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THE FOUNDATION FOR SCIENCE AND TECHNOLOGY

COUNCIL

THE FOUNDATION FOR SCIENCE AND TECHNOLOGY

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Mapping the UK's knowledge landscape

A new online tool will help the Council for Science and Technology (CST) to map the research landscape in the UK. The CST has launched a project to understand better how the UK's research community defines itself and the links that exist between research disciplines.

Researchers can visit a dedicated website and provide information about themselves (such as: position, research interests and collaborators), their perceptions of how their research areas fit within the landscape of connected disciplines and the main pieces of research infrastructure in their areas of expertise.

Once a sufficiently large number of users have submitted their views, partial statistical analysis will be used to generate a 'consensus view' of how disciplines connect with and rely on each other. This output will then be made publicly available.

www.ukknowledgelandscape.co.uk

The importance of the IRT sector

The innovation, research and technology (IRT) sector directly generated £3.7 billion in gross value added contributions to UK GDP in 2012 to 2013, according to a study carried out by Oxford Economics for the Association for Innovation, Research and Technology Organisations (AIRTO). Furthermore, the sector directly employed 57,200 people and paid an estimated £1.4 billion in tax.

Over the same period, after accounting for supply chain and wage-consumption impacts, it is estimated to have supported £7.6 billion in gross value added, 140,100 jobs and £2.9 billion in tax receipts.

The report argues that the Government could continue to fund the IRT sector at a low burden to the taxpayer while having a high impact on organisations looking to replenish their physical and intellectual capital. It could leverage the sector's impact by procuring innovative products and services, effectively pulling them into mainstream use.

www.oxfordeconomics.com/my-oxford/projects/281857

New advanced materials centre

The University of Manchester will be home to a new national research and innovation centre in advanced materials, the Chancellor George Osborne has announced.

The Sir Henry Royce Institute for Materials Research and Innovation will allow the UK to grow its world-leading research base in advanced-materials science, which is fundamental to all industrial sectors and the national economy.

The new Institute, supported by industrial partners, will have its £235 million research centre in Manchester. The Manchester centre will be supported by satellite centres or 'spokes' at the founding partners, comprising the universities of Sheffield, Leeds, Liverpool, Cambridge, Oxford and Imperial College London.

The nuclear materials component of the centre, one of 14 such components, will be supported by facilities at the National Nuclear Laboratory in Cumbria and the Culham Centre for Fusion Energy. The founding partners' facilities will be enhanced to a value of £132 million.

www.manchester.ac.uk/discover/news/article/?id=13438

Alan Turing Institute partners announced

The five universities selected to lead the Alan Turing Institute have been announced. The Institute will build on the UK's existing academic strengths and help position the country as a world leader in the analysis and application of big data and algorithm research. Its headquarters will be based at the British Library at the centre of London's Knowledge Quarter.

Business Secretary, Vince Cable, said: "Alan Turing's genius played a pivotal role in cracking the codes that helped us win the Second World War. It is therefore only right that our country's top universities are chosen to lead this new institute named in his honour."

Headed by the universities of Cambridge, Edinburgh, Oxford, Warwick and UCL, the Alan Turing Institute will attract the best data scientists and mathematicians from the UK and across the globe to break new boundaries in how we use big data in a fast-moving, competitive world.

The delivery of the Institute is being coordinated by the Engineering and Physical Sciences Research Council (EPSRC), which invests in research and postgraduate training across the UK. The Institute is being funded over five years with £42 million from the UK Government. The selected university partners will contribute further funding. In addition, the Institute will seek to partner with other business and government bodies.

www.epsrc.ac.uk/newsevents/news/alanturinginstitute

Extreme weather impact set to increase

Exposure of human populations to extreme weather is set to increase as global climate as well as population size, location and age continue to change, according to a Royal Society report: *Resilience to extreme weather*.

The report presents new maps showing the combined impact of climate and demographic changes across the world upon the exposure of people to extreme weather. The maps highlight those areas where there is the greatest increased risk of populations being vulnerable towards to end of the century.

The report focuses on the risks to people from floods, droughts and heatwaves. These are some of the most frequent and damaging extreme events that currently occur and their impacts will change with the changing climate.

The report calls for action at all levels of government – international, national and local – to make society more resilient to extreme weather events. In 2015 important international agreements may be reached on disaster risk reduction, sustainable development and climate change. These agreements will be much more effective in addressing extreme weather impacts if they are linked with, and reinforce, each other, says the report.

https://royalsociety.org/policy/projects/resilience-extreme-weather

See also page 30 of this issue.

Innovation: managing risk, not avoiding it

The first annual report of the Government Chief Scientific Adviser, Sir Mark Walport, published at the end of 2014, has a firm focus on innovation. "Innovation is essential for economic growth, health, wellbeing, security and resilience," it states. "We need innovation just as much today as we did at the time of the first Industrial Revolution, even if the reasons are slightly different."

It warns, though, that "innovation is not an unalloyed good – almost all innovations can cause both benefit and harm. Because of this, discussion of innovation has become almost inseparable from discussion of risk.

"A common denominator of innovation in every generation is that it solves problems, creates wealth and new employment, while at the same time potentially disrupting the status quo of existing wealth and employment, and creating new problems and challenges."

Societies respond to the downside of innovation through regulation, argues the report. However, the task of designing systems of regulation and practice that are based on rigorous evidence and well-informed public debate is difficult.

Innovation is often discussed mistakenly in generic rather than specific terms. For example, it is not sensible or meaningful, argues the report, to ask whether a technology such as nanotechnology is, in and of itself, a good or a bad thing. The questions are always specific. Are nanoparticles of a particular composition an appropriate way to monitor a specific environmental hazard? Or is there an unacceptable risk of inhalation of a particular nanoparticle that is released as a consequence of its use in a household product? Almost any technology has the potential for both beneficial and harmful uses. In every case the challenge is to work out how best to exploit the benefits while minimising the harm.

One of the biggest challenges is to distinguish between hazard, exposure, risk and vulnerability. Understanding this terminology really matters, argues the report. This is because hazard is frequently equated or confused with risk, and this leads to poor debate, confused communication and flawed decision-making.

The report comes in two volumes: an overview of the topic and also a volume of evidence and case studies.

www.gov.uk/government/publications/innovation-managing-risk-not-avoiding-it

Students 'should understand IP'

Business Minister Baroness Neville-Rolfe believes that students should have a basic understanding of intellectual property. In a speech she set out her vision that a basic understanding of intellectual property (IP) is a key part of building a successful, innovative future for the UK economy.

Baroness Neville-Rolfe said "every child should leave school with a basic understanding of IP principles" and that "IP must be an integrated part of learning from the earliest school years through primary, secondary and higher education".

The Minister was speaking at the winners' ceremony for the Intellectual Property Office's (IPO) StudentshIP Enterprise Awards. She announced the 10 university student projects that will share £450,000 for their plans to improve understanding and exploitation of IP through student-business partnerships.

Baroness Neville-Rolfe also launched *IP Tutor*, a new online learning tool designed to increase the level of IP knowledge among lecturers and students in higher education.

The tool will support the use and understanding of IP in student enterprise activities at universities.

www.gov.uk/government/publications/intellectual-property-for-universities

From Moss Side to Eden

Present at many key events of the 20th century, Sir Alcon Copisarow has played a number of important roles in shaping the course of British and international affairs. His memoirs, *Unplanned Journey: from Moss Side to Eden*, have recently been published.

His career took him from service during the Second World War in the application of radar technology to the world of international diplomacy as Scientific Counsellor and Government Laboratory Director, in association with Appleton, Cockcroft and Blackett. His work has ranged from improving the efficiency of the Bank of England to a role in overhauling the administration of Hong Kong.

The memoirs are available in hardback at a special offer price of £18 (plus £3.95 p&p) for Foundation members from Jeremy Mills Publishing Ltd (normal price £20). Tel: 01484 463341. Email: **sales@jeremymillspublishing.co.uk**

Government plans spaceport for the UK

Plans for Britain to be home to Europe's first spaceport have moved a step closer with the publication of the results of a three-month Government consultation. This has confirmed widespread support for plans to make commercial spaceflight operations in the UK a reality.

The Civil Aviation Authority (CAA) shortlisted a number of possible locations for the spaceport in July 2014 and this has now been updated. The shortlisted sites are: Campbeltown, Glasgow Prestwick and Stornoway in Scotland, as well as Newquay in England and Llanbedr in Wales.

www.gov.uk/government/news/industry-backs-governments-spaceport-plans

Minister responds on Strategy

Science Minister Greg Clark appeared before the House of Lords Science and Technology Committee on 10 March to answer questions on the Government's Science and Innovation Strategy.

www.parliament.uk/documents/lords-committees/science-technology/ScienceInnovationStrategy/ucST100315Clark.pdf

'An Act to promote the progress of useful Arts'

John Enderby

Professor Sir John Enderby CBE FRS is the Editor of *FST Journal*. He was Professor of Physics at the University of Bristol from 1976 to 1996. He was elected a Fellow of The Royal Society in 1985 for his pioneering studies into the structure and properties of liquids and amorphous materials. He served as a Vice-President of The Royal Society from 1999 to 2004. One of his responsibilities was the Society's publishing activities. Sir John was President of the Institute of Physics in 2004. He is now a consultant to IOP Publishing.

One of the many benefits in attending Foundation debates is the opportunity to meet and interact with men and women whose interests and backgrounds are very different from one's own. Indeed, the Chief Executive always reminds those present to sit at dinner in a way to make new friends. It was at one such meeting that I had the great pleasure to sit with Sir Hugh Laddie, who was at that time a British High Court Judge and a specialist in intellectual property (IP) law. He was considered one the leading English judges and academics in the field of IP law and was co-author of *The Modern Law of Copyright* (1980).

In the course of several subsequent conversations, I found that he had become increasingly concerned with the cost and the slowness of the legal process involved in patent disputes. In an almost unprecedented move, he resigned as a High Court Judge in 2005 and became a consultant for Willoughby & Partners, the UK legal arm of Rouse & Co International. Sadly he died in November 2008 and, in a fitting tribute to his wisdom and sympathy to those caught up in legal disputes, University College created an academic Chair funded by charitable contributions.

The Sir Hugh Laddie Chair is part of a living, practical IP academic centre and is of direct value to practitioners and major law firms. An annual lecture is also held in his honour. Hugh was interested in the difficulties that faced SMEs and this resonated with me as I had just become Chairman of a small company (Melys Diagnostics Ltd) and we were struggling with IP and its associated costs.

The motivation for the patent system is neatly summarised by the US Patent Act of 1790: "to promote the progress of useful Arts: The grantee or grantees of each patent shall, at the time of granting the same, deliver to the Secretary of State a specification in writing . . . which specification shall be so particular [as] to enable a workman or other person skilled in the art or manufacture . . . to make, construct, or use the same, to the end that the public may have the full benefit thereof, after the expiration of the patent term".

Economists Roberto Mazzoleni and Richard Nelson have identified four benefits that patents bring to innovation:

- patents motivate invention;
- patents induce disclosure and wide use of inventions;
- patents induce the development and commercialisation of inventions;
- patents enable orderly development of new, but related, products and services.

Not all economists agree, however. Michael Meurer and Jim Bessen are both economists and law professors. Drawing on an extensive database, they argue that, on average, the patent system is bad for innovation. They agree innovator firms often profit from their own patents but they are also most likely to be targeted by other patent holders in terms of litigation. The disincentives created by other people's patents outweighs the incentives for new entrants to build a patent portfolio. Therefore, globally, the patent system discourages innovation.

In UK law, a patent must meet four conditions. It must:

- be patentable (i.e. the subject-matter is eligible for patent protection);
- be novel (i.e. at least some aspect of it must be new);
- involve an inventive step;
- be susceptible of industrial application.

Problems faced by SMEs

An early problem faced by SMEs in the course of developing a product or service is to decide if IP protection is necessary. In a survey carried out by the UK Intellectual Property Office (IPO), it was found that nearly 64 per cent of small companies chose not to protect their IP through the patent system. Deterrents include the need to commission professional help, as well as the initial and on-going costs. For example, four years after the first submission, an application for renewal must be made to the relevant IP office and every year thereafter (up to 20 years).

Moreover, a patent must be written in a manner such that a person 'skilled in the art' could reproduce the product after the protection offered by the patent elapses. Many SMEs are uneasy about placing in the public domain detailed confidential information of the sort required by the examiner. Furthermore, as Sir Hugh pointed out,

the legal costs in pursuing infringements are often beyond the means of SMEs.

There is also a grey area surrounding software. The IPO points out that UK laws do not generally allow patents to be granted for software (although there are exceptions). Whether a computer-implemented invention is patentable depends on the contribution the invention makes. The example the IPO gives is that if the invention provides improved control of a car braking system, it is likely to be patentable. If it provides an improved accounting system, it is *probably* (my italics) not patentable.

The law on what is patentable is the same across Europe, so if something is not patentable under UK law, it will generally also be unpatentable elsewhere in Europe. The same does not apply to countries outside Europe. In the USA and Japan, the laws allow a wider range of computer-implemented inventions to be patented.

There is no such thing as an International Patent and IP protection must be sought on a country by country basis. This, of course, increases costs. However, after many years of discussion, Europe seems to be moving towards a simplified system to be implemented by the European Patent Office (EPO).

The objective of the new regime is to create the so-called 'unitary patent' that will allow patent protection to be obtained for 25 Member States (Italy and Spain are not participating but are free to join at any time in the future). There will be a single application without further administrative formalities.

"The future unitary patent will be in fact a European patent for which the protection will be effective in all Member States participating in the enhanced cooperation," states Jean Luc Gal, head of the Brussels bureau at EPO. The newly created Unified Patent Court will be competent to handle disputes concerning both future unitary patents and current traditional European patents.

It was hoped that the EPO might have been able to grant the first unitary patent as early as April 2014. However, before this could happen, the Agreement on the Unitary Patent Court must be ratified by at least 13 Member States including France, Germany and the UK. As this article went to press, only six countries have completed ratification.

Patent lawyers in the UK are unsure to what extent companies will benefit from the new system. One estimate is that the Unitary Patent will benefit the 10 per cent of existing patentees who validate in 13 or more European Member States. For the other 90 per cent of patentees, the position is less clear and will depend primarily on whether an increased geographical coverage for protection is likely to be of interest, as how well understood are the location of key markets. Furthermore, the benefits to SMEs, who generally seek protection in only three or four countries, will depend crucially on the level of renewal fees set by the EPO.

A cautionary tale

On 12 September 1958, Jack Kilby of Texas Instruments (TI) built a circuit using germanium transistor slices he had etched to form transistor, capacitor, and resistor elements. Using fine gold 'flying-wires' he connected the separate elements into an oscillator circuit. One week later he demonstrated an amplifier. TI announced Kilby's 'solid circuit' concept in March 1959 and introduced its first commercial device in March 1960, the Type 502 Binary Flip-Flop, priced at $450 each.

However, the flying-wire interconnections were not a practical production technique. So in the autumn of 1958 Kilby worked on a revised method that replaced the flying wires with gold wires: a film of oxide could be deposited on the semiconductor and the gold interconnectors put down on the oxide. The patent was filed on 6 January 1959. The fatal mistake was to include the word 'gold' in the patent application because it is difficult, if not impossible, to get gold to adhere to oxides.

Fairchild co-founder, Robert Noyce, conceived the idea of using aluminium as the connecting material because aluminium, unlike gold, adheres to the oxide insulating layer necessary to avoid short circuits. Noyce filed his "Semiconductor device-and-lead structure" patent in July 1959 and a team of Fairchild engineers produced the first working monolithic ICs in May 1960, having explored various schemes to isolate devices from each other within the silicon wafer.

Fairchild and TI engaged in prolonged litigation over IC patents for 11 years at tremendous legal costs. The US Supreme Court finally ruled in Noyce's favour but by then the companies had already settled on a cross-licence agreement that included a net payment to Fairchild.

The future

I hope this editorial has stimulated discussion about the merits, if any, of the patent system.

- Do patents really encourage and support innovation?
- Is there a better way to deal with disputes and infringements than going to court?
- The 20-year lifetime of patents is much shorter than the protection offered by copyright. Is the balance right?
- Can more be done to help SMEs protect their intellectual property?
- Is the Unitary Patent likely to be of general benefit?
- Should the rules about software be reviewed at the European level? □

An early problem faced by SMEs in the course of developing a product or service is to decide if IP protection is necessary.

SCIENCE AND INNOVATION STRATEGY

The Government has published a command paper, '*Our plan for growth*', setting out why it believes funding of science and innovation is fundamental to the UK's future economic growth. A meeting of the Foundation on 4 February 2015 debated this strategy.

A strategy for growth

Greg Clark

The Rt Hon Greg Clark MP is Minister of State for Universities, Science and Cities at the Department for Business Innovation and Skills (BIS). In May 2010, Dr Clark was appointed Minister of State at the Department for Communities and Local Government and in July 2011, Minister for Cities. In September 2012, he was appointed Financial Secretary to the Treasury before becoming Minister of State in the Cabinet Office in October 2013. He was appointed to his current post in 2014.

The challenge for the Minister of Science is to make science clear and visible at the heart of Government, in a way that reflects the reality that science policy is a matter for the long term, rather than the stuff of short-term politics.

When I was appointed in July, the Science and Innovation Strategy was already in preparation with a commitment to provide a 10-year forward look. The final document, *Our Plan for Growth: science and innovation*[1], was published just before Christmas. It is a document co-signed by the Chancellor, the Business Secretary and me, and it also embraces other Government departments – for example, the Department for Education played an active role in developing our approach to nurturing scientific talent.

It seems reasonable to consider how the UK is going to prosper in the future. In answering that question, we should reflect on what we are good at and whether those strengths are likely to be in demand in the future.

