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the science behind

The

Theory of

Everything

the hit film’s scientific consultant on Hawking, black holes and hangovers

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Mighty bites

Limpet teeth might be the strongest natural material known to man. Researchers from the University of Portsmouth have discovered that limpets – small aquatic snail-like creatures with conical shells – have teeth with biological structures so strong they could be copied to make cars, boats and planes of the future.

The study examined the small-scale mechanical behaviour of teeth from limpets using atomic force microscopy, a method used to pull apart materials all the way down to the level of the atom.

Professor Asa Barber from the University’s School of Engineering led the study. He says: “Nature is a wonderful source of inspiration for structures that have excellent mechanical properties.

“All the things we observe around us, such as trees and the shells of sea creatures, have evolved to be effective at what they do.

“Until now we thought that spider silk was the strongest biological material because of its super-strength and potential applications in everything from bullet-proof vests to computer electronics but now we have discovered that limpet teeth exhibit a strength that is potentially higher.”

Professor Barber found that the teeth contain a hard mineral known as goethite, which forms in the limpet as it grows.

He says: “Limpets need high strength teeth to rasp over rock surfaces and remove algae for feeding when the tide is in.

“We discovered that the fibres of goethite are just the right size to make up a resilient composite structure.

“This discovery means that the fibrous structures found in limpet teeth could be mimicked and used in high-performance engineering applications such as Formula 1 racing cars, the hulls of boats and aircraft structures.”

The research, underpinned by EPSRC investment, also discovered that, unusually, limpet teeth are the same strength no matter what the size.

Professor Barber says: “Generally a big structure has lots of flaws and can break more easily than a smaller structure, which has fewer flaws and is stronger... Limpet teeth break this rule as their strength is the same no matter what the size.”

The material Professor Barber tested was almost 100 times thinner than the diameter of a human hair, and the techniques used to break such a sample have only just been developed.
Targeting individual patient treatment

EPSRC and the Medical Research Council (MRC) are jointly investing £16 million in multidisciplinary research to develop molecular pathology tests leading to new tools that can precisely target individual patient treatment in a wide range of diseases. The research aims to reduce unpleasant patient side effects, as well as yield economic benefit through a reduction in the number of ineffective treatments. The research will be conducted through six nodes led by the universities of Edinburgh, Glasgow, Leicester, Manchester, Newcastle and Nottingham.

UK robotics network

EPSRC has launched a new national network to enhance the UK’s ability to develop and exploit the vast potential of Robotics and Autonomous Systems (RAS). The global market for service and industrial robots is estimated to reach US$59.5 billion by 2020.

Working with Innovate UK and other UK Research Council partners, the UK Robotics and Autonomous Systems Network will integrate and coordinate activities at eight dedicated EPSRC-funded RAS facilities, as well as EPSRC Centres for Doctoral Training across the UK.

Cybersecurity boost

EPSRC is co-investing with Innovate UK £5 million in a new research and innovation hub at the Centre for Secure Information Technologies Innovation and Knowledge Centre (CSIT) at Queen’s University Belfast.

The hub, focusing on cybersecurity for Smart Cities and the Internet of Things, will be supported by £9 million in core funding from the university.

CSIT will use the investment to build on its industry and academic partnerships worldwide, increasing the projected level of investment in its research to £38 million over the next five years.

£20 million for biotech

EPSRC is co-investing £20 million in 23 biotechnology projects, from making biofuel from household waste to using bacteria to make the building blocks for new medicines.

The projects have been funded through the Industrial Biotechnology Catalyst – a collaborative programme between EPSRC, the Biotechnology and Biological Sciences Research Council (BBSRC) and Innovate UK.

£270 million for quantum technologies

EPSRC is coordinating a £270 million UK Government initiative to establish a National Quantum Technologies Programme.

The investment is championed by the Quantum Technologies Strategic Advisory Board, a joint government, industry and academic initiative to help build a profitable, growing and sustainable UK quantum industry.

The programme includes a national network of Quantum Technology Hubs involving 17 universities and 132 companies, EPSRC Centres for Doctoral Training and feasibility studies. In September 2015, EPSRC invested £12 million in 10 Quantum Technology Fellowships.

The Quantum Technologies Programme represents the biggest single investment in a disruptive technology of the modern era, and will help transform vital UK sectors – from finance and telecommunications to energy, aerospace and transport.

£45 million for digital economy centres

Six new multidisciplinary digital economy research centres, worth a total of £45 million with partner contributions, will be created under the Research Councils UK Digital Economy programme, led by EPSRC, which is investing £23 million.

Involving over 150 university, industry and regional enterprise partners, the centres will develop a suite of innovative digital technologies – from personalised digital health services to interactive media in education.

Building on previous investments, the centres are a joint investment by EPSRC, the Arts and Humanities Research Council (AHRC), Innovate UK, the Digital Catapult and others.

£42 million Turing Institute launched

The Alan Turing Institute, a £42 million national research centre, has been launched to promote the development and use of advanced mathematics, computer science, algorithms and Big Data for human benefit.

Coordinated by EPSRC and headquartered at the British Library, within London’s Knowledge Quarter, the institute brings together leaders in advanced mathematics and computing science from the five lead universities, each investing £5 million. The centre will also partner with business and government bodies.

The centre’s work is expected to encompass a wide range of scientific disciplines and business sectors, combining theory and practical application.
Rehabilitation nation

EPSRC is investing £5.3 million in three university-led healthcare technology projects focusing on improving patients’ lives, allowing greater independence and benefiting those with a wide range of mobility and coordination difficulties.

The projects, whose themes emerged during an EPSRC creative workshop ‘sandpit’, are led by Newcastle University, the University of Bristol and the University of Warwick, working with 15 other university partners. They include: development of a prosthetic hand controlled by the nervous system; robotic clothing to help people with walking; and biosensors to monitor how patients use equipment or exercise during rehabilitation.

£3.7 million mega-microscope

EPSRC has invested £3.7 million in a new super powerful electron microscope that can pinpoint the position of single atoms.

The Nion Hermes Scanning Transmission Electron Microscope, one of only three in the world, is sited at the EPSRC SuperSTEM facility at the Daresbury laboratory complex near Warrington, overseen by the Science and Technology Facilities Council (STFC).

Covering a range of academic research, from developing new materials for space travel to creating a better treatment for anaemia, the microscope lets scientists examine how materials behave at a level a million times smaller than a human hair.

£10 million for manufacturing the future

Ten new research projects to advance the UK’s manufacturing capability, develop new functional materials, and accelerate the translation of the science of functional materials through to application have received a £10 million investment from EPSRC.

The projects include developing thin-film materials and new manufacturing methods for wearable technology; improving the mass production of carbon nanotube materials; and advanced manufacturing of nanoparticles for healthcare applications.

CRUK upgrade

EPSRC is deepening its strategic partnership with Cancer Research UK (CRUK) through new co-funded multidisciplinary research projects to improve our understanding of cancer, and boost innovation in cancer diagnosis and treatment.

The new partnership increases the amount of joint EPSRC/CRUK funding for collaborative research over five years.

£40 million for synthetic biology research

EPSRC is co-investing £40 million in synthetic biology research across the UK.

From materials used for advanced manufacturing to developing new antibiotics and better tests for diseases, the investment is in one of the most promising areas of modern science.

A total of £32 million will go towards three Synthetic Biology Centres at the University of Edinburgh, the University of Manchester and the University of Warwick.

An additional £8 million has been awarded to research partnerships across the UK to help create the DNA starting blocks required for synthetic biology applications.

The investment comes from EPSRC, the Biotechnology and Biological Sciences Research Council (BBSRC), the Medical Research Council (MRC) and capital investment from the UK Government.

£10 million for Internet of Things research hub

The EPSRC-led Research Councils UK Digital Economy programme is investing £10 million in a new research hub to explore the interdisciplinary challenges around security, privacy and trust in the Internet of Things (IoT), and to translate research findings into commercial reality.

The programme is a collaboration between EPSRC, the Digital Economy Unit, Innovate UK, the Digital Catapult, and the Future Cities Catapult and is led by several leading universities.

£4.5 million for water, energy, food nexus

EPSRC is investing £4.5 million in interdisciplinary research involving 19 university groups and partners to help tackle the interlinked challenges facing the UK’s water, energy and food security – known as the water-energy-food nexus.
The estimated contribution to the UK’s Gross Value Added (GVA) by engineering-related sectors in 2011, equivalent to 20 per cent of the UK’s total GVA.

The findings were made in an independent report on the economic impact of engineering in the UK compiled by the Technopolis group and commissioned by EPSRC and the Royal Academy of Engineering.

The report estimated that engineering-related sectors exported goods and services valued at around £239 billion in 2011, some 48 per cent of the total value of exports for that year. It also flagged up the importance of engineering research to key sectors including aerospace, pharmaceuticals, software and computing.

In addition, the report highlighted the role played by the high concentrations of graduate engineers across the sectors, and the ability of engineering facilities and businesses to attract substantial high-value, high-tech inward investment from around the world.

The report was given privileged access to over 500 individual case studies from the Research Excellence Framework (REF), the new system for assessing the quality of research in UK higher education institutions.

The 2014 REF was conducted jointly by the Higher Education Funding Council for England (HEFCE), the Scottish Funding Council (SFC), the Higher Education Funding Council for Wales (HEFCW) and the Department for Employment and Learning, Northern Ireland (DEL).

The case studies featured in the REF were drawn from around 50 higher education institutions, showcasing the impact of engineering research in all its forms. Together, they provide comprehensive evidence of the economic and social impact of UK engineering research over the last 20 years. One third of the case studies refer to increases in productivity and competitiveness, citing research that has led to new processes offering efficiency gains and cost savings.

Similarly, REF demonstrates the impact arising from the UK research base and, in particular, from engineering and physical sciences. EPSRC’s analysis of the REF case studies within the engineering and physical sciences panel shows:

- Over 85 per cent of case studies involved EPSRC-funded research and/or researchers, and significant numbers of the studies are relevant to key UK sectors such as manufacturing, aerospace and defence, and healthcare
- The studies cite over £1 billion of EPSRC funding – coupled with a similar level of funding from sources such as government, the EU and industry – demonstrating the high levels of additional investment EPSRC support can attract
- EPSRC investments are associated with over £60 billion of economic activity such as sales revenue and with over £16 billion of cost savings in the public and private sectors
- EPSRC investments are associated with the creation of 400 new spin out businesses, employing over 50,000 people and contributing £4 billion to the economy in terms of revenue

The duration of an hourly weather forecast predicting extreme UK conditions across the UK being developed by EPSRC-supported researchers at the universities of Bath and Exeter.

The project aims to help scientists and engineers understand how building designs react to different weather conditions.

Predicated weather conditions will be forecast until 2100, representing typical weather and events such as lightning strikes, rain, flooding and tornadoes.

These will be tested on more than 1,200 building designs to establish how external temperature, wind and sun cause issues for people living inside, such as over demand on heating and air decreases.
The ranking given to Professor Dame Wendy Hall in Computer Weekly magazine’s 25 Most Influential Women in UK IT list.

Dame Wendy is professor of computer science and Director of the EPSRC Centre for Doctoral Training in Web Science Innovation at the University of Southampton.

She is a founding director, with Tim Berners-Lee, Nigel Shadbolt and Daniel J Weitzner, of the Web Science Research Initiative, a long-term research collaboration between Southampton and MIT.

