associated with working in confined spaces.

CSIC has developed hardware and software technologies that help automate this task. Using a remotely controlled vehicle equipped with digital cameras, the tunnel walls are automatically inspected by capturing images of its surface.

Researchers from CSIC and engineers from London Underground using a 3D laser scanner to measure deformations in the London Underground Northern Line station at Euston. The photograph was taken by DIAL's Dr Phil Catton and it won third prize in the Engineering Department annual – and fiercely contested – photography competition.

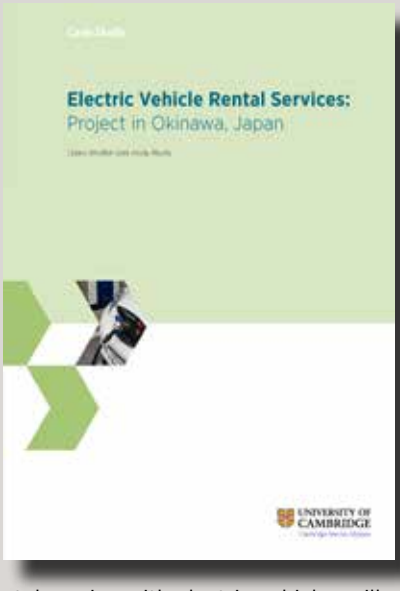
Increasing the uptake of electric car usage

A new report from the **Cambridge Service Alliance** looks at a pioneering electric vehicle rental service for holidaymakers in Okinawa in Japan. It is one of the first EV rental projects of its kind in the world and aims to help improve the environmental sustainability of tourism on the island.

However, low usage rates mean the rental companies are making a loss. It seems that customers were worried about insufficient recharging infrastructure.

One of the report's authors, Claire Weiller, suggests an ecosystems approach could help turn around this project and help others wanting to introduce similar schemes in the future. If all the companies involved shared information with each other and the customer, the customer could be reassured that they would arrive at their destination.

Talking about the research, Claire said: "It is very conceivable that this type of



rental service with electric vehicles will be offered by more and more countries, including in the UK where there are plans to develop the charging network to 70,000 stations by 2020."

The full report can be downloaded at: www.cambridgeservicealliance.org/news/113/61/Electric-Vehicle-Rental-Services---Case-Study-Report.html

Mike Sharman 1933–2013

Mike Sharman, who died on 20 December 2013, was the pioneering course director in manufacturing at the University of Cambridge's Department of Engineering who laid the foundations for the IfM.

In 1966 he launched the 'Advanced Course in Production Methods and Management' (ACPMM) with 12 handpicked graduates as 'guinea pigs'. This became the Advanced Course in Design, Manufacture and Management and is now the IfM's MPhil in Industrial Systems, Manufacturing and Management (ISMM) with its 40 places regularly five times oversubscribed.

An event to celebrate his life will be held in September.

IfM ECS news

Credit: Rob Phaal

Supporting the UK aerospace sector

IfM ECS is one of the partners delivering a government-funded programme aimed at developing the capabilities of small and medium-sized suppliers to the UK aerospace sector. The ambitious programme – Sharing in Growth – aims to raise the capability of UK aerospace suppliers to share in the growth of this global market.

The programme provides training and development to help overcome barriers to growth, boost exports and increase the number of high value jobs in the UK's aerospace and associated high value manufacturing sectors.

This sector is expected to double in size over the next 10 years and the forecast is for 27,000 new passenger aircraft and 40,000 commercial helicopters by 2030. To capitalise on this opportunity, suppliers need to constantly invest in their ability to deliver competitive performance.

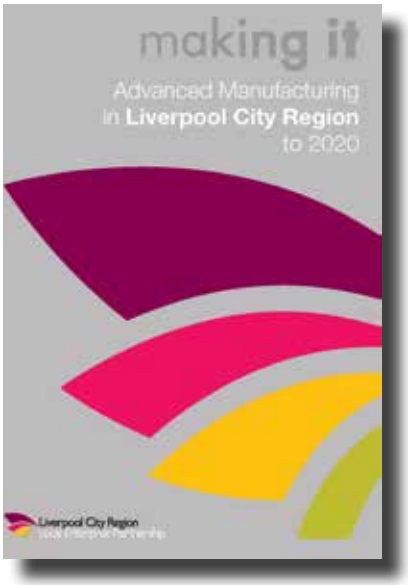
Sharing in Growth UK Ltd has been set up with support from the Regional Growth Fund and Rolls-Royce to deliver a £110 million programme over five years of intensive development activity to 30 to 40 UK suppliers.

New UK defence and security science and technology 'landscape' report

IfM ECS has been commissioned to produce a study for the Defence Science and Technology Laboratory and the Ministry of Defence – the *Defence and Security Technology Competency Report* – to help inform the development of the MoD's strategy for research and development in technology and to identify opportunities for cross-sector collaboration. It also aims to provide an authoritative assessment of the opportunities for the Ministry of Defence to engage with other government departments and agencies to harness wider UK investment in technology strategy.

High value manufacturing in the UK

Two UK regional studies on the future for high value manufacturing have been carried out by IfM ECS, one for the Liverpool area and one for Swindon and Wiltshire. Both studies were commissioned by the Local Enterprise Partnership (LEP) for the respective areas. The consultation document for the Liverpool area was presented at the 'Making It' conference on 31 October where the keynote speaker was the Rt Hon Dr Vince Cable, Secretary of State for Business, Innovation and Skills.



Regional roadmaps for Chile

The prosperity of Chile's Antofagasta region is founded on mining and food production, particularly fishing and agriculture. Working with IncubaUC, the business incubator for the Pontifical Catholic University of Chile, IfM ECS developed strategic roadmaps on behalf of Antofagasta's regional government for these key sectors to identify its primary opportunities by carefully aligning the necessary technological developments with external and market drivers.

New opportunities for open innovation

The Open Innovation Forum for leading companies in the Food and FMCG sector looks at hot topics and best practice in open innovation and addressing the 'Grand Challenges' facing the sector as a whole. The Forum currently has 19 members including Bacardi, GSK, Mars, Tesco, Tate&Lyle and Unilever.

Last year, the Forum took on a new challenge – to help its members develop their open innovation networks and find new potential partners. It ran two 'pitching' events at which innovators from start-ups, spin-outs, SMEs and universities presented their new business ideas to an audience of senior leaders and decision-makers from the 19 member companies. The areas the 'dragons' were particularly interested in included enhanced consumer experience; improved health and nutrition; more sustainable packaging processing; and extended shelf life and freshness. Both events have resulted in new partnerships being formed.

The Food and FMCG Forum has proved so successful that IfM ECS is planning to roll out the 'model' to other sectors, with the Health Open Innovation Forum launched in May.

Road 4 FAME

Unlocking the potential of IT for manufacturing in Europe

IfM ECS is running a series of roadmapping workshops for 'Road4FAME', a European project that aims to harness the innovation potential of IT architectures and services for the manufacturing industry.

Road4FAME is short for: Development of a Strategic Research and Innovation Roadmap for Future Architectures and Services for Manufacturing in Europe. Its mission is to help align ICT research with the needs of European manufacturing, understand the steps needed to make novel concepts work for manufacturing businesses and provide manufacturers with a frame of reference to develop their innovation strategies and identify business opportunities.