Science is clearly going to be an important element in any answer. The UK is not just 'good' at science; it is 'excellent', with 29 universities in the world's top 200. We have 1 per cent of the world's population, 3 per cent of its research funding, 6 per cent of published papers, 12 per cent of citations and 16 per cent of the most highly-cited articles. Over 55,000 researchers submitted work for the Research Excellence Framework (REF) and a full 76 per cent of that work was deemed to be world-class – an astonishing achievement. In innovation we are making progress and are ranked second in the world in knowledge-based capital.

This is a position of strength that informs the debate and discussion around the Science and Innovation Strategy. The importance of science is totally accepted within Government. There is, in the Strategy, a forward commitment of £5.9 billion into the UK's research infrastructure between 2016 and 2021, the most long-term commitment to science capital in decades.

We have set out five principles for the 10-year view period covered by the Strategy. These are: Excellence; Collaboration; Agility; Place; and Openness.

IN SUMMARY

- A 10-year strategy for science and innovation
- Embraces all Government departments
- Building on the UK's recognised research excellence
- Key role for education
- Ensuring the right infrastructure is in place

Excellence

Our success is not accidental. It comes from the investment made over a number of years. It comes from institutions and funding arrangements that have been tried and tested. These include, for example, the dual funding of research. While Ministers may decide on strategic priorities and challenges, the Government remains committed to the principle of peer review to judge excellence.

Quality Research (QR) funding is also very important. The idea that institutions can benefit in proportion to their record of excellence is particularly vital. Universities and other institutes have indeed proved themselves to be stable and enduring places in which scientific enquiry can take place.

The Research Excellence Framework (REF) and the competitiveness of the research process have helped to ensure that UK research is world-class. In my annual letter to the Higher Education Funding Council for England (HEFCE), I emphasised that excellence should be funded wherever it is found.

Collaboration

One of the most thrilling aspects of science (and I mean science 'in the round', encompassing the humanities and the social sciences too) occurs when discoveries involve people from different disciplines. In a meeting about Ebola with Chief Scientific Advisers from across Government, it was fascinating to learn that as well as the medical advances and discoveries, one of the key lessons has come from social anthropologists. Their insights into the cultural norms that dictate how people handle dead bodies have been particularly

influential in providing advice on the spread of that disease.

Boundaries are dissolving between disciplines, but that is not to say that disciplines are not important. In the future, we have to allow for and promote (but certainly not impede) the opportunity to collaborate – whether within disciplines, between sectors of the economy, or between industry and university research.

Agility

There will be opportunities in the years ahead, which we simply do not know about yet. In deciding priorities for the next 10 years, and committing the science capital budget, the Government very deliberately kept part of the funding back in what was termed an 'agility fund'. This will allow us, perhaps in four or five years' time, to support projects and research programmes that will be compelling at that time, even though we may not be aware of them at the moment. If we are not sufficiently agile, as well as rigorous, other countries will outpace us.

Place

Institutions – and universities in particular – are often synonymous with particular towns and cities. In the past, though, the importance of place has been overlooked in the world of science policy. Yet, the importance of institutions for the economic prosperity of their local areas is now widely accepted and understood. Most of our great towns and cities would not be what they are today without the universities and innovative businesses that are based there – these are at the centre of their local economy and the local culture. In every one of the 39 Local Enterprise Partnerships (LEPs) that bring together local councils and businesses in every part of England, there is at least one Vice-Chancellor on the Board and sometimes more.

It works the other way too. There are £12 billion of funds available across the country to reinvest in local economies. I am absolutely certain that some of the best recipients of that investment will be universities, research establishments and places where innovation takes place. In recent funding rounds – no doubt as a result of the participation of those same Vice-Chancellors – opportunities have been taken to support science facilities and institutions.

Openness

There is huge interest in science across the world. Every morning on the *Today* programme on Radio 4, there seems to be one or more science stories that are absolutely compelling – the public are interested in this and I think there is an obligation to share this work, especially when it is publicly funded. This is a vital element in bringing forward the next generation of scientists. As another example, open access science publishing has enhanced the availability and the prestige of our research.

Driving the future

The Strategy itself starts, quite deliberately, with a chapter entitled 'Nurturing Talent'. This recognises that none of the glories that we are privileged to enjoy could happen were it not for the talents of people working in science and innovation. The country has to build on that, making it possible for more people to be educated and trained to the right level.

So there is provision to train 17,500 maths and physics teachers because there is a particular shortage here. National colleges will be established in certain sectors. Postgraduate loans will be available for Masters students, ensuring that our own citizens have the chance to benefit from the excellence of our institutions. The loans will be for all disciplines.

Science depends, in many cases, on having the right infrastructure. The Strategy recognises the importance of opening new facilities, but also of making sure that the existing institutions can continue to flourish. I think Lord Krebs described it as the 'batteries not included' problem. The Strategy reflects a very clear decision to provide £3 billion funding for what we call the 'well-found labs' to make sure that we continue to address those needs.

The importance of research and development and scientific enquiry in other Government departments has been too little recognised in the past, so there is a commitment to review (in advance of the post-election spending review) how to achieve greater visibility and importance for science in other departments.

The chapter on catalysing innovation in the strategy reflects the improvements that have been made, but recognises that there is further to go in developing and exploiting some of the discoveries that we make. Two new Catapults are being established – one in energy systems and the other in precision medicine. Further investment is planned in some of the existing Catapults.

Finally, looking to our place in the wider world, the Strategy emphasises the importance of an initiative by David Willetts: the Newton Fund. In this, the UK recognises the strength of the connections between our institutions and those in overseas countries, as well as the need for funding joint research projects and collaboration. □

[1] *www.gov.uk/government/publications/our-plan-for-growth-science-and-innovation*

One of the key lessons of Ebola has come from social anthropologists. Their insights into the cultural norms that dictate how people handle dead bodies have been particularly influential in providing advice on the spread of that disease.

Delivering a prosperous and resilient economy

Ann Dowling

Professor Dame Ann Dowling DBE FRS FREng is President of the Royal Academy of Engineering. A world authority on combustion and acoustics, she was Head of the Department of Engineering at the University of Cambridge from 2009 to 2014. Dame Ann is a non-executive director of BP, a non-executive member of the board of the Department for Business, Innovation and Skills (BIS) and was a panel chair for the Research Excellence Framework.

IN SUMMARY

- This is a crucial time for science, engineering and innovation
- Open dialogue between project partners is vital
- We need to step up our investment in STEM education
- Apprenticeships should be regarded as equal to academic education
- We need greater support for the more expensive science and engineering courses in universities

This is a crucial time for science, engineering and innovation in the UK. The next election will be followed by a very challenging Comprehensive Spending Review in which all areas, including science and innovation, will come under close scrutiny.

The Strategy sets the scene very well for the challenges ahead. Indeed, the very fact that we now have a single document that takes a long-term view across science, innovation and skills is an encouraging development.

It highlights two reviews being undertaken to inform policy development: one led by my counterpart at the Royal Society, Sir Paul Nurse, which is looking at the Research Councils; and one that I am leading, addressing collaboration between businesses and academic researchers.

I have been asked to look at a specific question: how to foster long-term strategic research collaborations between academic researchers and companies, in order to deliver broad-based benefits to the UK.

I have had a close involvement in the Research Excellence Framework and have been impressed by the impact case studies, which provide compelling evidence that university research results in an enormous range of successful applications.

Often, those impacts may be quite unexpected by those who conducted the original research, which emphasises the importance of investing across a wide base of research activity.

However, there are also many examples of companies benefitting because they have planned to work with academia. Certain companies – notably those with structured, well-planned interactions with universities – are cited over and over again.

One critical success factor is the development of trusting relationships that enable the collaborating partners to have an open dialogue over a period of years. Without this, it is virtually impossible to expect a company to share their long-term vision with the academics. And if they are not prepared to do that, there is a serious risk that the academics will try to answer the wrong questions!

Understanding industry's long-term needs can be a very rich seam for generating exciting, intellectually-stimulating research questions. Every researcher sets out to answer a question and we are perhaps missing out on opportunities for academics to be inspired by questions derived from the needs of companies.

So, together with my review team, I am looking for:

- gaps in current policies and provision;
- opportunities to scale up successful approaches or to transfer good practice in one sector (or discipline) to others;
- innovative new ideas for interventions that could make a real difference to our performance.

We are also looking at how recent policy developments have impacted on the landscape – for better or worse.

In particular, the Review will consider the impact of the UK's industrial strategy and how we can use developments here to promote business-university collaboration. The Review will look across all regions, sectors, research disciplines, types of companies and universities.

Capital expenditure

The Science and Innovation Strategy gave some clarification on plans to invest the £5.9 billion in science capital committed in the Spending Review 2013.

The consultation on capital had shown strong support for using this money in rather low-key ways, providing well-found labs in the science base and equipment to support individual research grants won by peer-review. However,

there is a lack of clarity about what else is included under this heading – it does, for example, include our international subscription to CERN – and we are concerned about how much more is expected to come out of this pot.

£2.9 billion is for capital investment in high-profile 'grand challenge' projects. This raises concerns about who is going to pay for the running costs. The integration of capital commitments with resource planning and skills development is vital.

STEM

The Strategy highlights the importance of nurturing scientific talent. The UK does not have the mineral wealth that other countries can draw on. Our future wealth and prosperity will come through our scientific knowledge and from adding value through innovation.

Engineering UK reports in its 2015 *Annual Digest* that the UK needs to recruit an additional 1.82 million people to work in engineering between 2012 and 2022 (data from UK Commission for Employment and Skills). Yet, currently we only train just over 100,000 new engineers a year, both technicians and graduates. We need to nearly double that rate.

The Strategy notes that in 2014, some 130,000 students sat physics, biology and chemistry GCSEs. However, only half of all students achieved a C grade or above in mathematics and two sciences. Some 300,000 people each year fail to achieve the basic level of mathematics and science required for progression to further education or employment in our sectors.

Over the last 10 years, the number of students taking mathematics at A-level has increased significantly, but the number of students taking A-level physics remains stubbornly low at around 35,000. Only one in five A-level physics students is female – a figure that has remained unchanged in the last 20 years.

The Government highlights opportunities for young people through vocational pathways: in particular, apprenticeships. These are an excellent model of training and we in science and engineering must support this route as being equal to the academic pathway, and not an inferior option.

Many young people certainly recognise the value of engineering apprenticeships. Major engineering companies like Rolls-Royce, BAE Systems and BT get thousands of applicants for a few hundred places.

Yet the real growth in apprenticeships over the last five years has occurred in retail, health and social care, and in business. And the number starting apprenticeships is actually falling.

It is important to remember that apprenticeships are jobs with training. They are in the gift of employers, and employers need to feel sufficiently secure in the economic outlook to make a decision to employ young people and put them on a training programme.

Higher education

There is an increase in the number of students across all the key STEM disciplines. However, many universities (particularly the pre-1992 group) are now full to capacity and there is, in general, little appetite for expansion.

Laboratory-based subjects are expensive to deliver. They require large amounts of space and infrastructure. HEFCE provides additional support for high-cost subjects but this is insufficient to cover the costs of teaching, consumables and equipment.

Historically, universities subsidised science and engineering courses through other lower-cost subjects. But with students now paying their fees themselves, they expect, rightly, that the money will be spent on them and not used to support other, more expensive subjects.

Non-UK engineering students now represent around a quarter of the cohort. Without these students paying full fees, many of these courses would be unsustainable. International students help universities balance their budgets and are also an important contributor to UK exports. However, the perception in the Indian subcontinent and the Far East is that, through changes in visa requirements and in rhetoric, the UK has raised barriers to overseas students.

For the future

We need a systems approach to solving the skills shortages in the UK, addressing both enthusiasm for engineering and opportunities for education and training.

A major programme to change the perceptions of engineering and science is required, so that students and their influencers see that pursuing these subjects opens up a world of opportunities.

We need to ensure that people can come into engineering at all stages of their career. I welcome the Government's commitment to provide funding for HEFCE to work with the engineering profession and develop engineering conversion courses for non-engineering graduates.

There has to be an increase in the supply of specialist teachers, not only in mathematics and physics but also in computing, and design & technology.

We need to increase employer engagement in the education system, supporting careers advice

and providing real-life context to STEM so that young people can see these subjects brought to life.

Higher education needs greater investment to expand provision in science and engineering.

Finally, tackle the issue of immigration to allow talented scientists and engineers to study and work in the UK.

There is much to commend in the Science and Innovation Strategy. However, the science and engineering community, together with the Government, still has much to do in order that the UK's research base, innovation system and skills can achieve the scale and strength needed to deliver a prosperous and resilient future. ☐

Science as part of the growth agenda

Mike Lynch

Dr Mike Lynch OBE FRS FREng is the Founder of Invoke Capital, which invests in fundamental European technologies. He has founded and advised a number of companies ranging from Neurodynamics to Blinkx. He is best known for founding Autonomy in 1996, the UK's largest software company, a member of the FTSE 100 with a market capitalisation of $11 billion. He was its CEO for 15 years until it was acquired by Hewlett Packard in 2011. He is a member of the Council for Science and Technology (CST).

IN SUMMARY

- Pure and applied science are coming closer together again
- The pure versus applied science debate represents a flawed analysis
- We need to pick themes to support, not sectors
- The issue of IP rights urgently needs addressing
- We must seize the opportunities for growth

We find ourselves in a time where there has been cost-cutting in all areas of public expenditure. The reality, though, is that science has not seen anything like the cuts suffered by the arts. So how did we convince the Chancellor and what does science have to deliver in return? The concept of 'growth' is central here, although this needs to be understood more broadly than in purely economic terms. This would include areas where science can produce benefits that are societal, for example, in healthcare.

The former Chief Executive of Rolls-Royce, John Rose, used to say there are only three ways of creating value. First, there is prosperity, dig it out of the ground and mine it, although sadly we are not sitting on vast gold reserves under Peckham; second – grow it, and living in Suffolk I am convinced that the UK farmer is already extremely efficient so there is not much more to be gained here; and third – use know-how to turn one thing into something more valuable. That is why science and innovation are crucial to the growth agenda.

We have gone through a period where a separation has developed between applied (or industrial) and pure science. For the first 200 years of its existence, those two halves were very closely linked in institutions like The Royal Society but then they drifted apart. Today, there is a very conscious effort to bring them back together.

Science can be divided into three categories. First, we can have scientific knowledge that is there for 'wonder', addressing questions on, say, the origin of the universe. Then there is blue-sky research – things like quantum physics, which may not be immediately useful, but are likely to become so. Finally, there is traditional applied science: for example, using some of those quantum results to produce photonic devices for the electronics world.

The traditional debate about funding blue-sky or applied science is, I believe, based on a fundamentally flawed analysis. The work done in maximum entropy in astronomy, for example, underpins machine learning, which is one of the most commercially-important areas of applied algorithm work. We need to focus more on themes and how these can deliver impact.

So it is not a matter of dispensing with blue-sky research because the emphasis is now on the growth agenda. The problem is that we have not succeeded in the past in exploiting these advances. The UK has not been good enough at converting scientific discovery into economic impact. Yet in reality, it is an enviable problem to have – many countries would wish to have a science base like ours.

Uncertainties

What difficulties are there in implementing this Strategy? The first is allocating funding between different areas of research. Any organisation, whether a Research Council or company, develops institutional inertia. Lots of people get involved in a particular areas, they become very

good at applying for grants and, over time, this approach becomes embedded. It is then very difficult to 'turn the tap off' and rebalance. So while no one should be picking winners, the idea of picking themes is attractive.

We need a mechanism to break up this inertia. How do we balance support for supercomputing research, which has a good history of Government funding against something like algorithms that does not? There is a need to rebalance. Another example might involve comparing the benefits to society from genomics on the one hand and a traditional area like particle physics on the other.

Assumptions have to be challenged if the Strategy is to be aligned with the growth agenda. Of course, this is easier said than done!

One thing to be careful of in any strategy is not trying to do too much. There is always a political context but trying to solve regional economic problems by, for example, bending the science strategy would be a very bad mistake. This Strategy does, I think, tread a reasonable line on this.

The next issue is technology transfer and science exploitation. The most important thing to understand here is the level of ambition. Read the publications of a university's technology transfer office and the impression given is that this is working incredibly well. Yet, while everyone has an outstanding example of what has been achieved, in the context of the science base the efficiency in moving from science excellence to economic impact is still very low. The UK has to do much, much better at this. We are definitely going the right way, but real success involves a much greater scale of transfer.

One major technical barrier to this is the issue of IP – Intellectual Property Rights. Some university Vice-Chancellors believe it should always be owned by the universities. Others say it should be automatically available to other partners so there is no restriction on implementing the technology. Another camp thinks that the researcher should own the technology, not the institution. This can be a really big problem for a small- to medium-sized company (SME) trying to work with a university. This issue really has to be resolved: it is a major barrier to successful technology transfer.

A relatively simple issue is the VAT rules. Move a small business onto the end of a bench in a university – which is exactly what the Strategy wants to achieve – and suddenly the institution is liable for VAT. Small problems like this can easily be resolved and allow collaboration to move forward.

Encouraging more young people to choose the STEM subjects – Science, Technology Engineering and Mathematics – has been a long-standing problem, one that has resisted a series of initiatives over the years. So probably best not to rely on a single approach to the matter in this Strategy – a Plan B will also be necessary!

There are good initiatives in the Strategy, particularly the idea of getting STEM-qualified female teachers back into teaching after having a family – I think that would be a very good thing. In order to augment the current, limited number of teachers, perhaps it is time to start thinking about some new approaches, like Massive Open Online Courses (MOOCs).

The scientific community needs to understand that the Strategy represents a pact. Due to the importance of science and what it can deliver in terms of growth, it is being preferentially treated. The implication, though, is that this faith has to be vindicated. Science will have to demonstrate how it is succeeding.

The scientific community needs to understand that the Strategy represents a pact. Science is being preferentially treated. The implication, though, is that this faith has to be vindicated.

