APRIL 2017 | Issue 7

Institute for Manufacturing REVIEW

Manufacturing a better world

- Industrial sustainability
- Food safety
- Diagnosing disease
- NanoManufacturing: clean water and green batteries

UNIVERSITY OF CAMBRIDGE
Department of Engineering

IfM MANAGEMENT TECHNOLOGY POLICY

INSTITUTE FOR MANUFACTURING: IfM

The IfM is part of the University of Cambridge's Department of Engineering. With a focus on manufacturing industries, the IfM creates, develops and deploys new insights into management, technology and policy. We strive to be the partner of choice for businesses and policy-makers, as they enhance manufacturing processes, systems and supply chains to deliver sustainable economic growth through productivity and innovation.

IfM EDUCATION & CONSULTANCY SERVICES LIMITED: IfM ECS

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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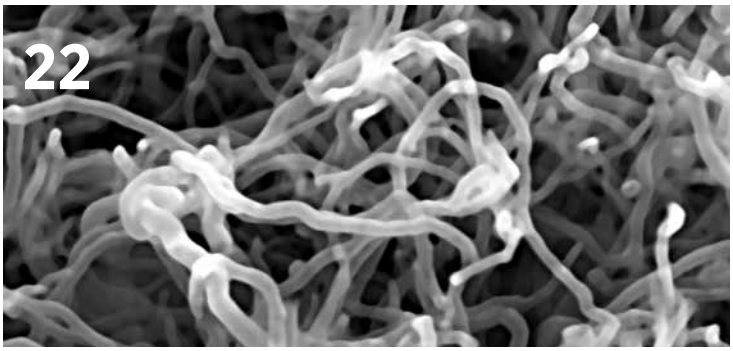

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Manufacturing

Those of us who have spent our careers working in and thinking about manufacturing know how important it is. At the IfM, we have people researching – and teaching – many different areas of manufacturing. Whether we are exploring better ways to manufacture carbon nanotubes, or to design more resilient supply chains or to develop new business models, what we have in common is that all of us are passionate about what we do. We believe that manufacturing matters.

The world is facing many challenges. By 2050 we are likely to have 9 billion people on this planet. How can we ensure that every one of those people has clean water, enough food to eat and access to decent healthcare? How can we ensure that we will have sufficient – and clean – energy? And how can we increase the availability of rewarding jobs and improve standards of living across both developing and developed societies?

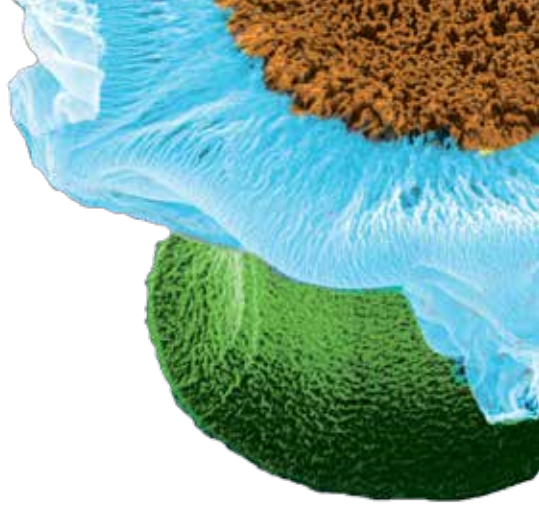
Practical solutions

There are some clear ways in which the research we do can help to address some of these challenges. In this issue of the *Review*, for example, you can read about how innovative biotechnology and manufacturing technologies can help diagnose deadly diseases (page 16), and how nanomanufacturing is helping to develop more energy efficient batteries and more effective water filtration devices (page 22). Our work on supply chains is directly supporting global food safety and food security (page 13). And, of course, our Centre for Industrial Sustainability (page 8) is focused on developing practical ways in which industry can become more efficient and less resource hungry and, in the process, more sustainable.

Seizing opportunities

But it is not all about solving problems. Manufacturing is as much about seizing opportunities. New additive manufacturing processes are enabling new distributed manufacturing models and the advent of mass customisation. As demonstrated by our two inspiring alumnae (page 32), these technologies and the new ways of working they enable are already being put to good use in disaster relief situations and to support local enterprise in developing economies. In pharmaceuticals, our Centre for International Manufacturing is looking at how continuous production technologies mean medicines can be made in larger volumes in different places, potentially offering patients greater customisation and personalisation. These are all fertile areas of study for our researchers.

There are also other ways in which IfM research is important. Manufacturing is about understanding how to take a scientific or technological breakthrough and use it at scale. But it's not just about



a better world

developing new production technologies and building smart factories, important though that is. It's also about making them work commercially, finding the right business model, designing the right supply chain and leveraging all the connectivity and analytics of the new digital world. The work we do here is about finding new and better ways to do these things, to bring innovative products and services to market in order to deliver ongoing economic and social benefit.

Addressing grand challenges

Another important strand of work at the IfM is focused on how can we help organisations make progress in addressing global 'Grand Challenges'. Even defining one of these grand challenges is problematic. Understanding what we are trying to achieve is hard enough, let alone how to go about it. Putting a man on the moon – or, indeed, a woman on Mars – has a clear objective. But when it comes to determining what constitutes success in relation to, for example, global health outcomes, different stakeholders will have different views.

Challenge-led research can be very different to traditional academic research. For example, addressing manufacturing-related grand challenges may require significant advances in engineering tools and infrastructure – requirements for success which may not be evident from the outset. It generally requires the bringing together of academic disciplines, practitioners and stakeholders – many of whom are not used to collaborating with each other. Grand challenge research also needs ongoing input from fundamental science, technology development, engineering demonstration and scale-up efforts.

The scale, scope and complexity of these endeavours means that in most cases they need new sets of partnerships and completely different cultures of collaboration. The IfM's Centre for Science, Technology and Innovation Policy (CSTI) is exploring the implications of this complexity for those government R&D agencies charged with supporting challenge-led innovation. How can funding agencies strategise, cooperate and coordinate around grand challenge research endeavours? How can they design effective programmes for supporting initiatives which can cope with all this complexity? How can they ensure research activities are informed by the right mix of disciplines and communities – not only researchers and industrialists, but users and stakeholder groups? How can they identify appropriate challenge 'stretch goals', assess the potential for impact of particular proposals, and measure the success of such complex endeavours?

One of the ways in which the IfM is uniquely well placed to support these national and global challenges is through its research-meets-practice model. The IfM has long been a centre of excellence for roadmapping research (page 28). Through IfM Education and Consultancy Services (IfM ECS) this powerful technique for developing strategy and building consensus around a shared vision has been widely deployed in the public sector, both in the UK and internationally. With the development of Policy Links (page 5), a new knowledge transfer unit within IfM ECS, we are further enhancing these tools and providing additional analytical capabilities.

While we have people with different skills and experience under one roof, the IfM is a division of the University of Cambridge's Engineering Department. Collectively, we share the engineer's guiding principle to use our knowledge and skills to make something better – to manufacture a better world.

Professor Andy Neely
Head, Institute for Manufacturing

IfM news

Professor Andy Neely's new role leading the University of Cambridge's engagement with industry

On 1 March 2017 Andy Neely, Head of the IfM, was appointed as the University of Cambridge's new Pro-Vice-Chancellor for Enterprise and Business Relations. He is leading the University's strategy to enhance and develop its engagements and partnerships with industry and commerce, and the wider enterprise economy.

Andy will remain as Head of the IfM for the rest of this academic year. Dr Tim Minshall has been appointed as Deputy Head and has taken on much of the day-to-day-running of the IfM.

Andy said: "Universities make a difference in the world through their research, education and engagement and I am looking forward to working with colleagues from across the University to help strengthen our relationships with large and small firms alike."

The University of Cambridge Vice-Chancellor, Professor Sir Leszek Borysiewicz, said: "Andy has an impressive track record in working in higher education and with business and industry. This will help strengthen the University's efforts to consolidate as well as develop business partnerships and enterprise opportunities."

IfM lecturer recognised for teaching excellence

Dr James Moultrie has been awarded one of the University of Cambridge's Pilkington Prizes – awarded to individuals who have shown teaching of exceptional quality.

Senior Lecturer in Design Management at IfM, Dr Moultrie is one of just 12 individuals from across the University to receive the award.

He was recognised for his transformational work in providing MET students with the management competence, business acumen and interpersonal and organisational skills they need to become world-class leaders.

This is the third time that IfM teaching staff have been recognised with a Pilkington Teaching Prize. The award has previously been won by Dr Claire Barlow (1997) and Dr Tim Minshall (2012).

IfM providing supply chain expertise to future manufacturing research hub

The IfM's Centre for International Manufacturing (CIM) is part of a new research hub to transform the way medicines and other high-value materials are made. The hub, led by the University of Strathclyde, is one of just six in the UK, each receiving £10 million of UK Government funding though the Engineering and Physical Sciences Research Council (EPSRC).

The Future Continuous Manufacturing and Advanced Crystallisation Hub is supporting industry in moving from 'batch crystallisation' to 'continuous crystallisation'. As a more dynamic process, it allows manufacturing to take place within smaller, more cost-effective facilities using smaller quantities of expensive ingredients and less energy, with more control over the final product quality and performance. The CIM team will study how these technologies and processes will transform the supply chains for medicines and other high-value products.

Policy Links: new unit to support innovation and technology policy-makers

Policy Links has been established within IfM Education and Consultancy Services (IfM ECS) to work closely with UK and international policy practitioners. It provides new evidence, insights and tools based on the latest academic thinking and international best practice.

Funded by the Gatsby Charitable Foundation, the unit transfers knowledge emerging from the IfM's Centre for Science, Technology and Innovation Policy. In the UK, its clients already include the Department for Business, Energy & Industrial Strategy, Innovate UK, the High Value Manufacturing Catapult network and the British Standards Institution (BSI).

Internationally, the team works with national and regional innovation and industrial development agencies and with international organisations such as UNIDO and the OECD.

The Policy Links team: (from left to right) Dr David Leal-Ayala, Dr Michele Palladino, Ella Whellams and Dr Carlos López-Gómez.

Policy Links is currently working with the Government of Trinidad and Tobago and the Inter-American Development Bank (IDB) to develop a strategic roadmap for productive development policy in Trinidad and Tobago.