PrISMS – Practical & Innovative Solutions for Manufacturing Sustainability

Working with SMEs and start-ups in the East of England

In 2012, a new £2.25 million programme was launched with two key aims: to create more than 140 new jobs in the Eastern region and safeguard many more and to help companies take a sustainable approach to all aspects of their business. The Practical and Innovative Solutions for Manufacturing Sustainability – otherwise known as PrISMS – programme is part-funded by the European Development Fund and delivered by IfM ECS.

The PrISMS programme is well on course to meet its target of working with 120 companies by July 2015. IfM ECS's team of practitioners has already helped more than 80 companies in a number of ways, such as developing their business strategy, making their production and operations more sustainable, and determining the most appropriate markets and products for their business.

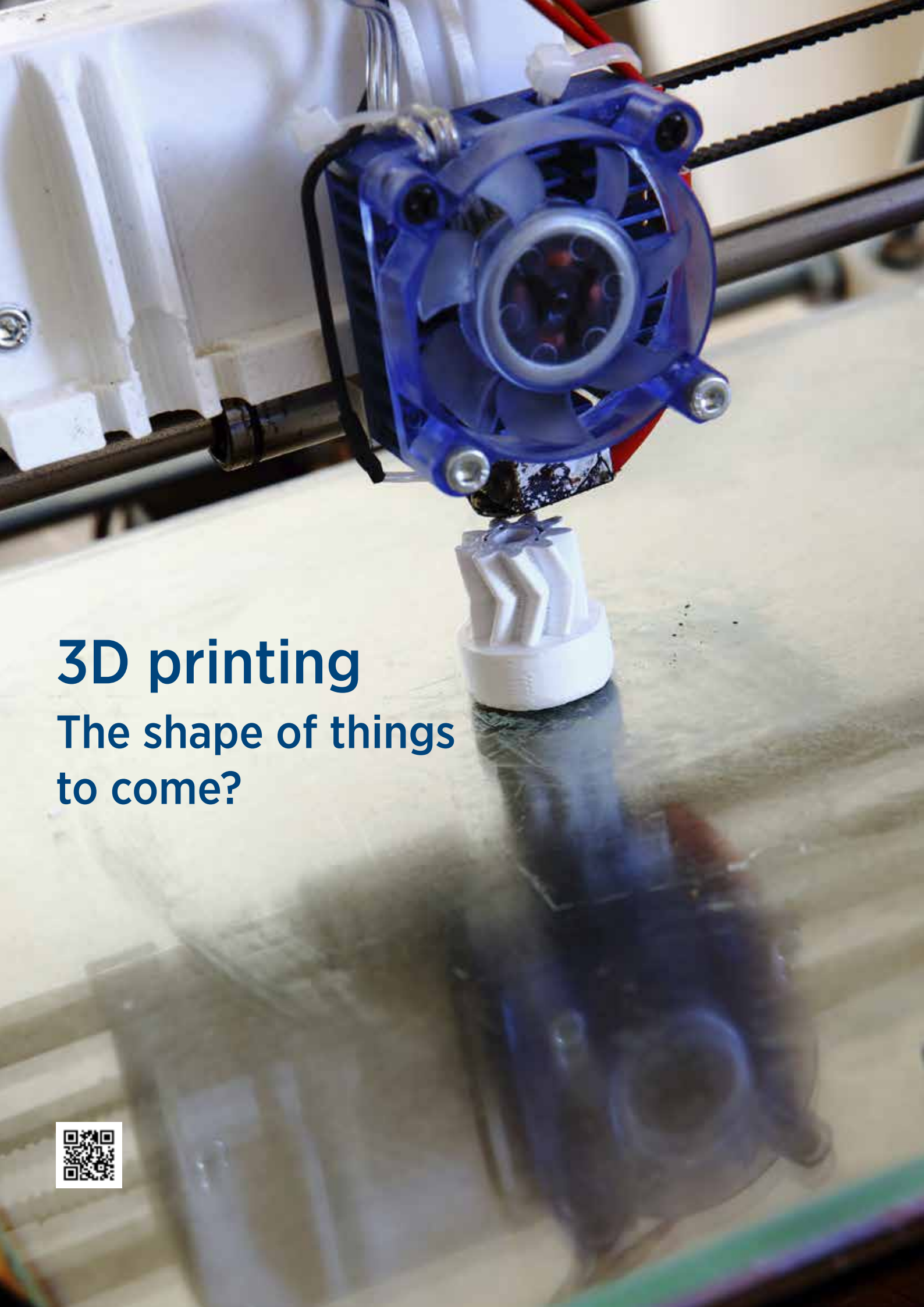
Become an IfM member

The IfM has two membership schemes which have been established to build closer, long-term relationships between companies and our wide range of expertise, and to provide tailored support appropriate to your needs.

Corporate membership: for access to research-based strategic, technical and business expertise, geared to the needs of large international companies.

Company membership: for access to strategy and capability development geared to the needs of small and medium-sized companies, plus discounts on IfM services, training programmes and workshops.

For more information, go to: www.ifm.eng.cam.ac.uk/membership



3D printing

The shape of things to come?

Dr Simon Ford, from IfM's Centre for Technology Management, explains why we need to take a clear-eyed view of this much hyped technology if it is to realise its potential.

If you ask the proverbial man or woman in the street what they understand by the terms 'stereolithography', 'selective laser sintering' and 'fused deposition modelling', you're likely to be met with a blank expression. Say the words '3D printing', though, and you're likely to be met with an entirely different response.

Over the last couple of years, 3D printing has attracted significant media attention. Stories about 3D printed Stradivariuses, undetectable plastic guns, novel building designs, personal miniatures, medical devices and a variety of other 3D printing objects, have become an almost daily occurrence in the mainstream press. 3D printing has been heralded as a technology that will transform the world, with commentators claiming that it could be "bigger than [the] internet" (Financial Times) and "the PC all over again" (The Economist). Even Barack Obama has added his voice to the clamour, stating in his 2013 State of the Union Address that 3D printing "has the potential to revolutionise the way we make almost anything".

While 3D printing is now attracting significant attention and generating high expectations, the process of 'additive layer manufacturing' (the academic term for 3D printing) can be traced back to technologies that were first developed and commercialised in the 1980s. Two of the leading 3D printing companies, 3D Systems and Stratasys, were founded in that decade based on innovative stereolithography (SLA) and fused deposition modelling (FDM) technologies.

Between their founding and the present day, the technologies have been used for many years to help prototype development and create custom tooling moulds. The present excitement stems from the increasingly widespread use of 3D printing for the manufacture of final products.

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Alongside the development of high performance industrial 3D printers such as those developed by 3D Systems and Stratasys, the 'maker' movement has spawned a plethora of lower-priced, lower-quality, consumer-grade machines based on FDM technology, such as those offered by RepRap, MakerBot, Ultimaker and PrintrBot. The result of these two parallel developments is an industry that is now worth an estimated £1.3 billion.