Challenges

British science faces a series of very high-profile challenges. There is absolute excellence in the science base and the first priority is to maintain that. We now have a Strategy from a Government that understands the importance of science over other calls for funding. We have made great strides in starting to achieve impact from our people and our science base.

However, science must take a hard look at itself. Institutional inertia must be tackled. Excellence must be maintained at all costs. Finally, while blue-sky research is absolutely consistent with the growth agenda, that argument only works if opportunities to translate it are fully executed. □

FURTHER INFORMATION

Our plan for growth: science and innovation (Command Paper 8980)
www.gov.uk/government/publications/our-plan-for-growth-science-and-innovation
Association for Independent Research and Technology Organisations
www.airto.co.uk
Dowling review
http://www.raeng.org.uk/policy/dowling-review
Government Office for Science
www.gov.uk/government/organisations/government-office-for-science
Innovate UK (formerly the Technology Strategy Board)
www.gov.uk/government/organisations/innovate-uk
Newton Fund
www.rcuk.ac.uk/international/newton
Nurse Review of Research Councils
www.gov.uk/government/publications/nurse-review-of-research-councils-terms-of-reference
Research Councils UK
www.rcuk.ac.uk

RESPONSE FROM THE ROYAL SOCIETY

Professor Alex Halliday FRS, Physical Secretary and Vice-President of The Royal Society, gave a response to the speakers before the general discussion began.

This is a crucial time for science, engineering and innovation in the UK. The next election will be followed by a very challenging Comprehensive Spending Review in which all areas, including science and innovation, will come under close scrutiny.

The view of The Royal Society is that the Strategy is a very positive statement about the role of science in society.

Untapped potential

However, there are aspects of science policy that need more deliberation. The Research Excellence Framework (REF) has allowed the UK to think more nimbly about its universities' activities and how to obtain strategic advantage. Yet it has untapped potential. By reading outputs and looking at impact statements, it can provide a measure of how good this country is in certain areas. It is currently used for allocating funding, but the information could also be used to help decide which areas should grow through greater support.

The Research Councils are to be reviewed by a study led by the President of The Royal Society, Sir Paul Nurse. Looking across the Atlantic, the American National Science Foundation's primary goal is to fund exciting ideas, getting the great ideas out of the science community and putting money behind them. Sir Paul's review will examine how good the Research Councils are in achieving this for the UK.

Supporting strategic science

The issue of UK strategic capability is very controversial. It is not yet clear how the country should support major strategic science that is being carried out through national laboratories and other non-university institutions.

The Strategy refers to 'place' as one of the criteria for selecting where to put resources for new science initiatives. There are opportunities to connect with local communities more effectively here and that is a great opportunity for the future.

The debate

Issues raised in the debate included:

Arguments about the value of intellectual property (IP) hinder collaboration between universities and industry, particularly with middle-sized companies. Big businesses with expert legal advice can afford to negotiate IP agreements with universities, while start-ups with a few graduates from the university may not concern themselves with this. Mid-sized businesses can afford neither the time nor expense of negotiating agreements with universities who have access to expensive legal advice. Sometimes they simply walk away, and the research is not exploited.

Much of the problem is that every university had a different perspective on IP. A way forward could be a consensus on a selection of model pro-forma IP agreements. Technology transfer depends on trust, and trust cannot exist if the parties are wrangling about IP.

The impact of research and innovation is crucial to the UK but needs to be measured other than just in traditional economic growth metrics. The public needs to be aware of the impact, which needs to be communicated, and needs to be seen to be aligned with policies that might alleviate social issues such as unemployment.

The REF showed which universities had achieved most impact from their research. Perhaps there should be a national target for research and impact; but there are challenging problems in measurement.

The tax credit system for R&D is flawed. The broad definition of R&D by HMRC gives credits for spending that is not actually R&D. Adjustment of the rules could focus benefits on areas where the added value from exploitation is greatest.

There should be a clear policy regarding the contribution from public sector research establishments. PRSEs make an important contribution and, alongside Departmental R&D budgets, are an essential part of the research landscape. The contribution of research institutes funded by charities or companies should also be recognised. ❐

In 2010, the Hauser Report proposed the establishment of what became known as the Catapult centres for technology translation. Four years later, Dr Hauser was asked to review the network. His subsequent Report was the basis for a debate at The Foundation for Science and Technology on 12 November 2014.

The translation of research

Hermann Hauser

IN SUMMARY

- The UK is very good at science, less so at translation
- Government should grow the Catapult network at a rate of about two per year
- Catapults need to link more closely to SMEs and to universities
- There is a major opportunity for the UK in healthcare
- Science translation represents a 'third mission' for universities

Dr Hermann Hauser CBE FREng is co-founder of Amadeus Capital and Chair of the Hauser Review of the Catapult Network. He has founded or co-founded companies in a wide range of technology sectors, including Acorn Computers (where he helped spin out ARM), Active Book Company, Virata, Net Products, NetChannel and Cambridge Network Limited. He has also been a member of the Prime Minister's Science Advisory Group, the Council for Science and Technology and actively supported many initiatives to support research.

I want to look at some of the problems associated with science translation and highlight the mismatch between expenditure on science, where the UK is excellent, and the amount spent on translation, where it is not. Then I will outline the findings of the Review itself.

The role of universities

What are universities for? Everybody agrees that producing highly-skilled graduates is by far the most important thing they do. To illustrate just how important that is, the earning power of the students educated by UK universities is roughly a hundred times the income these institutions generate from intellectual property (IP). There is also general agreement that research is a key mission that has been entrusted to our universities – and that is done particularly well in the UK.

Since the days of Lord Sainsbury, however, universities have had a third mission, which is supported by the third stream of funding – higher education innovation funding (HEIF) – and this is all about science translation.

Britain has four universities in the world's Top Ten – Cambridge, Imperial, UCL and Oxford. Measured by citations, the UK is second only to the USA and in terms of results per pound spent, it reaches number one in the world. However, spending on translating the wonderful science we produce is disproportionately lower.

Figure 1 (page 15) shows the amount of money that various countries spend on translation, compared with the UK. Compare the amount spent on Catapults with the sums Germany spends on Fraunhofer Centres. Or take Finland, which spends roughly the same amount as the UK on translation but is a much smaller country.

Science translation works mainly through the transfer of people. It may not be the professor leading the group, but somebody in that group has to take the technology and all the know-how and do something with it, in a start-up or a larger company.

Scientific breakthroughs

Now there are different types of scientific breakthroughs. At its simplest, these can be divided into evolutionary and revolutionary breakthroughs. One is appropriate for licensing and the other is much more appropriate for start-ups.

An archetypal evolutionary development is the jet engine: in the UK, Rolls-Royce has done fantastically well in keeping up with the latest developments. With revolutionary breakthroughs like the electric car, though, it is not the mighty German car industry that makes the best in the world at the moment, it is a Californian start-up called Tesla. This car was conceived from the ground up as an electric car and it was that willingness to leave the past behind and think about new technologies in a holistic way that allowed them to exploit the opportunity. Tesla now has a market capitalisation that is more than half that of Mercedes or BMW, so in a very small number of years they have created an enormous amount of value.

The Catapults

There were a number of criteria for using taxpayers' money to support new institutions, i.e. the Catapults, that help with technology transfer:

Science translation works mainly through the transfer of people: somebody in that group has to take the technology and all the know-how and do something with it.

1 Unless the potential market is measured in billions of pounds, it will not 'move the needle' for UK plc;
2 This is not about filling holes but building on mountains;
3 The institution has to focus on a platform technology that benefits a whole sector, not a single company;
4 There has to be a means of exploiting the results for UK plc. But this does not mean keeping the whole value chain in this country. A multi-billion dollar opportunity is normally global in nature. If it is global, it is unlikely that every part of the value stack can best be done in this (or any one) country.

The right strategy is to pick a high-value part of the value stack and say 'this is ours; if anyone wants to play here, they have a fight on their hands and we are going to win it'. The other parts can be done elsewhere in the world. In consequence, having this connectivity with the rest of the world is a very important part of any national initiative.

At the end of 2014, there were already seven Catapults:

- High-value manufacturing;
- Cell therapy;
- Satellite applications;
- Offshore renewable energy;
- Digital economy;
- Future cities;
- Transport systems.

Two new Catapults are due to be launched in 2015: energy systems and precision medicine.

Two actually pre-existed the Catapult initiative – high-value manufacturing and satellite applications. I went to see Vince Cable and complained about the high-value manufacturing Catapult and told him it was not what I had in mind. It comprised seven different centres rather than one and I had strongly recommended there should just be one centre per sector. Having visited them, I have changed my mind and there is a very simple reason: manufacturing technologies are so very different from each other that a single centre would not have been appropriate.

There has been a discussion whether Catapults ought to be involved in the skills-base, i.e. helping train young people in these advanced techniques. I met a number of young people at one of the Catapult centres who really appreciated being able to get their hands on the latest lathes. It was good to see these young people engaged with the latest technology, which they would not have had access to at their local polytechnic or university.

The satellite applications Catapult had a wonderful database of satellite images of Britain. Many companies have been able to access this image bank and write programs that take advantage of the database. In fact, there have been so many of them, it was necessary to build an incubator!

So the two that pre-existed can already show very clear and impressive results. One of the most striking features is the funding model: a third should come from Government, a third from industry (it is important to recognise that this should not be more than a third because if it were, then industry might as well do it themselves, but also not less than a third because then it is not really clear whether industry really wants it). The final third comes from competitive bids for projects from industry or the EU.

I was particularly taken by the cell therapy Catapult. It is located on the 12th floor of Guy's Hospital. Two floors above is the research laboratory of Fiona Watts, one of our superstars in cell and stem cell technologies. Two floors below there are the hospital beds where the trials can take place. It is an ideal position.

The right strategy is to pick a high-value part of the value stack and say 'this is ours; if anyone wants to play here, they have a fight on their hands and we are going to win it'.

Conclusions

After visiting these centres, I reached nine conclusions, which are in my Review:

1 The Catapults that already exist need continuing support;
2 They need set milestones, with periodic reviews;
3 There has been unanimous support for the 1/3:1/3:1/3 funding model. This is, indeed, very similar to the Fraunhofer model;
4 The network of Catapults should grow by one or two a year to end up with, say, 20 by 2020 and 30 by 2030;
5 There is a need to redouble our efforts in building relationships with SMEs;
6 Being industry-led is the correct option for the Catapults but there has to be greater emphasis on building relationships with universities;
7 We need to set new, more detailed Key Performance Indicators (KPIs) because people will work to score highly on their evaluation criteria. This aspect needs some

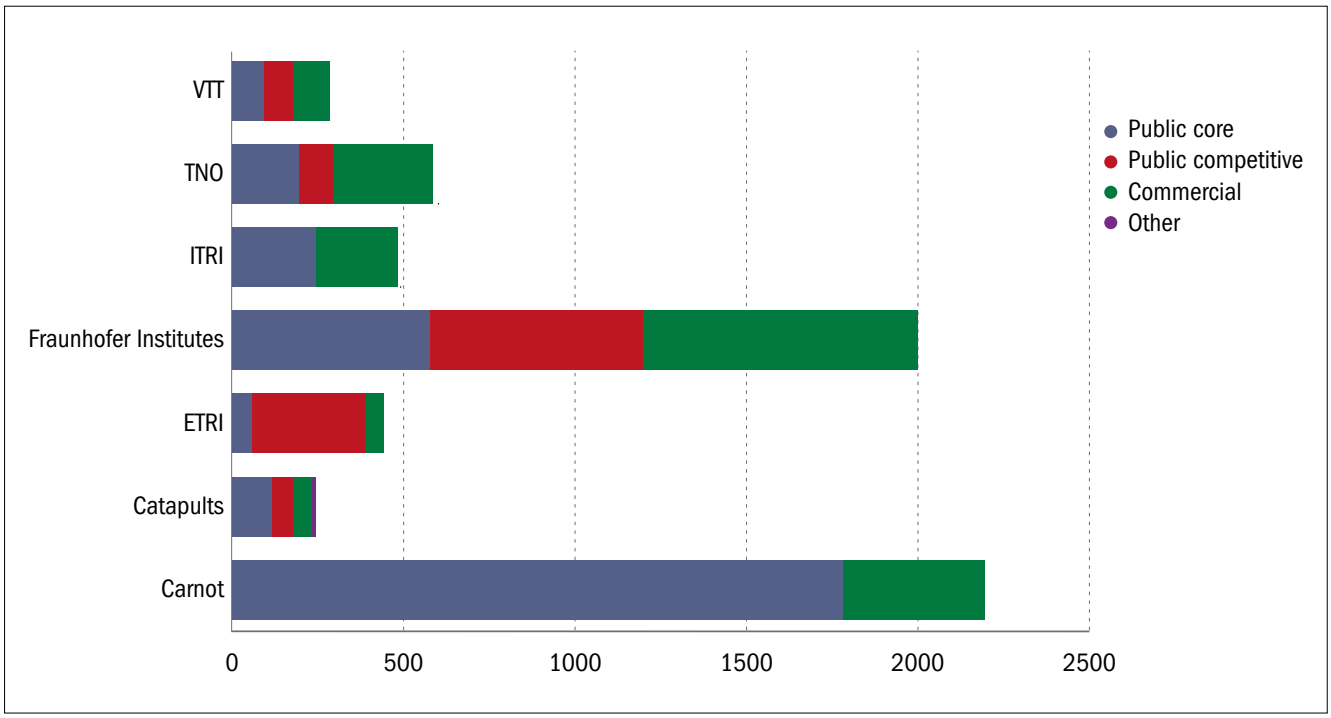


Figure 1. Funding for science-translation programmes in different countries (€ millions)
(VTT – Finland; TNO – Netherlands; ITRI – Taiwan; Fraunhofer – Germany; ETRI – Korea; Catapults – UK; Carnot – France)

thought and also more detailed collection of data. We will be working with the Open Data Institute (ODI) to get access to Government data, more easily and automatically;

8 Catapults also have a function as a 'neutral convener' within clusters – bridging the gap between universities and industry. It is still unusual for university professors to move out to industry and back (especially back!). Maybe Catapults, as half-way houses to industry, can help;

9 There are a number of Government initiatives that are 'catapult-like'. It would be a shame if the experience already gained from the first seven Catapults was not made available to these other initiatives.

Of course, none of this will go anywhere unless you have entrepreneurs and unusual people like Steve Jobs. What characteristics do they have? Well, passion is really the number one thing to look for, and unreasonable optimism that the project is going to work. The ability to lead a team is important and, of course, access to venture capital.

The next big thing?

Looking to the future, where are the big opportunities? The biggest single opportunity lies, I believe, in the health sector. It is a $1 trillion opportunity – the figure comes from a very simple back-of-the-envelope calculation. In the USA, they spend about $3 trillion a year: one-third is spent on diagnostics and keeping people out of hospital, with the remaining money going to treat people who are ill. The hope is that within the next three to five years, this balance will swing towards 50:50.

That is the most monumental change in terms of the health spend, towards keeping people out of hospital. It will be partially enabled by personalised medicine and, of course, this is increasingly linked to the internet of things and machine learning. The connection to the internet of things is obvious in that there will be so much more information about people's basic parameters like blood pressure, heart rate, respiration and skin resistance, etc.

However, in the combination of the internet of things and machine learning, in my opinion the machine learning is by far the more important. The internet of things will produce another deluge of data and there are not enough people in the world to analyse that, so there has to be an automatic technique of doing so. Fortunately, computer scientists have devised some very powerful machine learning techniques to do just that. □

Passion is really the number one thing to look for, and unreasonable optimism that the project is going to work.

Facilitating technology translation in key market areas

Simon Edmonds

Simon Edmonds is Director of the Catapult Programme at Innovate UK (formerly the Technology Strategy Board). Before moving to the TSB Simon was Director for Innovation at the Department for Business, Innovation and Skills (BIS). He was responsible for many innovation and growth reviews and manufacturing strategies, including the £2.7 billion Regional Growth Fund.

I was fortunate enough to work with Hermann Hauser on his first Report, in 2010, and went to the Technology Strategy Board – Innovate UK as it is now known – to implement it.

The UK has a globally strong academic base, huge inventive capability at universities, charitable sectors (such as the Wellcome Trust, Cancer Research, etc) and leading businesses, but there is a weakness in technology transfer. This was partly a result of the Government removing support from this intermediate sector over several decades.

To quantify the problem, Tera Allas, Director General of Economics at BIS, produced a Report in January 2014 alluding to the world-class strengths that we have in many aspects of the system, but pointing out the real and concerning weakness in the technology transfer area. It is in this area that Catapults are going to play a leading role.

Catapults are also helping to develop our skills base. There are two shining examples of that: the Advanced Manufacturing Research Centre in Sheffield and the Manufacturing Technology Centre at Ansty Park in Coventry, which is building a state-of-the-art training facility.

In terms of international comparisons, our R&D spend has been static at about 1.8 per cent of GDP since the early 1990s. However, everybody else is making strides forward. The UK has now moved from an innovation leader position within the EU, to an innovation follower – and that cannot be right for an economy of our size and ambition.

Delivering innovation

So what was the answer? The first Hauser Report looked at competitor nations in some detail: the result was a proposal for technology and innovation centres, or Catapults as they became known.

After the Coalition came to Government we made a very strong pitch for their establishment. But you have to remember the economic conditions at the time. When the Coalition came to power, one of the first things they did was enter a 60-day review period, which resulted in £6 billion of public spending cuts. Yet during that same period we managed to make the case for £200 million spending on Catapults.

IN SUMMARY

- The UK has an acknowledged strength in research but a weakness in technology translation
- The country has fallen behind in terms of innovation compared with our competitors
- The Catapult network is designed to address the translation challenge in key market areas
- The network needs to grow steadily in order to maximise the benefits to the UK
- This will require further public investment

The Hauser Review talks about expanding this network for the future: yet clearly, in May 2015, we will have a new Government. There are already debates about the level of spending cuts. Well, we have persuaded Government of the necessity for investment in this area before – we will have to do so again if we are to achieve the 30 proposed for 2030 by Hermann's Review!