More information about Policy Links: **www.ifm.eng.cam.ac.uk/services/policy-links**

Policy Links report on 'Megatrends' launched at UN conference on manufacturing

The joint report by Policy Links and the United Nations Industrial Development Organization (UNIDO), *Emerging Trends in Global Advanced Manufacturing: Challenges, Opportunities and Policy Responses*, analyses the megatrends shaping the future of manufacturing. The interim report was presented in April at the Global Manufacturing and Industrialisation Summit in Abu Dhabi.

Head of IfM's Policy Links unit and report co-author, Dr Carlos López-Gómez, says the report provides an international context to inform policies and support manufacturing innovation and economic growth: "The boundaries of manufacturing as an economic activity are increasingly blurry and advanced manufacturing is, in fact, inherently multidisciplinary. Modern manufacturing involves activities across a range of industries, technologies and components.

"As a result, policy-makers need to look beyond traditional industrial sectors to get a full understanding of the challenges and opportunities facing advanced manufacturers."

The report is part of the ongoing collaboration between UNIDO and the Institute for Manufacturing at the University of Cambridge.

Read the report: **bit.ly/2nnJB92**

IfM news

New appointments

Dr Tim Minshall, Reader in Technology and Innovation Management and Head of the **Centre for Technology Management** has been appointed as **Deputy Head of the IfM**.

Dr Mohamed Zaki has been appointed Deputy Director of the **Cambridge Service Alliance (CSA)**. He has been with the CSA for four years and his current research interests are in big data advanced modelling and its application to digital manufacturing and services.

Nick Hazell has joined **IfM ECS** as a Senior Industrial Fellow. A MET alumnus, Nick has held senior R&D roles in a number of global food companies including Mars and PepsiCo, Nick is based in Sydney and is working with companies in Australia to put IfM research into practice.

Dr Carlos López-Gómez has been appointed as Head of IfM ECS's new **Policy Links** unit. Previously a Research Associate in the IfM's **Centre for Science, Technology and Innovation Policy**, Carlos has advised the UK Government and international institutions, including UNIDO and the European Commission.

Dr David Leal-Ayala has joined Policy Links as a **Senior Policy Analyst**. David provides expertise in manufacturing engineering and innovation for all the projects undertaken within Policy Links. He has several years' of experience in consultancy, industrial and academic roles, both in the UK and abroad.

Dr Michele Palladino is a policy analyst at **Policy Links**, with expertise in industrial economics. He is an economist and project manager with several years' experience in the consulting sector and in academia, both in the UK and abroad.

Innovative food start-up impresses Open Innovation Forum 'dragons'

A start-up that uses artificial intelligence and DNA analysis to create health-benefiting ingredients won the 5th Food & FMCG Innovation Pitching Event held in London at Food Matters Live in November.

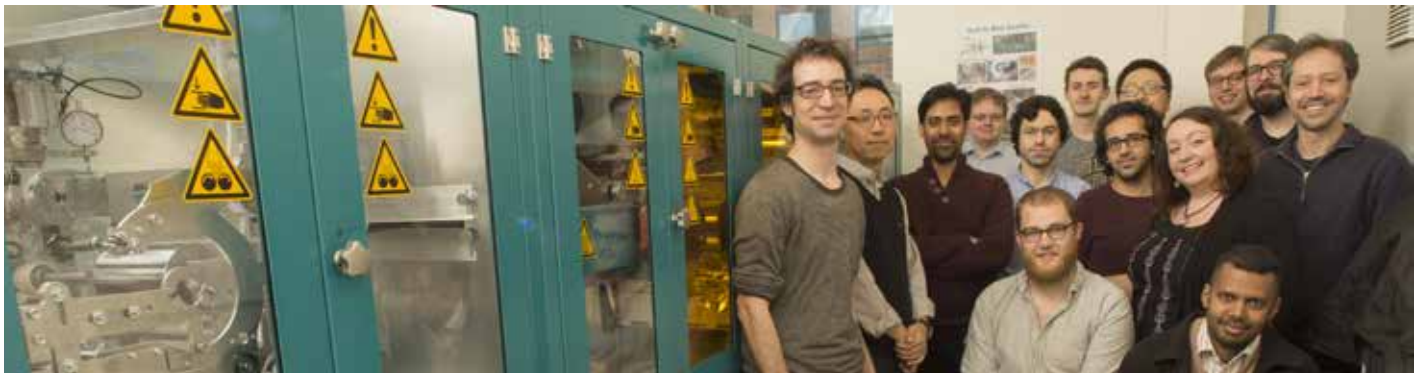
Dublin-based Nuritas discovers and unlocks ingredients from food sources in a new way, providing natural, sustainable and scientifically-proven health solutions for a variety of applications from medical food to cosmetics.

The company was one of 18 start-ups, spin-outs and research groups that pitched their innovative ideas and products to a group of senior leaders from Mars, Tesco, Procter & Gamble and PepsiCo among others. These are part of the Open Innovation (OI) Forum, a programme that provides support and opportunities for companies involved in the Food and FMCG value chain.

To find out more or to register your interest: **www.ifm.eng.cam.ac.uk/events/oipitching17/**

Nanomanufacturing scale-up

The IfM's NanoManufacturing team has taken delivery of a Coatema roll-to-roll processing machine to its labs. It can be used for a variety of substrates and replicates the process used in large coating lines in factories.



The NanoManufacturing Group with its Coatema roll-to-roll processing machine.

MET alumni shine

Two of our MET alumni have been recognised as showing exceptional promise in their chosen fields.

Recent MET graduate Keno Mario-Ghae (2015) was named Young Engineer of the Year at the National Microelectronics Institute's (NMI) 2016 Awards. Keno is working as a Project Engineer at Imagination Technologies, which creates and licenses processor solutions for graphics, video and vision processing.

In presenting the Young Engineer award, NMI CEO Derek Boyd said Keno had not only "applied his unique combination of talents to make a significant difference in Imagination Technologies in a short space of time with impressive ideas applied to the business," but also highlighted that "his passion for using technology as a cure to challenges of poverty" is what made Keno stand out from an impressive field of nominations.

Another MET alumnus, Christopher Bellamy (2012) was named the Young Design Engineer of the Year at the British Engineering Excellence Awards. Christopher was recognised for inventing, designing and developing creative and novel solutions for customer problems while working at Jaguar Land Rover. He pioneered a human-centric design process, and close work with the company's consumer insight and human factors teams has delivered outstanding results.

Christopher said that the MET course at the IfM played "a pivotal role in inspiring, educating, and leading me in the right direction".

Keno Mario-Ghae is NMI's Young Engineer of the Year.

How stuff gets made: award for outreach project

IfM, in collaboration with Churchill College and the University of Cambridge's Faculty of Education, has won funding from the Royal Academy of Engineering's Ingenious public engagement programme for an innovative outreach project to challenge outdated views of manufacturing and inspire primary school children to think about how we make things.

The pilot project will be run in schools across rural Cambridgeshire during the next school year.

Project leader and IfM Deputy Head, Dr Tim Minshall, says the project's aim is to widen the appreciation of what manufacturing is, what manufacturing engineers do and why their work is so important. He added: "We hope that it will help address the sometimes inaccurate and incomplete perceptions of manufacturing held by many primary school children and their teachers."

The project received £7,000 from the Royal Academy of Engineers and is also supported by funding support from Churchill College and the Sharman Family Trust.

Become an IfM member

The IfM has two membership schemes that aim to build closer, long-term relationships between companies and our wide range of expertise, and to provide tailored support.

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 for small and medium-sized companies, plus discounts on IfM services, training programmes and workshops.

For more information: **www.ifm.eng.cam.ac.uk/membership**

Industrial sustainability – paradox or paradigm?

Two factories make identical chocolate bars using identical machines. Why does one use 500% more energy than the other?

This is the type of question that Professor Steve Evans, Director of the IfM's Centre for Industrial Sustainability (CIS), is working with manufacturers to answer in his ambition to make manufacturing more sustainable. Professor Evans explains that this chocolate factory example is not actually that extreme or uncommon and that the environment, society and manufacturers can all benefit from increasing non-labour resource efficiency, re-thinking business models and transforming industrial systems.

Continuing population growth is changing how we manage and consume resources like water, energy and minerals. As a result, manufacturers increasingly need to think hard about how, where and what they make and how to adapt to stay prosperous.

At the Centre for Industrial Sustainability we are focused on increasing our understanding of how to transform industrial behaviour to develop more sustainable environments, economies and societies.

The greatest opportunity to increase industrial sustainability comes about when we consider the industrial system as a whole. The optimisation of any one part is ultimately constrained by the other parts. Our research focuses on three aspects to accelerate the transition of manufacturing towards a sustainable industrial system:

- Resource efficiency (eco-efficiency)
- Manufacturing systems transformation (eco-factories)
- Sustainable value exchange (sustainable business models)

Sustainability should not cost more

There are two roadblocks preventing us from realising a sustainable industrial system: a belief that sustainability costs money and a presumption of efficiency. There is a false notion that you have to make a choice between economy and sustainability. Many people associate increasing sustainability with expense, but in fact, environmental and economic efficiencies are often aligned. When we reduce waste, increase energy efficiency and improve resource productivity, we actually save money, raise profitability and enhance competitiveness.

Despite this, many organisations are locked into the mind-set that believes that improving efficiency performance requires money and big capital investments. Our research has shown there are many efficiencies to be found without spending any money.

The second roadblock is even harder to shift. The presumption is that because energy costs money, factories would not be paying more for energy than is absolutely necessary. It's a presumption that doesn't stand up to the data. We can point to vast reams of evidence that says that this is not the case.

Our conservative estimates of the benefits the UK could gain through increasing energy- and resource-efficiency amount to £10 billion per annum in additional profit for manufacturers, 300,000 new jobs and a 4.5% reduction in our total annual greenhouse gas emissions. That's a 12% profit increase for UK manufacturers without spending any money.

While there are many 'quick wins' that can be implemented to change performance, a trigger to change is needed – and this only comes about after being made aware of the variation in performance.

You need to be inefficient to become efficient

There are plenty of technologies, techniques and tools available to help you save resources like water. But why would you want to save water?

We have found the critical component to being efficient is to realise that you are inefficient. That's a really big part of the work that we do, and at times it sounds trivial, but it's immensely important. There is no point directing people to information and websites that can tell them how to save water if they don't know whether they have actually been wasting water. Research has shown that these techniques are not going to be used if people do not know they have a problem in the first place.

"Our conservative estimates of the benefits the UK could gain through increasing energy- and resource-efficiency amount to £10 billion per annum in additional profit for manufacturers, 300,000 new jobs and a 4.5% reduction in our total annual greenhouse gas emissions. That's a 12% profit increase for UK manufacturers without spending any money."