Search engine: Wendy Hall

90%:

The percentage of UK researchers across all disciplines who use research software in their work.

Today there are very few science areas left which do not rely on IT and thus software for the majority of their research.

To ensure consistency and sustainability, in 2010 EPSRC invested in the creation of the Software Sustainability Institute (SSI) which provides resources to support all engineering and physical science researchers, helping them generate ‘better research with better software’. To this end the SSI has published over 70 guides and top tips on everything related to software and research.

The SSI has conducted pioneering work to understand the research software community and to develop the resources, training and best practices that will allow this community to conduct better research.

Gregory Wilson, Executive Director of the international Software Carpentry Foundation, says: “We routinely point to the SSI as a model that others should imitate.”

Search engine: Software Sustainability Institute

How I spend my time

Annette Bramley, Lead, EPSRC Healthcare Technologies team

30% Working with my team on calls for research proposals.

It’s my team’s job to have its finger on the pulse of the latest research. We also work hard to ensure we target investments in areas most needed across the UK – by the NHS, for example. To this end, we invite academics to submit research proposals in areas identified as strategically important – such as antimicrobial resistance and sensing systems for healthcare. We do this through ‘calls’ announced on our web site, social media and elsewhere.

Because the research landscape shifts over time our investment strategy has to evolve with it. The conclusions from a recent review we conducted with academics and other partners will steer our investments for the next few years.

In addition to the vital research we target through calls, we invest in great research ideas through individual grant proposals from academics. This remains a core aspect of what we do.

20% Managing our investment portfolio.

EPSRC invests a significant proportion of its budget in healthcare technologies – from regenerative medicine to robotic surgery.

We seek peer review advice on every research proposal we receive. It’s EPSRC’s job to manage this process, and my responsibility to make funding decisions for healthcare technologies based on peer review advice. Excellence is the primary criterion, and the highest priority proposals are funded. Making funding decisions is a huge responsibility, and I’m conscious of the passion and effort that academics put in when preparing an application.

My team spend a lot of time visiting university groups whose research we have invested in. By understanding their progress, needs and concerns, we can get the best out of our investments and develop ideas for the future.

20% Working with charities, business and government.

I spend a lot of time talking with business, charities and other potential partners, to understand their challenges, and to illustrate to them how research in engineering and the physical sciences could help. I also identify opportunities for us to work together, and for them to work with the researchers we support, ensuring the research we invest in is relevant and can be taken up in healthcare applications.

20% Internal networking and management.

My team spend a lot of time on the road, so it’s important we take time to share the knowledge we’ve picked up. Healthcare Technologies span EPSRC’s remit – from biochemists developing new wound dressings, to mathematical modellers predicting the spread of disease. We work closely with colleagues across EPSRC, such as in the Manufacturing and ICT teams, sharing knowledge and looking at opportunities.

It’s also important for me to spend time developing the individuals within my team, so they can work well as a team together and build their careers.

10% Other UK Research Councils and Innovate UK.

It’s important for the Research Councils and funding organisations like Innovate UK to work together, particularly in a multidisciplinary applied subject like Healthcare Technologies. We’ve got a track record of working together on programmes of research and training like the UK Regenerative Medicine Platform and EPSRC Centres for Doctoral Training; and some of my time is spent managing these. We share ideas about future priorities and calls and discuss the peer review and funding of multidisciplinary proposals that cross research council boundaries. We’re all based in Swindon so it’s easy to meet up for coffee and talk shop.
Natural language
EPSRC-supported computer scientists at Heriot-Watt University and UCL (University College London) are working with the Met Office to develop a technology that translates vast and complex data, such as weather information, and turns it into an easily read, ‘naturally’ written prose, as if written by a human.

Crop logic
EPSRC-supported researchers at the University of Edinburgh have discovered how communities of beneficial bacteria form a waterproof coating on the roots of plants. This helps protect the plants from microbes that could potentially cause disease.

Breast cancer predictor
Research at London’s Institute of Cancer Research, co-supported by EPSRC, has led to the development of a new test which can predict the survival chances of women with breast cancer by analysing computerised images of ‘hotspots’ where there has been a fierce immune reaction to a tumour. The analysis is made possible through the use of statistical software previously used in criminology studies of crime hotspots.

Honed bones
EPSRC-supported research at The University of Manchester into disorders such as arthritis has led to new x-ray software which automatically outlines bones – saving thousands of hours of manual work.

Insects inspire hearing aid
An insect-inspired microphone that can tackle the problem of locating sounds, as well as eliminate background noise, could chart the future of modern-day hearing aid systems.

Sat-nav savvy
Grant Ferguson, 17, from East Dunbarton, has become the first person to pass a new-style UK driving test, which includes following directions on a sat-nav.
Quantum wasp
An EPSRC-supported team from Glasgow University have harnessed the strange power of quantum mechanics to create a digital image using fewer than one photon per pixel. Conventional digital cameras sample around 100,000 photons per pixel to make an image. The team used a technique known as quantum ghost imaging to create an image of a wasp wing using just 50,000 particles of light.

Search engine: Wasp wing quantum

Braking news
A new flywheel-based regenerative braking system has shown it can reduce the carbon footprint of rail travel on Britain’s diesel-powered trains, and can potentially increase capacity on crowded lines.

The system was co-developed by Artemis Intelligent Power, a company formed to commercialise EPSRC-supported research at the University of Edinburgh; Ricardo; and rail technology company Bombardier Transportation.

Search engine: Regenerative braking Artemis

Predicting harbour waves
University of East Anglia researchers have developed sophisticated computerised mathematical modelling techniques to predict the behaviour of harbour waves. The EPSRC-supported work has enabled coastal engineers to design and repair sea walls, and has been applied to a number of industrial projects, working with industrial partners.

Search engine: UEA EPSRC sea wall

3D-printed nerves
Scientists at the University of Sheffield have succeeded in using a 3D-printed device to help nerves damaged in traumatic incidents repair themselves.

The device, called a nerve guidance conduit, is a framework of tiny tubes which guide the damaged nerve ends towards each other so that they can repair naturally. Patients with nerve injuries can suffer complete loss of sensation in the damaged area, which can be extremely debilitating.

The EPSRC-supported team used the device to repair nerve damage in animal models and say the method could help treat many types of traumatic injury.

Search engine: Sheffield 3D nerve

Rolling road
A new ‘rolling road’ installed at the University of Bath will allow researchers to accurately analyse fuel efficiency and vehicle emissions. The road, known as a dynamometer, will aid work carried out at the university’s Centre for Low Emission Vehicle Research (CLEVeR).

EPSRC has invested £1.8 million in equipment funding for CLEVeR, with the University of Bath contributing £600,000.

CLEVeR will address many of the future research challenges associated with low and ultra-low carbon vehicles.

Search engine: Bath clever rolling
Patents up
The number of patents filed at the European Patent Office (EPO) by UK companies rose by 4.8 per cent in 2014 to 6,823, a sign of sustained investment in research and development activity according to the Intellectual Property law firm, Withers & Rogers. The increase is above the 1.2 per cent average across the 38 EPO member states, but falls behind China and the US, which respectively increased by 18.2 per cent and 6.8 per cent over 2013 figures.
Search engine: EPO Withers 4.8

Alternating antibiotics
An international research team, supported by EPSRC and led by Professor Robert Beardmore at the University of Exeter, have shown that using alternating doses of antibiotics might offer effective treatment against bacterial infection.
Crucially, alternating doses also reduces the risk of the bacteria becoming resistant to antibiotics, and so helps to maintain the long-term effectiveness of the drugs.
Search engine: Alternating antibiotics

Anti-glare coatings
EPSRC-supported researchers at Loughborough University have developed a multi-layer anti-reflection coating for glass surfaces, which reduces the sun’s reflection from photovoltaic panels while at the same time improving their efficiency.
Search engine: Loughborough anti-reflection

Graphene lightbulb
A graphene lightbulb with lower energy emissions, longer lifetime and lower manufacturing costs than for conventional bulbs has been developed through research at The University of Manchester’s National Graphene Institute, in which EPSRC has co-invested over £60 million.
A spin out company, Graphene Lighting PLC, has been formed to produce the lightbulb. Two-dimensional graphene is the strongest, most conductive material known to man, and was first isolated by EPSRC-supported researchers in 2004.
Search engine: Graphene lightbulb

Nanoneedles for self-repair
Scientists have developed tiny nanoneedles that have successfully prompted parts of the body to generate new blood vessels, in a trial in mice.
The international research team, co-led by Professor Molly Stevens, from Imperial College London, and Houston Methodist Research Institute in the USA, hope their nanoneedle technique, which delivers nucleic acids (our genetic building blocks) to a specific area, could ultimately help damaged organs and nerves to repair themselves and help transplanted organs to thrive.
Search engine: Imperial nanoneedles
Stitch and chips
Researchers at Nottingham Trent University have developed a way to embed clothes with tiny radio-frequency identification (RFID) data chips which cannot be seen in situ by the naked eye. The chips are embedded into yarns which are then woven to make fabric for clothing.

The chips can contain all the information which is usually communicated via barcode.

The patent-protected technology could lead to enhanced security at retail outlets, generating efficiencies in manufacturing and stocktaking, and allowing for clothes donated to charity to be tracked around the world.

Measuring one millimetre by 0.5 millimetre in size, when bought in bulk the chips can cost only a few pence each. The research was funded by the EPSRC-led RCUK Digital Economy programme.

Search engine: Invisible chips Nottingham

Flight plans
EPSRC has invested £2.8 million in a project to find ways to address the UK’s airport congestion without relying solely on new airport building and expansion.

Led by a team at Lancaster University, the work will create new algorithms and develop computer models based on huge quantities of data from individual airport and airline operations, air traffic management systems, airport authorities, civil aviation authorities, airlines and the travelling public.

Search engine: EPSRC Lancaster £2.8 million

Designs for life
Research by EPSRC-supported researchers at the University of Salford suggests that well-designed classrooms boost the academic performance of primary school children.

Search engine: EPSRC Salford classrooms

Doubling data speeds
UCL (University College London) researchers supported by EPSRC have demonstrated a new way to process fibre optic signals which could double the distance at which data travels error-free through transatlantic submarine cables.

Search engine: Fibre optic UCL transatlantic

Twisted light boosts net speed
Scientists at the universities of Bristol and Dundee are exploring a new way of transmitting data using ‘twisted’ light beams.

If successful, the technology will boost internet speed.

Search engine: Drinkwater twisted light
Kerry O’Donnelly Weaver, a student at the EPSRC Centre for Doctoral Training in Chemical Biology at Imperial College London, has been named by the Royal Society of Chemistry (RSC) as one of its 175 Faces of Chemistry, an initiative launched to mark the RSC’s 175th anniversary celebrations.

Kerry (pictured) shares top billing with luminaries such as Kevlar inventor Stephanie Kwolek; green chemistry pioneer Professor Sir Martyn Poliakoff; Marie Curie, who was the first person to be awarded the Nobel Prize in two different disciplines; and Alfred Nobel himself.

Together with fellow CDT student Angela de Manzano, Kerry created FungiAlert, an award-winning device for the early detection of plant disease, and also formed a company to bring the research to market.

Kerry says: “We wanted to design a product that would help to increase food production, focusing our idea on technology to help farmers reduce crop losses. If global crop losses were reduced by just one per cent, 24 million people would get to eat.”