Although the origins of the largest 3D printing companies lie overseas, the UK is home to a number of leading research institutions that are investigating the potential of 3D printing. The potential importance of the technology has been recognised by the UK government and is reflected in the investments it has made into the EPSRC Centre for Innovative Manufacturing in Additive Manufacturing, and the Centre for Additive Layer Manufacturing. Such research is important and necessary. Historically, the UK has been good at such experimental research and development, and novel technologies are expected to emerge from research institutions. However, where the UK has often been less successful is in the commercialisation of technologies from these institutions. It is here that research at the IfM comes in.

Led by Dr Tim Minshall of the Centre for Technology Management, ***Bit by Bit: Capturing the Value from the Digital Fabrication Revolution*** is a project that seeks to understand how value is being created and captured in the 3D printing industry, and how UK firms will be affected by 3D printing technologies. The project is jointly funded by the Engineering and Physical Sciences Research Council (EPSRC) and the Economic and Social Research Council (ESRC) under the 'New Economic Models in the Digital Economy' theme. The need for cross-disciplinary approaches is reflected in the make-up of the investigating team, with Professor Ian Hutchings from the IfM's Inkjet Research Centre, Dr Chander Velu, Lecturer in Economics of Industrial Systems at the IfM and Dr Finbarr Livesey, from the University's Department of Politics and International Relations, bringing their knowledge of digital fabrication science, business models, and economic policy respectively to bear on the project.

Dr Tim Minshall is leading the research project

Join the 'Bit by Bit' advisory network

The need for input and guidance from academics, industrialists and policymakers has led to the creation of an 'advisory network' for the project. A first meeting involving members of this network was held in December at the IfM, including representatives from the BSI (the UK's National Standards Body), the Centre for Science and Policy, Dyson, the Institution of Engineering and Technology and Nesta. Participants contributed their perspectives on the specific challenges that we should investigate within our overall project plan. We are looking for more people with an active interest in the impacts of 3D printing.

If you would like to join this growing community, or find out more about the project, contact:

Dr Simon Ford: sjf39@cam.ac.uk
Dr Letizia Mortara: lm367@cam.ac.uk

Under their leadership, the research team of Dr Letizia Mortara and Dr Simon Ford are currently engaged in the first part of the project: investigating the industrial emergence of the 3D printing industry. Such an investigation is necessary at the beginning of the project as it is only through an understanding of historical patterns and processes that we can hope to gain insights into how current events are unfolding and how they will shape the future.

This historical study involves analysis of supply and demand in the industry; supply in the form of equipment manufacturers, and demand in terms of the early users of 3D applications such as prototyping, in the aerospace and automotive sectors, and in the development of hearing aids and orthodontics. Later in the project the researchers will explore the different business models companies are using to capture value from 3D printing, and how 3D printing enables new business models to be adopted in the digital economy.

During the course of the project, the team also hopes to welcome a number of visiting researchers to the IfM. The first of these was Dr Christian Sandstrom from Chalmers University whose study into the adoption of 3D printing in the hearing aid industry was provocative in that it indicated that while 3D printing had provided some efficiency and cost benefits to hearing aid manufacturers, its adoption had caused very little impact on the competitive position of the companies operating in the industry.

So, while 3D printing is certainly big news, there is still a long way to go. As with all disruptive technologies, uncertainties abound. 'Bit by Bit' will help both industry and government better understand and benefit from the undoubted opportunities to create and capture value that 3D printing will provide.

Credit: Rob Phaal

Skype 'rockets' produced by a 3D printer in a US Microsoft retail outlet. Each one takes 20 minutes to produce.

Dr Simon Ford

Dr Letizia Mortara

Keep in touch with the project

You can find updates on this project and digital fabrication trends on **Twitter** (twitter.com/dfab_info) and on the project **blog** (capturingthevalue.wordpress.com). You can also join the growing community of interest around this topic by signing up to the Bit by Bit 3D Printing Interest Group on **LinkedIn**. Or you can email the research team at:

Dr Simon Ford: sjf39@cam.ac.uk
Dr Letizia Mortara: lm367@cam.ac.uk

Using inkjet technology for digital fabrication

We are all used to inkjet technology for printing at home or in the office and, in recent years, it has had increasing impact in commercial printing. However, it can also be used to deposit materials other than ink as individual droplets at a microscopic scale. This allows metals, ceramics, polymers and biological materials (including living cells, as seen on page 4) to be patterned on to substrates under precise digital control. This approach offers huge potential advantages for manufacturing, since inkjet methods can be used to generate structures and functions which cannot be attained in other ways.

Inkjet Technology for Digital Fabrication, edited by Professor Ian Hutchings and Dr Graham Martin from the **Inkjet Research Centre**, with contributions from both academic researchers and leading names in the industry, provides a comprehensive overview of the use of inkjet printing for digital fabrication along with practical information on industrial applications.

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Wiley	£110.00	

"Our world is changing around us and the conditions which our children and their families might face will be very different from our own and this will have an impact on the manufacturing system."

Predicting the unpredictable: **the future of manufacturing**

Dr Dai Morgan from the IfM's Centre for Industrial Sustainability (CIS) reflects on the UK government's recent Foresight report on the future of manufacturing. »

Energy by Jean Illingworth

Predicting the future is a fool's errand. Ask anyone still holding their breath for mass personal transport in the form of a jet pack, or those who in the 1980s imagined that a portion of the population would be living on moon bases by now. You can pick your individual misstep (how many personal computers would there be a world market for? What about this thing called the internet. . .?) but it is clearly a tough task for any budding Nostradamuses out there.

Yet for those charged with the governance of companies and countries, gazing into an uncertain future and making provision for it is a necessary task. The UK Government Office for Science has a unit for doing just this. In a process known as 'foresight', the Office convenes experts to commission and synthesise research in and around particular fields and deliver insight and advice to help the UK government prepare for the challenges of the next 30 to 40 years.

The recent troubles in financial services and the emergence of the first green shoots of re-shoring have encouraged the government to regard manufacturing with increasing favour. It was little surprise, therefore, that it became the subject of the most recently published Foresight exercise. Professor Steve Evans, Director of Research in Industrial Sustainability at the IfM, was one of the nine 'lead experts' who spent two years reviewing a mass of evidence from researchers and industrialists from 25 countries to understand what manufacturing in the UK might look like as far ahead as 2050.

Will manufacturing still be important to the UK economy?
A key message to government was that while manufacturing in the UK is never likely to recapture the high levels of employment it once offered – there are now as many graduate-level jobs in manufacturing as there are unskilled labour jobs – it still has a crucial role to play in maintaining the country's balance of payments and international competitiveness. The report emphasised that an understanding of production is fundamental to successful R&D, design and servicing and will be critical if the UK is to create world-leading innovative products at the right price and quality.

ARM – world leader in semi-conductor IP – is a good example of this. It does not produce the components that are used in vast numbers of smartphones, but its ability to capture value through IP would be fundamentally circumscribed without an intimate understanding of the act of production. Manufacturing isn't – and never will be – just about making products and selling them.

So what might the future look like?
The report's authors chose not to make themselves a hostage to fortune by painting a picture of a single future, or even a range of futures. Instead they describe a palette of technologies and forces which will shape and influence the system of manufacturing and the society it serves.