More information about industrial sustainability: **http://bit.ly/2pCL7c3**
Contact: **Professor Steve Evans**
Email: **se321@cam.ac.uk**

Efficiency variations

One of the most interesting things that we have found is the significant variation in the efficiency performance between two factories belonging to the same company, or even variations in the performance between shifts at the same factory.

One extreme example that we have found in a company was a 500% difference in the energy it takes to make the same chocolate bar between two factories using the same equipment. But large variations are not that unusual. We have worked with manufacturers that were using 40% more energy on Monday than Thursday in the same factory or using 80% more water in factory number one than factory number two.

What we've found is that once people can see that there's a high variation in performance, they then use their standard 'good old production engineering techniques' to resolve it.

For example, Toyota's UK factory, which was already a world-leading efficient factory, reduced the energy it takes to make one car by 77%. As a result, Toyota can make four cars for the same amount of energy that it previously used to make one car.

Toyota did not buy any expensive new hardware to make that level of improvement. If other organisations can also make products with half the energy that it currently takes them today, then we are going to also halve the cost of energy consumed and significantly reduce pollution.

About 75% of the energy generated in China's power stations, which is responsible for a large part of the nation's air pollution, goes into factories. If you halve the energy consumed, then you can close every third power station in China. That's how powerful efficiency is.

China has been very successful in growing its manufacturing industries to become a large manufacturing-based economy. But it is not very efficient. We are looking to work with Chinese organisations to help them use less energy and water and to reduce pollution and to do that without spending vast amounts of money.

Low-tech solutions to increase efficiencies

While increasing sustainability should not cost huge amounts of money, it does require imagination and skill. Our Centre concentrates on those elements. We are focused on what low-tech solutions can offer, not on expensive high-tech solutions. But low-tech does not mean easy.

It is much easier for a CEO to sign a cheque to buy a wind turbine than it is to get the heads of three departments together to figure out a way to save energy. This is because most energy savings are not going to be found in one single place. You have to get marketing talking to design, you have to get design talking to manufacturing, and you have to get facilities management talking to production schedulers. These are people who don't normally gather together to save energy or to save water.

These people are often working in different parts of an organisation with the only natural point of convergence being the CEO. It is a major challenge to ask a company to make the sorts of changes that we are advocating because the CEO has to become directly involved. It's much easier to buy that wind turbine!

Moving from linear to cyclical manufacturing systems

The biggest challenge and where the biggest wins will come from is around resource productivity – being efficient with raw materials, minimising waste and looking at ways to capture value from waste.

The best way to do this is to move away from the traditional linear manufacturing system of 'take-make-waste' to a cyclical or 'closed-loop' system where waste is used to make new products.

Foraging factories in a circular economy

There is currently a lot of interest in designing flexible high-tech factories that can manufacture different products – customised outputs. But there is also unexploited potential for these factories to use these same technologies to process different types of materials – in other words, to have variable inputs.

Factories tend to use homogeneous input materials and cannot easily adapt their machinery to use different ones. By enabling factories to use a range of input materials that are available locally, irregularly and at a low price, waste

What is sustainability?

Academics, government, industry, the media and the general public use the term 'sustainability' with different meanings and in different contexts.

The most commonly held general definition of sustainability is that it describes the ability to sustain economically, environmentally and socially over multiple generations, also know as the 'triple bottom line'.

In our work with manufacturers we encourage them to develop their own interpretation of what sustainability means, because that works better, and each organisation will have a slightly different view.

"It is much easier for a CEO to sign a cheque to buy a wind turbine than it is to get the heads of three departments together to figure out a way to save energy."

materials could be turned into valuable products.

For example, factories could source seasonal waste from their local areas such as the left-over plant material when a crop is harvested. Production in this context is entirely intelligence-driven, based on direct information from consumers and their products.

This 'foraging factory' approach is a circular economy model that could be viable for a large number of small localised operations. It has been estimated that manufacturing under this model will produce four times the 'value' in terms of added services. It will also use half the amount of natural resources and be carbon neutral.

Sustainable business models

As a research centre we spend a significant amount of our time investigating ways to increase efficiency. But we spend even more time looking at sustainable value exchange – also known as sustainable business models..
There are some interesting opportunities for transforming the way that value is exchanged between manufacturers and customers that can lead to increased sustainability.

For example, the traditional automotive manufacturing business model is for customers to buy the car and also pay for the fuel that the car uses.

As a result, there is no direct incentive for automotive manufacturers to build the most fuel-efficient car possible.

An alternative business model involving the car manufacturer retaining ownership of the car and leasing out the car with fuel included in the monthly charge provides more incentive for the manufacturer to make a more fuel-efficient car.

As a result of this alternative value exchange, the car manufacturer would become more profitable the less fuel their customer uses. I believe that we will see many companies transform their business models over the next 20 to 30 years so that they improve their value exchange opportunities and deliver more value economically, environmentally and socially.

Tools to capture sustainable value

The IfM's Centre for Industrial Sustainability has developed three powerful innovation tools:

- Cambridge Value Mapping Tool
- Sustainable Value Analysis Tool
- Business Transformation Tool

Together these tools provide companies new perspectives on new forms of value and provide a structured approach to maximise value among stakeholders, and provide an organised method for implementing sustainable change in a business.

More details: **bit.ly/2nNhReg**
Contact: **Dr Doroteya Vladimirova**
Email: **dkv21@cam.ac.uk**

Foraging factories of the future may source seasonal waste from local crop harvests.

IfM Podcast

Interview with Professor Steve Evans about how the Centre for Industrial Sustainability is working to develop knowledge and tools that accelerate the transition towards a sustainable industrial system.

bit.ly/2qhHPHN

Dr Curie Park visited local landfill sites with Sri Lankan garment manufacturers to survey the type and volume of textile waste materials available for use.

Centre for Industrial Sustainability case study: Developing high-value products from industrial waste

CIS has been working closely with leading Sri Lankan garment manufacturing companies to transform waste streams into high value products through innovative remanufacturing processes and new business models.

Garment manufacturing is Sri Lanka's single biggest industry, generating 44 per cent of its GDP along with at least 30,000 tonnes of textile waste each year. Currently, there are no textile recycling facilities in Sri Lanka and the textile waste is exported or burnt for low-value energy generation for the cement industry. Every year more textile waste is being generated, increasing the waste problem.

CIS Research Associate Dr Curie Park has been working in Sri Lanka investigating the opportunities for high value innovation in post-production textile waste as part of the international collaboration project, TransTextile.

Three interdisciplinary research teams were formed across textile process and chemical process engineering disciplines, and fashion, interior and graphic design disciplines to research and develop innovative ways to add value to the textile offcuts.
Five promising innovation routes were identified. These include using the waste materials to make beanbags, denim interior panels and 3D printing powder. A number of Sri Lankan textile manufacturers are now investigating other innovation opportunities and commercialisation routes with CIS.

In a further development, Dr Park has identified a Korean company Sejin Plus that manufactures high-press fibre panels from polyester. CIS is working with the company to investigate the feasibility of using textile waste from Sri Lanka to manufacture these panels, which are used for interior and exterior building materials.

TransTextile

TransTextile, led by Professor Steve Evans, is funded by an Engineering & Physical Sciences Research Council (EPSRC) Global Challenge Research Fund pump-prime grant, which supports projects that contribute to the economy and society of developing countries. The project involves Sri Lanka's top two garment companies (MAS and Hirdaramani) and three universities (University of Moratuwa, University of Peradeniya and AOD). It was made possible by CIS graduate Dr Lloyd Fernando who is Director of Sri Lankan brand packaging company, Shore 2 Shore.

For more information about this project contact Dr Curie Park
Email: cp538@cam.ac.uk

IfM Podcast

Find out more about the IfM's work to turn waste into high-value products in Sri Lanka and Brazil. **bit.ly/2qiI5Gh**

Thought for food

Dr Mukesh Kumar leads research in supply chain resilience at the IfM. He describes how his work is helping to tackle one of this century's most important challenges: food safety. »»

According to the World Health Organization, an estimated 600 million people – that's almost 1 in 10 of the world's population – fall ill after eating contaminated food every year and of those around 420,000 die.

It seems that every few years a major food contamination scandal erupts – and when it does it is likely to affect large numbers of people. In recent memory, there was the German *E. coli*-contaminated beansprouts that killed 53 people and affected nearly 4,000 people in total. In China 54,000 babies were hospitalised in 2008 and 6 died from drinking formula that was contaminated with melamine.

More recently, 13 European countries were involved in a different kind of food scandal when horsemeat was substituted for beef in a range of burgers and ready meals. Unlike the other examples, this one posed no risk to public health, but it triggered a highly charged response from consumers who were upset by the unwitting consumption of a type of meat they were either prohibited from eating by their religion or that they were culturally conditioned to avoid.

Why do these incidents keep happening? One of the reasons is that as consumers in the developed world, we expect our supermarket shelves to be stocked with fresh food all year round. To make this possible long, complicated food supply chains have evolved comprising dozens of companies crossing many borders. And therein lies the potential for inadvertent contamination or, as in the horsemeat case, for deliberate fraud. This is further exacerbated by patchy international standards and the fact that much of the world's food production takes place in developing countries that may have neither the awareness nor the means to comply with the more stringent food safety practises adopted in developed nations.

Food safety and maintaining public confidence is a complex business – and one in which global supply chains play a critical part. One of the issues we need to understand is the respective roles played in the supply chain by developed and developing nations, and the different challenges they face.

To this end, our research has focused on the UK and India, mapping the supply chains that connect these two countries in order to identify potential vulnerabilities.

India seemed like a good country to study for a number of reasons. Of the developing countries exporting food products to the UK, it accounts for 20% of cases where products are rejected because they fail to meet the required standard.

Agriculture is one of India's most rapidly growing sectors and research into its food safety practices has been limited. And, although it is the second largest producer of fresh fruits and the sixth largest producer of fish, around 30% of India's produce is lost due to contamination or to problems keeping the produce refrigerated at the right temperature across the supply chain. The overuse of antibiotics has also been a longstanding issue in marine exports from India.

As a leading centre of research into supply chain configuration, the IfM has developed a number of approaches for mapping supply chains and assessing risk. We do this using a combination of desk research, in-depth interviews with companies, site visits and analysis of company documentation. We have also been using what is known as the 'Six Ts framework' to examine key characteristics of the supply chain (see table below).