The low-cost device is inserted into the soil and alerts the user to the risk of fungal spores before they infect the crop. “You can look at it as a smoke alarm for farmers – it alerts you to the problem before it destroys everything,” says Kerry.

“The development of FungiAlert has been an intense and steep learning curve, but this has only added to the enjoyment of running the company. We have truly loved being able to drive our project from idea and product development, to now having the opportunity to commercialise our invention.”

Kerry and Angela were awarded a prize of £20,000 as well as entrepreneurial training and support from Imperial Innovations, an organisation which creates, builds and invests in pioneering technologies developed from academic research.

Search engine: FungiAlert Kerry
Thinking small

Professors Miles Padgett and Lee Cronin, from the University of Glasgow, have joined forces once again to design, build, and test a new type of high resolution 3D printer system – capable of creating complex shapes at microscopic levels.

With investment from EPSRC and the Royal Society, the team have developed a low cost, flexible and modular system combining the Padgett Group’s expertise in optics with the Cronin Group’s multi-faceted complex chemical systems research. The result is a manufacturing system that uses stereo-lithography ‘light printing’ to rapidly build low-cost 3D laboratory devices and systems with micro-scale features.

Professor Cronin says: “3D printing is used widely in manufacturing industries, but has recently been taken up as a research tool. Commercially available 3D printers have already been used to cheaply fabricate devices with sub-millimetre features. However, as a research tool they can lack the flexibility needed in research laboratories.

“Our printer can print intricate geometries and allows entire, large-scale 3D devices to be fabricated without any intermediate processing steps and allow large area objects to be stitched together like sewing pieces of material.”

The teams are exploiting the innovation to develop 3D fluidic chemical laboratories for drug discovery and cell engineering. For more on 3D printing/Additive Manufacturing, turn to page 18.

Search engine: Padgett Cronin 3D

Crack shot

Dr Katherine Tant [pictured], an EPSRC-supported researcher at the University of Strathclyde, has developed a system that uses sound waves to spot potentially dangerous cracks in pipes, aircraft engines and nuclear power plants while ensuring they operate reliably and without compromising their integrity. The system also has potential applications in medical imaging and seismology.

Search engine: Tant Strathclyde cracks

Well equipped

Adrian Cox, from the University of Southampton, explains the thinking behind a new EPSRC-led equipment-sharing initiative that gives all researchers access to the vital kit they need for their work.

Adrian writes: Scientific equipment has always been an important requirement for many researchers. To make it easier for them to find the equipment they need, EPSRC is co-investing in a new equipment.data web portal.

As project manager, I have been working with a number of UK universities, supported by Research Councils UK (RCUK), to build a comprehensive open source web site that harmonises the equipment databases of individual institutions, creating a single national equipment sharing portal.

The site uses a relatively simple piece of programming technology that provides a ‘shop window’ for UK higher education equipment and facilities. Not only does it improve accessibility, it also encourages conversations with the aim of stimulating greater collaboration in the sector.

This simplicity has resulted in over 40 institutions now contributing with many more in the process of joining. There are now over 10,500 items of research equipment on the database.

The project’s success has already been recognised in a new report by Universities UK and is moving into a new phase, jointly funded by EPSRC and the Joint Information Systems Committee.

Search engine: Equipment data ac

She said it

“A lack of new preservation methods could be putting the future survival of many important artefacts in jeopardy.”

EPSRC-supported University of Cambridge scientist, Zarah Walsh, whose team have developed a safer, greener material for conserving waterlogged wooden artefacts, such as those recovered from Henry VIII’s ship Mary Rose, which could preserve important pieces of our history for future generations.

Search engine: Zarah Walsh artefacts
Sweet success

Twenty years of research by Professor Luet Wong at the Department of Chemistry, University of Oxford, is about to bear its first fruit in the form of a new and natural way to produce the elusive nootkatone molecule – a tiny compound with huge commercial clout.

Produced in miniscule amounts by plants such as grapefruit, nootkatone is a highly sought-after natural compound used in a host of products – from citrus-based soft drinks and confectionery to perfumes. The global market for flavours and fragrances is worth over US$22 billion.

The trouble is, nootkatone, which gives grapefruit its aroma and flavour, is created by some of the most complex reactions in biology. It takes around 400,000kg of grapefruit to produce 1kg of nootkatone, which puts it in the same price bracket as beluga caviar.

What’s more, grapefruit supply is affected by disease; and in hurricane years nootkatone can be impossible to source. Professor Wong turned to the orange tree for a solution. Oranges produce valencene, a readily obtained citrus extract very similar to nootkatone. However, while it’s relatively easy to convert valencene into nootkatone, existing methods use heavy metal catalysts and peroxides – toxic chemicals that require careful disposal. Professor Wong’s team used the techniques of synthetic biology to develop a natural enzymatic process to convert valencene into nootkatone, devising a technology that could be used to make a host of established products and potential new ones through a sustainable, biological process.

Professor Wong says: “Our technique currently uses our enzymes to transform commonly available natural extracts into our target flavour and fragrance compounds.

“The process requires little energy and generates almost no waste in contrast to conventional chemical processes. Valencene is also available from multiple sources; and supply is always plentiful. The real benefit is that the end product is completely natural.”

The EPSRC-supported research is being taken forward by spin out company, Oxford Biotrans.

The company has joined forces with De Monchy Aromatics, a UK-based supplier of aroma chemicals and essential oils, to manufacture and market nootkatone on a commercial scale. Crucially, the product complies with strict EU and Food Standards Agency guidelines.

This is just the start of the story. A pipeline of flavour/fragrance products is under development, and Oxford Biotrans’ technology has the potential to be used in the production of pharmaceuticals, agrochemicals and other specialty chemicals. It could even open the door to new fragrances, pharmaceuticals and natural insect repellents.

About Nootkatone

Nootkatone is a citrus ingredient characteristically associated with grapefruit. It has two main uses or potential uses:

As a flavour and fragrance ingredient

Nootkatone has a rare characteristic that enables it to last on skin and cloth for an extended period of time, making it highly valuable for personal care products.

For insect control Nootkatone is a type of terpene – highly-aromatic chemicals which deter animals that might eat the plant, and act as natural insect repellents. It is effective against a range of insect pests including ticks, bed bugs and mosquitoes.

Search engine: Nootkatone Wong
Bubble gun
Professor Tim Leighton, from the University of Southampton, has made his debut on BBC TV’s The One Show. Interviewed by Dr Michael Mosley, Professor Leighton demonstrated a close-to-production model of an extraordinary ultrasonic cleaning tool resembling the nozzle of a petrol pump that fits on to the end of an ordinary domestic tap, hose or industrial nozzle.

Described by One Show presenter Matt Baker as “unbelievable technology”, StarStream®, invented by Leighton (pictured left with the device) and his colleague Professor Peter Birkin, can enhance the cleaning power of a gentle stream of water from a household tap by up to 1,000 times. Numerous potential applications include cleaning products for hospital hygiene, dentistry, food preparation, manufacturing and the power industries.

The fundamental research for StarStream®, which will be produced commercially by Ultrawave Ltd, was supported by EPSRC; an early prototype featured in Pioneer 7 in 2012.

Search engine: StarStream

Seeing sound
Ever since musician Professor Eduardo Miranda met a patient with Locked-in Syndrome 11 years ago, he has been on a mission to create a way for the paralyzed to make music.

The EPSRC-supported Plymouth University researcher’s latest invention is the Brain Computer Music Interface which allows people to create music using just their eyes.

By connecting electrodes to the back of a person’s head, the system can tell where they are looking by monitoring brain activity. Flashing icons representing different snippets of music appear on screen and the user can then make a selection, just by staring at one. In real time, another musician plays an instrument according to the score generated from the user’s selections.

Search engine: Miranda music

He said it
“I can envisage this developing into a routine tool that your local surgery can use when you go for your annual check-up.”

UCL’s Professor Allen Goodship on EPSRC-supported research which, for the first time, has enabled detection of a genetic ‘brittle bone’ disease known as Osteogenesis Imperfecta by simply scanning a patient’s limbs.

Working with the Royal National Orthopaedic Hospital, the team’s technique uses spatially offset Raman Spectroscopy, developed at the Science and Technology Facilities Council’s Central Laser Facility, to shine a laser through the skin to analyse the chemistry of the underlying bone.

Search engine: Goodship brittle bone

Search engine: Wilkinson Prize

Professor Philip Nelson, Chief Executive of EPSRC, has been elected as the next Chair of the Research Councils UK (RCUK) Executive Group. Professor Nelson will take on the role from 1 October 2015.

Search engine: Nelson RCUK chair

An award-winning new dental bone graft material is set to bring a shot of innovation to the field of advanced dental surgery. The team behind the invention – Dr Niall Kent, from the EPSRC Frontier Engineering Centre for Nature Inspired Engineering at UCL (University College London), and Dr Alessia D’Onofrio – claim the material significantly improves on existing bone substitutes.

After winning first prize in a competition run by the Royal Academy of Engineering’s Enterprise Hub, the team hope to take the dental graft material, called Aerograft, to market.

Search engine: Aerograft

Professor Sir David Payne, Director of the EPSRC Optoelectronics Research Centre at the University of Southampton, has been listed in Debrett’s top 500 most influential people in Britain.

Search engine: David Payne

Helene Jones, a student at the EPSRC Centre for Doctoral Training in Advanced Composites for Innovation and Science at the University of Bristol, has designed and developed a hand-held laminating tool, known as the Dibber, for use in the layup of advanced composite components. The tool could be used by laminators to manufacture composite materials in industries such as aerospace.

Search engine: Dibber Helene

Two EPSRC-supported researchers, Dr Patrick Farrell from the University of Oxford, and Dr David Ham, from Imperial College London, are co-recipients, with Marie Rognes and Simon Funke, of the 2015 Wilkinson Prize, awarded every four years to honour outstanding contributions in the field of numerical software. The open source software is being used by scientists in areas such as understanding the movement of Antarctic ice sheets.

Search engine: Wilkinson Prize
Future build

Ester Coma-Bassas, an EPSRC-supported architect based at the Welsh School of Architecture, describes her latest work on the ground-breaking SOLCER energy positive house, the first in the UK capable of exporting more energy to the National Grid than it consumes.

Ester (pictured) says: “My research focuses on the concept of Buildings as Power Stations (BAPS), developed by SPECIFIC, an Innovation and Knowledge Centre in South Wales funded mainly through major investments from EPSRC, Innovate UK and the Welsh Government.

The project was led by Professor Phil Jones, from Cardiff University, and the house was designed and built by his team from the Welsh School of Architecture, as part of the Wales Low Carbon Research Institute’s SOLCER project, in partnership with SPECIFIC.

As the name suggests, Buildings as Power Stations is all about integrating and implementing energy systems into buildings to optimise energy self-sufficiency while providing a comfortable environment for its occupants.

The design of the house was a big challenge. Instead of taking a traditional approach where design and aesthetics are the most important thing, I needed to focus on the building’s performance, while ensuring affordability and replicability within the social housing sector. It was also important to develop new design, modelling and assessment software for architects to use, as most are unfamiliar with ‘performance-driven’ design and systems optimisation.

Building low carbon homes is generally perceived to be costly and difficult. We used affordable, off the shelf technologies available locally, and were able to integrate all systems into one design, resulting in an energy positive house.