A number of emerging technologies were considered to be particularly important, such as: the use of biotechnology in production processes, additive manufacturing, and the use of sensor systems and big data analysis to gain real-time feedback on the user's experience.

While none of these ideas is new, their influence is expected to become pervasive and in some combination change the way we manufacture goods and provide services. It is expected that the systems which emerge will be more geographically dispersed, faster and more responsive to the needs of the customer and able to access more customers and markets than ever before.

The less reliant a company's value chain is on energy, water and key materials, the less sensitive the individual firm will be to key disruptions. The more value it can deliver to the customer, using fewer materials and less energy, the better.

The Foresight report sought input from a range of countries from which a surprisingly consistent picture emerged. One of the key issues they all pointed to was that the search for sustainability would be a major force shaping the future of manufacturing.

Our world is changing around us and the conditions which our children and their families might face will be very different from our own and this will have an impact on the manufacturing system. Water

Delegates at the EPSRC Centre for Innovative Manufacturing in Industrial Sustainability's annual conference.

scarcity, security of key raw materials and, of course, climate change were amongst the issues highlighted as having the potential to disrupt manufacturing activities.

While the brunt of climate change impacts are expected to fall first on those least able to cope with the consequences, the global connectedness of manufacturing systems means that those disruptions can easily cascade through to UK operations. Companies that are both resource-efficient and resilient will be able to survive such disruptions; however, those whose operations are competitive and lean but unprepared will be at serious risk.

What will this mean for companies?
For 200 years the manufacturing system has consistently delivered labour productivity. Leading firms are already applying those same productivity tools and techniques to environmental metrics and delivering substantial performance improvements over time, with little or no investment.

The less reliant a company's value chain is on energy, water and key materials, the less sensitive the individual firm will be to key disruptions. The more value it can deliver to the customer, using fewer materials and less energy, the better.

New technologies, the global competition and the challenges and opportunities of sustainability will drive innovation. So how are companies going to remain

competitive while increasing their resilience to disruptions?

To survive, companies will not only need to be increasingly 'knowledge intensive' but will also need to understand how to extract value from their knowledge through business model innovation. Selling value rather than 'things' through service-based offerings will increasingly become the norm, not just in jet engines and photocopiers as with Rolls-Royce and Xerox, but with a whole range of products that are currently sold by piece or by weight.

Imagine retailers providing a clothing service which allowed you to walk into a store as if it were your personal wardrobe, removing and returning clothes in equal measure. Or perhaps you will no longer own a car, but have a 'personal vehicle' on something like a mobile phone contract, where you pay for monthly access to the hardware and a fee for your per-mile usage.

These models focus on what the customer wants and values rather than just on selling products and, if properly designed, they offer the incentive for the companies to make the most of the materials they own, and to minimise energy use in delivering the value to the customer. Such models have the potential to deliver more value, more sustainably.

Alongside the business model, the manufacturing strategy is another competitive weapon that will be subject to new forces. How will we deliver these new business models? How will the potential for disruption affect what gets made where and how we make it? How can resilience be built into supply chains that need to be lean and competitive? Might new technologies enable in-store manufacturing and highly personalised products – the jumper that is literally made to measure or the insole for your trainer that is shaped to your exact specification on the spot?

Quick guide to sustainable manufacturing practices

Many of the trends in business model innovation and resource constriction point towards circular models of production and consumption. Materials will no longer be sent on linear journeys from cradle to grave, but cycled through re-use, remanufacturing and recycling processes. If repair, remanufacturing and recycling become commonplace, would we still ship our raw materials across great distances to be recycled?

Imagine retailers providing a clothing service which allowed you to walk into a store as if it were your personal wardrobe, removing and returning clothes in equal measure.

There is no manual that provides the answer to any of these questions. So, amongst all this uncertainty, there is one thing we can be reasonably sure of: over the next two decades we will see manufacturers experiment with radically new ways of doing business.

How is this shaping our research agenda?
It goes without saying that industrial systems are complex. Our job is to try to understand how future industrial systems might be organised and if they are capable of delivering sustainable outcomes for businesses and society as a whole.

Research in many of these areas is under way. At the IfM we are fortunate to have a number of colleagues who are already studying some of the influential technologies and paradigms highlighted in the report. From research on bio-diagnostic sensors to additive manufacturing technologies, such as inkjet printing and laser assisted cold spray, researchers are seeking to characterise and understand the potential of these new technologies. Alongside them, we also have research centres investigating the development and the emergence of industries and the implications for supply chain and industrial policy.

What we need to do now is adopt a pragmatic approach to the study of industrial systems which can combine innovative research with rapid experimentation in practice. This challenge will require not only deep technical competences, but an ability to integrate knowledge across a range of disciplines from material science to supply chain management and behavioural psychology. Eventually this understanding will lead to better modelling of the industrial system, which will allow companies and academics to improve the speed and quality of experimentation.

It is not just academia which will need to be more joined up to meet the challenges ahead. Indeed, one of the key recommendations from the Foresight report is that the government should set up a Government Office for Manufacturing. In the same way that the Government Office for Science provides a home in government for the science, so the manufacturing office would be responsible for creating systemic views of the issues and making them accessible to everyone from the Treasury to DEFRA and DECC.

If the participants in the industrial system are to deliver a more holistic response to the changing demands of the global population, caring for economic, environmental and societal considerations, then an unprecedented degree of coordination and collaboration between government, industry, academia and society will be required. Although the future remains stubbornly unpredictable, we all have a part to play in shaping it – for good or ill.

The Centre for Industrial Sustainability is a research partner in the EPSRC Centre for Innovative Manufacturing in Industrial Sustainability, along with Cranfield University, Imperial College and Loughborough University.

Dr Dai Morgan
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Small is beautiful

Why ultra precision manufacturing is such a big deal

Are you happy with your smartphone? Bill O'Neill, Professor of Laser Engineering and Director of the IfM's Centre for Industrial Photonics isn't. In fact, he is rather dismissive of the current crop with their basic satellite navigation and camera functionality. Instead, he is contemplating the next generation of 'personal assistants' which will be able to monitor your heart rate, tell you how much alcohol you have in your bloodstream or give you a complete check-up by analysing the chemistry of your sweat. This phone will have a whole array of miniature sensors and microprocessors embedded in it derived from the latest breakthroughs in microelectromechanical systems (MEMS) technology.

But to make devices like these requires extraordinary levels of precision – the ability to manufacture intricate features that are smaller than 100 nanometres. To put that number into perspective, a human hair is comparatively huge at somewhere between 50,000 to 100,000 nanometres in diameter. Diagnostic smartphones are just one example of the new kinds of products that are going to need ultra precision manufacturing. The emergence of carbon-based or polymer semiconductor materials like graphene is driving research and development in areas such as the production of lower cost, more efficient solar cells and 'printed electronics' that can be used for flexible display screens and smart labelling. These have the potential to be created cheaply and in very large volumes but if that is to become a reality, companies are going to need a whole new set of production capabilities.

The ultra precision research carried out by Bill O'Neill and his team at the IfM is focused on building these kinds of machines and developing the associated systems and processes that can make things at these nano levels of precision. The team works in close collaboration with other researchers across the University of Cambridge who are experts in the new materials and are developing new devices based around them.