An improving picture

Our research revealed plenty of signs that firms within the supply chain are making significant improvements to their operations. For example, in order to increase transparency and traceability, the food exporters in India – who largely control the supply chains – are moving away from the traditional Indian supply chain model that uses local traders or wholesalers as middlemen. They

Traceability	Capturing data at both the company and supply chain level
Transparency	Making that data visible across the supply chain
Trust	Creating trust between buyers and suppliers using mechanisms such as joint agreements and vendor approval schemes
Training	Ensuring that training is carried out to approved standards – critical in an industry where many of the primary production processes are manual
Time	Reducing transit time to minimise spoilage and maximise shelf-life. Understanding how long the whole network takes to respond to disruption and where the critical points are is important in the event of a product recall.
Testability	Using appropriate testing (which at the moment is not adequately supported by international standards.)

The Six Ts: Defining ways of working that will support food safety and public health.

recognised that the farmers needed to develop better food safety and quality practices and the only way they could influence the farmers was by having a direct relationship with them.

The food exporters are also increasingly focusing on their core competencies and outsourcing to specialists those activities in which they have no expertise. They are also putting in place better ways of monitoring the performance of these suppliers. All of which represents best practice in the world of food safety.

Interestingly, it is consumer perception – rather than food safety standards – that is driving some of these changes in behaviour. One of the companies we studied has responded to consumer concern over the use of agro-chemicals by using bio-pesticides and bio-fungicides, and by importing water purifiers from Spain to avoid water contamination and to reduce the presence of chemicals to below their permitted levels.

More to be done

Nonetheless, significant challenges remain. A lack of harmonised international standards is one of the greatest barriers to progress. The current testing regime is also unhelpful. It relies on end-product testing, which is highly inefficient if contamination is happening at the point of production. Companies are increasingly looking at testing much earlier in the product life-cycle when the products are still in the production facilities.

Supply chain traceability is also an issue. The companies we studied demonstrated good practice in capturing data about their own activities, but they typically do not share data with other supply chain partners. Using technology for sharing information was patchy, but there was an increasing recognition of its importance.

Food Security

The world's population is on course to reach nine billion by 2050. According to the Food and Agriculture Organization of the United Nations, global food production will need to increase by 60% if those nine billion are to lead healthy and active lives. However, more than one-third of the food produced today is lost or wasted.

The IfM's Centre for International Manufacturing has been looking at the issue of waste in the supply chain. In developed countries much of that wastage happens when perfectly good food is discarded either by retailers or by consumers. In the UK, for example, 30 to 40% of food is wasted in this way. In developing countries most of the wastage occurs at the early stages of the supply chain. About 40% of India's fresh fruit and vegetables rot before reaching consumers' plates. By mapping these global networks, we are able to identify ways in which they can be reconfigured to improve efficiency and reduce risk.

Food security is one of the University of Cambridge's Strategic Research Initiatives bringing together researchers from crop scientists and engineers to specialists in policy, economics, public health – and supply chains.

For more information about the University's work on Food Security visit: www.globalfood.cam.ac.uk or contact Dr Jag Srai, Head of CIM and member of the Cambridge Global Food Security Initiative steering committee.
Email: jss46@cam.ac.uk

Digital solutions

Looking at our results it is clear that research in other areas – such as the use of sensors and big data analytics – could have a vital role to play in food safety.

Digital solutions could allow all the activities that underpin food safety to be managed in real time and to agreed standards across national borders.

Nestlé is sponsoring an IfM PhD student to develop a better understanding of food safety risks, a useful categorisation of the supply chain information needed to manage those risks and the digital technologies needed to capture and analyse that data.

The ultimate aim is to develop a digital food supply chain framework to support food safety in a complex global food system.

This project will be an extremely important next step. Our work so far has enabled us to develop a set of best practices that are designed to help Indian firms continue to improve food safety, customer trust and, by extension, the perception of the food sector in developing countries more generally. However, it also exposed a number of vulnerabilities in these cross-border supply chains and one of the key ways of addressing them is by using new digital technologies and big data.

To find out more:
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Diagnosing deadly diseases

University of Cambridge engineers and scientists from Fluids in Advanced Manufacturing and Cambridge Analytical Biotechnology groups have joined forces to develop an on-the-spot low-cost tool for the rapid diagnosis of infectious diseases. Research team member and Gates Cambridge Scholar, Cassi Henderson, explains how the new technology could save lives in developing countries where there is little or no access to medical pathology laboratories and specialist technicians.

Treatable infectious diseases are among the major causes of death in low- and middle-income countries. One of the main problems is that some infectious diseases share similar or identical symptoms and often the only way to confirm the illness is to take a blood sample and run a series of specialist diagnostic tests in a laboratory.

The potentially life-threatening bacterial disease leptospirosis is one such infection that produces febrile symptoms that are difficult to distinguish from other illnesses such as dengue fever, typhoid fever, malaria and viral hepatitis. Leptospirosis can be cured, but an individual's chances are much improved if the disease is diagnosed and then treated with antibiotics within the first five to seven days of infection.

Accurate diagnosis requires a blood test to be analysed in a pathology laboratory. As a result, leptospirosis is often under-diagnosed and has a high mortality rate in low-income countries. It has been recognised as a neglected disease by the World Health Organization (WHO), which has established a reference group to direct global research and action to address it.

It is critical that health practitioners are able to detect the difference between bacterial and viral infections like leptospirosis and dengue fever because they require very different treatments. This is especially important in light of the rise in global antibiotic resistance with clinicians reluctant to administer antibiotics without a confirmed diagnosis.

Combining biotechnology and manufacturing

To address this, we are using innovative biotechnology and manufacturing technologies to develop a low-cost test that can deliver a real-time result without the need to send blood samples off to a centralised pathology laboratory or the need for specialist technicians to process the samples, both of which are in short supply in low- and middle-income countries.

The aim is to integrate the whole testing process into a single instrument similar to the home pregnancy test, known as a point-of-care diagnostic test. Rather than needing a medical practitioner to take a full blood sample from the patient, the instrument will only require a small finger-prick blood sample. The first diagnostic test that we are developing will detect leptospirosis, with the plan to adapt the system to detect other infectious diseases in the future.

Local and low-cost manufacturing

Whatever test we design must also be affordable if it is to be used in low-income

Professor Gordon Awandare (wearing a light blue lab coat) and his research team at the West African Centre for Cell Biology of Infectious Pathogens, University of Ghana, are working with the University of Cambridge to develop a low-cost tool for the rapid diagnosis of infectious diseases.

countries. A barrier to low-cost diagnostics in the developing world arises from long supply chains and logistical challenges where medical equipment has to be transported long distances and to remote locations. The other challenge that is key here is the purchasing power parity.

To overcome this, we are using novel technologies to enable the diagnostic tests to be manufactured locally, targeting less than $0.50 per test.

One of the more expensive components of the test is the enzyme that is used to amplify the pathogen's genetic material (DNA/RNA) to high enough levels to be detected from a finger-prick blood sample. The high cost and required specialist skills of traditional methods of manufacturing the enzyme, together with requirements for refrigeration of the product, would present a barrier to local production. To address this, we have developed a technique that allows for direct purification of the enzyme from cell culture that packages the enzyme ready for use and bypasses the complex multistep process. The enzyme has been genetically modified using synthetic biology techniques so that it can be collected easily by sedimentation. The protein has also been given a pink colour to make it easy to see when the enzyme has been successfully produced and collected. These two features should make it possible for individuals with minimal training to manufacture the enzyme locally in low resource regions. While critical to performance, the enzyme is just one component of a successful point-of-care test. In addition to manufacturing the enzyme, we are developing a novel technique to extract the pathogen's DNA/RNA directly from the blood sample. This DNA/RNA extraction system and the enzyme will both be contained on a diagnostic card that can also be manufactured locally and ultimately manufactured with local materials. The diagnostic test will be linked to a mobile phone app for data collection

Diagnosis methods

There are two primary ways to test for pathogens in blood: testing for the body's delayed immune response to the presence of a pathogen (immunoassays) or directly testing for the presence of the pathogen's genetic material (nucleic acid tests that detect DNA for bacterial infections or RNA in the case of viruses). Directly testing for the DNA/RNA of the pathogen can enable earlier detection than immunoassays.

However, the total amount of pathogenic DNA/RNA in a small finger-prick of blood can be quite low, particularly in the early stages of infection. To find a pathogen in such a small blood sample we need a way to replicate the pathogen's DNA/RNA (amplification) to a high enough level that it can be detected by a diagnostic test.

The standard laboratory process used for nucleic acid amplification is a 'polymerase chain reaction' (PCR), but PCR testing usually requires specialist laboratory based equipment.

Alternative DNA replication

We are working to customise an alternative nucleic acid amplification method that has higher amplification efficiency and requires simpler equipment to perform the test. Our current focus is on designing the enzyme (the nucleic acid polymerase) that performs the amplification and its integration into a hand-held sample-to-answer diagnostic test.