The house, which will be monitored to assess its performance, is proof that it’s possible to produce low-cost, practical buildings that can generate, store and release their own renewable energy.”

Ester is funded by SPECIFIC through the EPSRC and the Welsh Government-funded Sêr Cymru Solar project. Partners include BASF, Tata Steel, Pilkington and many Welsh SMEs – enabling knowledge and skills transfer between local industries.

In 2015 Ester was named Young Achiever of the Year at the Construction Excellence in Wales Awards.

Search engine: SOLCER House
Ground effects

Dr Mike Brown, from the University of Dundee, is leading a research project to determine whether cheaper, more environmentally friendly, and more effective foundations can be developed for the offshore renewables industry.

The EPSRC-supported project is looking at the use of screw piles for offshore installations. Screw piles are foundations screwed into the ground and are widely used onshore, one example being to support motorway signs and gantries.

Currently, the main foundation solutions being considered for offshore wind installations are driven piles, large monopiles or concrete gravity-based structures. Driving of piles in large numbers offshore causes concerns over plant availability and impact on marine mammals. Screw piles are potentially very attractive as a lower cost and more environmentally friendly option.

Search engine: Dundee screw piles

New wave radio

Leo Laughlin, a doctoral student at the EPSRC Centre for Doctoral Training in Communications at the University of Bristol, has co-led the development of technology that enables a radio device to transmit and receive on the same channel at the same time.

Because only one channel is required for two-way communication, the device uses half as much of the radio spectrum compared to the current technology. Part of the evolution to 5G mobile, the research is also relevant to the design of the radio circuitry in current 3G and 4G cellular mobile devices.

Developed with MSc student Chunqing Zhang, Professor Mark Beach, Dr Kevin Morris, and industrial mentor, Dr John Haine at u-blox, the prototype design could offer a range of benefits. In wi-fi systems it would double the capacity of a wi-fi access point, allowing more users and higher data rates.

For mobile/cellular systems, capacity and data rates would be increased, or network operators would be able to provide the same total network capacity with fewer base station sites, leading to benefits in the cost and environmental impact of running the network. It could also allow for global roaming on 4G networks.

Leo says: “Until now there has been a fundamental unsolved problem with radio communication. “Since the radio spectrum is a limited resource, and with network operators paying billions of pounds to access the spectrum, solving this problem would bring us one step closer to the faster, cheaper and greener devices of our connected future.”

Search engine: Leo duplex

Utterly fabulous

UtterBerry, a wireless sensor for civil engineering instrumentation and monitoring developed by Heba Bevan

Search engine: Utterberry

Harry Bhadeshia, professor of metallurgy at the University of Cambridge, has been knighted in the 2015 Queen’s Birthday Honours List.

In a prolific career, supported throughout by EPSRC, Professor Sir Harry has made huge scientific contributions towards the invention of new iron alloys.

Search engine: Bhadeshia REF armour

Professor Dimitrios Nikolopoulos, from Queen’s University Belfast, is leading a project to create new computer software that will dramatically increase the ability of supercomputers to process masses of data at higher speeds than ever.

Professor Nikolopoulos says: “The new software, developed with University of Manchester researchers and a team from the Science and Technology Facilities Council’s Daresbury Laboratory, means that complex computing simulations which would take thousands of years on a desktop computer will be completed in a matter of hours.

“This research has the potential to give us insights into how to combat some of the biggest issues facing humanity at the moment.”

Search engine: SERT QUB

Dr Ali Salehi-Reyhani, a former EPSRC-supported doctoral student at Imperial College London’s Institute of Chemical Biology Centre for Doctoral Training, and Dr Duncan Casey, from the Institute of Chemical Biology, have developed a handheld, disposable research tool that instantly analyses mixtures such as groundwater or blood.

For many researchers, the device could make the need to transport samples back to the lab a thing of the past as analysis could take place in situ.

To bring the tool to market, the team set up a spin out company, anywhereHPLC, which has gone on to win awards, including the first prize of €20,000 at Climate-KIC UK’s Big Idea Bootcamp. Dr Reyhani is now a postdoctoral researcher at Imperial.

Search engine: anywhereHPLC
The layer game

Additive Manufacturing (AM) has come a long way in just over two decades, and is graduating into mainstream manufacturing. EPSRC is right at the heart of this revolution.

Additive Manufacturing is known by many names. Depending on the context, it is also referred to as Rapid Prototyping and 3D printing – the media-friendly technology that has seen the arrival of 3D chocolate printers and other consumer-based products. The common denominator to all these variants is the basic process – that of adding material to make a product, layer by layer.

Perhaps the most important report on UK manufacturing in recent years, the UK Government’s The Future of Manufacturing Foresight Report, cites Additive Manufacturing (AM), as a key enabling technology for high value manufacturing. It says AM’s benefits, such as smarter supply chains, digital manufacturing flexibility and design freedoms, will dramatically change the way components are designed, developed, manufactured and supplied. The report mentions AM no less than 35 times. AM is also identified by Innovate UK, the government’s innovation agency, in its High Value Manufacturing Strategy as one of the key competencies necessary for future manufacturing success. It is not a technology to ignore.

Why is this technology so important? Firstly it is cross-sectoral, with applications from aerospace and automotive parts, to medical devices, drugs and even food – there is now research into printing processed foods, as well as personalised high value products such as jewellery.

AM can also enable companies to reduce key business metrics – lead times, production times and material cost. The conditional tense is important; AM cannot match conventional processes such as milling for making particular, high volume parts with micron-level tolerances – yet.

But the AM R&D landscape is shifting fast, and the global momentum is accelerating, driven by breakthrough innovations such as new processes for rapid volume manufacture and exciting advances in new AM materials. In 2014, the market for all Additive Manufactured products and services worldwide grew at a compound annual growth rate of 35 per cent to US$4.1 billion, according to Wohlers Report 2015.

Making most of the UK research possible is EPSRC, which has invested in Additive Manufacturing research and training since the early 1990s, when the technology was emerging as a new research discipline.

In the early days, there were several distinct but related technologies, each with their own benefits and limitations: stereolithography, fused deposition modeling, laser sintering and 3D printing. Between them, they set the blueprint for much that followed. In the UK the vanguard of this technology was led mostly by EPSRC-supported engineers at the start of stellar academic careers, among them Chris Sutcliffe, Phill Dickens, Bill O’Neill, Bernard Hon and David Wimpenny.

Over 20 years later, many of these early pioneers continue to drive the R&D agenda in Additive Manufacturing; they have also nurtured the brightest new talent, including Professor Richard Hague, Professor Russ Harris and Professor Neil Hopkinson, who all started their careers as EPSRC-supported PhD students. All now lead their own departments.

Closing the circle, in 2015 Phill Dickens was awarded an EPSRC-funded Foresight Fellowship, a role designed to link work across the entire UK Additive Manufacturing landscape and to help make the technology more competitive with conventional manufacturing processes. He recently co-founded consultancy firm, Added Scientific, with colleagues from The University of Nottingham, including his former PhD student, Richard Hague (see page 28). 

(Continued on page 21)
Manually actuated prosthetic hand created via laser sintering.
Doctoral student Amanda Hüsler operating a contact angle measurement system.
The breadth and depth of Additive Manufacturing research in the UK is nationwide. From laser-based processes that improve post-process finishing of AM parts at Heriot-Watt University in Edinburgh to polymer laser sintering research at Exeter University, engineers and increasingly chemists and physicists are making breakthroughs on a swathe of AM processes all the time.

Factor in the myriad ways in which EPSRC-supported researchers are using Additive Manufacturing techniques to bring their research to fruition – from 3D-printed canine prosthetics to AM-generated concrete panels for large-scale buildings (see page 28) – and the nationwide picture becomes particularly healthy.

AM is also changing fast. “There is a continuing need for research in Additive Manufacturing, both in underpinning the knowledge gaps in the current commercial exploitation but also in the novel areas of new materials, new products, and new processes,” says Dr Brakspear. “It is increasingly important as an enabling tool for high value manufacturing – such as in the aerospace, healthcare and specialist industrial sectors.”

Long-term and consistent EPSRC-funded research is now helping engineers to overcome some of the significant hurdles for successful commercialisation of the technologies, such as low speed and product size limitations. This report reviews some of the primary AM research fields.

Turn up the volume

The most conventional Additive Manufacturing technique is laser sintering, a layer by layer powder-based process.

Laser sintering is mainly used to create very high quality nylon parts for use in industries such as aerospace. However, it is slow, and unsuitable for large production runs, causing AM pioneer Professor Neil Hopkinson to remark: “Conventional laser sintering is like painting a room with a biro – it’s just not a good way to do it quickly.”

In the early 2000s, together with his team at the EPSRC Innovative Manufacturing and Construction Research Centre (IMCRC) at Loughborough University, Neil Hopkinson and his team set about refining the process so that it could be applied to large-scale component manufacture. What they came up with was a revolutionary Additive Manufacturing technology, High Speed Sintering (HSS), that is set to change the way certain components are created using AM.

Similar to laser sintering but based on a print head and infrared system, HSS is capable of producing high volume production parts not possible using conventional laser sintering and can thus be applied to rapid large-scale component manufacture.

The invention dates back to 2003, when Professor Hopkinson successfully applied for an EPSRC grant to investigate a new manufacturing process.

Further EPSRC-funded projects followed, including one that enabled the IMCRC team to create personalised footwear using Additive Manufacturing.

The next breakthrough came in 2011 when, supported by a grant from the Higher Education Funding Council for England (HEFCE), the team built a new High Speed Sintering test machine from scratch.

(Continued from page 18)

Additive Manufacturing

Additive Manufacturing is radically different from conventional manufacturing processes such as machining, casting, forging and moulding. It forms objects by building up matter, layer by layer, rather than removing it. A high energy source, usually from a laser, is used to melt or fuse powders. The design of these components is developed using computer-generated 3D models and digital design data.

Paired with computer-aided design (CAD) software, this technique affords the creation of new types of object with unique material properties.

The fastest-growing areas for Additive Manufacturing include the medical and dental sectors, where it is being used to create customised prosthetics, implants, replacement tissues and intricate body parts, including blood vessels. Hearing aids and medical implants are already being customised rapidly for individual requirements and then produced by AM.

Additive Manufacturing has also been embraced in the aerospace sector, where it is being used to create low-weight, high strength components, among other applications.

AM: the benefits

- Greater design freedom
- No tooling
- Production numbers can be low
- Fast response to orders
- Combine parts – reduce assembly
- Customised products
- Makes it possible to manufacture in new locations/on site, reducing transport costs and carbon footprint
A stainless steel dome structure created via Selective Laser Melting.
The machine was completely designed using off-the-shelf technology and was subsequently patented by Neil Hopkinson and Dr Helen Thomas. In the same year, Loughborough University loaned the newly-built HSS machine to the University of Sheffield, which had the facilities and set up that would enable Professor Hopkinson, who also transferred to Sheffield, to prove to industry that the technology can compete with traditional manufacturing techniques and laser sintering.

Work proceeded apace, supported by investment from Innovate UK and with project partners including BAE Systems, Cobham, British printing group Xaar, Unilever and Sebastian Conran Design. In just one year, Loughborough University, which holds the intellectual property to the technology, had signed its first licencing deal.

In 2015 the project team proved their machine can build plastic parts up to three times larger and 100 times faster than comparable Additive Manufacturing machines, and is capable of challenging conventional injection moulding for high volume production parts.