Having done so much of the materials research in this country, we need to capitalise on it by creating production-level competencies. If we don't invest in this now, we'll end up without a significant foothold in production.

As Bill is quick to emphasise, it is critical for the UK economy that we invest in the manufacturing capabilities as well as doing the baseline research. "Having done so much of the materials research in this country, we need to capitalise on it by creating production-level competencies. If we don't invest in this now, we'll end up without a significant foothold in production. This was exactly what happened with semiconductors even though the UK carried out much of the underlying research in the 1960s. We can't allow the same thing to happen with the polymer electronics industry and the new opportunities that are coming with carbon and graphene science. This is the case we put to the government."

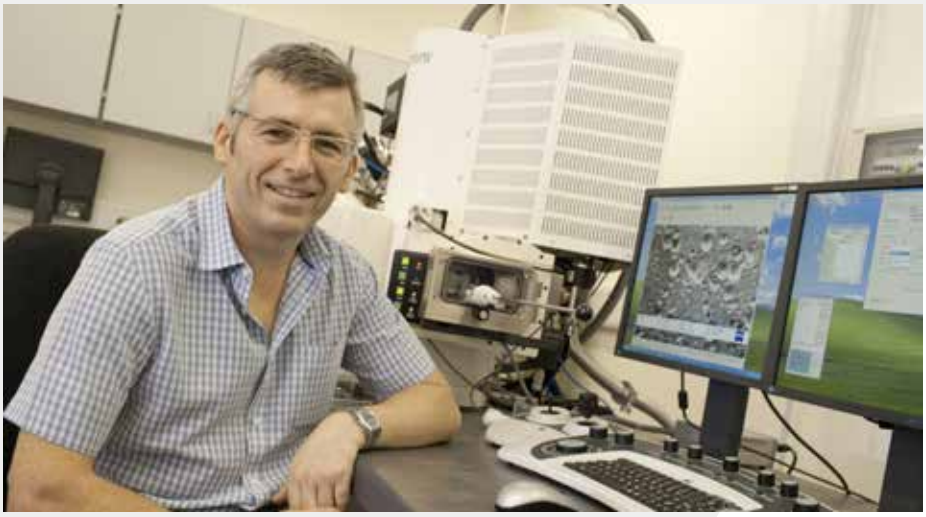
And the UK government has clearly listened. In 2011, the Engineering and Physical Sciences Research Council (EPSRC) awarded funding of £6 million to the Centre for Innovative Manufacturing in Ultra Precision, a joint venture between the University of Cambridge and Cranfield University. The collaboration with Cranfield is an important one, which builds on the respective expertise of the two institutions.

"Cranfield has decades of experience of designing machines, including some of the most precise machine tools in the world. By virtue of the extensive materials research taking place across the University (in particular at the Centre for Advanced Photonics and Electronics (CAPE) and the Department of Materials Science), the Cambridge team has had much more experience of working with the new generation of unconventional semiconductor materials. We also have laser and focused ion machinery so can provide new energy sources for processing materials. The partnership with Cranfield coupled with the cross-Cambridge collaborations creates a very strong team with the potential to transform the way we think about and make the next generation of products."

The research carried out by the Centre is focused on three key areas. The first is looking at 'roll-to-roll' printed electronics which, as the name implies, is a process whereby conductive inks are printed onto rolls of plastic, optical film and other flexible materials. This process promises mass production at a fraction of the cost of producing conventional electronics and the ability to print onto large and flexible materials has obvious benefits for things like display systems.

The second research area is based around more conventional machine systems but ones which can produce very precise mechanical components with accuracies of a few tens of nanometres. At the moment these machines are huge but the new systems being designed at Cranfield are very compact with extremely high levels of accuracy and efficiency.

Thirdly, the IfM team is developing a hybrid of focused ion beam and laser technology. At the moment, semiconductor materials are usually processed using focused ion beams (FIBs) but the process is a slow



Professor Bill O'Neill
For more information, contact: wo207@cam.ac.uk

Jack Bamford: Ultrafast laser etching of glass for micro fluidic systems

one. By combining a FIB system with laser technology, its efficiency will be increased by three orders of magnitude, transforming what was a high precision but low productivity system into a high precision and high productivity system. It will be able to deal with high volume additive and subtractive manufacturing processes using a wide range of the new semiconductor materials with a resolution down to, in the first instance, 30 nanometres.

These three research 'platforms' are focused on developing the underlying machine capability. Over and above these are a growing number of research projects looking at the devices these machines can make and how the new materials they are working with respond to these production processes.

The Centre benefits from the involvement of industrial research partners including Carl Zeiss, Jaguar Land Rover, Oxford Instruments and the National Physical Laboratory. Working with industry and building a much bigger, highly connected ultra precision community to help develop a fully fledged manufacturing capability in the UK is one of the Centre's key aspirations. One of the obstacles it needs to overcome is that a lot of companies using ultra precision processes and equipment do not consider themselves to be within the ultra precision 'sphere'. The Centre has started a national outreach programme to raise the profile of ultra precision with the aim of creating an effective national hub for industry and academia where knowledge and resources can be shared to mutual advantage.

As Bill describes it: "The endgame for us is to provide industry with a wide range of experts in various disciplines that are centred around the design, development and production of ultra precision products and processes." And also, apparently, to get a better phone.

Focused Ion Beam (FIB) microscope which can image and machine materials at a scale of 10nm.

Key industrial partners include:
Aerotech
AIXTRON
ALE
Carl Zeiss
Cranfield Precision Engineering
Hexagon
IPG Lasers
Jaguar Land Rover
Michell Instruments
Oxford Instruments
National Physical Laboratory
SPI Lasers