For more information:
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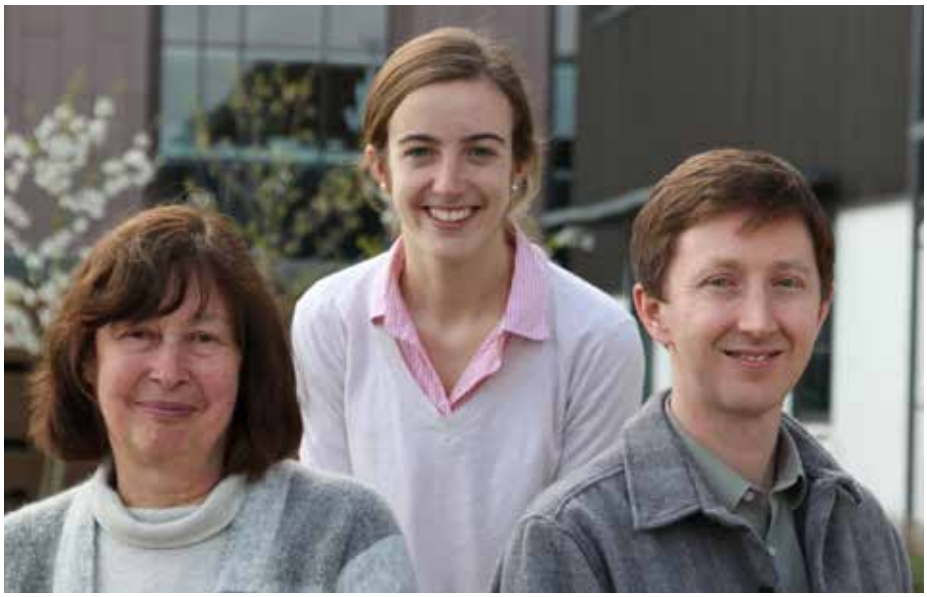
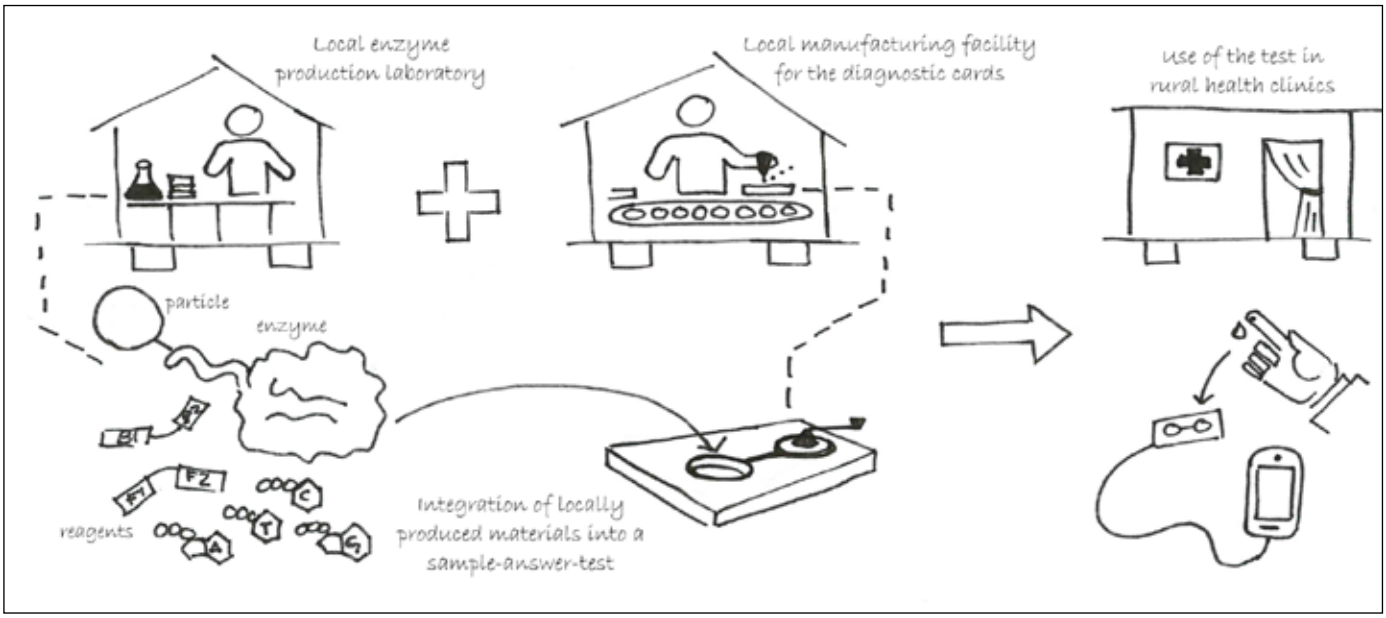
"... we are using innovative biotechnology and manufacturing technologies to develop a low-cost test that can deliver a real-time result without the need to send blood samples off to a centralised pathology laboratory or the need for specialist technicians to process the samples."

and transmission when required. This project has brought together people from multi-disciplinary areas of expertise in diagnostics, synthetic biology, microbiology and parasitology, colloidal science and manufacturing engineering. We are also working in collaboration with Universiti Putra Malaysia and Professor Gordon Awandare, from the West African Centre for Cell Biology of Infectious Pathogens at the University of Ghana, to develop specific aspects of the system, but would welcome new partners in both the UK and internationally who would like to adapt these approaches to other diagnostic needs.

We hope to deliver a sustained improvement in healthcare, while also developing local economies, by using advances in synthetic biology and the application of latest manufacturing research to deliver a robust local fabrication set-up. This will also drive local enterprise, improve technological education and management of infection. We see this as a sustainable approach to point-of-care low-cost diagnostics.



Project leaders Professor Lisa Hall, Department of Chemical Engineering and Biotechnology, University of Cambridge (left) and Dr Ronan Daly, Head of the IfM's Fluids in Advanced Manufacturing Group (right) with Gates Cambridge Scholar, Cassi Henderson (centre).



The diagnostic card containing the novel engineered enzyme and DNA/RNA extraction component is being designed so that it can be locally manufactured in low- and middle-income countries. The integrated test would pair with a mobile phone for data collection and transmission during its use in the field. © Cassi Henderson

Disaster relief operations

Earthquakes, tsunamis, floods and droughts: when a natural disaster strikes, relief organisations react by providing medical treatment, food, water and shelter. However, in these difficult and chaotic circumstances mistakes are inevitably made and supply networks often prove to be insufficiently resilient.

How can we get better at this? How can critical infrastructures like national rail networks bounce back more quickly in the aftermath of a disaster? How can we make sure we are moving the right products and services to the right places?

Disaster Operations Management is becoming an increasing focus of global research. Senior Research Associate Dr Tariq Masood and colleagues from the IfM's Distributed Information and Automation Laboratory (DIAL) recently organised a five-day international workshop in Cambridge as part of the Disaster Resilient Supply Chain Operations in South Asia (DROPS) project.

The workshop brought together two different sets of expertise: senior practitioners, government officials and academics involved in disaster preparedness, mitigation and relief together with specialists in supply chain operations, resilience and big data analytics.

Among the experts at the workshop was the former Chairman of the national organisation for disaster relief in Pakistan; an Additional Secretary of the Finance Ministry in Pakistan, which is also responsible for creating and managing the newly established $3 billion National Disaster Risk Management Fund (NDRMF); and heads of two big data organisations working in South Asian countries.

The group looked at mapping disaster relief supply chains, developing resilience frameworks, understanding how big data analytics can support DROPS and constructing disaster scenarios. They considered case studies and lessons learnt from natural and disease-related disasters and supply chain operations mainly in Pakistan, Nepal, Bangladesh, Sri Lanka, India, New Zealand and the USA.

Using this evidence, they developed a framework for designing resilient supply chains for disaster relief operations in a variety of disruption scenarios to underpin future investments for sustainable economic development.

This project was funded by an EPSRC Global Challenges Research Fund Institutional Grant, in collaboration with the Cambridge Engineering Design Centre and Department of Architecture.

A second workshop has been held in Lahore earlier this year, funded by industry in Pakistan, with the delegates keen to implement the findings from this project. The NDRMF is also planning to incorporate the DROPS framework in order to increase the resilience of their future projects.

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Maintenance matters

Dr Maria Holgado from the IfM's Centre for Industrial Sustainability (CIS) has been researching maintenance and particularly how it can make a vital contribution to a company's long-term sustainability – when measured economically, socially and environmentally.

Maintenance used to be regarded as 'a necessary evil' by manufacturers – expensive, time-consuming and a drain on resources. It is now a mainstream view amongst researchers that maintenance (or asset management more broadly) is not only a 'must do' but also represents an opportunity to add value and to improve productivity and performance. However, it seems that this view has yet to take hold in all corners of UK manufacturing. A recent report from Bosch Rexroth UK suggests that, with some honourable exceptions, the UK's industrial maintenance practices could best be characterised as: "firefighting, reactive maintenance that is increasingly ill-suited to the demands of a modern industrial environment".

There remains, therefore, work to be done in persuading manufacturers that taking a strategic approach to maintenance will deliver a wide range of economic, environmental and social benefits.

Economic sustainability

Research has shown that maintenance helps manufacturers achieve competitive advantage through cost, quality, delivery performance and flexibility. Effective maintenance programmes have also been shown to play an important part in fostering innovation at the factory level. Economic sustainability at both the business level and the production process level can be improved in a number of ways: operating costs are reduced by minimising failure and smarter investments are made in new equipment and technologies. Capturing and analysing maintenance data also helps companies predict the useful life and failure rates of their assets and hence supports better planning and decision-making.

Environmental sustainability

A good maintenance strategy can also improve environmental sustainability by helping the company to use its resources (water, air, energy, materials) more efficiently, reduce its atmospheric emissions and improve its land conservation. The lifecycle of machines is also an important part of environmental sustainability. As well as informing sound purchasing decisions, a clear maintenance plan will help to preserve equipment integrity and extend its lifecycle.

Social sustainability

Managing assets is as much about people as it is about machines and systems. With today's fast-moving technologies, maintenance teams are expected to acquire new knowledge and skills on an almost continual basis. Companies need to have a clear development programme but they also need to ensure that maintenance personnel are involved in defining the procedures they are expected to implement. Doing so reduces the risk of failure and improves plant safety. Our research indicates that the involvement of maintenance teams also improves adherence to environmental and safety standards.

Maintenance should no longer be regarded as a necessary evil. Our research has shown that by taking a more proactive approach to maintenance, manufacturers can unlock value and achieve long-term sustainability.

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Untangling the spaghetti

NanoManufacturing: clean water & green batteries

The IfM's NanoManufacturing group, under the leadership of Dr Michaël De Volder, is developing nanotechnologies to supply clean water for developing nations and build better batteries for renewable energy. Dr De Volder explains some of the strategies his team is employing to realise these goals.

Globally, 663 million people do not have access to clean drinking water. As a result 1,000 children die each day from preventable diarrhoeal diseases.

Water purification is currently undertaken using a number of different pore filtration and membrane chemistry processes, but these can be quite energy expensive and infrastructure heavy. For example, desalination uses reverse osmosis technology, which consumes a vast amount of energy and requires a large and complex processing plant.

In developing countries a number of small-scale water purification methods are in use that rely on ceramic water filters, solar disinfection and other hybrid filters. Some of these methods are successful in removing bacteria and protozoa and some methods are useful in removing heavy metals or organic pollutants. However, in order to prevent more deaths and reliably provide clean drinking water, we urgently need a more efficient and economical water purification process that can be used in remote areas.

Nanofilters

Nanotechnology offers this promise. Our research is currently focused on developing nanofilters that can remove bacteria, organic pollutants and, potentially, viruses from water. We are employing the special characteristics of carbon nanotubes (CNTs) in this endeavour.

CNTs are nano-sized tubes made up of a sheet of carbon atoms that can have diameters down to 100,000 times smaller than a human hair. These nanoparticles are excellent at capturing pollutants, and as a result, CNTs could revolutionise water purification processes.