Today, though, there are seven Catapults. All of them are up and running. This represents an investment over five years of some £1.4 billion in private and public-sector funding. My organisation establishes and oversees them. This has been achieved at a reasonable pace and we should be able to progress them more quickly as time goes on. There are two new ones being set up: energy systems and precision medicine.

One of the Review's recommendations was 'invest in what you have' and we are doing that. For example we are investing in cell therapy manufacturing. In the 2014 Budget, the Chancellor announced a £55 million investment in a cell therapy manufacturing centre and a further £19 million investment in graphene at the Centre for Process Innovation at the University of Manchester.

New facilities have either been opened – the second building at the Composite Centre in Bristol was opened in October by Vince Cable – or are under construction: there is a biologics manufacturing centre being erected at Darlington, a training centre at the Manufacturing Technology Centre in Ansty, and an aerospace centre. These are all capital facilities and we are

requesting an equivalent amount of resource funding from Government.

What is a Catapult centre?

These are physical centres where organisations can access world-leading technology expertise, great people and, in addition, gain the opportunity to undertake collaborative research and development projects with business or contract research from business. What we create there is a critical mass of activity.

Figure 1 shows where they sit within the system. Universities and other research centres operate at the lower technology readiness levels (TRLs). Businesses are much closer to market and the Catapult centres are in the middle, as indeed is Innovate UK, which spans that whole area.

The timeline has been quite fast because we have been establishing a brand new network. High-value manufacturing was pulled together in 2011 and there has been a steady progression of Catapults with four opening in 2013 alone, and two more to come by April 2015.

The decision on where to locate each of them is absolutely critical because these are each established as a single physical entity – apart from higher-value manufacture, which is a consortium of seven organisations. It is critical that we have a good location and we take a great deal of time determining where that location could be.

In some cases this is obvious, like Harwell for satellite applications where the European Space Agency has its Business Incubation Unit and a large part of the UK's space infrastructure is located. Even so, that Catapult has already formed three external outreach centres since it is not always possible for everybody to come to one location. Most Catapults are now thinking of developing along the lines of a national centre, but with outreach facilities. The digital Catapult recently opened in Euston Road, London, but one of its early announcements was the support of three separate nodes of activity in Sunderland, Bradford and Brighton.

So location is very, very important and while there may be some obvious gaps on the map of the UK, this is for good reasons of university engagement and clustering around businesses.

Many of the people in the Catapults have given up very significant roles to come and take part in the network, as did many of the chief executives in the first of them, the high-value manufacturing Catapult. The centres are proving to be places where people want to come and build their careers.

We have a very effective governance structure with extremely capable and prominent chairs. So Catapults really are driven by the people that work within them. We can obviously fund equipment, data facilities and great locations, but it is people that make the decisions and people that make Catapults work.

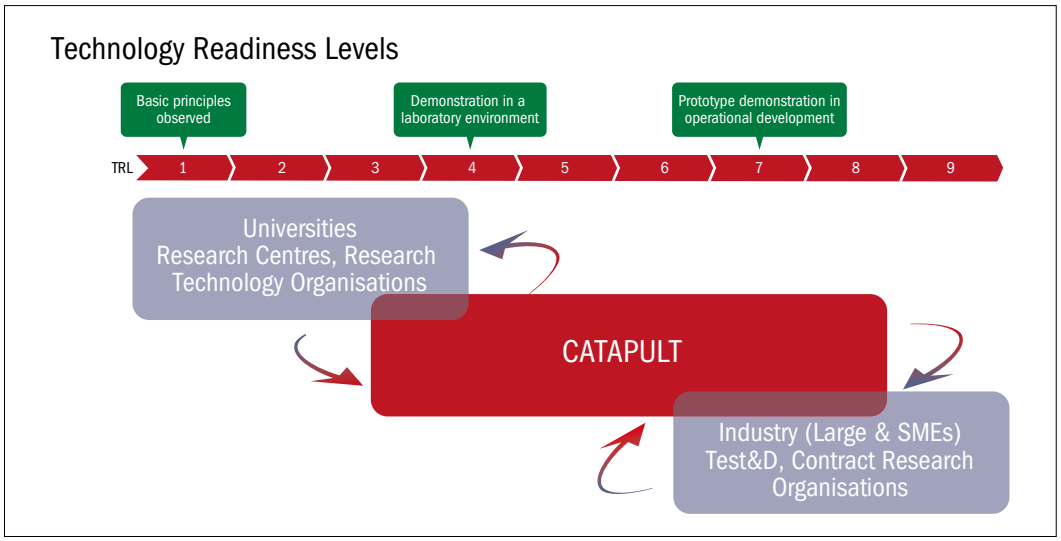
The Review

The Hauser Review was undertaken in response to a challenge from Vince Cable and then David Willetts. They asked: "What next? There are now seven of these Catapults, what should we be looking for with an economy of our size?"

The Review recommends organic growth. Growing some of the existing Catapults is one method: for example, moving from the establishment of the cell therapy Catapult to setting up cell therapy manufacturing and then inviting the industry to cluster around that location. It is like

Location is very, very important and while there may be some obvious gaps on the map of the UK, this is for good reasons of university engagement and clustering around businesses.

Figure 1. The place of the Catapults in the innovation spectrum



the Formula 1 story – keep all of the technology and all of the expertise in one place. Will we do more of that? I think we will.

Yet there are other challenges highlighted in the Review. First, there is SME engagement. There is a lot of work going on in Catapults to achieve this. We are engaging with SMEs in a number of them, but there are a lot of very high-growth businesses out there. I know, from my own experience in running SMEs before joining Government, that they just do not have the time to go and find a lot of the things that are on offer. So we recognise that the Catapults will have to do much of the work to get engagement going.

Similarly, we are getting stronger at engagement with universities and the Research Councils. We are reaching towards the research base. Each Catapult will have, typically, two structures that help inform its strategy. One will be a research advisory group while the other will be an industry advisory group.

Targets

By far the most stretching challenge is to achieve the 30 Catapults by 2030 – and 20 by 2020. This will need significant public investment. Vince Cable was recently making the case to Treasury for a doubling of the Innovate UK budget. Creating this pipeline of new Catapults is going to be very interesting work. The Fraunhofer network in Germany has been operating since 1947 and currently has 67 institutes. Yet it also has a further 51 centres in waiting, so it is not a static organisation. It is looking forward at the next areas of technology and markets.

In order to create the pipeline proposed for Catapults and deliver the network, there needs to be a robust funding model – and that will surely be a matter for discussion over the coming months. ❐

The Catapults – building the skills base

Adrian Allen

Adrian Allen OBE is Commercial Director of the University of Sheffield Advanced Manufacturing Research Centre (AMRC) with Boeing. The Centre was launched in 2001 as the result of a proposal Adrian and the University of Sheffield Professor Keith Ridgeway made for a joint venture between Boeing and the university. Prior to joining the Centre, Adrian held senior positions in the advanced tools and aerospace industries, including a period as sales director at Sheffield tooling company Technicut.

In the 10 years since we opened the first Advanced Manufacturing Research Centre (AMRC) building, a thousand direct jobs have been created. The site has become home to two founding members of the Advanced Manufacturing Catapult. Yet a little over 30 years ago, it was a derelict slag heap where striking miners, led by Arthur Scargill, were facing lines of police in a battle over jobs.

I believe the ultimate reason we are building the Catapults today is to create significant numbers of sustainable jobs. Those jobs have been created through university-led innovation, developed with both local industry and global players.

Companies attracted to the area by the presence of the AMRC include Rolls-Royce, which has invested in a new factory to manufacture single-crystal turbine blades here.

We have turned a sow's ear into a silk purse and we are very proud of what has been achieved, but it could not have happened without the Department of Trade and Industry (DTI), the Department for Business, Innovation and Skills (BIS) and now Innovate UK.

What has become the AMRC began with no funding support from anyone. However, the Regional Innovation Unit for Yorkshire saw the potential and helped to get the ball rolling.

The AMRC was born out of frustrations surrounding technology transfer. In those days, it was virtually impossible for innovative small firms to sell their products or ideas into big multinationals. Trying to convince a global giant that there is a better, quicker, cheaper, safer and greener way of creating their systems is not easy, particularly if your disruptive product competes with theirs by lasting longer: it eats into their profit. But I think

IN SUMMARY

- Success can be measured in terms of the creation of sustainable jobs
- Start-ups face an almost impossible task trying selling their innovation into large businesses
- Catapults have the capacity and capability to help transfer technology
- Catapults have significant regional impacts as well as national ones
- Catapults are an important vehicle of job creation

there is a way of overcoming this difficulty.

I had experienced the frustrations at first hand, with a new cutting tool, developed to speed production and cut the cost of components for the Joint Strike Fighter. The tool worked 12 times faster than anybody in the major aerospace manufacturers thought that it could. Boeing picked up on the idea, but I could not make a sale because it is impossible for a large company to put its trust in a start-up.

However, I saw an article by Boeing's Chief Technical Officer (CTO) who said he had people scouring the world for the best, quickest, cheapest, safest, easiest, greenest way of making parts and his wish was to create an unbiased source of information, a centre of excellence to accelerate this quest.

Centres of excellence

He proposed setting up centres in key areas of his business such as air-traffic control and avionics. We bid for one in advanced machining and the AMRC started to take off.

How do you create a centre of excellence – one with the capacity to undertake the work, the capability to do it right, and the commitment to do something different? It is not easy as stakeholder needs can differ greatly – sometimes the needs of Government, universities and industry differ and conflict. Governments may want job creation, a university wishes to move up the rankings while industry wants profits, seeing reduced R&D and low labour production as enablers. Workers want still other things. So, how to develop a clear-cut proposal that offers benefits for all and no conflict?

Sheffield had historically built a global reputation for excellence in steel and manufacturing and 55 per cent of local jobs were in manufacturing. However, many of these were traditional craft-based industries and the technological revolution in the last century saw new technologies and CNC machines replacing traditional methods, with 92,000 manufacturing jobs eventually being lost.

To stay in business, it is necessary to remain at the forefront, with new tools, techniques and technologies, so there was a local need for the kind of change a centre of excellence could bring.

The Sheffield region had the essential capacity, capability – and most importantly the commitment to invest. So we approached the DTI and our Regional Development Agency and the plan gathered momentum.

Capability entails having the best people, best product, processes, plant and equipment. We must have those if we are to entice the world's best to come to Sheffield – and keep them here. Since the launch of the AMRC, the same process has been replicated and Sheffield is now home to two of seven such centres of excellence that make up the UK's High-Value Manufacturing Catapult.

Demand for our services is such that, today, we face the problem of competition between existing and potential AMRC partners. If one major aero-engine manufacturer is a partner, it can be difficult to do joint development work with another. There are ways to overcome this, though, and as a commercial director I do not want to turn down dollars that create sustainable wealth and jobs in my region.

Regional impact

All the Catapult centres have significant regional impact. SMEs are important but there are so many of them and there is a cost to engagement. It costs just as much to visit a one-man-band as it does to go to a billion dollar business. That does not mean we underestimate the importance of smaller businesses, but the costs – in terms of time and money – have to be taken into account. So we need to do things slightly differently in order to engage effectively. It is important to realise that when we help a large company such as Rolls-Royce win a massive order, this creates jobs for SMEs in Ansty, Derby or wherever in the UK, as for reasons such as locality and responsiveness, big firms will engage smaller companies.

The Government is quite rightly focussing on growth and jobs. New tools, techniques and technologies can be the worst thing for jobs because they are often not labour-intensive. Take an aircraft bulkhead that used to have 44 riveted parts in the old days – a new version has six. That means the fixtures and the jigs that go with it come down from 53 to five. Crucially, 50 assembly workers come down to five. So how does that create jobs?

New opportunities

That bulkhead now costs 73 per cent less, so we can generate more sales, more profit – and more jobs – for the same investment. Do nothing, do not invest in the future, and the final five assembly jobs will go.

We often talk about next-generation manufacturing but where are the next generation, the new engineers coming from? All the Catapults have a wealth of good, skilled young people working in them. We have hundreds of home-grown, British-educated scientists and businessmen, but now we also have apprentices who have been given a phenomenal opportunity thanks to our Catapults.

Success by my definition can be measured in new jobs. We now have just over 280 youngsters between 16 and 22 actively engaged in paid-for, fast-track apprenticeships – on a former slag-heap! And we plan to take on and train a further 250 year-on-year, with every one backed by industry. ❐

In order to create the pipeline proposed for catapults and deliver the network, there needs to be a robust funding model.

The debate

Issues raised in the debate included:

There was some debate on the locations of the Catapults with some in the audience commenting on their absence from the South West, Wales and Northern Ireland. Others, though, stressed the importance of ensuring that the Catapults were placed where they could be most effective.

It was argued that innovation prospers best in clusters and that clusters take a very long time to mature. Successful clusters emerge in locations where there is a readiness by academics to engage with commerce and industry and where, on the other hand, commerce and industry are open to innovation and collaboration, rather than insisting on keeping traditional patterns of work.

Commercial exploitation

Some speakers were concerned that Catapults could undermine the important contribution being made by Research Technology Organisations (RTOs) in eliminating the 'translation gap'. Some also challenged the suggestion that privatisation of RTOs had diminished that contribution. It was also argued that there could be mutually beneficial collaboration between RTOs and Catapults.

The discussion also considered whether the current management of the Catapults adequately reflects the gender balance of the UK. There are no women at leadership level although there are some in non-executive positions at Board level. Although recruitment processes were open, the Panel acknowledged the desirability for the centres to recruit more women at a senior level.

There was disagreement about whether the evidence for judging the benefits claimed for Catapults is yet available. The Panel acknowledged that, although some of the seven have scored important successes, and all are equipped with high-quality staff and infrastructure, the initiative is still relatively new and so "the jury is still out".

The Hauser Review made an important recommendation that Key Performance Indicators should be agreed. The aim has to be to devise measures which would give the Catapults the right goals and incentives while still ensuring that they work ahead of the market. If continuing funding support from both Government and industry is to be assured, they need soon to produce hard evidence of their value and successes, particularly in comparison with other options for exploiting research.

Intellectual property issues (which can be a big concern of universities) must not be allowed to impede the work of the centres to facilitate successful innovation and commercial exploitation. Collaboration with the Research Councils seems to be working well and this initiative is important for all parties.

Commercial exploitation

The Catapults are making a valuable contribution to skills training through apprenticeships. And university research students are working in, and being supervised by, the Catapults. However, the longer-term jobs created by successful commercial exploitation facilitated by Catapults is likely to be far greater than the shorter-term jobs created in the centres themselves. □

Intellectual property issues (which can be a big concern of universities) must not be allowed to impede the work of the centres to facilitate successful innovation and commercial exploitation.

FURTHER INFORMATION

Review of the Catapult Network: Recommendations on the future shape, scope and ambition of the programme *by Dr Hermann Hauser CBE FRS FREng FInstP*
www.gov.uk/government/news/hauser-report-calls-for-long-term-expansion-of-catapult-network
Catapult Centre Network
www.catapult.org.uk
Innovate UK
www.gov.uk/government/organisations/innovate-uk
University of Sheffield Advanced Manufacturing Research Centre (AMRC)
www.amrc.co.uk

Scotland's research community needs to agree priorities for the future and identify how to maximise the contribution of research and innovation programmes to the economy. A meeting of the Foundation, held jointly with The Royal Society of Edinburgh on 29 October 2014, discussed these challenges.

What makes a good science policy?

Muffy Calder

My role as Chief Scientific Adviser primarily concerns science for policy, not policy for science. By 'science for policy' I mean using scientific principles and evidence to shape policies. So I want to look at the questions we need to ask about science policies and how the resulting evidence can be applied.

The question being addressed is: 'How can we maximise the strengths of our research and innovation base in Scotland?' Before it can be answered, it needs to be unpicked a little.

First, what are Scotland's strengths in these areas? How can they be measured? Who or what would be the beneficiary if specific aspects were maximised?

We need to consider what has been done in the past, what worked and what did not work so well. These are all pretty big questions. It is not possible to go into all of them in great detail here, but it may be valuable to delineate some of the parameters.

Everyone has their view of Scotland's research strengths. Here is my personal list:

- biosciences (specifically, the life sciences of pharmaceuticals, animal breeding and health);
- biotechnology, bioinformatics, systems and synthetic biology;
- regenerative medicine;
- sensors, imaging systems and quantum technologies;
- e-health and linked data initiatives;
- stratified medicine;
- renewable energy, especially marine aspects;
- computer science and informatics;
- nanoscience and nanofabrication engineering, in particular facilities such as the James Watt Nanofabrication Centre in Glasgow, which is unique in the UK;
- fundamental physics;
- Peter Higgs and all the particle physicists who are working to prove the theories.

IN SUMMARY

- Eight innovation centres set up under the Scottish Funding Council
- Synthetic biology identified as an opportunity for Scotland
- Perhaps we should fund distributed centres of excellence rather than critical mass at one institution
- Timescales for infrastructure vary across different disciplines
- We must foster greater diversity

What measures are important to us? Again, this is my own list, which only shows a selection of the parameters that may be relevant:

- jobs;
- numbers of people involved in science and engineering;
- number, size and types of organisations;
- financial contribution to GDP;
- the number of international scientists (as a proxy for the excellence of science and engineering that happens in Scotland);
- paper citations and patents;
- new career-workers entering the field;
- diversity of the workforce;
- new companies and inward investment.