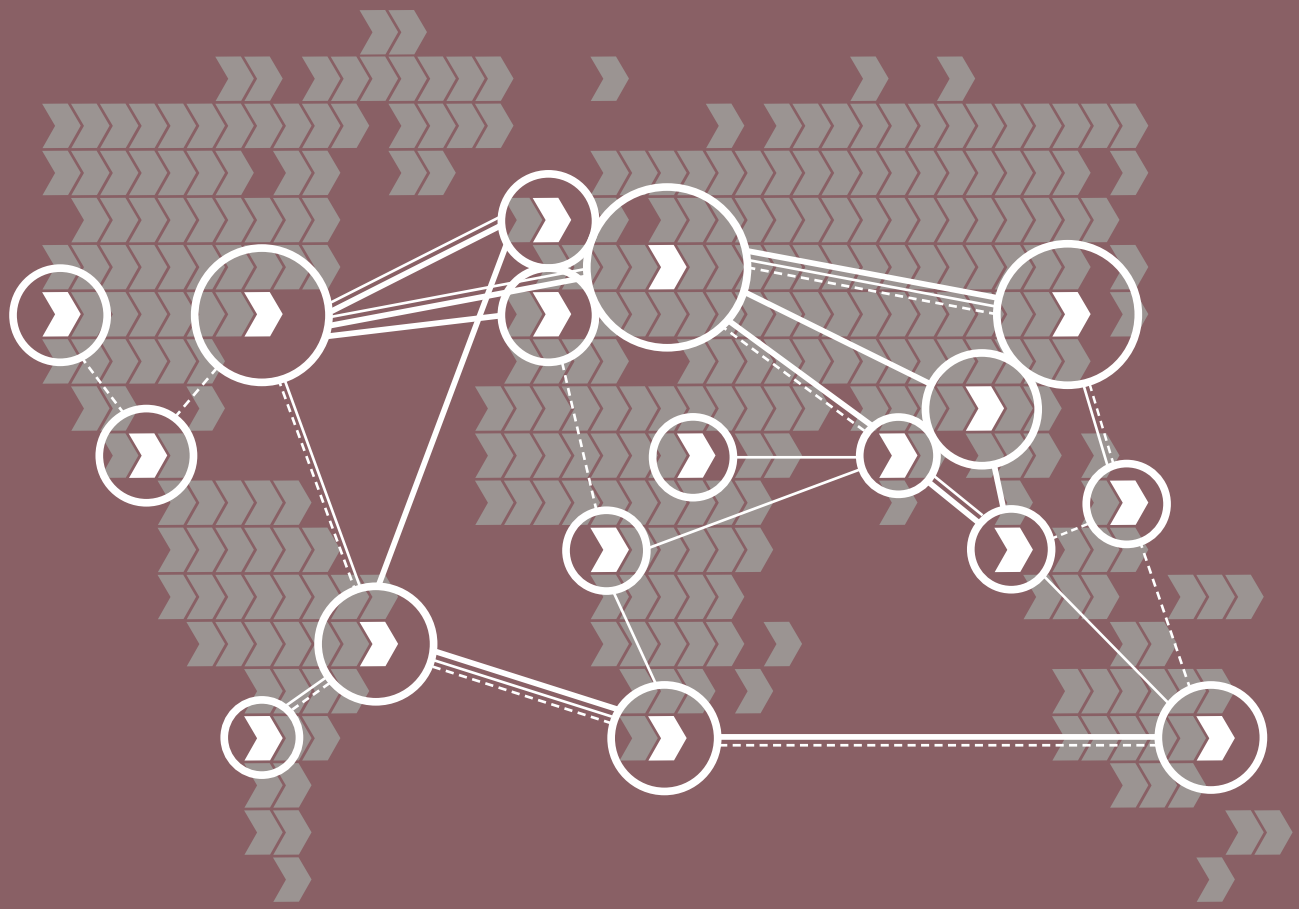
Investing in the future

The EPSRC Doctoral Training Centre in Ultra Precision Manufacturing

As part of the initiative to develop an ultra precision skills base, the EPSRC has invested a further £6 million in a centre for doctoral training (CDT), also jointly run by Cranfield and Cambridge. Students at the CDT take a one-year Masters of Research (MRes) followed by a three-year PhD. For UK students and EU students who have studied full-time for three years in the UK, the EPSRC provides full funding and industrial sponsors offer additional financial support during the PhD phase.

The CDT welcomed its first intake of students in 2012. Recruitment is under way for the 2014 cohort.

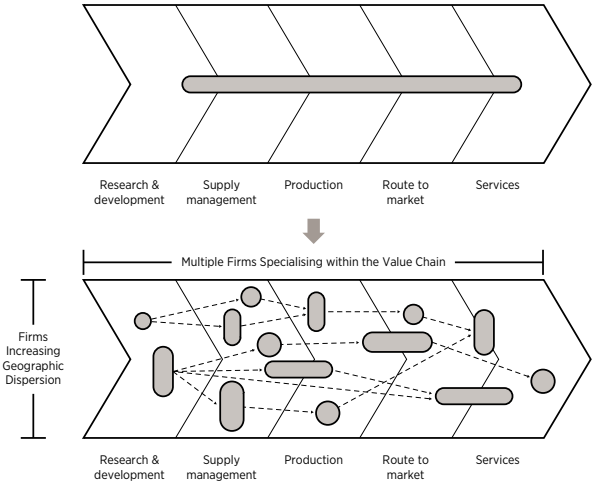
Twenty-first century supply chains
Transforming the pharmaceutical industry



The Centre for International Manufacturing (CIM) is leading the research programme in REMEDIES, a £23m sector-wide initiative to understand how pharmaceutical supply chains in the UK are set to change. Dr Jag Srai, Head of CIM, considers the implications for government, industry, healthcare providers – and patients. ❯❯

The internationalisation of supply chains through offshoring, outsourcing and the need to access new markets has brought with it complexity, risk and sustainability challenges. Indeed, many firms are faced with rethinking their supply chain footprint and are considering whether more local supply chains may better serve the more demanding 21st century consumer. New technologies are also helping companies meet the needs of more niche markets and customers, as demonstrated by the rapidly evolving pharmaceutical sector.

In the 1990s supply chains were more transparent, based on local suppliers serving established markets. Most multinational companies would carry out and, therefore, control everything from research and development, through all aspects of the physical supply chain – procurement, production and distribution – to marketing and after-sales services. The situation today could not be more different. Supply chains have been transformed into complex global value networks as multinationals have increasingly focused on what they are good at and outsourced everything else to specialist companies with technical expertise in a particular area – often bringing with them the advantages of low-cost labour. The typical supply chain for industry sectors such as pharmaceuticals now involves hundreds of these kinds of specialist firms. So multinationals need to find ways to design and manage these large and complex networks to maximise their competitive advantage. And that task has to be carried out in the context of the wider industrial landscape which itself is subject to continuous change in its market, technological and geopolitical conditions.



FROM: a traditional, vertically integrated firm encompassing the full value chain

TO: a 'global value network' of interconnected, specialised firms with increasing geographic dispersion

In simpler times, multinationals were able to concentrate on continuous improvement programmes, many of which achieved impressive results in terms of better inventory management, greater speed to market and reduced plant downtime. However, these new highly distributed networks have made the continuous improvement task harder and the challenge of managing these operations is fundamentally redefining 21st century supply chain thinking.
It is now vital for companies to understand and analyse the broader supply network and not just the 'tier one suppliers' (organisations with whom they deal directly) but also the tier two suppliers who supply the tier ones and further on down through the increasing levels of specialisation. Companies now need to look at their extended (or 'end-to-end') supply chain beyond their traditional boundaries to assess the effectiveness of the network as a whole.

Pharmaceutical companies are a good example of this new paradigm. The context in which they operate is changing. These days, patient outcomes and compliance with treatment regimes are paramount: it's no longer just about delivering products on-time, in-full to a distributor. Patient expectations, in both developed and emerging markets, are changing – they want instant access to more affordable and, where appropriate, more personalised products.

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New diagnostic technologies are also being developed which have the potential to recognise the patient – rather than the healthcare provider – as the ultimate consumer and to service their needs more effectively. These new remote patient management diagnostic tools and 'apps' will be integrated within sophisticated IT systems to monitor patients and, potentially, to order personalised solutions for them.

At the same time, new technological developments in manufacturing processes mean that the industry is poised to switch from its current batch-processing model to a continuous manufacturing process. Interestingly, the emergence of this new technology has been informed at least as much by the industrial supply chain opportunities it might deliver as the potential benefits it has for product functionality. Traditionally, production processes were seen solely as the purview of the R&D and process engineering teams with very little input from further down the value chain, except in modest ways such as specifying improvements to the stackability of products on pallets or in containers.