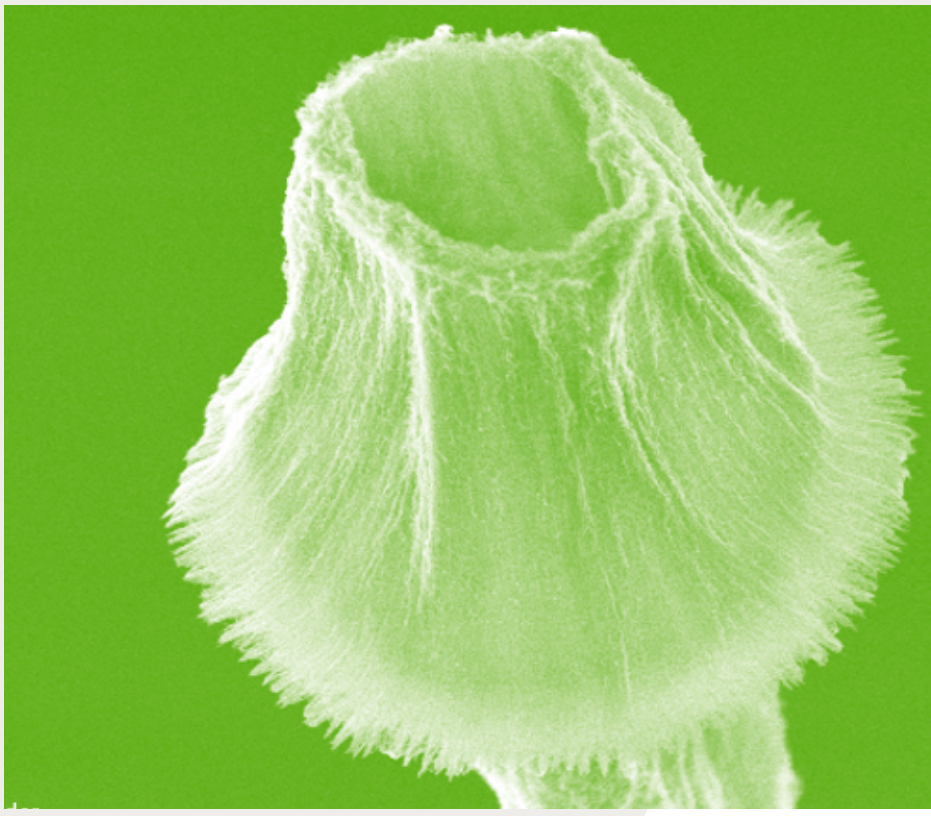
Since the Middle Ages, carbon (charcoal) has been used for filtering water. CNTs are made up of the same atoms, but have a much larger surface area and are therefore even more efficient at capturing pollutants. This includes adsorbing chemical contaminants such as aromatic molecules like benzene and heavy metals.

Untangling nanotube spaghetti

While it is now relatively easy and cheap to manufacture CNTs, they are typically sold in a spaghetti-like tangle that results in poor control over the pore structure and thus water flow. The challenge we are addressing here is the development of manufacturing techniques with better control over the assembly of CNTs to create organised structures of nanotubes with controlled pore size.

Carbon-nanotubes make better batteries

Interestingly, other environmental applications of CNTs such as in energy storage devices also require fine control over nanoparticle organisation and pore structure. The IfM NanoManufacturing group has been exploring how nanotubes can be mixed with other nanoparticles to improve the performance of lithium-ion batteries. This research has found that CNTs are excellent conductive additives



Growing nanotubes from seed

A longstanding challenge in nanotechnology is controlling the arrangement of CNTs. Dr De Volder's team has perfected a technique for growing a wonderful diversity of carbon nanotube structures. The starting point is a well know synthesis method using ethylene, hydrogen and helium feedstock gases, which are heated up to 700-800 degrees Celsius, and then interact with 'nano-seeds' (iron nano-particles) from which the nanotubes grow – like a plant growing from a seed. The team has perfected this process to organise nanotubes in an amazing array of different architectures. Some of the nanotube structures created actually look like exotic plants and flowers. The structures each contain more than one million organised carbon nanotubes.

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for batteries and that controlling the arrangement of CNTs imparts new functionalities such as foldable electrodes.

CNT additives could be used in electric and hybrid vehicles in the future with some early reports estimating that they could potentially reduce both battery production costs and battery weight.

Scaling up for real-world application

While we are designing different nanotube structures to deliver the most efficient systems for water filtration or energy storage, we are also looking at how to scale-up production. To deliver water filters and batteries at a high volume and low cost we need to be able to manufacture them in bulk using a manufacturing platform that is compatible with industrial standards.

The most common process for manufacturing battery electrodes and most water filters is roll-to-roll processing. Roll-to-roll processing is a continuous manufacturing method that allows for large area production of materials. In late 2016 we took delivery of a continuous roll-to-roll processing machine, which is now being used to perfect our manufacturing of CNT batteries and filters.

Our work is demonstrating that nanotechnology has the potential to contribute to game-changing innovations in the future.

Doctoral student Sarah Jessl in the lab.

Being open about IP

Dr Frank Tietze leads the IfM's research into innovation and intellectual property management. He describes how open intellectual property (IP) can contribute to society by accelerating the uptake of sustainable technologies and systems.

To sustain a population of nine billion people by 2050 the world is going to need increasingly socially-responsible and environmentally sustainable innovation.

Key industry sectors such as energy, water, agri-food and transport are already under pressure to move to more sustainable methods of production and consumption. However, there are barriers in the way.

A protectionist approach to IP is sometimes perceived to be one of these barriers. IP might be used to protect and prolong the life-cycle of existing technologies and systems, thereby making it harder for new and more sustainable technologies to be adopted. However, with societal pressure to move key sectors to more sustainable systems, there is a need to change this status quo.

Electric car manufacturer Tesla is doing just that. Tesla CEO, Elon Musk, 'shocked' the world in 2014 when he announced that his company was joining the open source movement and giving away its technology patents for free.

But why would a company that had worked so hard to develop and protect its technology from its global car manufacturer competitors suddenly give its technology away for free?

Tesla initially developed a patent portfolio to protect its technology from being copied by the big car companies. However, Tesla's concern that the established automotive manufacturers would ramp up their production of electric cars and overwhelm Tesla never came to pass.

Dr Frank Tietze at the Strategic Intellectual Property Forum

Instead, Tesla saw the electric car market stagnate at less than one per cent of total vehicle sales. So Tesla changed its strategy from trying to prevent others from building electric cars to trying to encourage others to build electric cars in an effort to stem "the enormous flood of gasoline cars pouring out of the world's factories every day."

One reasoning behind Tesla's decision might be that more electric cars being built will result in more battery recharging stations being built – making electric cars become more visible and a more conventional choice.

Tesla believes that an open IP strategy can strengthen rather than diminish its position by building the size of the electric car market, and as a result, build its own share of the total automotive market.

"Tesla changed its strategy from trying to prevent others from building electric cars to trying to encourage others to build electric cars in an effort to stem "the enormous flood of gasoline cars pouring out of the world's factories every day."

"Open IP is well advanced and mature in the software and healthcare industries. In healthcare, for example, it has given access to life-saving medicines to millions of people, particularly in developing countries through patent pools, such as the Medicine Patent Pool. And it is becoming increasingly important for societies in the areas of social and environmental issues."

Careful management of IP at a firm-level, supported by policy-level awareness can be a powerful instrument to support sustainability transitions in other industries too.

For example, energy supply is challenged by the rapid depletion of natural resources, air pollution and greenhouse gas emissions, nuclear risks and security of supply. With water supply we are restricted by water scarcity, pollutants, extreme environmental events such as flooding and costs associated with supplying water to communities in poor countries and remote communities.

The agri-food sector is also challenged to sustainably produce more food and address malnutrition in poor countries. These solutions rely on new knowledge. As a result, IP is becoming increasingly important as global societies evolve to knowledge economies.

If the ownership of IP is fragmented in an industry it can slow down technology innovation and uptake. However, if firms open up their innovation processes and move away from traditional internally focused closed innovation cultures where IP is used to protect and prolong life-cycles we may see knowledge sharing leading to accelerated cumulative innovation cycles and a more rapid uptake of sustainable alternatives.

Open IP is well advanced and mature in the software and healthcare industries. In healthcare, for example, it has given access to life-saving medicines to millions of people, particularly in developing countries through patent pools, such as the Medicine Patent Pool. And it is becoming increasingly important for societies in the areas of social and environmental issues.

IP Interest Group

The IfM runs an IP interest group for manufacturing companies where participants meet regularly to discuss IP-related issues from a business perspective, such as technology acquisitions, licensing strategies or how patent data can be used to identify development partners. The group provides a trusted platform for its members to engage in in-depth discussions on strategically relevant IP topics.

Strategic IP Forum

The Strategic IP Forum (SIPF) is an open event series launched in spring 2015 that focuses on strategic IP topics from a business perspective. SIPF brings together interested individuals from the Cambridge region and beyond including CTOs, portfolio managers, VPs, Technology, Heads of Innovation/IP/Licensing from a range of manufacturing companies and sectors to engage in an IP expert community. The next SIPF will take place on 18 May 2017.

While producing medicines in developing countries relies on multinational pharmaceutical companies sharing their IP, small companies can also play strategic roles in helping society move towards more sustainable systems.

As technology progress is cumulative there will always be phases of closed IP for small companies to build-up their portfolio. For these companies, closed IP is being used as a strategy to make a social impact. For example, Nutriset, which manufactures food for famine relief, is protecting not only its invention Plumpy'Nut, but also its entire business model by patents.

Plumpy'Nut is a peanut-based paste for the treatment of severe malnutrition and can be administered at home rather than through a supervised hospital treatment. As a result it can treat more patients.

Nutriset says that it uses patents to enable the development of local production plants for Plumpy'Nut in developing countries from being taken over by global manufacturing sites in more developed countries. The local production of Plumpy'Nut helps with creating skills and employment in the regions where Nutriset's product is most needed.

We hope to be able to enhance societal and environmental transitions by further study of the successful IP models of those companies that have either gone down the open IP route or chosen to protect their IP aiming for sustainable transition. Our research reveals how these different IP models can be used for sustainability transitions under different scenarios and how IP can be used to build a circular economy and increase sustainability through new business models.

For more information about the IfM's research into IP or if you would like to join the IP Interest Group or Forum:
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PhD Spotlight

Bang Ming Yong: working with not-for-profit technology start-ups

Research area: Innovation management of technology not-for-profits.