The beneficiaries of a strong science and innovation base (which will influence which aspects we want to maximise) could include:

- the economy – a simple word but a very complex beast;
- the wellbeing of people who use the results of science and engineering;
- the wellbeing of the scientists and engineers themselves, and their personal fulfilment through the pursuit of science and engineering;
- science and engineering itself as a body of knowledge;

Professor Muffy Calder OBE FRSE FREng FBCS was Chief Scientific Adviser for Scotland at the time of this meeting and is Professor of Computing Science at the University of Glasgow. She was previously a Royal Society Leverhulme Research Senior Fellow and Dean for Research in the College of Science and Engineering at the University of Glasgow.

- companies, both large and small, and where they base themselves (within the UK or abroad).

Strengthening science and innovation

What has already been done to strengthen science and innovation in Scotland? Take three recent initiatives. First, and one of the most significant, was the setting up of eight innovation centres within the 'Innovation Scotland' framework. They focus on stratified medicine, digital health, sensors and imaging, oil and gas, data science, industrial biotechnology, construction and aquaculture. They are all funded by the Scottish Funding Council and are industry-led. Their aim is to bring together more closely the work of university researchers and the industrial community.

Second, the Scottish Science Advisory Council published a report on synthetic biology. Its goal was to highlight the opportunities for this new area of science in both the environment and the economy. It looks at the opportunities for fundamental science, industrial biotechnology, medicine and health, energy and agriculture in a Scottish context. The report concludes that there has been great progress, particularly with respect to platform technologies for synthetic biology, and there is still everything to play for. The challenge now is building on this progress and seeing the results.

The third initiative concerns people, specifically recruiting and retaining the best and brightest into STEM subjects. Progress in this area over the past decade has been impressive. During the nine years up to 2012/13, the number of degree students in engineering, mathematics, life and physical sciences rose by between 40 and 60 per cent depending on the subject – physical sciences topped the list with an increase of 63.8 per cent.

However, we must not become complacent: during the same period the number of business administration students swelled to twice the number of engineering students. The number of law students well exceeds the number of physical science students and the number of economics and politics students increased by 75 per cent, to more than twice the number of students of mathematics. Finally, the number of IT students fell by 58 per cent. So, although the increase in science students is very encouraging, it needs to be seen in context.

Scotland currently has four universities in the Times Higher World Top 200, so we are already doing something right. We need to continue that and enhance that.

What can we learn from other countries? Two countries that stand out are Israel and Finland, for different reasons. In Israel, all young people are conscripted and some of their top scientists work in specialist science and technology units. When they finish, many go on to set up a small company to commercialise the work they did in the unit. This is a very interesting model, although not one I necessarily think we should adopt.

Finland, on the other hand, uses a very different model. It has been highly successful through large companies such as Nokia over the past decade, but they too are concerned about changes. It has set up initiatives to encourage innovation and the growth of small companies, as we have in Scotland. One of their key messages, I understand, is not to forget the scientist. Initiatives that focus too much on mechanisms in order to achieve specific goals, may be less successful, ultimately, than initiatives that fund individuals to pursue goals that are important to them.

Funding mechanisms

The Research Councils are increasingly funding research in terms of 'critical mass'. But to what extent does that critical mass need to be in one institution?

Many topics can be pursued in a distributed fashion and in Scotland there is a long history of doing that successfully, particularly in areas other than the life sciences. I am a little worried that we are trying to apply the life science model to all the other sciences – that may not work so well. Strong clusters and good mobility between groups are important here. Factors such as the speed of the trains between Glasgow and Edinburgh are relevant.

Funding mechanisms also need to accommodate the different timescales needed to establish infrastructure in different types of science. For example, high-energy physics may need a 20 to 30 year timescale, life sciences five to 10 years, while computing science may only require one year or even less.

There needs to be a mixture of funding mechanisms – funding for thinking, for tools, for empirical investigations. Although people may prefer bottom-up funding mechanisms, top-down funding has benefits too: offer finance for a particular topic and researchers may be motivat-

There needs to be a mixture of funding mechanisms – funding for thinking, for tools, for empirical investigations.

ed to come up with possibilities for new science that had not been thought of before.

People

Last but not least, we must not forget people. It is essential that we encourage diversity, both in terms of age and gender. Recently there has been a much greater emphasis on young career researchers, which is good. However, for many scientists, the forties are their golden years, the time when they consolidate everything they have done and set the scene for the next two decades. The middle-aged scientists should not be forgotten! They must be allowed to flourish and be protected from becoming ground-down by other responsibilities.

As for gender, the news is not good. In university entrance for engineering technology subjects, the male-to-female ratio is 85.5 per cent and in computer science it is 81.7 per cent. We must encourage more girls into these subjects, they are missing the opportunity to participate in key science and engineering disciplines, and those disciplines are missing their possible contributions. It is interesting to note that I sit on an EU future and emerging technologies advisory committee and the countries I mentioned earlier in being outstanding for support of scientists, Israel and Finland, are both represented by women.

To recap, we need to identify the potential beneficiaries of a strong science and innovation base as they will influence which aspects we decide to maximise. Scotland's innovation centres must be allowed to run and develop – it is important not to tinker with them too much. We should set them up, let them go and see what they can do. These things take a long time to get going so we should not be unrealistic in our expectations.

Finally, and most importantly, do not forget the individual. We not only need to support good individuals in doing good work, but we need to trust them to deliver. □

Changing the innovation landscape

Alice Brown

The Scottish Funding Council supports science and innovation in Scotland in different ways. It works within a dual support system that involves two types of bodies: the Funding Councils for the different parts of the UK as well as the Research Councils (RCUK). Charitable bodies such as the Wellcome Trust and Cancer Research UK also contribute valuable funding for research.

The Funding Councils supply the resources (driven by Research Assessment Exercise results) that support the capacity of higher-education institutions to carry out research. The Research Councils provide funding for activity, largely on a competitive basis. Their focus is on strategic research and outcomes, supporting critical mass and centres of excellence, and encouraging multidisciplinary collaboration. An important goal is to provide a highly-skilled workforce as the basis for economic growth and sustainability, and to support national capability in essential disciplines.

As part of this approach, RCUK focuses on six cross-cutting themes: the digital economy; lifelong health and wellbeing; living with environmental change; global uncertainties; nanoscience; and energy. It covers arts and humanities as well as sciences: it is important not to forget the relationship between science and non-science fields.

IN SUMMARY

- Scotland's success in securing funding reflects the high quality of its research
- Recent experience highlights the need for more collaboration between academic research and business and industry
- Innovation Scotland has a focus on research pooling
- Innovation Centres will create open communities of university staff, research institutes, businesses and others
- There has been a shift in the innovation landscape towards an increased emphasis on the impact of research beyond the academic arena

Strategic approach

The Scottish Funding Council's strategic plan includes eight outcomes, of which three are central

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Capital funding should be balanced to cover the spectrum of research engagement, from contributing to large-scale international projects through to supporting small- to medium-sized ventures.

to research and innovation: a developed workforce; an internationally-competitive research base that is improving its reputation and standing in the world; and collaboration between universities and industry for the exploitation of research.

In terms of a research and innovation strategy, there have to be some underlying features. First, science (research) budgets should be protected ('ring-fenced'). There should be an appropriate balance between fundamental and applied research, at the same time ensuring that research is 'translated' whenever possible. Research funding should, to a large extent, be competitive, with decisions governed by the Haldane principle (merit must be the only criterion of selection for projects). Our framework of dual support should be maintained, and research excellence should be supported, which may mean a concentration of resources.

Capital funding should be balanced to cover the spectrum of research engagement, from contributing to large-scale international projects such as the Large Hadron Collider and the Square Kilometre Array, through to supporting the small- to medium-sized ventures that are essential to high-quality research in universities. Whole-life costs of equipment, such as maintenance and technical support, need to be covered. Finally, we need to continue to invest in the best people and support skills development. The international mobility of students and researchers must be facilitated. Research and business interactions are essential.

Within this framework, does Scotland need a separate science and innovation strategy? There is no shortage of research and innovation strategies; there are many in place, published by such diverse bodies as the Medical Research Council, the Department for Business, Innovation and Skills (BIS), Life Sciences Scotland, the Natural Environment Research Council (NERC) and many others. Provided Scotland can influence such strategies, it could be argued that Scotland's requirements are covered. In addition, Scotland's key industry sectors have set out their own innovation strategies.

Engagement

Scotland's success in securing research funding emphasises the quality of its research work. As elsewhere in the UK, its universities account for a significant proportion of this, thanks to their continuing ability to attract the world's top talent, as well as investment by Government and the institutions themselves.

However, over the past decade we have seen a shift in the innovation landscape towards an increased emphasis on the impact of research beyond the academic arena. This highlights the need for more collaboration between business and industry. Scotland's investment in higher-education R&D as a percentage of GDP is in the top quartile of OECD countries. In striking contrast, our business expenditure in research and development as a percentage of GDP is near the bottom of the lowest quartile. Clearly, there is a need to stimulate more companies in Scotland to invest in R&D, and to ensure that the R&D carried out in our higher-education sector makes a contribution to supporting innovation in businesses and thus support the wider economy.

This need is being addressed by the 'Scotland Can Do' framework launched by John Swinney, the Cabinet Secretary for Finance, Employment and Sustainable Growth, in 2013. This framework is designed to be aspirational. It recognises the need for highly skilled, innovative, entrepreneurial people and the importance of closer engagement between academia and industry in order to drive innovation. It sets out to encourage an increase in entrepreneurship and innovation activity by individuals and businesses, so that more businesses are formed and existing businesses launch more products and services. It supports people from all walks of life who have the ambition and skills to create, lead and grow successful businesses.

The framework puts entrepreneurship and innovation at its core, seizing the opportunities offered by Education Scotland's 'Curriculum for Excellence', college reform and the world-leading strength of Scottish universities. It aims to commercialise more of Scotland's knowledge and intellectual capital to increase collaboration between business and the academic sector. This should lead to a greater focus on, and share of, global markets as Scottish business leaders grow in confidence and expand their horizons internationally.

The innovation landscape

During the past four years, the SFC has increased its support for innovation, working closely with Scottish Enterprise, Highlands and Islands Enterprise, and colleagues in the Scottish Government. In this context we have been developing 'Innovation Scotland' to build on past and continuing investment. Innovation Scotland is an overarching framework for a range of investments that are designed to support high-quality research and its translation for the benefit of the economy as well as the health and wellbeing of the people of Scotland. In this it supports the Scottish Government's statement of purpose: 'A more successful

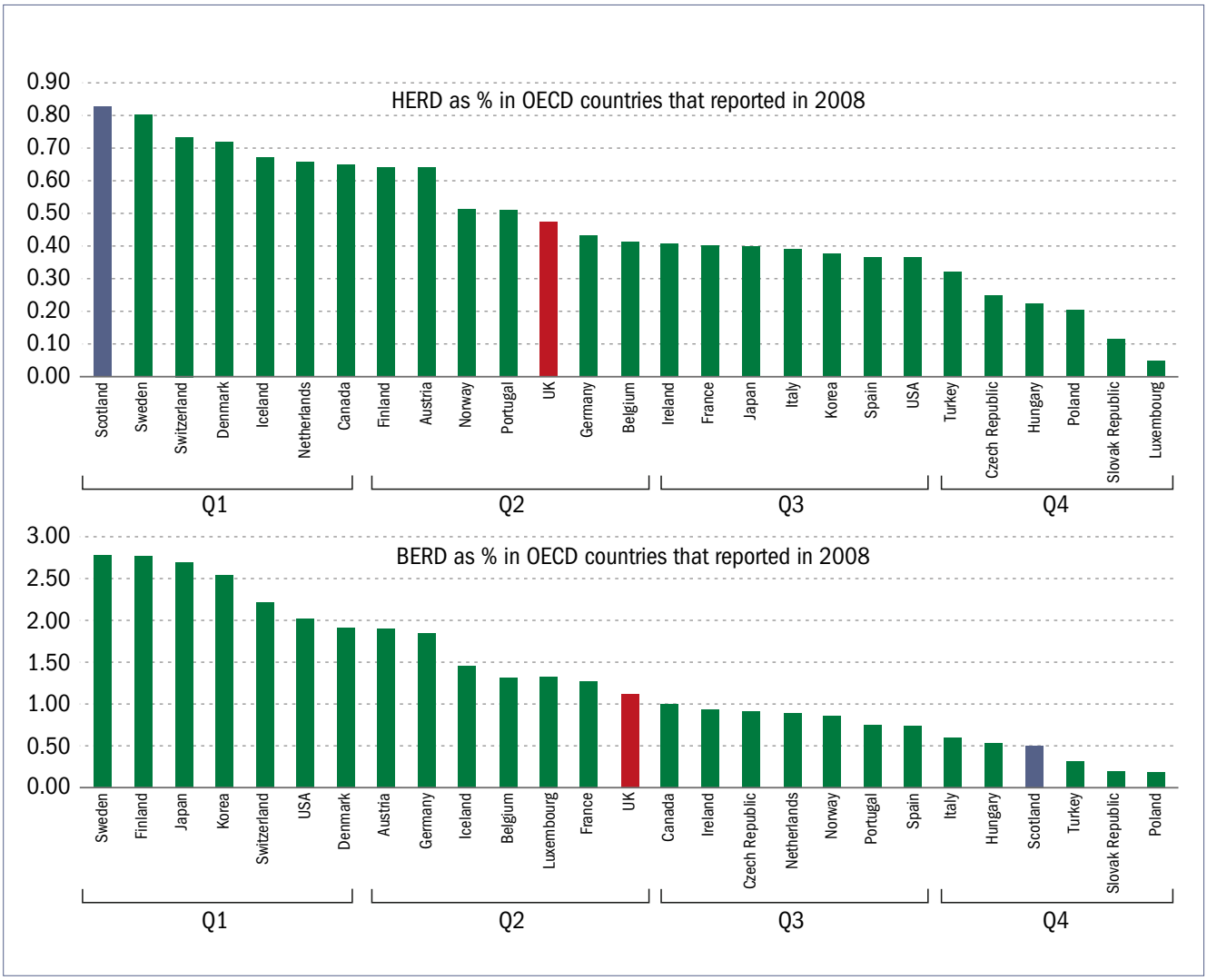


Figure 1. Higher-education R&D expenditure (HERD) and business R&D expenditure (BERD) as a percentage of GDP in OECD countries (2008)

country, with opportunities for all of Scotland to flourish, through increasing sustainable economic growth'.

The 'Innovation Scotland' programme focuses on an important feature in the innovation landscape: research pooling. Designed to support excellence, build critical mass, and increase competitiveness and leverage, research pooling also provides state-of-the-art shared facilities and delivers high-quality training.

Importantly, it also facilitates culture change, in particular greater collaboration and more partnership working. The Max Planck International Partnership, for example, now links five of our universities with five Max Planck institutes. The Innovative Medicines Initiative places Scotland at the heart of European drug discovery initiatives. There are several other examples of partnership working that have come about as a result of this culture change.

Our most recent and high-profile development is the Innovation Centre Programme. Innovation Centres will support skills and training to develop the next generation of researchers and knowledge-exchange practitioners. They will create sustainable and internationally-ambitious open communities of university staff, research institutes, businesses and others to deliver economic growth and wider benefits for Scotland.

The Scottish Funding Council has committed, in principle, £110 million of core funding for the Innovation Centres between 2013 and 2018. Each Innovation Centre is expected to obtain further investment from industry and other sources of public funding. We now have eight: the Digital Health Institute; Stratified Medicine Scotland; the Centre for Sensor and Imaging Systems; Industrial Biotechnology; the Scottish Aquaculture Innovation Centre; the Oil and Gas Industry Centre; the Construction Scotland Innovation Centre; and the Datalab. Two more are set to open shortly. These centres will become an important part of the Scottish innovation landscape. □

A time of challenge and opportunity

Anne Richards

Anne Richards CVO CBE is Global Chief Investment Officer for Aberdeen Asset Management. She began her career as a research fellow at CERN, the European Organisation for Nuclear Research and moved into the investment field in 1992. Anne is a Chartered Engineer and a Fellow of the Chartered Institute for Securities and Investment. She is a member of the Financial News List 100 Women in Finance and a member of the Board of Leaders of 2020 Women on Boards.

IN SUMMARY

- We are becoming a knowledge economy, driven by innovation and intellectual capital
- We need to maintain a skilled workforce
- Universities and colleges must deliver the necessary skills
- Scotland has one of the highest numbers of life science graduates, per capita, in Europe
- Our approach has to be strategic, opportunistic and flexible

It is a daunting challenge to try and condense what every shape and form of business might want from a science and innovation strategy. I will start with a UK perspective before moving on to look at Scotland in particular.

There are three issues that are key to a successful science and innovation strategy: business itself, through its own drive for innovation and advancement; a skilled and talented workforce that is the product of our education system; and public policy initiatives that provide the framework and environment to allow the first two to flourish.

We work in a global economy and must adapt to stay competitive. Technology has permeated every aspect of our lives and continues to shape our business and personal lives. It is estimated that by 2020, there will be 7.7 billion people in the world but they will be vastly outnumbered by the number of devices connected to the internet, estimated to be about 30 billion by then. Currently, Google processes 3.5 billion searches every day. This demonstrates the potential for businesses to grow through e-commerce and digital marketing. Technological advances mean that businesses of any size and in any location can reach a global customer base, but this also means that competition is fierce.

The UK is ranked as the ninth most competitive country in the world by the World Economic Forum and scores highly in 'adopting technology to enhance productivity'. In 2013, we had the second greatest stock and flow of foreign direct investment in the world, beaten only by the USA. However, this has much to do with language and time zone, so we should not be complacent. Importantly, we need to make sure that it is not just large businesses that benefit from our science and innovation strategy. Small businesses and entrepreneurship are vital to the health of the economy.

The economy is changing

The structure of the UK economy is changing. We are becoming a knowledge economy, powered by innovation and intellectual capital. What drives a knowledge economy? The four key knowledge sectors in the economy most usually mentioned are low carbon, the creative industries, electronic manufacturing services, and knowledge-based business services – all sufficiently broad that they cover a multitude of sins or, more accurately, employ them.