Recent research, however, suggests that the supply chains themselves are starting to redefine both product design and the production technology used to manufacture pharmaceuticals. This proactive approach is resulting in the development of advanced production facilities that can deliver new and different options in terms of scale, flexibility and variety as companies strive to better serve the needs of the end-user.

From the companies' perspective there are major supply chain gains to be had from continuous manufacturing, including a reduction in inventory levels, better quality assurance, greater flexibility in adjusting production volumes, and perhaps the ability to recycle chemicals within agreed operating and regulatory frameworks. What might these changes mean for

patients? Because companies will be able to manufacture a wider range of products more quickly and have the flexibility to scale production up or down as required, they will be able to provide their end-users with a better, faster, more personalised service and produce pharmaceuticals which are currently uneconomical because of small patient populations.

And what might future product, process and supply networks look like in a continuous manufacturing model? Our research suggests that companies will be able to adopt a range of different supply chain models which can offer more localised production and dynamic replenishment models. They are likely to be characterised by geographically dispersed production networks, supported by more repeatable processes, and the flexibility to adapt production volumes in response to demand. Another key advantage is that fewer production steps will mean that the manufacturing process can be streamlined in contrast to batch-processing which often involves multiple stages taking place across a variety of locations.

However, these continuous manufacturing and supply models do need to overcome some major hurdles. This is a still a very uncertain environment in which both industry and governments are unclear as to the impact this technology will have on industry structures. Within the industrial ecosystem as a whole there is work to be done to change the mindsets of policymakers and regulators to support these new patient-centric business models operating within a clear regulatory framework. Within companies, buy-in is needed particularly from process engineers who are faced with not fully proven technology and quality assurance processes.

But the potential opportunities continuous manufacturing may provide are considerable from the patients' point of view. And companies could be looking at major cost savings from fewer, smaller plants, reduced capital expenditure and operating costs coupled with significant improvements in yield and more consistent quality. These are interesting times for the pharmaceutical industry. Watch this space.

REMEDIES: reconfiguring UK pharmaceutical supply chains

REMEDIES is a new £23m project that includes £11m of UK government funding and which provides an opportunity to reconfigure existing pharmaceutical supply chains in the UK by exploiting the latest technology advances in medicines and patient-centric delivery models.

Part of the UK government's Advanced Manufacturing Supply Chain Initiative (AMSCI), the project will be led by GlaxoSmithKline, providing major inputs on clinical supply chains, with the Centre for International Manufacturing leading on commercial supply chain and overall research coordination, AstraZeneca focusing on formulation developments and the University of Strathclyde team within the Centre for Continuous Manufacturing and Crystallisation looking at active processing.

CIM will lead the research activity as part of this sector-wide initiative evaluating new technology innovations within the UK pharmaceutical supply chain. Other industrial partners include the major contract manufacturing organisations, equipment manufacturers and technology and system providers spanning the end-to-end pharmaceutical supply chain.

The collaboration also involves key institutional bodies across the UK pharmaceutical ecosystem (skills agencies, user representatives, regulators and health sector specialists) to ensure more adaptive future supply chain models are supported by consistent standards and a unified approach to regulation. Activities will include two sector-wide platform projects focused on the end-to-end clinical and commercial supply chain, and several technology-specific application workstreams.

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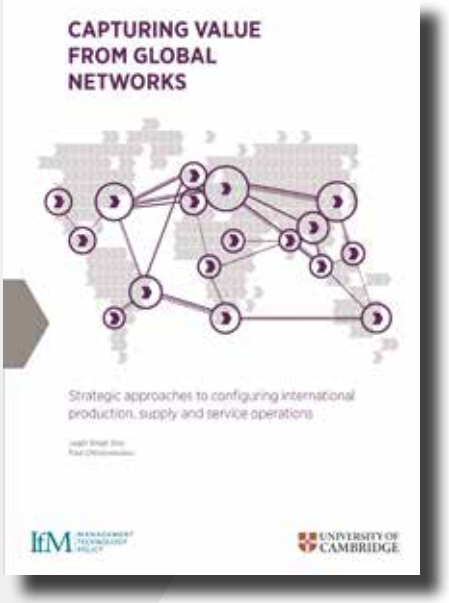

In April the Centre for International Manufacturing is publishing a new report outlining its strategic approach to the design and management of global value networks: *Capturing value from global networks: strategic approaches to configuring international production, supply and service operations* by Jagjit Singh Srai and Paul Christodoulou. (paperback £35.00)

The report will provide the focus for the 18th annual **Cambridge International Manufacturing Symposium** on Thursday 11 and Friday 12 September 2014. The Symposium will examine the key themes of the new report and the implications for manufacturing, supply networks and corporate policy in the 21st century.

Buy the report online at:
www.ifm.eng.cam.ac.uk/resources

Book your place at the Symposium at:
www.ifm.eng.cam.ac.uk/events

Cambridge: the view from Mars

In October 2013, Mars and the University of Cambridge announced a formal collaboration. Its dual aim: to help Mars tackle global sustainability challenges that both its business and society share through first-class academic research, and to involve the University and its students in the development of new commercial applications.

Since Frank C. Mars started making and selling butter cream candy from his kitchen in Tacoma just over a hundred years ago, Mars has grown into a $33 billion multinational business. Unusually, the company is still owned by the Mars family today and it is this private ownership that gives it the freedom to invest in a range of leading projects which other companies might not be able to. This has had important advantages for the company and – Mars intends – for the rest of us as well.

From the outset, the Mars business has been passionate about Research and Development (R&D). The business was built upon technological breakthroughs, from the launch of the revolutionary Milky Way in 1923 and the Mars Bar (invented in war-torn Slough), to the development of new types of rice for the US Army in the tropics, and the establishment of a research centre for pet nutrition in the UK in the 1960s.

Now a highly complex organisation, with a presence in more than 74 countries and across six business segments (petcare, chocolate, food, drink, the Wrigley brand and Mars Symbioscience which focuses on global health issues and life sciences), arguably R&D is more important to Mars than ever. At the same time, the company is famous for its strong corporate values. 'The Five Principles of Mars' – Quality, Responsibility, Mutuality, Efficiency and Freedom – are qualities which all team members live and breathe from the moment they step through the door.

David Crean, Staff Officer for R&D, explains how these twin 'drivers' of R&D and corporate responsibility continue to have a positive impact on the way Mars works: "Things are changing significantly in terms of the research. The first – and, really, only question – we perhaps used to ask ourselves was 'how do we gain competitive advantage?' These days, although we obviously want to remain competitive, it's much more about who we can work with, and how we can share information to tackle some of the huge challenges facing the world today. As a business, for example, we use close to seven million tonnes of raw materials every year and we need to make sure we are doing that sustainably and responsibly. The sustainable supply of raw materials, food safety, food security – these are issues that affect all of us – and are issues that we recognise we must play a part in solving."