Centre: Centre for Technology Management

A passion for technology innovation and entrepreneurship and a desire to contribute to Malaysia's burgeoning ICT industry is the driving force behind Bang Ming Yong's seemingly endless energy.

Not only is he undertaking a PhD full-time, Bang is also developing a virtual reality tour of the IfM building, is Treasurer of the Cambridge University Entrepreneurs and volunteers at not-for-profit technology start-ups around Cambridge.

Awarded the Malaysian Government's most prestigious postgraduate scholarship, the King's Scholarship, Bang said the choice of where to study was easy: "I have always wanted to study innovation and in particular why innovation clusters are so successful. With such a high concentration of high-tech companies, there is no better place than Cambridge to study.

"Cambridge's innovation cluster environment fosters individual and collective success and in addition to informing my research, I have also been able to personally engage with a large variety of entrepreneurs and tech organisations, which would not have been possible at another university."

It was Bang's introduction to Cambridge non-profit biometrics technology company Simprints that sparked his interest in studying the business models of not-for-profit technology start-ups.

"I decided to volunteer at Simprints and thought that all the other volunteers would also be students. They weren't. On my first night of volunteering I met retired consultants and experienced engineers, as well as students who were volunteers.

"Finding resources is a challenge for not-for-profits when they are starting from nothing. There are a lot of dimensions to resources and technology is just one part.

"Start-ups attract resources from various places – a university partnership gives them access to MBA students to develop their business plan, while a connection with a law firm can deliver pro bono legal services."

In addition to business models, Bang is interested in how social incubators and social enterprise networks can provide the support and tools to drive entrepreneurial businesses and deliver social good.

"There is a really interesting social network effect in technology clusters where organisations support one another. The common link between the organisations to deliver 'technology for good' appears to override any competition concerns.

"My analysis of the different strategies and business models used by successful not-for-profit technology companies, such as Raspberry Pi, will enable me to develop a framework that will help guide new technology start-ups."

Bang Ming Yong (top) and receiving the King's Scholarship.

Bang obtained his B.Eng in Electronic Engineering from Universiti Sains Malaysia in 2013. After graduating he worked in manufacturing and construction industries for two years, including with National Instruments, prior to starting his PhD.

"There is a really interesting social network effect in technology clusters where organisations support one another. The common link between the organisations to deliver 'technology for good' appears to override any competition concerns."

Roadmapping a better future

IfM Education and Consultancy Services (IfM ECS) has helped more than 300 public and private sector organisations with their strategic and technology innovation planning through the powerful technique of roadmapping.

Dr Rob Phaal and his team from the IfM's Centre for Technology Management have been researching the application of roadmapping for more than two decades and the Centre is regarded as a world leader in this field.

In the public and not-for-profit sectors, IfM ECS has worked with national governments, public R&D agencies and industry bodies to help identify sector and technology opportunities and prioritise those that will have the most significant economic and social impact.

Tackling complex challenges

IfM ECS also works with government departments and regulatory organisations on developing industrial policy and putting it into practice in a rapidly changing landscape. Roadmapping can help underpin policy development for particular sectors or technologies, and explore cross-sector opportunities for productive collaboration. It can also be used with other tools and approaches such as foresight and scenario planning to gain insights into possible futures. The process is a highly effective way of building consensus among a diverse group of stakeholders and gaining their commitment to an action plan.

Better treatment for children with brain injuries

IfM ECS has worked with a wide range of not-for-profit organisations that are looking for ways to make the most of emerging technologies. One such example of where well managed technological innovation can save lives is with the medical treatment of children with an acquired brain injury.

Approximately 40,000 children in the UK suffer a brain injury each year. The impact of brain injury on a child is complex. As well as physical disability, a brain injury will impact upon a child's development and access to education, as well as their social and vocational outcomes.

The Brain Injury Healthcare Technology Co-operative (part of the National Institute for Health Research) believed that technological innovation could play a large part in filling some of the gaps in service provision and improving the outcomes for this vulnerable patient group. IfM ECS coordinated a roadmapping workshop with the Co-operative to bring together senior representatives from NHS England, NHS Trusts, academia, industry and patients to identify areas of unmet clinical need and develop a roadmap to deliver the solutions.

The workshop explored ways to improve outcomes across the patient journey, create ideas for future research and service-development projects, and encourage wider collaboration between brain injury professionals and other service providers.

As a result, the workshop participants identified four action priorities – technology communications to improve coordination between hospitals, rehabilitation therapy services and social care; strategies to improve educationalists' understanding of how acquired brain injury impacts learning and behaviour; techniques to raise awareness of resources and support available for families; and programmes to evaluate rehabilitation technologies and disseminate advice to patients.

Finding people lost at sea

Another organisation that IfM ECS has worked with is the Royal National Lifeboat Institution (RNLI). The RNLI recognised that there were a lot of changes happening in global search and rescue communications technologies and rapid advances in real-time innovations in tracking people lost at sea, but did not know how best to respond to all these changes.

IfM ECS worked with RNLI to develop an overall picture of the current state and planned and predicted changes across global rescue radio operations and personal 'calling for help' technologies. Roadmapping proved to be a powerful tool for the RNLI to collate insights and technical intelligence for the development of a single, coherent vision of the search

and rescue communications landscapes. As a result of the roadmapping process, the RNLI Innovation Team is prepared for new technological advances as well as having a good appreciation of communications and training requirements for future lifesaving platforms.

"The roadmapping process allowed us to gather deep technical insight and connected our RNLI technical community with technology developers and researchers who are now aware of our technical challenges and lifesaving ambitions. We have a valuable and engaging way to communicate technical information and influence the future direction of innovation and investment both internally and externally."

Dr Will Roberts

Senior Innovation Manager of the RNLI

Helping a charity chart its future

IfM ECS also worked with a unique University of Cambridge spin-out charity to help it develop its medium-term strategy. Africa's Voices Foundation (AVF) uses the latest digital technologies combined with traditional radio to amplify and elevate the voices of Africans – in all of their diversity – to the levels of development and governance actors. Roadmapping helped AVF to clearly define and prioritise its different strategy options and understand the implications of these alternatives. It also helped the organisation to explore different business models. Each option was evaluated using a range of different factors such as its potential for growth, its synergy with the Africa's Voices vision, and Africa's Voices' capability to develop and sustain it in the future.

"IfM's approach enabled us to consider some very disparate and complex issues in a systematic and informative way. It was a great surprise to see how methods that were originally developed to address technology problems could be applied so efficiently in areas of social sciences. The graphical approach provides for good communication outside the workshop group."

Dr Sharath Srinivasan

Co-Founder and Director of AFV

For more information about roadmapping research:
Contact: **Dr Rob Phaal**
Email: **rp108@cam.ac.uk**

To find out how roadmapping can help your organistion:
Contact: **Rob Driver**
Email: **rad74@cam.ac.uk**

Manufacturing a better world

Student design projects

The Manufacturing Engineering Tripos (MET) course is a programme for 3rd and 4th-year students who have successfully completed the first two years of an engineering degree. During their first year of MET, groups of three or four students complete a major design project to develop a new product.

Having first identified a customer need, they research the market, develop original design concepts and create a full business plan. The projects have generated some exciting new ideas and innovative technology aimed at solving some of the world's major challenges.

The students' work is showcased every year in the Design Show at the IfM.

This year's Design Show will be on 7 June at the IfM.

Infinity Bakery

A solar oven that aims to reduce disease and save energy by offering an affordable, sun-powered cooker to developing communities. The oven, which concentrates the sun's rays, is made from recycled oil drums, wood, bamboo and clay, so it can be produced locally and quickly.

This project generated a lot of media interest including an article in the *Huffington Post*: '11 simple inventions that could save the world'.

Team: Daniel Cox, William Hatcher, Keno Marie-Ghae and Leyla Sudbury.

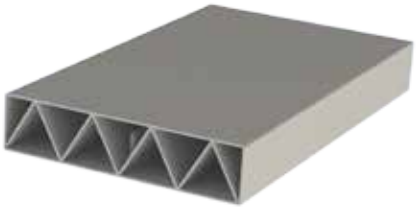
A working prototype in Dar Es Salaam, Tanzania.

BottleBrick

A small-scale community PET bottle recycling solution that recycles and reforms waste plastic bottles into building bricks for the developing world, eliminating use of concrete and reducing landfill waste.

Bottle Brick uses a novel process of reforming a waste PET drinks bottle into a stackable, interlocking, tessellating shape, which when filled with sand may be used as a structural brick.

Team: Michael Daley, Danyal Hasan, Edward Holt and Jordan Salmon.



Low-cost Bed

A bed made solely from cardboard that can be deployed in minutes and provides heat insulation from the ground, as well as improved levels of comfort. The bed is designed for use in homeless shelters in the UK, particularly during winter when bed shortages occur; as many can be stored during the day and placed on the floor at night. It is also designed for disaster relief situations where the immediate needs of people have been met, including shelter, food, sanitation and medication. Here it can provide an additional level of comfort and tackle problems caused by sleeping on damp or hard ground.

Team: Stephanie Brown, Richard Cadman, Jonathan Godden and Tayo Moore.

MyPod

A portable sensory room that targets a wide range of issues that are experienced by people with Autistic Spectrum Disorder. Its main function is to offer relaxation techniques in the form of rocking and pressure application, both of which are techniques that have been validated by psychologists. The sensory pod can be rocked externally by a teacher or parent, which makes for easy interaction during the calming period. Rocking can also be generated internally by the user, so that they can feel independent if they want to.

Team: Joseph Mambwe, Sarah Tong and Bruno Sussat.

Making **a difference**

We interviewed two MET graduates who are changing the face of humanitarian aid by using innovative manufacturing engineering solutions to help people around the world that are affected by disaster or war. **Susan Long** (MEng 2005) and **Abi Bush** (MEng 2014) both work for non-profit organisation Field Ready, which provides humanitarian solutions in health, water and sanitation using new technologies such as 3D printers and laser cutters as well as conventional manufacturing techniques.

Susan, who is based in the Middle East, is working on Field Ready's Syria response programme to assist with the humanitarian crisis. She is part of the team that has developed a locally made 'lifting airbag', which rescue workers use to reach people trapped under rubble following shelling. Rescue teams were unable to get enough of the standard airbag kits for their needs and none at all in besieged areas. The locally made airbag kit costs roughly $450 compared to imported standard units, which cost around $5,000.