David Chapman, who is responsible for developing Xaar’s AM business, says: “This is potentially industry-changing as it will increasingly allow companies to provide products on demand.”

In 2015, EPSRC invested £1 million in a new project to enable the Sheffield team to build a large High Speed Sintering machine capable of working with a number of different materials. The technology is being licensed to industrial machine manufacturers on a non-exclusive basis, and Loughborough University is actively seeking new licensees, with new machines expected on the market from 2017/18.

Professor Hopkinson says: “I believe that in 10 years’ time producing volumes of over a million using Additive Manufacturing will be commonplace.”

Head of Intellectual Property Commercialisation at Loughborough University, Dr Joanne Whitaker, who has helped to drive the development of HSS technology, says: “Credit for this breakthrough must go to Loughborough and Sheffield universities themselves, as the technology could not have been developed so quickly or smoothly without their long-term collaboration.”

AM goes large

Speed and physical size have been traditional limitations of Additive Manufacturing. But Professor Iain Todd, based at the University of Sheffield’s Department of Materials Science and Engineering, working with project partners Rolls-Royce and the Manufacturing Technology Centre, has succeeded in fabricating an unusually large component, a 1.5 meter-diameter titanium front bearing housing for the Rolls-Royce Trent XWB-97 engine, the power-plant for the Airbus A380.

The project, borne out of Professor Todd’s EPSRC-supported research, marks the first time Additive Layer Manufacturing has been used to produce such a significant load-bearing component, rather than the conventional processes of casting or forging.

Neil Mantle, Head of the Rolls-Royce Centre of Competence – Additive Layer Manufacturing, says: “Without the early support from EPSRC, Iain Todd and his researchers at the University of Sheffield and follow-on support from Innovate UK and the Manufacturing Technology Centre...

(Continued from page 21)

(Continued on next page)
in Ansty, it would have taken a
significantly longer time to develop
the technology needed to create such
challenging components.”

The significance of this project cannot
be underestimated; it marks the
successful application of a ‘disruptive’
technology in a highly regulated
industry where all components are
tested to destruction, and where
confidence in processes and part
integrity must be absolute.

Later in 2015, one of the most
prominent names in aerospace, GE
Aviation, is introducing a fuel nozzle
built using AM into its GE LEAP 56
engine. It took 15 years to develop,
test and approve.

**Multifunctional materials**

Additive Manufacturing is a technology
that is as much about materials
science and chemistry as it is
engineering and machine building.

At The University of Nottingham,
which hosts the EPSRC Centre for
Innovative Manufacturing in Additive
Manufacturing, in partnership with
Loughborough University, Professor
Richard Hague and colleagues are
using Additive Manufacturing to
create a range of multi-material,
multifunctional products.

Professor Hague says: “Conventionally,
Additive Manufacturing uses single
materials, a polymer or a metal, which
are fused together with a laser. You
can create interwoven geometries but
they’re still passive.

“Our research involves activating
these materials and making them
functional. So, rather than make
a component, you make the whole
system. In the future this might mean
that, rather than print a part and
assemble the electronics, the whole
object could be built in one print.”

This exciting research paves the way
for a host of different ‘embedded’
products including sensors,
batteries, solar cells, LED screens,
and antennae. They could also
revolutionise healthcare.

Working with the university’s School
of Pharmacy, Professor Hague’s group
is researching new mechanisms
combining Additive Manufacturing and
drug delivery, including personalised
dosages and drug implants
customised for individual patients.

University of Nottingham bio-engineer
Professor Kevin Shakesheff, an
EPSRC RISE Leader, has already
co-developed 3D scaffolds that can
be injected into the body without the
need for surgery, and which leave no
solvents or toxic by-products. He has
also demonstrated how the technology
could be used to print human organs.

Professor Shakesheff says: “We know
how to reprogram cells to become
stem cells; we have technologies such
as 3D printing and advanced materials
that can build those cells into organ
structures, and we understand a lot of
the cell and tissue biology that allows
tissues to form and repair.

“I can’t see any fundamental barrier
that will stop future generations being
able to grow a personalised organ.”

**The importance of lasers**

The laser is a crucial part of many
Additive Manufacturing processes,
providing a highly localised and
controllable source of heat that can
be translated at high speeds; indeed
metal powder-based AM processes
almost exclusively use a laser to melt and fuse the powder.

Lasers also have an important role to play in post-processing of AM parts, both for shock peening (a process to increase the resistance of materials to surface-related failures) and for machining/polishing; these aspects are both being investigated within the EPSRC-funded Centre for Innovative Manufacturing in Laser-based Production Processes (CIM-Laser), together with a focus on laser-powder interaction fundamentals to improve process consistency.

**WAAM**

In addition to this work, CIM-Laser is using its research to fully understand a remarkable new Wire+Arc Additive Manufacturing (WAAM) technique, developed by Professor Stewart Williams at Cranfield University, to reduce variation in the process, and increase consistency and reliability.

Dr Filomeno Martina, a Research Fellow in Additive Manufacturing at Cranfield, who joined the academic staff after completing his PhD in AM at the university, supervised by Stewart Williams, says: “Wire+Arc is different from other AM processes in that it utilises arc welding tools combined with wire feeding.

“This enables much higher deposition rates and potentially limitless part size. In fact, we have been able to manufacture parts around three metres in length.

“Thanks to low capital and material costs, this can be done in a much cheaper way, too. Compared to machining from solid, WAAM is typically 50 per cent to 60 per cent cheaper.”

In a remarkable breakthrough, Professor Williams’ Wire+Arc process has already been used to make a 1.2 metre titanium part of an aircraft wing – one of the largest metal parts produced using Additive Manufacturing.

Designed by BAE Systems engineers, the component forms a main structural element of an aircraft wing structure. It took just 37 hours to build from a digital model. Previously this process would have taken weeks. The team are working with BAE Systems to improve the process and to develop additional parts and processes that can be applied commercially.

**AM and the UK economy**

Until recently, less attention had been focused on the non-technical side of Additive Manufacturing.

Thanks to support from EPSRC, Dr Tim Minshall and a team at the Institute for Manufacturing at the University of Cambridge have researched the linkages between the technical, economic and policy issues affecting the diffusion of Additive Manufacturing technologies.

“What’s particularly helpful is the support and openness of EPSRC-funded colleagues with deep knowledge of the technical aspects of Additive Manufacturing, coupled with the strong engagement of industry and policy partners,” says Dr Minshall.

“With this support, we can do several things. We’ll be able to examine the current and potential disruptions to business models resulting from the application of AM technologies in a wide range of sectors; we’ll have the chance to support multidisciplinary research that explores the impact of AM technologies on the re-distribution of manufacturing activities; and we’ll be able to assist with the development of a national strategy for Additive Manufacturing.”

**A National Strategy for Additive Manufacturing**

The UK is amongst the global leaders in both the development of knowledge and successful application of Additive Manufacturing/3D printing technology, but there are gaps in the industrial ecosystem that need to be addressed if the UK is to capture value from the opportunities presented.

To respond to these issues, a steering group of experts from industry, academia and government, including Rolls-Royce, GKN Aerospace and Innovate UK, is developing a new UK National Strategy for Additive Manufacturing, due to be published in 2016, to help accelerate the industrialisation of this radical new way of making things.

Robin Wilson, Innovate UK’s Lead Technologist for High Value Manufacturing, says: “The creation of a supporting infrastructure in the UK is essential in order to provide companies with the necessary design and process knowledge, skills, materials data and risk management information.

“The steering group has enabled us to engage with a wide group of over 150 stakeholders, to identify the key barriers and enablers.

(Continued on next page)
Additive manufacturing – a personal journey

Additive Manufacturing/3D printing has its roots in the development of Rapid Prototyping during the 1980s and 90s. RP as it was known, was considered a great step in the reduction of lead times for a number of products, effectively allowing prototype parts and concepts to be produced in a matter of hours rather than weeks and months.

EPSRC was quick to invest in blue-skies research in this new technology. The potential benefits were obvious, but the research was in its infancy, and commercial exploitation was clearly a long way down the road. Over the decades, EPSRC support has been constant, both for research and PhD training.

Enabling technology: Worldwide, research groups throughout the 90s began to explore the uses of 3D printing technology. At that time this was principally: stereolithography; fused deposition modeling; laser sintering and 3D printing – distinct technologies with their own benefits and limitations.

Development continued apace, with new software tools and the continued improvement of materials and processes, to enable Rapid Prototyping to be more relevant to customers. This was embodied in the provision of more robust parts for test of form and fit and even the advent of Rapid Tooling; utilising the use of layer-by-layer technology to produce tooling for injection moulding.

My team, which included Richard Hague, an EPSRC-supported industrial CASE student, continued to research and develop the technology at The University of Nottingham and started to show its potential to a range of sectors and industries through patents.

A new era: As the 2000s began, using layer-by-layer techniques to produce actual products became a logical next step.

Research began into the use of prior RP technologies as manufacturing tools, with those skilled in the art beginning to realise the fundamental design and product potential that could be achieved.

During the 2000s new technology came on stream with metallic systems becoming available. My research group was growing, and in the mid-2000s Richard took over as head as I became the Director of the EPSRC Innovative Manufacturing and Construction Research Centre and Associate Dean of Research.

Concentration: Recognising the move to manufacturing as being one that would massively expand the potential application of AM and 3D Printing, Richard along with colleagues, Ricky Wildman, Ian Ashcroft and Chris Tuck, began to explore multi-faceted and multidisciplinary projects in order to show the importance of coupling design, materials and process together with multifunctional structures. This allowed strategic partners and alliances to benefit from the entire offering that AM was beginning to present as a manufacturing solution for high value, custom and bespoke products. It was clear that 3D printing was not just about the machines.

An explosion: From 2011, the advent of 3D printing and the explosion of consumer 3D printing systems has brought about a significant degree of interest in the field, but importantly, a significant amount of misinformation.

To tackle this problem, Richard, Ricky, Ian, Chris and myself formed a spin out company, Added Scientific, to allow research partners to cut through the hype and focus on what added benefits they could realise from this exciting technology, whether their interest be in how to implement it or in specifics such as new materials, processes and design requirements.

Professor Phill Dickens
The EPSRC Centre for Innovative Manufacturing in Additive Manufacturing, led by The University of Nottingham in partnership with Loughborough University and industrial partners, is a nucleus of research activity focused on developing next-generation multifunctional AM technology—combining multiple materials and functions for complex electrical, optical and structural properties in a single manufacturing process.

3DP-RDM: The adoption of Additive Manufacturing is likely to lead to dramatic transformations as companies simplify their supply chains and adopt novel business models.

The 3D Printing Enabled Re-distributed Manufacturing (3DP-RDM) network, led by the University of Cambridge, brings together academic, industry and policy experts to explore interconnected technological, commercial and policy issues surrounding AM, including skills, standardisation, process control, recyclability and the protection of intellectual property.

The EPSRC Centre for Doctoral Training in Additive Manufacturing and 3D Printing, led by The University of Nottingham, in partnership with Loughborough, Newcastle and Liverpool universities, is training over 40 doctoral students to become the next generation of leaders, scientists and engineers in this diverse and multidisciplinary field.

Each PhD project has a specific link to an industrial partner who can see the potential benefits of Additive Manufacturing technology to their business.