Perhaps it is more relevant to look instead at what this means for the occupations of individual workers, rather than the industrial sectors in which their businesses sit. The march away from machine operatives and skilled trades to professional, managerial and technical work is very marked. It is therefore vital that we address the issue of maintaining a skilled workforce, partly to head off rising inequality in the population and partly to ensure a sufficient number of skilled workers to support business and economic growth.

There is increasing employer demand for higher skills. Among private-sector businesses, 60 per cent believe they will need more highly skilled workers over the coming three to five years. This is most pronounced in engineering, high-technology and science firms, where 80 per cent predict a growing need. However, manufacturing and construction are not far behind, with over 70 per cent of firms predicting they too will need more highly-skilled workers. Even in retail and hospitality, which might be viewed as relatively low-tech, the figure is over 50 per cent.

According to the Royal Society of Chemistry, in 10 years the chemical-using industries will require employees to be more highly-skilled and technologically literate to enable them to work more flexibly. The Science Council estimates that the ICT workforce alone will grow by 39 per cent by 2030. Translating these desires into concrete numbers results in estimates of an almost

40 per cent increase over the next 15 years, or around three-quarters of a million additional digitally-skilled personnel between 2013 and 2017 – these are huge numbers. Clearly, in terms of job creation and (from a Government perspective) future taxation potential, we will reap many benefits if we can meet these needs.

It is interesting to see how low the demand is in the public sector, by comparison. Perhaps that is something that should give Government pause for thought. Arguably, the NHS, our school system, even our police forces and local authorities are ripe for change.

Overcoming skills shortages

Two-thirds of business leaders believe that faster growth in their organisation will lead to a shortage of necessary skills. Already, nearly 60 per cent of employers say that they are faced with this challenge. Microsoft reported that there were 100,000 unfilled vacancies in its partner companies across the UK last year. This seems madness in a world where we are concerned about unemployment.

Despite this, almost a quarter of parents believe that digital skills are irrelevant to their children's future. As a mother of teenage sons, I have quite a lot of sympathy with those who feel that arguments about the relative merits of 'Clash of Clans' (a video game) versus those of quadratics and calculus can be stretched to breaking point at times, but anyone who is excluded from the digital world for economic or other reasons is going to find the workplace a much tougher environment once they leave school. By some estimates, over 80 per cent of jobs will soon have some tech component.

Therefore, we now have three challenges before us:

- getting the right science and technology education in schools;
- getting the right education through our universities and colleges;
- reskilling and upskilling older people as they move through careers that could last 30 years.

Each of these challenges has its own particular characteristics. At school level, we rely on teachers who themselves may not be well-equipped in the rapidly changing world of technology and science. We need to find new and imaginative ways of delivering up-to-date knowledge. For example, in terms of technology, children often learn best from those who are just a few years older than themselves, who may possibly still be in school or at university. Can we harness unconventional ways of teaching that have the dual benefit of delivering effective education in technology while relieving pressure on the already overburdened teaching profession?

Universities and colleges

We need to address two questions in our universities and colleges. First, are our specialist computer science and science courses delivering the skills that employers are looking for? Although some courses have extremely high employment rates six months after graduation, others are inexplicably low. There needs to be a better understanding of why some courses are failing to meet employer requirements. We also need to acknowledge that in a digital age even subjects seemingly unrelated to technology and science may benefit from including these areas in their curricula. For example, in the creative arts an understanding of web design could be a key area. In psychology or neural science, understanding artificial intelligence-based approaches to research, and vice versa, might be vital. Are we doing enough to encourage this type of cross-curricular rigour?

Second, how can we ensure that workers continue to keep their skills up-to-date after they have left the formal education sector? Longer, and indeed multiple careers over a lifetime, mean that people will continually need to reskill and upskill. Ongoing investment in keeping people skilled will ensure that they are less vulnerable in the labour market.

A very valid argument can be made that employers are not doing enough to provide the vocational and apprenticeship approaches that seem successful in other countries. Germany is an oft-cited example, but it has its own challenges with new business creation, so this approach is not a panacea for every economic ill. One of the most encouraging developments over the past few years has been the increased emphasis on apprenticeships but there is much more still to be done here.

In Germany, more than half of young people choose vocational education. In Austria and the Netherlands, the figures are even higher, at 67 and 71 per cent respectively. By contrast, in the UK only 32 per cent of young people choose vocational education. As part of an integrated training and development strategy, an apprenticeship scheme is an ideal way for organisations to develop their talent pipelines.

Businesses also need to take responsibility for retraining their existing staff, including financing external training courses.

Other developments where industry and the higher-education sector could work together more include the provision of specialist education, such as MOOCs (massive open online courses, open to all and which can be studied anywhere). These can be in science, other areas of research, or more basic 'tech for non-techies'. 'Learn while you earn' programmes are of increasing importance

How can we ensure that workers continue to keep their skills up-to-date after they have left the formal education sector? Longer and indeed multiple careers over a lifetime mean that people will continually need to reskill and upskill.

and employers need to embrace them more fully.

One particular aspect of this problem, which is worse in the UK than many countries, is our poor record in attracting girls and young women into science, engineering and technology. The current gender imbalance in high-tech is extremely damaging. We are wasting half of our potential brainpower by failing to tackle this: if left unchallenged it will greatly diminish our economic potential.

Scotland's advantages

Much of what I have discussed so far is not specific to Scotland. They represent generic challenges that are faced by every country in the world in some shape or form. The interesting question is whether Scotland has any unique advantages upon which it can capitalise, in order to increase its growth potential and produce a better-skilled workforce.

Personally, I believe that we do. Scotland has five of the top 200 universities in the world. Globally, in fields such as biotechnology, optoelectronics, artificial intelligence, computing and many other disciplines, we have a world-class reputation. Our fossil fuel industry has made us a leader in the development of new technologies.

Scotland was an early entrant in the field of informatics and data science. The Research Excellence Framework results confirmed Edinburgh's position as the largest and best informatics research centre in the UK. Informatics at Edinburgh delivers more world-leading research than anywhere else in the UK. In the chemical sciences, Scottish outputs and citations rank among the highest when adjusted for its size. Our very long legacy of scientific and medical research puts us in a prime position to lead in the field of global health. Finally, in terms of education, our devolved powers mean that we have the flexibility to respond imaginatively to the challenges of the 21st century, with scope to explore novel approaches.

Having the skills and education needed to service existing businesses is an important benefit, but perhaps more important is the creation of new businesses. The University of Edinburgh is ranked second in the UK in terms of the volume of intellectual property (IP) spin-out company formations. Between 2003 and 2012, Strathclyde was ranked second in Scotland and fifth in the UK for this type of activity. The University of Dundee has now spun out over 25 companies, many reflecting strengths in life sciences, medical devices and engineering.

However, the picture is a bit less positive when we look at the number of new start-ups coming out of the higher-education sector – that is, businesses formed by staff or recent graduates. This seems to suggest we generate ideas brilliantly, but could use more support for starting new companies.

Overall, we have reason to be optimistic. When compared with the USA, and when research income is normalised, Scottish universities have more new technology disclosures, licences and spin-outs than their American counterparts.

Health

Global health is one of the most critical issues on the agenda of world leaders – and not just because of the current tragedy of Ebola. Life sciences are key to a range of areas from healthcare to agriculture and from energy to food and beverages. Here again, Scotland is strong, with one of the highest numbers of life science graduates per capita in Europe.

Over the past 20 years there has been a growing relationship between big pharmaceutical companies and the biotech industry. This has reinforced the importance of academia in driving innovation in this sector. But – and it is a big but – life sciences start-up investment in Scotland appears to fall dramatically short, as a proportion of total UK investment. Over 80 per cent of life science start-up investment is in London, the East and South-East of England, although these areas together have only about 40 per cent of the total academic research power of the UK.

This highlights another problem that we have in Scotland. We are good at generating ideas and good at forming new companies to exploit those ideas, but poor at scaling them up from a handful of employees to major employers. This has to change: we need to find a better way of linking academia and pharmaceutical companies together in mutually-beneficial research collaborations in order to feed the future pipeline. Despite the lack of current investment, most investors acknowledge that there is still huge potential in the biotech and pharmaceutical markets.

What makes a successful strategy?

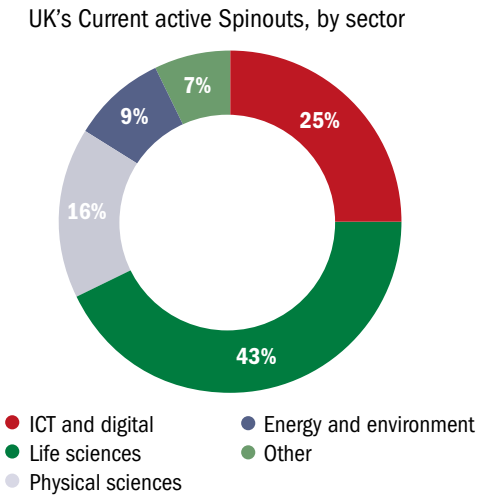
From a business perspective, a successful science and innovation strategy needs to include a cradle-to-grave approach to skills and education. It needs

FURTHER INFORMATION

Stratified Medicine, Digital Health, Industrial Biotechnology; Aquaculture, Sensors and Imaging, Construction, Data and Oil & Gas
http://news.scotland.gov.uk/News/-14-million-for-Innovation-Centres-1002.aspx
Aberdeen Asset Management www.aberdeen-asset.co.uk
Research Councils UK www.rcuk.ac.uk
The Royal Society of Edinburgh www.royalsoced.org.uk
Scotland Office www.gov.uk/government/organisations/scotland-office
Scottish Funding Council www.sfc.ac.uk
Scottish Government www.gov.scot

New Spinouts			
	2011/12	2012/13	change
England	125	101	−19%
Wales	17	15	−12%
Scotland	**27**	**26**	**−4%**
N. Ireland	6	8	33%
	175	150	

New Start-ups			
	2011/12	2012/13	change
England	2,415	3,146	30%
Wales	256	246	−4%
Scotland	**142**	**172**	**21%**
N. Ireland	0	0	
	2,813	3,564	



UK active spin-outs by sector

to break down barriers between business and academia. It should recognise that many non-STEM industries need employees with STEM skills. It needs to have a means of bridging the capital gap often faced by entrepreneurs and start-ups, to support them from concept through to prototype to production. Finally, it needs to be international in scope, acknowledging the global nature of STEM and putting Scotland on the map as a premier location in which to do business.

To summarise, we need to ensure that our approach is strategic, opportunistic and flexible. Being strategic involves determining drivers, refraining from tinkering, providing efficient transport (for example, between Edinburgh and Glasgow), ensuring good education and skills, and supporting teaching and research. We need to take advantage of opportunities that present themselves, not forgetting the scientist and allowing them academic freedom to 'ask the daft question'. And we need to be flexible, with the ability to modify rapidly in response to changing situations and events. □

The debate

Key issues raised in the debate are summarised here.

Girls have traditionally been conditioned to view STEM subjects as male-oriented and shied away from them. This is also true, albeit to a lesser extent, of digital skills. Government, teachers and parents should demand that STEM subjects and digital skills are taught rigorously to both sexes. STEM careers need to be made attractive to students from a young age, with a 'holistic' educational strategy. Radical proposals often revolve around insufficient demand to provide the skills that businesses need. Educationalists, families and students themselves need to be aware of the needs of business, now and in the future.

Investment in R&D

It is not clear why investment in R&D by Scottish companies is so low. A basic problem may lie with the UK Government's monetary and fiscal policy. In the current climate, companies are finding it difficult to do any more than pay dividends to their shareholders. Justifying R&D expenditure with only long-term and uncertain payouts is difficult. However, the structure of the company may be relevant, and its international reach is important. Competition is the key. If Scotland can provide not only the research but also the follow-up, such as highly skilled operators and manufacturing expertise, its economy may benefit.

Intellectual property rights

Will intellectual property rights always be a stumbling block to full collaboration and trust? Or is this is an oversimplification? Academics are not a homogeneous group. Some may only wish to see the results of their research published in journals, but others are anxious to collaborate with business and see their research commercialised into the market and used for public benefit, or at least to increase choice. They may be willing to accept conditions that would enable them to spin off companies or set up new companies. Similarly, businesses are aware that research cannot be compartmentalised. □

TRANSPORT RESILIENCE

How can the UK transport networks be made more resilient to extreme weather events? That was the question debated at a meeting of The Foundation for Science and Technology on 22 October 2014.

Making our transport systems more resilient to weather

Richard Brown

Richard Brown CBE, the Chair of the Transport Resilience Review, was Chief Executive of Eurostar from August 2002 to April 2010 and then Chairman until June 2013. He was previously Commercial Director and Main Board Director of National Express Group plc, where he set up its UK Trains Division, at the time the largest UK passenger franchise operator. He has spent 37 years in the transport industry, and was a Director of British Rail's Intercity Division before privatisation. He is a Board Member of HS2 Ltd.

IN SUMMARY

- The UK has some of the most intensively-used transport systems in the world
- Recovery strategies are as important as mitigation plans
- Determining the appropriate level of spending is difficult
- Operating expenditure is at least as important as capital funding
- There is a great deal of good practice in the UK

Among the major issues considered by the Review[1] were: why transport resilience is important; the principles which should be applied in planning for resilience and delivering it; and the key risks. The UK transport network includes some of the most intensively-used systems in the world. Heathrow is the busiest two-runway airport in the world in terms of the number of aircraft movements. Our railways have the highest density of train operations in terms of train miles per track mile of any in Europe. For large parts of each day, the country's strategic roads are close to capacity.

Resilience is of particular importance for the freight industry. Food and fuel are increasingly delivered 'just-in-time', so extreme weather, causing road closures or railway delays can very quickly lead to interruptions in supply with substantial consequences.

Even existing levels of extreme weather are already pretty disruptive and the scientific consensus is that there will be more such events in future. The country needs to plan for more intense localised rainstorms in both summer and winter – as happened for instance in 2007. There are likely to be hotter and drier summers and rising sea levels.

Resilience

The Review considered three aspects or 'layers' to the challenge of resilience: the first is 'physical' resilience – protecting the roads, railways, airports, etc, so that they can keep people travelling and keep freight moving, even in extreme weather. It is, though, unrealistic to think this can be achieved in every situation and so the speed with which transport operators and infrastructure operators can recover normal operation is just as important. How well these organisations communicate with users and passengers is important too. All three issues contribute to better resilience.

Food and fuel are increasingly delivered 'just-in-time', so extreme weather can very quickly lead to interruptions in supply.

There is, in fact, no clear economic rationale on how much to spend. The Department for Transport's WebTAG tool provides a rationale for investment in transport infrastructure but there is no comparable framework to judge the necessary spending on resilience.

Second, there has to be some prioritisation of work. The Highways Agency is actually very good in this area and Network Rail is getting much better.

The impact on infrastructure of 'points of failure' is an issue. At the same time in early 2014, the main railway line to Devon and Cornwall through Dawlish was lost, the M5 was very nearly closed due to flooding and the A303 – the other main road to the South West – was also briefly closed for flooding. As another example, Gatwick Airport is very dependent on the rail link with London. Importantly, it takes passengers away from the airport as well as bringing them to it. If that line goes down, Gatwick quickly gets into trouble as arriving passengers back-up in the airport buildings.

Following David Quarmby's review of snow and ice resilience in 2010, most local authorities

now have a clearly defined network of roads that are gritted when there is a snow warning. We believe something similar is needed for flooding and for wind.

The rate of deterioration in road and railway lines is driven by just two things: the weight of usage (the number of vehicles and the total weight on the system) and the weather. Understanding the impact of weather and calculating how much to spend in order to avoid premature renewal of assets is a key part of asset management. So a clear recommendation of the Review was that resilience should be an integral element of all asset management plans.

Another clear finding was that current expenditure (whether it is called Opex or resource expenditure) is more important for resilience than capital expenditure. It matters how well the drains are maintained, vegetation managed and trees monitored. For years, the Treasury has sought to bear down on Opex, but cutting back in this area has real implications for resilience.

IT

The dependence of all modes of transport on IT and electrical systems is striking. On Christmas Eve 2013, Gatwick was capable of running a full flight programme, the flood defences on the airfield were operating effectively and although some of the electrical systems failed, back-up generators met demand.

However, water then got into the basement of the North Terminal and knocked out some of the electricity sub-stations and took out the IT. The airport was simply unable to check in passengers and get them through security quickly enough to put them on the planes. That was the core of the problem. It was an IT problem, not an operations problem.

Flood prevention

There are a myriad of organisations in this country responsible for planning to prevent floods. The Environment Agency has strategic responsibility, but is only able to fund schemes to protect homes and wildlife. County councils and unitary authorities have responsibilities for producing flood-risk management strategies in their area. Then there are regional flood and coastal defence committees that produce shoreline management programmes. There are more than 100 internal drainage boards, some of which are much older than most other local authority institutions, particularly for low-lying areas, which would otherwise flood.

Yet everyone understands that water recognises no local authority or agency boundaries. There is a big challenge here. It is also an important task for transport operators to improve liaison with what I call 'non-transport agencies' i.e. particularly county councils, unitary authorities and the Environment Agency, and to look at ways in which flooding of transport facilities can be either prevented or mitigated by wider flood prevention schemes.

Most of the major road network, having been constructed in the last few decades, is fairly resilient physically. It has good drainage, by and large. The main issue for the Highways Agency is that when there is bad weather, particularly heavy snow, rain or indeed fog, there is an increased risk of accidents. A great deal of disruption planning goes into managing traffic flows to prevent incidents happening and, when they do happen, into ensuring the swift restoration of normal operations.