A few years ago, Mars deliberately asked itself some searching questions about how it organises itself. One of the main conclusions it came to was that it should be working with the best available people – which is where the University of Cambridge came in. Over the years, Mars had worked with the University on a number of one-off projects. The relationship developed into something more sustained and purposeful when an alumnus of the IfM's Manufacturing Engineering Tripos joined Dave Crean's R&D team and talked persuasively about the work the IfM was doing, particularly in technology management. This led to a number of projects with the IfM using approaches developed by the Centre for Technology Management and delivered through IfM's dissemination arm, IfM Education and Consultancy Services (IfM ECS).

These days ... it's much more about who we can work with, and how we can share information to tackle some of the huge challenges facing the world today.

Dave Crean said: "We certainly got a lot out of these projects and I think the IfM did too. All good collaborations are based on personal relationships; ours has developed steadily over the years and has been supported by very high quality work. So in terms of strategic partners, Cambridge was right up there. We thought it was time to get more serious about this relationship."

About two years ago, Mars brought its technology committee over to Cambridge and IfM ECS organised a University-wide briefing day, to show Mars executives some of the research activities it was engaged in, such as sustainability, wind turbines, energy and managing risk. Professor Peter Guthrie, head of the Engineering Department's Centre for Sustainable Development, who chaired the event, said: "This was a very useful exercise. It clearly demonstrated that there is both an appetite for, and the capability to develop an in-depth and productive relationship between the two organisations to address the hugely diverse challenges that food production, processing, distribution and consumption present."

This led to a discussion about setting up a more organised and strategic relationship which would continue to benefit both parties.

One of the things that prospective collaborators soon learn about the University of Cambridge is that it does not operate as a single entity but as a whole series of very loosely connected networks. Combine this with the fact that Mars is also a confection of different businesses in different countries and the potential for complexity is clear. Mars's broadest aspiration, therefore, is to understand the University's networks and, where appropriate, support them. While Mars is keen that individual parts of its business can access the University's expertise, they are also careful to ensure that the relationship is not over-managed by the global R&D team. IfM ECS's role, in addition to delivering particular projects, is to help Mars navigate its way around the University networks.

Although it is still early days, the collaboration is already beginning to bear fruit. Research programmes particularly in the areas of food security and food safety, are being actively progressed. New technologies to support the sustainability goals of the Mars business, as well as the nutritional profiles of its products, are also on the agenda.

In addition, Mars is keen to put Cambridge students right at the heart of some of its key design challenges, looking to them for their fresh perspective. For Mars, this is an opportunity to listen to completely new observations – unencumbered by experience – on some of the issues they face. For the students, it is a great opportunity to get a feel for some of the complex problems they might encounter in the workplace in future. Training and development for Mars employees is another important strand of the relationship and IfM ECS is currently developing leadership courses for Mars's R&D and supply chain teams.

Dave Crean is optimistic about the potential benefits of the collaboration: "One of our principles is mutuality. Everything we do should benefit society as a whole. Working with the University of Cambridge is part of our commitment to addressing these challenges and to sharing our findings with both the research and industrial communities." Professor Lynn Gladden, the University's Pro-Vice-Chancellor for Research, is equally positive: "The University is looking forward to working closely with Mars to expand what was already a very successful long-term relationship into a range of new areas."

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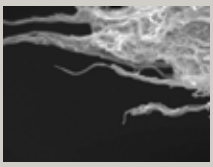

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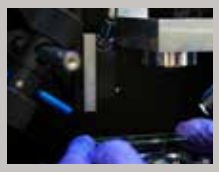

4-year PhD in Ultra Precision

A one-year taught MRes course in Cambridge followed by a three-year PhD research programme at Cambridge, Cranfield, or another UK university through the National Centre Programme of the EPSRC Centre in Ultra Precision.
www.cdt-up.eng.cam.ac.uk

Practice

IfM Education and Consultancy Services (IfM ECS) works with companies of all sizes to create and capture value and with national and regional governments to support and grow their industrial sectors. It does this by transferring the new ideas and approaches developed by researchers at the IfM through a programme of education and consultancy services.

Working with multinationals around the world to:

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- capture value from global networks
- move to service-based business models.

www.ifm.eng.cam.ac.uk/services/overview/large

Working with UK government and with other national and regional governments to:

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- create the conditions that will turn new ideas into emerging industries.

www.ifm.eng.cam.ac.uk/services/overview/government

Working with small and medium-sized manufacturing companies throughout England and Wales to:

improve their business performance using structured tools and processes developed by researchers at the IfM.

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www.ifm.eng.cam.ac.uk/executiveeducation

IfM COURSES & CONFERENCES 2014

IfM runs a series of conferences, courses and workshops throughout the year which are based on IfM research and cover a range of manufacturing and management themes.

10 April — **MAKING THE BUSINESS CASE FOR DATA QUALITY PROGRAMMES**
Webinar in which IfM researchers and practitioners will explain the need for formal risk management processes to address information quality risks.

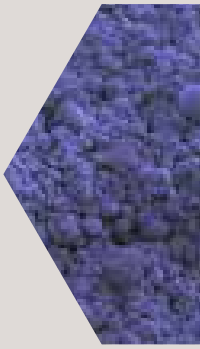
14 May — **HOW TO IMPLEMENT OPEN INNOVATION**
Practical approaches to help businesses successfully implement open innovation.

20 May — **VISUAL APPROACHES FOR STRATEGY AND INNOVATION MANAGEMENT**
Explore and apply the fundamental principles of visual design for presenting management information.

11–12 June — **STRATEGIC ROADMAPPING**
A thorough introduction to strategic roadmapping, guiding participants through each step of the roadmapping process.

11–12 September — **THE ANNUAL CAMBRIDGE INTERNATIONAL MANUFACTURING SYMPOSIUM**
Capturing value from global networks: implications for manufacturing, supply chains and industrial policy.

15–17 September — **THE CAMBRIDGE TRIBOLOGY COURSE: FRICTION, WEAR AND LUBRICATION**
Intensive three-day programme offering an excellent opportunity to gain an overview of the field of tribology.



23–24 September — **REALISING THE POTENTIAL OF EARLY STAGE TECHNOLOGIES**
A two-day workshop covering the fundamental issues associated with the management of early stage technology and innovation.

30 September — **FUTURE OF SERVICES IN A DIGITAL AGE**
Unique insights from leading service providers and academic institutions and offers a valuable opportunity to hear the latest developments in service thinking.

7 October — **STRATEGIC ROADMAPPING**
A thorough introduction to strategic roadmapping, guiding participants through each step of the roadmapping process.

8 October — **TECHNOLOGY INTELLIGENCE**
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23 October — **VALUING AND SELECTING TECHNOLOGY PROJECTS**
This workshop will explore techniques applicable at different stages of the project life cycle, including both new approaches and established techniques.

4 November — **VISUAL APPROACHES FOR STRATEGY AND INNOVATION MANAGEMENT**
Explore and apply the fundamental principles of visual design for presenting management information.

For more information about our courses and conferences or to make a booking go to: **www.ifm.eng.cam.ac.uk/events**

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IfM ECS is owned by the University of Cambridge. It transfers to industry the new ideas and approaches developed by researchers at the IfM. Its profits are gifted to the University to fund future research activities.

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