The number of EPSRC investments in Additive Manufacturing-related research projects

46

The number of research organisations collaborating with EPSRC on Additive Manufacturing-related research

29

The amount invested by EPSRC in Additive Manufacturing-related research

£44m

Foresight Fellowships: In 2013 the UK Government published The Future of Manufacturing Foresight Report which looked at the long-term picture for the UK manufacturing sector up to 2050, investigating global trends and drivers of change.

Additive Manufacturing was identified as an underpinning technology that will enable developments in other scientific areas and will cut across all sectors. EPSRC has funded two Fellowships whose recipients will respond to the AM-related technology challenges identified through innovative research projects and key agenda-setting activities.

Design the Future: This initiative explores adventurous new approaches to engineering design through diverse feasibility projects.

A number of these projects focus on Additive Manufacturing: developing new design tools, challenging designer preconceptions and engaging the end-user in the design process.

£28m

Contributed by industry for EPSRC-supported Additive Manufacturing research projects

Novel Manufacturing Instrumentation: EPSRC has invested in a number of projects to develop new manufacturing instrumentation; improve existing processes and develop new capabilities in Additive Manufacturing.

Researchers at the University of Sheffield are creating a High Speed Sintering machine capable of high part throughput and multi-materials (see page 23), and a group at Keele University are developing next-generation 3D printers which can chemically pattern during production. If successful, this technology could have profound impact on medical device and electronics manufacture.
Adding value

From canine implants to DIY 3D printers, EPSRC-supported researchers are using Additive Manufacturing techniques to bring a host of diverse projects to fruition. They have also pioneered new AM technologies.

Metal masters

Researchers at the University of Liverpool have formed a company, Fusion Implants, to manufacture high-performance veterinary implants from titanium using Additive Manufacturing technology.

The company’s patented technology builds on long-term research led by Dr Chris Sutcliffe that allows the mass manufacture of porous titanium material, enabling the animal’s bone to grow into the implant, forming a natural bond and improving performance considerably.

The company’s latest product, a surgical implant for use in canine knee reconstructions, is already being sold to veterinary practices.

Dr Sutcliffe’s AM research dates from the early 2000s, and through long-term collaboration with Renishaw, the UK’s only manufacturer of metal Additive Manufacturing systems.

One of the first EPSRC investments was led by Professor Bill O’Neill at the University of Liverpool, to develop metallic object construction using a specific Additive Manufacturing technique.

Further EPSRC-supported investments followed, with Dr Sutcliffe driving new research in areas such as selective laser melting (SLM) technology.

Sutcliffe used an EPSRC grant, part-funded by medical devices company Stryker, to buy an advanced German Additive Manufacturing machine to develop new, better SLM processes for metals including titanium.

The confidence and expertise the team developed when mastering this technology resulted in MTT Technologies commercialising the research and designing, building and selling a machine. The titanium components developed included porous medical devices that are now used to make primary hip and knee joints by one of the largest implant companies in the world. “When we started to exploit our EPSRC-sponsored research ours was one of 20 technologies from all around the globe,” says Dr Sutcliffe. “Over time we became the primary technology they invested in.”

MTT was acquired by Renishaw in 2011 and forms the backbone of its global AM business. Today, Chris Sutcliffe is Renishaw’s R&D director, a role he combines with academic research at the University of Liverpool.

Renishaw’s AM business is going from strength to strength, and the company recently expanded its Additive Manufacturing Centre into a new 90,000sq ft premises in Stone, Staffordshire.

Group Engineering Director Geoff McFarland says: “Working with EPSRC, particularly through its Centres for Innovative Manufacturing and Centres for Doctoral Training, allows us to take our pipedreams and talk to experts about how they might be applicable to the real world. The hit rate is surprisingly high.”

The collaboration is two-way, with Renishaw staff often directly involved in EPSRC projects. The company also has a track record of hiring graduates from the EPSRC Centre for Doctoral Training in Additive Manufacturing and 3D Printing who have worked on the company’s projects.

Dr Sutcliffe says: “Our lab at Liverpool is one of the largest in the UK, and we have plenty of experience and many firsts. “We built the first Additive Manufacturing machine in the UK; helped develop alongside Renishaw the first UK-manufactured metal 3D printer; and invented and patented technology that has led directly to the commercial implantation of thousands of series-produced advanced 3D-printed implants.”

Concrete evidence

A team of EPSRC-sponsored engineers at Loughborough University, co-led by Dr Richard Buswell and Professor Simon Austin, developed an innovative 3D printing technique to create customised panels for large-scale buildings. The process was developed at the EPSRC Innovative Manufacturing and Construction Research Centre at Loughborough.

The team have since developed 3D concrete printers fitted to a gantry and a robotic arm. The printer can make things which cannot be manufactured by conventional processes such as complex structural components, curved cladding panels and other architectural features.

The team are collaborating with industry partners to commercialise the process, which could capture a significant share of the US$450 billion global concrete and cement market.
RepRap revolution

In 2005, Dr Adrian Bowyer, an engineering researcher working with the University of Bath’s EPSRC-funded Innovative Design and Manufacturing Research Centre, was awarded a £20,000 EPSRC grant to build a 3D printer capable of replicating itself. The result was RepRap, a remarkable DIY 3D printer that, through the development of open source software, paved the way for a global community of people who could use RepRap machines to develop their own products. By 2007, Bowyer had established a global ‘virtual’ team of over 30 volunteer collaborators, from software developers to designers and mechanical engineers. In 2009, three RepRap volunteers from New York, Zach Smith, Bre Pettis and Adam Mayer, used the knowledge from the project to set up their own company, MakerBot – supported by a US$25,000 loan from Adrian Bowyer. Four years later, the company was bought by Stratasys, one of the world’s largest 3D printing companies, for US$403 million.

The global DIY 3D printing market continues to grow exponentially, much of which can be attributed to one man’s vision and an EPSRC investment of £20,000.

Sole traders

Scientists at the University of Salford, working with East Lancashire Hospitals NHS Trust and Burnley company FDM Solutions, with support from EPSRC and Innovate UK, are developing made-to-measure insoles for the NHS using AM technologies.

Hospitals will be able to scan a patient’s foot shape and e-mail it to the company, which will then 3D-print and deliver insoles to the exact specification within 48 hours.

The process could revolutionise the way the NHS buys orthotics and other products. It could also improve quality and reduce consultants’ time, and transform supply chains in the NHS and other industries.
The Centre uses eye-tracking technology during robot operation to monitor operator points of attention.
i-Robot

The EPSRC Centre for Innovative Manufacturing in Intelligent Automation is working at the cutting edge of the human/machine interface. Manufacturing will never be the same again – and the UK is in the front row.

BMW and Rolls-Royce are doing it. Airbus has to do it. Germany is spending vast amounts of money on it. And a growing number of smaller manufacturing companies in Britain are now building a business case for automating manufacturing, using robots and other system components to augment labour deployed on complex assembly tasks to improve productivity and competitiveness.

Machines are more accurate and powerful than humans, they maintain quality control over time and they do not get sick (or they need less ‘downtime’ than humans).

Automated Manufacturing is crucial to the future of a competitive manufacturing economy in the UK, says Professor Mike Jackson, Director of the EPSRC Centre for Innovative Manufacturing in Intelligent Automation at Loughborough University. The Centre was established in 2011 to investigate automation applications in industry and to harness UK expertise in this field.

Partnered with Cranfield University, the Manufacturing Technology Centre at Loughborough and also with industry, the Centre’s research aims to understand the level of human skill applied to difficult industrial manufacturing tasks and brings together a unique blend of human factors and mechatronics, which combines electronic and mechanical engineering. The Centre also studies when automation is financially viable, a big issue for smaller firms.

Radical improvements

Professor Jackson says: “We are working to develop automated manufacturing processes previously considered too difficult to automate. Many of these technologies will enhance and maximise the use of the existing skill sets within the workforce rather than replace them.

“We aim to radically improve the effectiveness of manufacturing operations in key areas of UK industry, working to meet the needs both of large companies and manufacturing supply chains.”

Factory automation is high on the agenda of global manufacturers such as Airbus, Rolls-Royce and Control and Data Services, which are driven by a definable business need to speed up high value asset manufacture without losing quality. It comes as no surprise that these companies are the Centre’s key industrial partners.

Robots have transformed productivity in the automotive sector, and their application in the UK is one of the main reasons for the relatively recent resurgent fortunes of Britain’s vehicle manufacturing industry – the UK is now a net exporter of cars. The aircraft companies want to emulate parts of this; the EPSRC Centre is there to expedite research so that these companies can implement new practices quickly – making it one of the EPSRC Centres for Innovative Manufacturing with the biggest measurable impact on industry.

(Continued on next page)
Professor Jackson says: “Through our EPSRC-funded outreach programme, SMEs are benefiting from access to the sort of research they wouldn’t normally get.”

Musical instrument maker, Percussion Plus, is a case in point. The company’s Managing Director, Paul Cobbett, says: “Being involved with the robotics team at Loughborough and Cranfield universities has been an enlightening experience, turning a seemingly impossible task, of winding our percussion beaters, into what would appear to be a practical possibility. “The team have been informative throughout the project; they are an amazing, eclectic group of people.”

While the Centre’s research is not relevant to fully automated processes, such as high volume food manufacture, it comes into its own in the combination areas – where humans interact with robots.

“We look at the human skill in a manufacturing task, then we assess the degree of difficulty in automating that task,” says Professor Jackson.

“We then devise an intelligent solution where there is likely to be a person doing tasks that a human can perform better than a robot, and a robot doing tasks a human is not especially good at. Increasingly this involves a high degree of machine autonomy.

“For example, the robot can adapt by measuring things in the environment, and with the appropriate computer code written by our system designers, it can react, often in anticipation of expected changes.”

Professor Phillip Webb, EPSRC Centre Deputy Director at Cranfield University, says: “Where people and robots mix together you get the best of both worlds – the skill and adaptability of humans, and the brute force and accuracy of industrial robots.

“Naturally, when people work closely with automation, health and safety and regulatory compliance are priorities. “A key aspect of what we do is investigate how humans work with machines, and we look at the consequences of these interactions on productivity, safety and human welfare.”

The Centre is exploring what it calls ubiquitous safety, where conventional guarding is removed and replaced by sensory systems that continuously map the presence and location of operators. The technology adjusts the degree of collaborative automation according to the vicinity of the operators.
Being able to work closely with automation systems that are inherently safe should improve the efficiency of the people operating the machinery and increase functionality/reduce the cost of automation.

Challenges include the development of robust and effective monitoring systems and working through the processes for regulatory health and safety approval. The EPSRC Centre is driving this work forward, in the belief that this will be a cornerstone of future UK manufacturing automation.

**Catapult alignment**

Manufacturing, by definition, is all about the end product, and the Centre is an excellent example of how EPSRC-funded research dovetails with Innovate UK’s network of Catapults – technology and innovation centres where UK businesses, scientists and engineers work side by side on research and development, taking products to commercial viability.

The Centre works closely with the Manufacturing Technology Centre (MTC), a Catapult Centre based at Ansty near Coventry, which helps companies develop prototypes at an advanced stage of technological readiness. In turn, the EPSRC Centre provides state-of-the-art facilities, cutting-edge research – and the talent to match.