The biggest challenge is on local roads: there are more than 183,000 miles of local roads, just in England (our review did not cover Scotland and Wales but we did talk quite extensively with them). There are 152 local Highways Authorities in England – county councils, London boroughs, unitary authorities – and it is impossible for each of them to have the full capability and systems and processes in place to manage effectively, however hard they try. Each of those local Highways Authorities will have different priorities and a great deal of transport spending is not ring-fenced.

Paradoxically, roads can become part of the solution to flooding. Roads become drains because they are hard-surfaced with embankments on either side. It is complex.

Rail

Among the risks to the rail network is embankment stability, because most of the network was built 150 years ago. When they were built, there was no real science of soil mechanics, so they were constructed rather than designed. There are no records of the fill materials. There were well over 100 embankment failures over the 2013–14 winter across Network Rail. However, the organisation well understands its criticality.

The only area where we were critical of Network Rail was on the management of trees and vegetation. It has not received the attention it needed over the years. There were about 1,500 incidents of trees or branches blown down over that winter. There are too many trees on Network Rail's linesides.

The third area of vulnerability is the signalling. When the line is flooded, the signalling cannot detect trains anymore. Network Rail per-

Everyone understands that water recognises no local authority or agency boundaries. There is a big challenge here. It is also an important task for transport operators to improve liaison with 'non-transport agencies'.

formed well in autumn 2013, using temporary automatic signalling systems. It has a programme to put in 'axle counters' that do not depend on electric currents going through the track and are therefore much more resilient to water. Protection of the signalling systems from water and flooding remains an important priority.

Ports and airports

Ports are clearly vulnerable to high winds, as are highways. They are, however, very used to the problem because most of them are in coastal locations. Yet they are also vulnerable to rising sea levels.

The biggest risks for airports, as for the strategic highway network, are snow and ice. Wind is an issue, but they are well used to it because take-offs and landings are impossible in high winds: airports are very good at managing this.

The biggest issue, though, is contingency planning, so that when disruption occurs there is better coordination between the airlines and the airports. Recently, Heathrow cancelled more than 100 flights on a pre-emptive basis. It is much better to tell people in advance that there are no flights and then operate a service frequency that can be sustained in bad weather, rather than to be over-ambitious, letting people down and having large numbers of passengers in departure lounges.

The Review team were extremely impressed by the huge amount of good practice that exists. Most of what needs to be done is already being carried out somewhere, but needs to be applied more widely. There needs to be more sharing and learning about what works and about the criticalities both in and across modes of transport. In an ideal world, we would have a more joined-up system of planning for floods, but this is not an ideal world. My biggest concern is that, after a couple of mild winters, people relax and forget about the lessons previously learned. □

[1] *www.gov.uk/government/publications/transport-resilience-review-recommendations*

The consequences of changing climate for transport systems

Doug Johnson

Doug Johnson is Deputy Director of Applied Science and Scientific Consultancy at the Met Office. He has worked for the Met Office for over 40 years. He is responsible for leading the pull-through of Met Office science capability to new high-value products and services for external customers and stakeholders. Previously, he was Head of the Aviation Programme and Head of the Transport Business Unit delivering services to aviation, road, rail, and oil and gas exploration customers.

Take a look at the average global annual temperature over the past 150 years, back to 1850, which is when the industrial revolution started. The warmest years during that century and a half all occur in the last few decades. There is a trend, particularly since the 1940s, of an ever-increasing temperature rise in average annual global temperature.

That is not the only change we are seeing. Extensive glacial melt is occurring. Spring arrives around the world earlier every year. Animal migrations are changing quite markedly. There are changes in permafrost around the world and sea-level rise is now easily measurable. Scientists around the world who contribute to the Inter-governmental Panel on Climate Change (IPCC) are 95 per cent certain that the changes are due to human influence: in other words the burning of fossil fuels and the ensuing release of greenhouse gases.

The IPCC's Working Group 2 report for the fifth assessment looked at adaptations to vulnerability. They were very clear that the risks could be reduced by limiting the rate and magnitude of climate change. To do this, the human race would have to reduce the amount of greenhouse gases released into the atmosphere. Working Group 3 focused on mitigation.

It is possible, from analysis of ice cores and other methods, to estimate what the temperature change over a very long time period has been. Looking back over 400,000 years (the results are estimated from ice cores) there is a startling

IN SUMMARY

- Climate change is happening
- Natural variability will continue to bring significant events in the short-term record
- Changes to temperature, precipitation and sea level are all inevitable
- We need to adapt to climate change as well as reduce emissions
- Climate change will have significant impacts on transport systems that will have to be planned for

correlation between temperature and the CO_2 content of the Earth's atmosphere.

Now there have been some wide variations during those 400 millennia – due to changes in the Earth's orbit (which is a regular thing), changes in the output of the Sun (which is, once again, regular) and other aspects, all of which can be modelled. The Earth's climate can be simulated using numerical models, which achieve a high degree of conformity with real events when these items are included.

The problem that the scientific community is facing at the moment is that over the last 100 years or so, humanity has been putting dramatically increasing amounts of CO_2 into the Earth's atmosphere. In 2005 this had reached 387ppm and that is significantly higher than anything seen in the last 400,000 years. If CO_2 and the global average temperature are linked, then this will have resounding impacts. If we continue to release CO_2 at current rates, then by the end of this century the CO_2 content of the Earth's atmosphere will have more than doubled since pre-industrial times. That will have major repercussions on the climate, which is why humanity needs to take climate change so seriously.

Impacts to date

The Earth's climate is very variable already. The winter of 2013–14 in the UK was very wet, very stormy, with the highest precipitation on record in parts. Go back two or three years to 2009–10 and the winter was quite cold, as was the following one. So there is significant variability just across four years.

Now that is not going to change – predictions are that climate variability will increase still further. There will be more extreme periods of precipitation, more extreme periods of dry weather and even though the temperature is rising over the next few years, there is a strong chance that we will still have cold winters.

If the extra CO_2 being put into the Earth's atmosphere is not included in the models, then the upward kink in temperature over the last few decades is not apparent. The variability in the Earth's orbit and the variability in the solar radiation are not enough on their own to accurately predict the change in temperature that is being seen. Global average temperatures have risen nearly 0.8 °C since 1850 when humanity started to burn more and more fossil fuels.

The year 2003 was a special year for meteorology in Europe. It was the warmest summer for over a century. The number of extra deaths recorded due to heat stress were in excess of 35,000. At that time, this was a 'one in over one hundred years' event. Move forward in time with continuing emissions of CO_2 at the current rate, then by 2040 the type of summer seen in 2003 would be a 'one in two-year event', i.e. average. By 2060, it could count as a cold year!

By 2040, the type of summer seen in 2003 would be a 'one in two-year event', i.e. average. By 2060, it could count as a cold year!

Into the future

Climate change has therefore doubled the risk that we will get a 2003 event every other year by 2040. There will be more frequent hot summers, but because of climate variability we may still get a wet, cold summer occasionally in the future.

Over the long-term, winters will also get warmer and the winter season will get shorter. Snow and ice will become less prevalent, but we cannot rule out the kind of winter that we saw in 2009–10 over the short term. If the world continues to emit CO_2 at the current rate, though, by the end of 2020s there will only be a 20–30 per cent chance of a colder winter. So there is a clear need to adapt to a much broader range of temperatures.

Even if our emissions were to peak now and subsequently decrease, temperature rises will continue for some time because CO_2 is a very long-lived gas in the atmosphere.

Suppose emissions continue at the current rate – what would be the impact upon normal city daily maximum temperatures? A nice summer's day in London is currently about 25 °C. By the 2090s, it is quite likely that the daily maximum would be 5–6 °C higher, about 30–31 °C.

The highest ever recorded maximum temperature in the UK was in Kent, at 38.5 °C in 2003. By the end of this century, the maximum temperature, on the basis of current emission rates, could be 9–10 °C higher. So from 38.5 °C a decade ago, the maximum recorded temperature in the UK by 2100 could be as high as 47–48 °C, the very high temperatures often seen in the Middle East or the Indian sub-continent.

That is going to have a significant effect on roads, on maintenance of equipment, on electrical systems, on the installed air conditioning load – indeed, a whole host of items that will potentially impact the transportation network.

Rainfall

There is a great deal of evidence that extreme daily rainfall is becoming more common, not

Increased temperatures will mean a potential for increased rail buckling. Road surfaces will have to be maintained and repaired more frequently.

just in the UK but around the world. There will still be a large amount of variability, which is why it is so difficult to say what the exact trend will be in five or 10 years' time; it will be masked by natural climate variability.

There are definite hints that the character of UK rainfall is changing though. The expectation is that winters will get wetter with higher rainfall rates. Summers are likely to become, on average, slightly drier than now. However, the models indicate that summer rain could still have much higher intensity.

The other side of the coin is drought. Take Spain: on both UK and German modelling, what is today a 'one in a hundred year' drought is more likely to be a 'one in 20' or even 'one in 10-year' event by the 2070s. There will be a greater probability of droughts in Southern Europe towards the end of the century.

The same modelling indicates that, particularly in Southern England and the South West, the 'one in one hundred years' drought will become a more common event, perhaps 'one in 40 or 50 years' events. Yet these same models also show an increase in the probabilities of higher precipitation. If this is borne out, then while today light rainfall occurs much more often than heavy downpours, lighter precipitation events will become less frequent, but the heavier precipitation events more common. That could lead to more flash-flooding, both in the winter and in the summer. So summers may be drier in the future, on average, but there will be higher-intensity rainfall events when it does actually rain.

The Met Office recently did some work for Ofwat, the water regulator. The research indicated that what today would be a 'one in 30 year intensity' event would probably occur once in 20 years by the 2040s. That probability reaches almost 'one in 15' by the end of the 2080s, which is typical of what we are projecting in all areas of the UK.

The work for Ofwat used a fairly low-resolution model for the globe. We can now run a very high-resolution model on climate timescales at the Hadley Centre. Unfortunately, these are very expensive to run – they use a lot of super-computing power. So we used the resource we had to model the southern half of the UK.

This work was published in *Nature Climate Change* in June 2014 after it had been thoroughly peer-reviewed. The study showed some quite dramatic things, for the summer months in particular. It endorsed the wetter winters and the increase in rainfall intensity in the winter; there was no real change there. However, it further enhanced the high-intensity rainfall rates during the summer. It agreed with what we have been saying up until now, that summers will potentially be drier, but when it does rain the rainfall rates will be very high.

There is evidence of significantly more events exceeding high thresholds (such as 30 mm per hour, i.e. more than an inch of rain an hour). That indicates much more flash flooding in summer months in the southern half of the UK.

Sea-level rise is going to increase towards the end of the century. We have emitted so much CO_2 that the temperature is rising. While the oceans take longer to respond because they are very deep and have a high heat capacity, they are nevertheless absorbing that heat, expanding in volume and the ice-sheets are melting into the oceans. It is not feasible to prevent at least a half metre rise in sea level by the end of the century. Potentially it could be as much as a metre. Continuing to emit CO_2 just stores up trouble for future centuries.

Impacts on transport

All this has significant potential impact on transport. Increased temperatures will mean a potential for increased rail buckling. Road surfaces will have to be maintained and repaired more frequently or they will have to be altered in some way to counter the increase in heat. There will be more overheating of electrical equipment if we do not adapt. Movable infrastructure – such as swing bridges – could encounter problems due to expansion.

Increased higher rainfall intensity of rainfall will cause more flash flooding, particularly in the summer. There will be an increase in river flooding, potentially more landslides and more electrical equipment failure.

Sea-level rise and increased storminess will mean greater damage to coastal infrastructure. There will be more trees blown down, an increase in the number of vehicles being blown over and more speed restrictions on bridges and other exposed structures.

Even drought will have an impact, but perhaps in the longer term. There will be subsidence due to the reduction in soil moisture and a weakening of earthworks, which will be exacerbated when the rain does actually return.

On the positive side, shorter winter seasons will probably mean less snow and ice. ❐

Building tomorrow's railway today

Jerry England

IN SUMMARY

- Resilience is as much an issue for today as tomorrow
- Network Rail controls a huge amount of infrastructure
- Assets have long lifecycles and so climate change has to be taken into account
- New technology can help the railway predict potential disruption
- It is important to restore services as quickly as possible

This issue concerns the present just as much as the future: extreme weather events are here today. The worst storm in the South West in the past 100 years inflicted severe damage on the railway. The line through Dawlish was closed for two months and took £45 million to repair. There were 12 major storms between October 2013 and February 2014, all of which had a major impact on the network. We understand the challenge of making the infrastructure resilient and the urgency of both minimising disruption when it does occur and then reinstating services as quickly as possible.

This really is the age of the train. After nearly a century of decline, passenger numbers have doubled over the past two decades. Every year, people make something like 1.5 billion journeys on our railways and that is the highest figure since the 1920s. Over 100 million tonnes of freight are carried as well. Demand is still growing with an annual increase in demand of 3 per cent projected.

Network Rail has a major, five-year, £38 billion investment programme that will transform the railway over the coming years. This will provide more trains, more seats, better stations and reduce congestion. But we also have to look after that wonderful, physical legacy that our Victorian ancestors left us – including the bridges, tunnels and viaducts that are part of our British landscape. We have the opportunity to leave an equally valuable legacy to our descendants as part of a railway that is safer, better-performing and more cost-efficient than ever.

Success, however, comes with its own challenges – running more services has removed recovery times from our timetables, which means a small incident will now have wide-reaching consequences. Passengers are, understandably, less tolerant of disruption today. Mobile phones and social media have created a desire for rapid updates on services, and increase the reputational damage if we get this wrong.

Rail infrastructure

The rail network has more than 28,000 bridges, 625 tunnels and 184,000 earthworks. Other infrastructure operators such as the Highways Agency have nothing on this scale. Comparable railways in, say, France do not have the scale of civil engineering assets. A significant challenge is that the bulk of UK railway assets is over 100 years old – 150 years in many cases. The overwhelming majority of our embankments would not meet modern design standards: in fact, in today's terms, they were not 'designed' at all. We do not know what many of them are made of. They do not meet modern standards, there is no certainty as to why they are still intact and in an ideal world they would be replaced. That would cost tens of billions of pounds and there is little chance that we are ever going to have the money.

Yet these embankments have been in place for 150 years. There are between 50 and 150 failures a year, which, in terms of the scale of the assets, is not a huge number. The problem, though, is not the number of failures, it is their unpredictability.

The extreme weather in early 2014 reinforced the importance of continued, sustainable asset management. Despite the inherent vulnerabilities and the challenging circumstances, the railway performed pretty well. We do, though, recognise the need to improve resilience, particularly of our earthworks, drainage, river and coastal defences.

Jerry England is Group Digital Railway Director for Network Rail. He joined Network Rail in October 2007 and has undertaken a number of engineering and asset management roles, including most recently as Group Asset Management Director. Before joining Network Rail, Jerry was Major Projects Director with the Highways Agency, Chief Operating Officer for Thames Water and spent 20 years in the oil and gas industry.

There are between 50 and 150 embankment failures a year. The problem is not the number of failures, it is their unpredictability.

Leaves are crushed at a pressure of around 20 tonnes per square inch, forming a hard, Teflon-like coating that reduces a train's ability to grip the track.

We must take into account, when determining the appropriate level of resilience for the long term, the wider importance of the railway to the economy and to society at large. However, investing so that the railway could deal with every eventuality would almost certainly not be in the best interests of either the taxpayer or the fare-paying customer.

Future risks

Most of the assets have lifecycles well in excess of 30 years, often several times that much. The Met Office's climate-change projections point to an overall warming climate with drier summers and wetter winters – as well as sea-level rises, which will impact on coastal infrastructure. So, a strategy of adaptation to changing conditions is necessary. We need to identify and strengthen those measures that mitigate the causes of disruption as well as limiting the consequences when it does happen.

Examples of tactical efforts to limit the causes of disruption include fairly simple improvements to drainage – essentially installing bigger pipes – but also better understanding of the drainage infrastructure and improving the maintenance regime.

Trees and plants can also cause serious safety and performance problems for the railway. Our climate, the variety of trees and train frequencies together mean that Britain's railway faces more serious challenges than networks in other countries. We can clear trees within our boundary fence, but over half of all incidents involve third-party trees. If a large tree or a branch falls onto the track, obviously the line has to be closed until it is clear.

Unmanaged trees and plants can cause serious safety problems by covering up signals or falling onto tracks and overhead power lines. Overgrown trees and plants can also hinder workers from finding safe refuge when trains are passing, and hamper their ability to see trains approaching. Visibility at level crossings is a major part of our risk assessment too.

The famous 'leaves on the line' are hazardous for trains and can result in serious safety and performance issues in the autumn months. Leaves are crushed at a pressure of around 20 tonnes per square inch, forming a hard, Teflon-like coating that reduces a train's ability to grip the track: this affects both acceleration and braking.

Over time, much of the lineside vegetation will be cleared. We aim to discuss our plans in advance with people living right next to the railway before work starts. It can come as a shock for some people who are accustomed to lines of trees or hedges near their homes and workplaces. To balance this, we plan to support local tree-planting initiatives, but away from the railway.

To prevent snow and ice build-up, heating has been installed to conductor rails in the key locations where trains stop. The slight paradox, of course, is that heating the conductor rails potentially increases CO_2 emissions – these things are all connected!

The rail network is investing in snow-and-ice treatment trains – there are currently six in service with another four on order. They are used to brush snow and ice off the third rail and they also apply an anti-ice agent so that the trains can pick up the current.

These are all tactical solutions, but looking beyond these we have developed a set of resilience specifications to apply to new infrastructure. These include requirements for equipment to work under extremes of heat, cold, flooding, strong winds and so forth.

Systems

Resilience needs to be considered at system level as well as asset level. In a line-distributed network, points failures can make other resilience measures redundant. Resilience studies have therefore looked at options like diversion routes, which will be included in reviews of our long-term planning.