Abi was based in Nepal last year and has been working on a number of different projects following the devastating earthquake, including 3D printing low-cost medical equipment and replacement parts for clinics that lost much of their equipment in the earthquakes. In another Nepalese project, she has been working with a local design entrepreneur to help him to develop improved wood-fuel cooking stoves that reduce people's exposure to harmful chemicals in smoke.

Susan Long
MEng 2005

Job Title: Innovation Advisor (Turkey and Syria)
Organisation: Field Ready
Location: Middle East

Field Ready is not your average engineering organisation, how did you hear about them?
I heard about this innovative organisation doing something interesting and with real impact through networks that dated back to my time as an engineering student. After reaching out to hear more, I took what was meant to be just a month-long break from my previous employment to volunteer and ended up not going back!

What does your work mainly involve?
A great deal of my time is spent meeting with current and potential partners, to understand their work and the challenges they face. Field Ready isn't about a specific product or technology, but rather seeks ways to use innovation to make things when and where they are needed, and to see this become the normal way to do things. This approach means every programme is individual. I spend a lot of time talking to people internally and externally to try and work out what this should be!

What sort of impact are you making?
Within the very short time I have been involved with Field Ready's Syria response I have seen a 'lifting airbag' move from an idea to now being used to rescue civilians in the field. The airbag functions as a

Testing Field Ready airbag (right)

Airbag deflated

jack and allows rescue workers to access those trapped under rubble following shelling.

Standard kits cost around $5,000 and rescue teams in Syria were unable to get nearly enough for their needs and none at all within besieged areas. An engineer in the UK supported our engineers in Syria to design, prototype and test an airbag system, which can be made entirely from readily available tools and materials for roughly $450 (more than a 90 per cent reduction in cost).

What's next?
Growing Field Ready's impact across the Middle East region and working with the team that is responding to the Syria crisis; allowing more people to make the things they need to move forward with their lives.

What was the driving force behind your manufacturing engineering career and have your views changed since working in the field?
For quite some time I have been concerned about the loss of jobs in various industrial sectors and the impact that this has on communities that have been built around them, like the deindustrialised part of the country I grew up in. I have been troubled by the thought that many young people living in these communities may never receive the benefit of jobs that industrialisation previously created.

Distributed manufacturing seemed to me a way technology could help to alleviate this. Field Ready has given me an insight into how it can do this and more by dramatically reducing the costs and delays in providing needed items to humanitarian crises, but also providing mechanisms for global networks to support those in extreme situations to make their own economy out of making things.

Susan Long (in blue shirt) with Syrian engineers and Field Ready staff who had just participated in a 3D printing and innovation training workshop.

Why did you decide to study manufacturing engineering?
The breadth and diversity of the course. The fact that you learn how to develop products, and how global supply chains function, which was immensely useful when I worked in trade and investment in Asia and Africa. As a hands-on person, I was also attracted by the time spent in industry, and as an avid traveller, completing my final placement overseas was a huge bonus!

What is the most useful advice you could offer to a secondary school student trying to decide on a career path?
Develop skills in what you are passionate about, put in the groundwork to get good at it and don't get stuck on the idea that there is a specific path. I have met lawyers, filmmakers, retail experts, teachers, even an abattoir expert, who have used their professional experience in different ways.

What do you like to do outside of work?
I've made a couple of fashion collections and furniture for friends and myself. I like combining fabrics from different places I've lived and reusing everyday and industrial items.

"Field Ready has given me an insight into how it can do this and more by dramatically reducing the costs and delays in providing needed items to humanitarian crises, but also providing mechanisms for global networks to support those in extreme situations to make their own economy out of making things."

Airbag inflated

Abi Bush printing a fetoscope (used to listen to an unborn baby's heart) for a health post in an Internally Displaced Persons camp in Nepal.

"For me, the idea of distributed manufacturing has gone from a neat academic concept to an essential paradigm shift for the future."

Abigail (Abi) Bush
MEng 2014

Job Title: Engineering Advisor
Organisation: Field Ready
Location: Nepal (2016) and Paris (2017)

Why did you decide to study manufacturing engineering?
When I set out at university, I really wanted to learn how to design great products. Part of that was understanding the physics underpinning how things work, which is covered on the main engineering course. However, there is a lot more to designing a product than the maths – there is how it will be made, who it will be used by, and the impact a product will have throughout its lifecycle. And of course, getting your hands dirty and prototyping! Additionally, I think it is increasingly important for engineers to be able to make informed decisions about how and where products are made, from social, environmental as well as economic perspectives. The MET course is one of the few ways to explore this wider perspective.

Tell us about how you came to join Field Ready?
I used to volunteer with Engineers Without Borders whilst I was at university, and through that network heard about this amazing organisation called Field Ready, which was trying to change how aid is delivered. Fortunately, I was successful in my application for the Nepal program, and here I am!

What projects have you worked on or are currently working on at Field Ready?
During my time in Nepal, my work was quite varied, but I did end up doing quite a bit on developing 3D printable medical supplies.

Many aid agencies are working to provide assistance to clinics and health posts that lost a lot of their equipment in the earthquake, but they face some major challenges given the specialist nature of medical supplies. For example, many of the more sophisticated pieces of equipment donated by aid agencies break under the tough environmental conditions and it can be very difficult to get spare parts. This is because the donated items typically come from very far away, so it is expensive to ship spares, and the equipment tends to be quite dated so spares may not even be available.

Often, we would go to a health clinic and find equipment that wouldn't work because, say, a plastic connector was broken, and the clinic would be unable to fix the problem without having to buy a completely new piece of equipment. At this point, a laptop and a 3D printer become a brilliant resource to design and print replacement parts on the spot.

Sophisticated equipment aside, even simple and basic supplies were taking aid agencies three to four months to procure from

Using a 3D printed otoscope

places like India and Germany. This inspired us to start work on 3D printable medical devices, such as otoscopes, kidney trays and tweezers.

We are testing this model right now with a number of our designs and a 3D printer travelling with a doctor around a few remote clinics in Nepal.

What does an average day look like for you?

Much of my day is spent on the CAD design software Solidworks, or just with a pen and paper exploring new ideas, or with a 3D printer prototyping and making.

Something that might be more surprising is that an average day in the field can typically involve a lot of calls and meetings! This is for both internal and external reasons. The Field Ready team is distributed over nine countries, so it takes a bit of work keeping up with what everyone is doing and making sure we are all heading in the same direction. Externally, we are always talking to different potential partners and exploring the supply chain or quality challenges they have to see if we can help. Additionally, for every design we make we need to seek user feedback, especially with more critical devices such as medical products. In Nepal, where transport is tricky, we could spend an entire day just travelling to reach the people who are using our products so that we can check that everything is still working well.

What is the most rewarding experience you have had at Field Ready so far?

In Nepal, we completed a piece of work for a local entrepreneur (Madhukar KC) who makes and installs clean cook stoves (biomass stoves that produce less smoke). The key to his design is an improved burner that enables more oxygen to get to the burning wood. He has been iterating on this concept for more than 10 years, by carving wooden patterns by hand, then giving the patterns to a sand-casting factory to manufacture in cast iron. However, when we met him he still hadn't quite reached the government requirements for cook stove performance, which was limiting the growth of his business.

He had an idea for a design that could do it, but it was too complex for him to make by hand in wood. My colleague Ram spent a couple of days with him turning his idea into a 3D computer model and then we printed out his design.

Since then, the new stoves made from our 3D printed pattern have passed the government requirements enabling Madhukar to win contracts for more than 200,000 stoves. It was really exciting for me to see the huge impact just a single 3D print can have, particularly through

"I think it is increasingly important for engineers to be able to make informed decisions about how and where products are made, from social, environmental as well as economic perspectives. The MET course is one of the few ways to explore this wider perspective."

Traditional biomass cookstove in action

Cookstoves: 10 years' worth of iterative development of burner design

working with local innovators and manufacturers. That 3D print has improved Madhukar's business, the sand casting manufacturer's business, in addition to all the customers who benefit from cleaner cook stoves. We have also increased the likelihood that aid agencies will buy locally rather than importing from elsewhere.

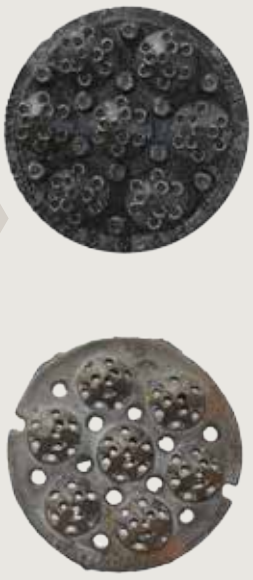
Has Field Ready changed the way that you look at manufacturing engineering?
Definitely. For me, the idea of distributed manufacturing has gone from a neat academic concept to an essential paradigm shift for the future. Through working with Field Ready, I have seen how the way we currently manufacture products leaves us vulnerable to crisis. When transport infrastructure and communications infrastructure is damaged, international supply chains are not as effective as one might hope. In many more cases than I originally thought, making things locally is quicker and cheaper, and more responsive to the needs at hand.

Much of the exploration of distributed manufacturing in the academic world is focused on the circular economy and sustainable cities; the idea of flexible machines capable of making a wide range of products in one place, coupled with digital supply chains where information, not goods, travel around the world. This means the skills needed to manufacture goods would be embedded at a local level, not just an international level. For me, distributed manufacturing is about resilience, not only against major humanitarian crises, but also the social crises we are seeing due to the collapse of companies and industries in particular localities.

What is the most useful advice you could offer someone who wants a career where they can make a positive difference?
There are a million ways to make a positive difference, and the answer isn't always to try and match your skills to what is typically perceived as 'making a positive difference'. Effecting positive change in the world can often start with positive change in yourself: through developing your skills, your sense of self and enthusiasms, you will only increase what you can offer to other people in the world, no matter if you are working for an NGO, a university, a carpentry shop or a bank. Finding out what skills and passions you want to develop is of course somewhat harder than it sounds, and it takes a bit of experimentation.

What's next?
I'm concentrating on some of the challenges we are seeing coming out of the Syria crisis. Given that these are developing countries, the challenges are technically a lot more demanding than others we have seen.

What is your biggest passion outside engineering?
I love adventure sports; living in Nepal last year was great for trying a few new things such as trekking and white water kayaking. However, being back in Europe has given me an excuse to get back to skiing, and I enjoyed a week learning to ski off-piste earlier in the year.



3D printed pattern for burner (top) and final cast iron burner

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