Professor Ken Young, the MTC’s Technology Director, says: "The EPSRC Centre creates a unique supply chain for talent in intelligent automation. These skills are not available to us from anywhere else and will form a pivotal part of our future workforce."

Professor Jackson says: "We are part of a unique pipeline from discovery through to industrial deployment. Work initiated within an academic environment can be developed through an established innovation pathway, via the Manufacturing Technology Centre and Cranfield partners, to reach major industrial companies with the funding and commitment to exploit the results. This pipeline is bi-directional to create feedback on advanced industrial challenges to the EPSRC Centre for the next generation of EPSRC-supported research projects. This continuous bi-directional pipeline is central to our success and value, and unique within the UK.

"By the end of 2016, 15 projects we have initiated will be progressed to TRL 4+ [an advanced state of technological readiness] and supported for development by industry. "Industrial partners in this research have committed £1 million. They have high confidence that funds invested through us will lead to a significant positive financial return through new innovations in production processes."

Richard Mellor, Chief of Manufacturing Technology Operations, Controls and Data Services, Rolls-Royce Group, says: "Working with the EPSRC Centre for Innovative Manufacturing in Intelligent Automation has facilitated some very positive collaborations. "The Centre has quickly built a knowledgeable team able to help with real challenges. Its strong alignment with the Intelligent Automation theme at the Manufacturing Technology Centre provides a strong route to exploitation."
Hawking, drinking and bits of string

Theoretical physicist, Professor Jerome Gauntlett, from Imperial College London, who was the scientific consultant on the Oscar-winning Stephen Hawking film, *The Theory of Everything*, describes his days as a PhD student in Hawking’s Relativity Group, the power of string theory – and why he could have become a winemaker instead of one of Britain’s leading theoretical scientists.

I had a rather unusual education growing up in Australia, first attending a Montessori School for my primary education and then, for some of my secondary education, a small community school that my parents helped to set up.

I had always liked maths and astronomy but in a somewhat haphazard way; it wasn’t until I went to the University of Western Australia, where I did a joint maths/physics degree, that I realised that, in addition to playing football, my passion was theoretical physics.

I was awarded a Commonwealth Scholarship, which allowed me to do my postgraduate study in theoretical physics at the Department of Applied Mathematics and Theoretical Physics (DAMTP) at the University of Cambridge. From then on I have just followed my nose, taking postdoc positions in Chicago and at CALTECH before returning to the UK.

**The biggest outstanding challenge** in fundamental theoretical physics is to find a consistent framework that unifies Einstein’s theory of General Relativity with the Standard Model of Particle Physics. Looking for such a theory of quantum gravity has challenged theoreticians for decades. I have mostly worked on string theory, or M-theory as it now also called, which remains a promising approach for achieving this ambitious goal.

One of the most remarkable aspects of string theory is that it has produced enormously rich new mathematical ideas as well as deep insights into other aspects of theoretical physics such as black holes and quantum field theory.

There has been an extremely fruitful interaction between theoretical physicists and pure mathematicians to develop our current understanding of the subject.

It seems certain that there are deeper mathematical structures still waiting to be discovered whose development will be essential in elucidating exactly what string theory is. I am currently involved in an EPSRC Programme Grant pursuing this goal.

I have also recently been pioneering new techniques arising from string theory, involving black holes, which may lead to new ways to think about real-world condensed matter systems, such as high temperature superconductors. It has been very stimulating interacting and collaborating with condensed matter physicists on this interdisciplinary endeavour.

**One aspect of theoretical physics** that is not always emphasised is that it is a very social and collaborative effort. Over the course of my career I have been very fortunate to have worked with many talented and creative collaborators.

*(Continued on next page)*
I joined Stephen Hawking’s Relativity Group as a PhD student in 1987. My supervisor was Professor Paul Townsend who is an inspirational scientist and mentor. I worked on membranes and 11-dimensional supergravity, which at the time were considered to be almost heretical topics. This all changed in the mid-90s when these and other ideas were appreciated to be key for developing a deeper understanding of the structure of string theory.

My first conversation with Stephen was when I was in the tea room commiserating with another student over our hangovers. Stephen wheeled up to us and started typing while we went deathly silent. He then gave me a lifelong valuable piece of advice: “Don’t ever get drunk on port”. My now wife, Professor Fay Dowker, was Stephen’s PhD student at the time and this provided another contact with Stephen.

The scientific atmosphere was incredibly stimulating. Important progress was happening in several different directions led by Stephen, other scientists at DAMTP, as well as the vast retinue of eminent international visitors. The impact of Stephen’s best-selling book, A Brief History of Time, was just beginning and it was fascinating to see Stephen’s celebrity life start to take off in earnest. I recall a particularly memorable Christmas party with Stephen, several members of the Relativity Group and Shirley MacLaine trying to discuss “love energy”.

I became involved in The Theory of Everything film when a colleague at Imperial, Professor Stephen Warren, who knew someone working on the film’s art production, made the connection that saw me being invited to work on the film as the ‘Theoretical Physics Consultant’. There were several aspects of my involvement, including providing various input about the scientific content of the script. There are many different kinds of films that you can make about Stephen and this is just one of them; while I think it is a very good film, it is certainly not a scientific documentary. That being said it does touch on many of Stephen’s major achievements.

There is a scene in the film when Stephen is given 10 hard questions to answer. To demonstrate [in a very stylised way] how clever Stephen is, he starts working on them a couple of hours before the deadline and then ends up answering nine of the questions. I had to write up 10 reasonable questions and model answers for this scene. I was slightly disappointed that you can’t quite see the questions in the film, as the toughest was one which would be very simple for a graduate student to answer today but very hard then! I also wrote up most of the equations on the blackboards in various scenes and so they should be correct!

I enjoyed meeting and talking with Eddie Redmayne, the actor who won an Oscar for his role as Stephen in the film. He was keen to get a crash course in black hole physics and he was also very interested in discussing some details about Stephen’s gestures and movements. He did a phenomenal job capturing Stephen in the film.

There will always be very talented young scientists drawn to understanding the fundamental laws of Nature but I think the career path is getting more difficult because of the increasing pressure on securing funding for projects with short-term impact.

The support I have received from EPSRC, which includes both an Advanced and a Senior Fellowship, has been very important in my career and I am very grateful. Government investment in research in blue-skies fundamental sciences is critically important. I am concerned that the ‘Impact agenda’ puts such support under threat. History has repeatedly demonstrated that progress in science, and also in technology, is very hard to predict. The biggest developments often come from completely unexpected areas. If 19th century funding bodies were seeking to improve communications, they might have entertained the idea of investing in breeding programmes to make pigeons fly faster and to have increased endurance, rather than support James Clerk Maxwell’s esoteric ideas on electricity and magnetism!
Understanding the fundamental laws of Nature is one of humanity’s greatest cultural achievements, and I believe that everyone should have access to this knowledge. Outreach events are one way to achieve this, and I regularly give public talks and also talks at schools, both secondary and primary.

Around the time *The Theory of Everything* was released I gave several science talks titled A Brief History of the Science of Stephen Hawking. This provided a nice complement to the film, which concentrates on Stephen’s personal story. One of these was an ‘adults only’ event at the Science Museum; it was wonderful to see how much enthusiasm there is for science among young adults.

I think one day there will be a Theory of Everything in the sense of a consistent unification of the Standard Model and General Relativity. The main guiding principle at our disposal at the moment is theoretical consistency but one can hope that there will also be significant experimental input in the future. It is less clear, though, whether such a unification would be the final word concerning the fundamental laws of Nature.

If I hadn’t become an academic I might now be a winemaker. I did not get a postdoc position the first time I applied – perhaps due to the fact that my PhD was focused on topics which were unfashionable at the time. If I had also been unsuccessful the second time around I would have gone back to Australia and, at least to begin with, would have helped my parents make wine on their vineyard.

**I wrote up most of the equations on the blackboards in the film’s various scenes**

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**Almost) The Theory of Everything in 450 words**

The two cornerstones of theoretical physics are Quantum Theory and Einstein’s Theory of General Relativity (our theory of gravity).

Quantum mechanics describes the physics of the really small: atoms, electrons, protons and all of the particles observed when these particles are smashed into each other at very high energies in particle accelerators. It is a very weird world, in which particles sometimes behave like waves and waves sometimes behave like particles. But the weirdness is really there, and has been tested to incredible precision.

Three of the four known forces in the universe are quantum mechanical in nature: electromagnetic, weak nuclear and strong nuclear. These forces are described by the Standard Model of particle physics. The fourth force, the phenomenon we know as gravity, on the other hand, is quite different.

Einstein’s Theory of General Relativity explains how the curvature of spacetime is responsible for gravity, and accurately predicts the existence of black holes, whose curvature is so extreme that not even light can escape. General Relativity is also the basis for our theory of the origin of the universe – the Big Bang.

So, two beautiful theories, the Standard Model and General Relativity, and both very accurate. But... they are mathematically incompatible.

How can this possibly be? The resolution is that the two theories are associated with very different scales. On small scales – that of atoms and electrons in current particle physics – gravity is so weak that we can just forget about it. Similarly, General Relativity is applicable on very large scales when all other particle forces are negligible. This is why we can have the two incompatible theories co-existing.

However, we know that there are some situations where we need both theories: for example inside black holes and at the Big Bang, billions of years ago. A theory that unifies the two is called a theory of quantum gravity and would unify the fundamental laws of Nature. My work focuses on a particular approach to quantum gravity called string theory. Originally the key idea of string theory was that the most fundamental constituents of matter are extremely small one-dimensional objects, called strings, which would have no further sub-structure. The idea is that different vibrations of the string would give rise to all of the observed elementary particles as well as new ones to be discovered.

A remarkable aspect of string theory is that it is defined in 10 spacetime dimensions. We now know that there is a deeper structure, called M-theory, which includes membranes and other extended objects and the theory also exists in 11 spacetime dimensions.

The study of string theory has produced enormously rich new mathematical ideas, as well as deep insights into other aspects of theoretical physics such as black holes and quantum field theory, which are likely to be important in future developments irrespective of whether or not string/M-theory turns out to be the theory of quantum gravity.

Jerome Gauntlett
International rescue

Doctoral student Joshua Macabuag (pictured below) put down his research into tsunami effects at the EPSRC-sponsored EPICentre at UCL (University College London) to help rescue victims of the Nepal earthquake this April. He tells Pioneer about his work with the charity SARAID (Search and Rescue in Disasters).

I was on a training exercise with three other SARAID volunteers when news of the Nepal earthquake came through. Down in Cornwall, and out of mobile contact, we didn’t get the ops director’s message until around midday.

We headed straight back to London to be ready to fly to Nepal at a moment’s notice.

We were one of the first teams to arrive in Kathmandu, despite hold ups in New Delhi spent finding an onward flight that could take us and our two tonnes of kit.

It was frustrating, waiting in the transit lounge knowing there would be people dying in the rubble. Larger teams took even longer to arrive.

It was my first deployment with SARAID, and I was surprised by the eerie calm. The news broadcasts had been sensationalist, concentrating on areas with serious damage. The chaos getting there had also built up the tension. From the air, flying in at night, we could see fires where Nepalis were cremating their loved ones. But it was unexpectedly quiet when we arrived in Kathmandu. The city was functioning. The destruction was restricted to small pockets.

My role on the team is as an engineer. Like the technicians, I do the heavy work with drills and other kit to get
into damaged buildings and find survivors, but engineers have the additional responsibility of assessing whether it is safe to go in, what way to go, and whether the structure needs stabilising.