In spite of the best planning, weather disruption can still happen. A suite of control measures have been developed to mitigate this, including

FURTHER INFORMATION

Transport Resilience Review
www.gov.uk/government/publications/transport-resilience-review-recommendations
Department for Transport
www.gov.uk/government/organisations/department-for-transport
Environment Agency
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the implementation of contingency timetables and reduced services. Here we see value in a more fine-grained approach to weather forecasting capability than is currently available commercially, so we have implemented a network of 100 local weather stations in Scotland and are evaluating the benefits.

It is also important to predict asset performance, particularly those that are vulnerable to weather. Remote condition monitoring is being trialled on 250 earthworks using tilt meters. Where movement is identified, speed restrictions can help mitigate potential failure.

Going beyond that, imagine a future where a civils asset manager is able to make decisions about where he or she needs to intervene, based on data gathered from radar or listening devices, which are then fed back through on-train technology or even passengers' smart phones. That data is collated and analysed, allowing decisions on interventions to be made. It is inherently smarter and safer.

Remote condition monitoring is being trialled using tilt meters. Where movement is identified, speed restrictions can help mitigate potential failure.

Innovation and technology are – and will remain – vital for delivering a modern and resilient railway. The work that I am now leading to create a digital railway will take us closer to that objective. Our challenge in addressing resilience is first of all to build an economic level of resilience into the existing infrastructure, then predict and communicate disruption before it happens, mitigate the effects and, just as importantly, recover quickly. ❐

The debate

Issues raised in the debate included:

Inevitably, there can never be certainty that enough has been done to accommodate the likely effects of climate change because events are unpredictable, public attitudes change and there is a lack of knowledge about the condition of historic infrastructure. There are also resource constraints.

Issues of governance

There is, moreover, the problem of 153 different agencies whose work needs to be coordinated with that of the major transport network operators.

There is no master plan for the existing infrastructure that allows it to be managed so as to become more resilient to the effects of climate change. Such a plan would need to consider the governance of all the bodies concerned in transport networks, decide where expenditure was essential because of the effect on the economy (e.g. major logistic routes) and where it had lesser priority (e.g. Welsh coastal routes).

Performance monitoring

The variability of weather patterns makes it impossible to forecast when major disruptions may happen. Yet new techniques such as performance monitoring of embankments should enable operators to better understand the condition of the assets. The tasks would be to prioritise, develop better methods of recovery from disruption, and respond to the public's need for information.

The problems of pinpointing particular trouble spots at specific times and forecasting weather conditions over a three to six month period remain, although new supercomputers at the Met Office should help to improve forecasts. These would still be probabilistic though; would businesses want forecasts that could be wrong perhaps 40 per cent of the time? Seasonal forecasts are also improving.

Personal responsibility

Are people failing to take adequate responsibility for their own actions when disruption threatens? There is a temptation to think that it is the operator's responsibility to safeguard people from any misfortune. Yet with better spread of information, the use of mobile phones and social media, there is little excuse for people setting out for an airport when they should be aware of disruption and cancelled flights.

Economic loss

There is a particular need to understand the impact of disruption at ports or airports on road and rail services to industrial areas, with adequate planning in advance so as to reduce economic loss. Indeed, the absence of any reporting of economic loss from congestion is surprising. ❐

A round-table discussion on 16 October 2014 looked at ways to measure the effectiveness of 'Science and Society' programmes.

How well do we measure engagement?

Sir Geoffrey Chipperfield KCB summarises a round table debate organised by the Foundation. More details can be found on the Foundation website at: www.foundation.org.uk.

Sir Roland Jackson, Executive Chair of Sciencewise and former CEO of the British Science Association, said the theme 'What are the best ways of measuring the success of science and society programmes?' raised three fundamental issues: first, given the wide variety of dialogues about public engagement on different policies, what does success mean? Second, even if we know, how do we measure it in terms of cultural change and new attitudes? And, third, is there some overall measure of success, or can it be related only to specific programmes?

The report chaired by Lord Jenkin of Roding on Science and Society published in 2000 by the House of Lords Select Committee on Science and Technology[1] emphasised that public trust depended on meaningful dialogues with diverse groups without predetermined solutions. However, it did not call for a reconstruction of the institutions deciding policies so that they embraced wider interests.

A dialogue must have a purpose – was it to tell the public something, listen to the public views, or, best of all, collaborate with the public in determining policies. Of course, there will be advocacy to inform the public why a policy is being considered and what it means, but impact depends on changes to policy proposals and so success can be measured only for specific projects, although there may be a common approach.

Professor Nick Pidgeon, Professor of Applied Psychology at Cardiff University, asked how far the remit in the House of Lords report, that the public must understand scientists and scientists the public, had been met. There had been progress; many more dialogues with the public had been held and there had been good evaluation of certain processes. But measuring impact of the engagements was very difficult; how did one find specific evidence that the dialogue had been effective? The effects of the dialogue could be both indirect and subtle, as in changing preconceptions and habits of thinking about issues, wider than the proposal in question.

The ensuing discussion covered a wide range of aspects. Impact in many cases is impossible to establish because data, both quantitative and qualitative, is so poor. Often, this is due to insufficient provision for impact measurement in project budgets. There is no single 'public', but many different ones; so those engaged in one dialogue may not respond to concerns expressed in others. Notably, not enough effort has been made to include those who suffer from social exclusion or deprivation in impact studies.

For any public engagement, it is important first to decide the target audience and then to direct effort towards it. Efforts should be scaled to the size and importance of the target audience.

For success, it is vital to be clear what the purpose of your engagement is, and marshal the evidence to support it. For example, many efforts have been made to persuade girls to do physics. The result? Fewer girls study physics now than in the past. All that has been established is a point of view that more girls should do physics but past means or techniques for persuading them to do so have not been persuasive. There are lessons to be learned about this lack of impact, including an acceptance that success can only come from using different methods of persuasion.

The impact of public engagement may be short term (a decision on a power plant), medium term (a steady increase in students doing STEM subjects, for example), or long term (such as an acceptance that the use of fossil fuels must be limited). So no evaluation may capture the full impact of engagement, without considering impact over different time periods.

Can any evaluation be done objectively by the team carrying out the public engagement? Any such evaluation may well be driven by subjective concerns, and, in particular, by a desire to secure a further tranche of funding.

Sir Roland Jackson concluded the discussion by observing that all participants agreed that public engagement and subsequent evaluation was crucial. Yet even if the purpose and nature were clear, there was no easy solution to the problem of determining the means for evaluating the process and its impact. ❐

[1] *www.publications.parliament.uk/pa/ld199900/ldselect/ldsctech/38/3801.htm*

What are the lessons learned from the response to the Ebola outbreak?
25 March 2015

Professor Chris Whitty CB FMedSci, Chief Scientific Adviser, Department for International Development
Dr W Ripley Ballou, Vice-President and Head, Clinical Research and Translational Science, Vaccine Discovery and Development, GSK Vaccines
Dr Oliver Johnson, Programme Director, the King's Sierra Leone Partnership
Dr Gina Radford, Deputy Chief Medical Officer for England, Department of Health

Our plan for growth: science and innovation (Cm 8980)
4 February 2015

The Rt Hon Greg Clark MP, Minister of State for Universities, Science and Cities, Department for Business, Innovation & Skills and Cabinet Office
Professor Dame Ann Dowling DBE FRS FREng, President, Royal Academy of Engineering
Dr Mike Lynch OBE FRS FREng, Founder, Invoke Capital
Professor Alex Halliday, Physical Secretary and Vice-President, The Royal Society [Panellist]

Reception
3 December 2014

The Rt Hon David Willetts MP, MP for Havant
Sir Mark Walport FRS FMedSci, Government Chief Scientific Adviser, Government Office for Science

The Hauser Review of the Catapult Network
12 November 2014

Dr Hermann Hauser CBE FRS FREng, Chair, Hauser Review of the Catapult Network
Simon Edmonds, Director, Catapult Programme, Innovate UK
Adrian Allen, Commercial Director, University of Sheffield Advanced Manufacturing Research Centre (AMRC) with Boeing

Maximising the strengths of the research and innovation base in Scotland (debate in Edinburgh co-organised with The Royal Society of Edinburgh)
29 October 2014

Professor Muffy Calder OBE FRSE FREng FBCS, Chief Scientific Adviser for Scotland
Professor Alice Brown CBE FRSE FRSA, Chair, Scottish Funding Council
Anne Richards CVO CBE, Global Chief Investment Officer, Aberdeen Asset Management

How can the UK transport network be made more resilient to extreme weather events?
22 October 2014

Richard Brown CBE, Chairman, Transport Resilience Review for the Department for Transport
Doug Johnson, Deputy Director Applied Science and Scientific Consultancy, Met Office
Jerry England, Group Asset Management Director, Network Rail

Science and Society programmes: what are the best ways of measuring success? (Round-table discussion)
16 October 2014

Sir Roland Jackson Bt, Executive Chair, Sciencewise
Professor Nick Pidgeon MBE, Professor of Applied Psychology, School of Applied Psychology, Cardiff University

Regulating charities: a Whitehall perspective (House of Lords Luncheon for Learned and Professional Societies)
3 October 2014

Ben Harrison MBE, Policy Manager, Office for Civil Service at the Cabinet Office

What is the right level of response to anthropogenic induced climate change?
16 June 2014

Sir Mark Walport FRS FMedSci, Government Chief Scientific Adviser, Government Office for Science
David Davies MP, MP for Monmouth
Professor Jim Skea CBE, Imperial College London and the Committee on Climate Change
The Rt Hon Peter Lilley MP, MP for Hitchin and Harpenden

Making the most of UK/China research and innovation partnerships
11 June 2014

Professor Tony Cheetham FRS, Treasurer and Vice-President, The Royal Society
Michael Kwok, Managing Director and Head, Shanghai Office, Arup
Professor Robin Grimes FREng, Chief Scientific Adviser, Foreign and Commonwealth Office
The Rt Hon David Willetts MP, Minister of State for Universities and Science, Department for Business, Innovation and Skills

Making the most of UK/China research and innovation partnerships (Round-table discussion ahead of the evening debate)
11 June 2014

Sir John Boyd KCMG, Chairman, Asia House
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Responding to the rapid increase of Antimicrobial Resistance (AMR) in organisms
4 June 2014

Dame Sally Davies DBE FMedSci, Chief Medical Officer for England and Chief Scientific Adviser, Department of Health
Dr Jeremy Farrar OBE FMedSci, Director, The Wellcome Trust
Dr Patrick Vallance FRCP FMedSci, President, Pharmaceuticals R&D, GSK

Delivering the Agri-tech Strategy: improving the quality and productivity of the UK food production and processing sectors
21 May, 2014

George Freeman MP, MP for Mid-Norfolk, House of Commons
Dr Peter Bonfield OBE FREng, Independent Chair, British Food Plan, Defra and Chief Executive, BRE Group
The Lord Haskins, Former Chairman Northern Foods and House of Lords

Policy choices for the reduction of bovine tuberculosis (TB)
2 April 2014

Adam Quinney, Farmer and former Vice-President, NFU
Professor Rosie Woodroffe, Senior Research Fellow, Institute of Zoology, Zoological Society of London
Dr Miles Parker OBE FSB, Senior Research Associate, Centre for Science and Policy, University of Cambridge
Professor Chris Gaskell CBE, Principal, Royal Agricultural University

Turning knowledge into value: adding value to the marine sector from research and innovation
10 March 2014

Professor Ralph Rayner, Sector Director Energy and Environment, BMT Group
Professor Ed Hill OBE, Executive Director, National Oceanography Centre
Professor Rick Spinrad, Vice-President for Research, Oregon State University, President-Elect, Marine Technology Society
Professor Richard Clegg, Managing Director, The Lloyd's Register Foundation [Panellist]

The challenge of communicating the uncertainty in risk estimates to decision-makers
5 February 2014

Sir Mark Walport FRS FMedSci, Government Chief Scientific Adviser, Government Office for Science
Tom Bolt, Director, Performance Measurement, Lloyd's of London
Judith Hackitt CBE, Chair, Health and Safety Executive
Dr Michelle Harrison, CEO, Government and Public Sector Practice, WPP [Panellist]

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The economics of decarbonisation of the UK electricity supply: how much are we prepared to pay to meet carbon reduction targets?

27 November 2013

James Smith CBE, Chairman, The Carbon Trust
Dr David Clarke FREng, Chief Executive, Energy Technologies Institute
Baroness Verma, Parliamentary Under-Secretary, Department for Energy and Climate Change

An international initiative to drive down the cost of solar and associated storage

27 November 2013

Sir David King FRS, Foreign Secretary's Special Representative for Climate Change, Foreign and Commonwealth Office
Ian Simm, Chief Executive, Impax Asset Management

Maximising the value of UK strengths in research, innovation and higher education

13 November 2013

Professor Sir John O'Reilly, Director General, Knowledge and Innovation, Department for Business, Innovation and Skills
Ben Ritchie, Senior Investment Manager, Pan-European Equity, Aberdeen Asset Management
Professor Geoff Rodgers, Pro-Vice Chancellor for Research, Brunel University
Peter Marsh, Author 'The New Industrial Revolution' and former Manufacturing Editor, Financial Times [Panellist]

Digital participation: how can digital access be made available to everyone?

31 October 2013

Professor Alan Alexander OBE FREng, Deputy Chair, Royal Society of Edinburgh Inquiry into Digital Participation
Lorraine McMillan, Chief Executive, East Renfrewshire Council
Dr Alan Blackwell, Reader in Interdisciplinary Design, Computer Laboratory, University of Cambridge

Improving the career paths for MSc and PhD students, and postdocs (Round-table discussion in Cambridge)

17 October 2013

Dr Steven Hill, Head of Research Policy, Higher Education Funding Council for England
Harry Armstrong, PhD Student, Babraham Institute, Cambridge
Dr Helen Ewles, Research Associate, Department of Pathology, University of Cambridge

House of Lords Luncheon for Learned and Professional Societies

11 October 2013

Jonathan Bamford, Head of Strategic Liaison, Information Commissioner's Office

Raising the bar: can learned societies and professional institutions particularly the engineering institutions do more to contribute to economic growth?

24 September 2013

Professor Tim Broyd FREng FICE, Vice-President, Institution of Civil Engineers
Professor Jeremy Watson CBE FREng FIET, Vice-President and Trustee, The Institution of Engineering and Technology (The IET)
Patrick Kniveton FIMechE FIET, President, Institution of Mechanical Engineers
Professor John Uff CBE QC FREng FICE, Barrister, Keating Chambers [Panellist]

Maximising the use of public data: should research and publically acquired data be made more accessible?

10 July 2013

Professor Geoffrey Boulton OBE FRS FRSE, Chair, Royal Society Inquiry into Science as an Open Enterprise
Professor Sir Nigel Shadbolt FREng, Chairman and Co-Founder, The Open Data Institute
The Rt Hon David Willetts MP, Minister of State for Universities and Science, Department for Business, Innovation and Skills
Professor Sheila M Bird OBE FRSE, Programme Leader, MRC Biostatistics Unit, Institute for Public Health, Cambridge [Panellist]

Can university-business collaboration be used to maximise short-term economic growth and reduce unemployment levels in Wales?

3 July 2013

Professor Colin Riordan FLSW, President and Vice-Chancellor, Cardiff University
Sir Leszek Borysiewicz FRS FRCP FMedSci FLSW, Vice-Chancellor, University of Cambridge
Sir Terry Matthews OBE FREng, Chairman, Wesley Clover
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Cities of the future: science, innovation and city management

19 June 2013

Steve Quartermain, Chief Planner, Department for Communities and Local Government
Sir David King KB ScD FRS HonFREng, Chair, Future Cities Catapult
Richard Bellingham, Director, Institute for Future Cities, Strathclyde Business School, University of Strathclyde
Sir Mark Walport FRS FMedSci, Government Chief Scientific Adviser, Government Office for Science

Celebrating the centenary of the establishment of the Medical Research Council: what should be the research priorities for medical research over the next twenty-five years?

22 May 2013

Dr Sydney Brenner CH FRS HonFMedSci, Senior Distinguished Fellow, Crick-Jacobs Center, Salk Institute for Biological Studies
Sir Paul Nurse PRS FMedSci, President, The Royal Society and Director, Francis Crick Institute
Sir Keith Peters FRS FMedSci FRCP FRCPE FRCPath FLSW, Emeritus Regius Professor of Physic, University of Cambridge
Dame Kay Davies DBE FRS FMedSci, Director, MRC Functional Genomics Unit and Associate Head of Division of Medical Sciences, Department of Physiology, Anatomy and Genetics, University of Oxford
Sir John Savill FRS FMedSci FRSE FRCP, Chief Executive, Medical Research Council
Rt Hon David Willetts MP, Minister of State for Universities and Science, Department of Business, Innovation and Skills

The Armitt Review of the UK long-term infrastructure project pipeline

16 April 2013

Sir John Armitt CBE FREng, Chair, The Armitt Review of the UK Long-Term Infrastructure Project Pipeline
Professor Brian Collins CB FREng, Head, Department of Science, Engineering, Technology and Public Policy, University College London
Tim Yeo MP, Chair, House of Commons Select Committee on Energy and Climate Change

Open Access: the Finch Working Group report on expanding access to published research findings

6 March 2013

Dame Janet Finch DBE DL AcSS, Chair, Working Group on Expanding Access to Published Research Findings
Professor Douglas Kell, Chief Executive, Biotechnology and Biological Sciences Research Council
Steven Hall, Managing Director, IOP Publishing

Threats and opportunities: scientific challenges of the 21st century

6 February 2013

Sir John Beddington CMG FRS FRSE HonFREng, Government Chief Scientific Adviser, Government Office for Science
Dame Sally Davies DBE FMedSci, Chief Medical Officer and Director General of Research and Development, Department of Health
Sir Mark Walport FRS FMedSci, Government Chief Scientific Adviser Designate and Director, The Wellcome Trust

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