On our first day in Kathmandu, we were directed to some hotels and other residences that had collapsed; these were better tackled with hands and spades rather than our specialist kit. They were relatively small and built with light materials that were not difficult to move. Also, victims inside would either already have been rescued or would have perished, as the mounds of debris would have left them no voids to survive in. The following day, with more teams arriving from around the world, we divided the city up into radial sectors, and began a more systematic search.

In the end, around 2,000 international volunteers came to Nepal’s assistance; but found only five survivors alive, because it was so hard to get there in time. Nevertheless the people of Kathmandu were really appreciative – our efforts showed the world was focused on their plight.

I first visited Nepal in 2008. I’d gone to a rural area just outside Kathmandu on an engineering education programme to test ideas I’d developed as a student at Oxford to make the local mud-walled homes more resilient to earthquakes. I led on the design of a low-cost wall-cladding system using the kind of polypropylene mesh you find in flatpacks. The buildings’ retrofit is very simple – so as to be as affordable as possible, yet be robust enough to withstand earthquake.

When this year’s international search-and-rescue missions had ended, the Nepalese government asked for engineers to stay on to assess the safety of key buildings, like schools and hospitals. I quickly volunteered. This also gave me the chance to return to the historic town of Bhaktapur. The mud render of our two-storey demonstration house was cracked, but the walls had survived, and the building stood.

The 2008 project, at the start of my engineering career, saw me later joining the charity Engineers without Borders, through which I learned about SARAID. I also joined an EEFIT [Earthquake Engineering Field Investigation Team] reconnaissance mission to Japan to study the tsunami damage in 2011.

It was through EEFIT that I met Professor Tiziana Rossetto, the inspirational leader of UCL’s EPICentre, an EPSRC-funded hub of multidisciplinary expertise on disaster prevention.

I had always intended to return to academia after a stint in the commercial world. Looking for places to study for my PhD, I saw lots of options, but very few choices; EPICentre was number one. My research there, studying for an EPSRC-sponsored Engineering Doctorate, is closely related to what I saw in Japan – studying the resilience of buildings against the forces of tsunamis.

Academia gives me the stability I need to commit to SARAID. The training is very intensive – a full weekend every month. When consulting, I might be sent on an assignment abroad for weeks on end, which could not be matched with that commitment.

If anything, international aid will need to move faster next time there’s a disaster like this earthquake, which will mean better organisation, and better intelligence ahead of time. But it’s hard to know how that can be done when there’s a whole world to watch.
Wee will rock you

Step aside Kanye, a urinal that generates its own electricity was one of the biggest crowd pleasers at Glastonbury 2015.

The annual wonder-gig that is Glastonbury Festival is guaranteed to make the headlines. If the performers don’t make it to the front pages, the weather often takes centre stage. Or the toilets. Sometimes both.

In addition to first-time Glastonbury performances by the likes of Lionel Richie and Kanye West, the 2015 festival saw the debut of a remarkable new sanitation facility – a toilet block that needs no external power source to light its cubicles, instead relying on pee power to generate electricity.

Among its potential uses, it is hoped the technology will light cubicles in refugee camps, which are often dark and dangerous places, particularly for women.

The power comes from microbial fuel cell (MFC) stacks inside the toilet block. Live micro-organisms inside the fuel cells process the waste to produce electricity.

This technology is about as green as it gets

The invention is the brainchild of Professor Ioannis Ieropoulos, Director of the Bristol BioEnergy Centre located in the Bristol Robotics Laboratory (BRL) at the University of the West of England (UWE). The technology builds on EPSRC-supported research.

In 2010, EPSRC awarded a four-year Career Acceleration Fellowship to Professor Ieropoulos to develop his research into MFCs. In the same year, the BRL team launched the third generation of EcoBot, a robot which can power itself by digesting waste. They later proved that MFCs could also power mobile phones.

Professor Ieropoulos says: “The microbial fuel cells work by employing live microbes which feed on urine [fuel] for their own growth and maintenance.”
“The MFC is in effect a system which taps a portion of that biochemical energy used for microbial growth and converts that directly into electricity. It can utilise any form of organic waste and turn it into useful energy. What’s more, MFCs are like batteries that do not run out.

“This technology is about as green as it gets, as we do not need to utilise fossil fuels and we are effectively using a waste product that will be in plentiful supply.

“Not only is the technology a means of electricity generation, it can also improve sanitation. The work carried out under the EPSRC grant is primarily focused at developing this technology for the developed world.”

This is no small beer, and not just for festival-goers. Every day, around 38 billion litres of urine are produced by humans and farm animals worldwide.

Interviewed on Day One of Glastonbury 2015, Jane Healy, the festival’s sanitation manager, said: “For me, pee power is the future. Everyone at the festival is talking about it. It has created a buzz. Toilets are always a talking point at this festival, but I think this one tops the lot.”

University student, Eleanor Kirwan, who spent four days camping at this year’s festival, says: “I am a big fan of festivals such as Glastonbury but I’m more than aware of the sometimes detrimental effects that they can have on the environment. It’s great that technology being trialled at the festival could have such large-scale impact in the future.”

The bespoke toilet block, donated by timber construction experts, Dunster House, builds on an earlier project, also in partnership with Oxfam, centered around a urinal strategically situated near the student union bar at UWE. To make the trial as realistic as possible the urinal resembles toilets used in refugee camps by Oxfam.

Andy Bastable, Head of Water and Sanitation at Oxfam, says: “Oxfam is an expert at providing sanitation in disaster zones, and it is always a challenge to light inaccessible areas far from a power supply. This technology is a huge step forward. Living in a refugee camp is hard enough without the added threat of being assaulted in dark places at night. The potential of this invention is huge.”

Professor Ieropoulos says: “One microbial fuel cell costs about £1 to make, and a small unit like the UWE facility could cost as little as £600 to set up, which is a significant bonus as this technology is in theory everlasting.”

The Bill & Melinda Gates Foundation also supports the project, and has awarded BRL two grants totalling US$1.1 million under the Grand Challenges Explorations Scheme to help the team investigate generating electricity from urine and wastewater for countries of the developing world.
What is the most fascinating aspect of your research?

Discovery is what drives me. My research aims to improve techniques for damage detection in structures – these can include bridges, wind turbines and aircraft components such as landing gear. I find it fascinating to work with brilliant people who are full of ideas; the process of working in a team to solve a problem and the sense of achievement when you find something new that no one has discovered before are both important to me.

What is the most important topic in your field?

In engineering there are a multitude of really important challenges of profound importance to society. When EPSRC recently ran workshops to consult the academic community on the most important challenges, it was interesting to see the big issues that always came up; energy, food, water, security, health and global warming. The consequences to society of not supporting engineers and scientists to make discoveries to solve these problems are profound.

You chair EPSRC’s Engineering Strategic Advisory Team (SAT). What does this role mean to you?

The SAT comprises academics, industry and other experts in engineering, and advises on EPSRC’s research and training strategy. EPSRC needs these advisers. They act with integrity to ensure that EPSRC gets appropriate advice to assist it in the development of its plans for research and training, to make it aware of new opportunities and to help to communicate key messages. We also provide a good sounding board for new ideas. My role is important to me because of the significant role that EPSRC plays in shaping and supporting the UK as a world-leading research nation.

Does EPSRC listen to the SAT’s advice?

Always! I should point out that the role of the SAT is to advise, not to make decisions. The important thing here is that EPSRC always strives to obtain a range of perspectives from as many people as possible, balanced against the time taken to do so. The SAT provides one input and I think it is an efficient means of obtaining timely advice.

In profile

Professor Karen Holford
Pro Vice-Chancellor Physical Sciences and Engineering, Cardiff University. A member of EPSRC’s Strategic Advisory Network, Karen chairs EPSRC’s Engineering Strategic Advisory Team.

How close are we to seeing gender equality in the lab?

Recent high profile events have highlighted the subtle, and not so subtle, inequalities that still exist. On the face of it, we have processes in place that help to ensure that all people are treated equally in terms of recruitment and employment. But unconscious bias and in particular sexist attitudes and comments are still holding us back and putting women off from choosing to enter or remain in careers in science, technology and mathematics. It is vital to promote equality by modelling good behaviour; influential intellectuals should be very sensitive when speaking about gender issues in public.

Workplace banter is changing; influential people have challenged racism and homophobia to the point where it is no longer socially acceptable and I am optimistic that by challenging sexism it too can be made socially unacceptable.

What drew you to pursue a career in mechanical engineering?

I have always been fascinated by technology. I was an extremely curious child and I was often asking questions that people couldn’t answer, so I looked for the answers myself. This set me up for a career searching for answers. My dad had a garage so I was also very practical and used to help him out regularly. His influence, combined with my natural curiosity, kept me engaged right throughout secondary school, and I became the first person in my family to go to university.

If you hadn’t become an academic, what would you be doing now?

I’d like to think I would be managing a Premier League football club. Or I’d be a retired Formula 1 driver. My interest in Formula 1 comes from my parents – they both loved motorsport and used to take us all [four daughters!] to the British Grand Prix. Motor sport is exciting but what I really like is that it pushes engineers to be innovative and creative. The engineering in F1 cars is truly breathtaking.

How do you balance your work and personal life?

This is the most difficult and delicate balance to achieve, and I haven’t always got it right. Fortunately I have a hugely supportive family and very good friends; they know when to tell me that I am getting it wrong. I find the best way to get a balance is to try to prioritise what is important at any time and to constantly reassess the priorities.

If you were sent to a desert island, what three things would you take with you?

A toolbox so I can have shelter, food and water. Then I’d need entertainment so I’d like a solar-powered radio with winder and a football.

What advances in science and technology would you like to see?

As a sci-fi fan it has to be the teleportation machine (transporter). There are many situations where it would be incredibly convenient to say: “Beam me up, Scotty”.

What single item can’t you do without?

For most people it’s the iPhone; I am no exception – both personally and professionally. It’s a great example of the technological advances scientists and engineers have made over the last 20 years.

Liverpool season ticket or access all areas pass to the British F1 Grand Prix. Choose one.

That is the most difficult question in this entire interview! OK, this season I’ll have the GP pass and next season I’ll watch every Liverpool home game, please.

In short

Professor Holford is a Chartered Engineer; a Chartered Physicist; Fellow of the Learned Society of Wales and Fellow of the Women’s Engineering Society.

Among her achievements, she pioneered new acoustic emission structural monitoring technology in conjunction with MISTRAS, providing solutions for bridge inspection without the need for costly shutdowns. She is passionate about encouraging young people to study engineering and science, especially girls, and works closely with the Women’s Engineering Society and Women in Science and Engineering to help achieve this.
About the Engineering and Physical Sciences Research Council (EPSRC)

As the main funding agency for engineering and physical sciences research, our vision is for the UK to be the best place in the world to research, discover and innovate. By investing £800 million a year in research and postgraduate training, we are building the knowledge and skills base needed to address the scientific and technological challenges facing the nation.

Our portfolio covers a vast range of fields from healthcare technologies to structural engineering, manufacturing to mathematics, advanced materials to chemistry. The research we fund has impact across all sectors; it provides a platform for future economic development in the UK and for improvements for everyone’s health, lifestyle and culture.

We work collectively with our partners and other Research Councils on issues of common concern via Research Councils UK.

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