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More transparency needed in climate research

On 31 March, the Science and Technology Committee published its report on the disclosure of climate data from the Climatic Research Unit (CRU) at the University of East Anglia. Leaked emails from this unit caused an international furore, dubbed 'Climategate', just before the Copenhagen Summit on climate change last December. The Committee called for the climate science community to become more transparent by publishing raw data and detailed methodologies.

The focus on Professor Phil Jones and the Unit he heads has been largely misplaced, said the Committee. On the accusations relating to Professor Jones' refusal to share raw data and computer codes, the Committee considered that his actions were in line with common practice in the climate science community but that those practices need to change.

On the much cited phrases in the leaked emails – 'trick' and 'hiding the decline' – the Committee concluded that these were colloquial terms used in private emails and the balance of evidence is that they were not part of a systematic attempt to mislead.

On the mishandling of Freedom of Information (FoI) requests, the Committee considered that much of the responsibility should lie with the University, not CRU. "The University needs to re-assess how it can support academics whose expertise in FoI requests is limited," said the report.
www.publications.parliament.uk/pa/cm200910/cmselect/cmsctech/387/387i.pdf

• A separate investigation led by Lord Oxburgh, a member of the Council of the Foundation for Science and Technology, found "no evidence of impropriety whatsoever". However, the panel noted that it was "very surprising that research in an area that depends so heavily on statistical methods has not been carried out in close collaboration with professional statisticians". Closer collaboration would be helpful for climate researchers to work more closely with professional statisticians in future. This would ensure the best methods were used when analysing the complex and often 'messy' data on climate. Another member of the panel, Professor David Hand, President of the Royal Statistical Society, commented that the CRU scientists had not used "the best statistical tools for their studies" but that this had not made significant difference to their conclusions.

'Research the key' says Royal Society

The UK will face decades of slow economic decline unless it invests heavily in research, one of the country's few genuine areas of economic competitive advantage, according to a report by the Royal Society. The report warns that the UK's current advantage is in danger of being wiped out by the USA, China, India, France and Germany who have ramped up spending in science to boost their economies.

The Scientific Century: securing our future prosperity brought together leading figures from politics, industry and science to assess the role of science in any long-term strategy for economic growth and highlights the successful but fragile nature of the UK's innovation economy.

"As France announces a new €35 billion investment in the knowledge economy, the UK cuts university budgets by £600 million, with the threat of more to come. History shows us that new technologies drive economic development – look at the industrial and digital revolutions. The UK has been in the top two of the scientific premier league for the last 350 years. It would seem obvious that politicians would recognise the need to invest in this competitive advantage rather than cutting funds," said Sir Martin Taylor, chair of the report's advisory group.

The report explodes the familiar myth that the UK is good at science but bad at exploiting its results. It highlights the emergence of an innovation economy in the UK with universities becoming fledgling economic powerhouses. Patents granted to UK universities have increased by 136 per cent between 2000 and 2008 while university spin-outs employed 14,000 people in 2007-08 and had a turnover of £1.1 billion. The report also cites examples of science driving successful sectors of the economy such as pharmaceuticals, though business R&D is picked out as a weakness for the UK. In 2007 British companies spent 1.14 per cent of GDP on R&D while in the USA the figure was 1.9 per cent and in Germany 1.8 per cent.

To maximise the economic opportunities from science the Royal Society report recommends:

- creating a 15 year framework for science and innovation, with increased spending;
- prioritising investment in scientific skills and infrastructure, such as laboratories and equipment;
- expanding the R&D tax credit.

http://royalsociety.org/The-scientific-century1

Research Excellence Framework

The four UK higher education (HE) funding bodies announced the outcomes of the recent consultation on the Research Excellence Framework (REF) – the new system for assessing research in UK higher education institutions (HEIs) – on 26 March.

The consultation revealed overwhelming support for research to continue to be assessed though a process of expert review, and for the main factor in the assessment to continue to be the quality of research outputs produced by institutions.

There was widespread support in principle for an explicit assessment of the social and economic impact of research, subject to developing a robust methodology, and reservations about the weighting of this element within the overall assessment.

In the light of the consultation feedback, the four funding bodies have made some refinements to the proposals and announced initial decisions about the general arrangements for the assessment.

A pilot exercise that will be vital in developing the method for assessing impact is currently in progress. It involves 29 UK Higher Education Institutions and panels of experts made up of leading researchers and senior figures from a wide range of organisations that commission and use research including businesses, public sector bodies, charities and other third sector organisations. A full detailed announcement about the method for assessing impact and its weighting within the framework will be made after the pilot exercise has concluded in autumn 2010.

The four funding bodies are considering the overall timetable for the completion of the first REF exercise, in the light of feedback from the consultation and the refinements they are making.

The funding bodies are the Higher Education Funding Council for England (HEFCE); the Scottish Funding Council (SFC); the Higher Education Funding Council for Wales (HEFCW); and the Department for Employment and Learning, Northern Ireland (DELNI).
www.hefce.ac.uk/research/ref

The role of learned societies in policy development

Nancy Rothwell

Professor Dame Nancy Rothwell FRS FMedSci holds an MRC Research chair and is Deputy President and Deputy Vice-Chancellor at the University of Manchester. She is President of the Society of Biology, a Vice-President and Council member of the Royal Society, and a non-executive director of AstraZeneca

Learned societies exist primarily to promote and support individual academic disciplines. In the UK they are numerous, notably in science and engineering, but especially in biology. Even ignoring the many small, local interest groups, it is estimated that several hundred societies exist in biology. Some maintain close partnerships with others, some work largely alone.

The very diversity of learned societies can pose problems. With such a large number of specialist organisations, it can be more difficult for the concerns and priorities of the wider discipline to be heard, especially in the formation and development of policy where science has such an important role today. The proliferation of bodies may also lead to some replication of effort and activity.

The Society of Biology, established in late 2009, was formed to overcome these challenges. It is an overarching body representing biology in the same way that the Royal Society of Chemistry, the Institute of Physics and the engineering institutes do in sister disciplines across science and technology. The Society of Biology was formed – with significant help from the Foundation – from the integration of the Institute of Biology (IoB) and the Biosciences Federation (BSF), each of which had represented biology in different policy areas. Policymakers will now be able to look to a single body for advice on matters relating to bioscience, advice that has been distilled from the expertise of the many specialist learned societies within its membership.

The two 'parent' organisations also offered much complementarity. IoB comprised mainly individual members and fellows, including many school teachers, professional biologists and interested amateurs, and had a branch structure across the UK. The BSF in contrast was an umbrella body, including most of the larger learned societies in biology as well as key funding bodies, several major companies and a number of non-commercial organisations.

This diversity reflects in part an explosive growth in the study of biological systems and perhaps also an increasing specialisation in sub-disciplines of biology. It may also be in part due to the development and recent successes of interdisciplinary research.

Our approach to science, and biology in particular, has changed over the last few decades. As a young PhD student I joined a learned society: the Physiological Society was associated with the subject of my undergraduate degree. I gained a

As the single body representing the UK bioscience community, the Society of Biology is already taking an active role in contributing to policy making.

Responding to the recent HEFCE consultation on the Research Excellence Framework (REF), the Society argued that while the retention of the peer review process in the current proposals alongside a range of performance indicators was to be welcomed, there were still issues of concern. One of these was the 'impact' measurement which is proposed to carry a 25 per cent weighting in the new REF. On the basis of the novelty of this element, the well-recognised difficulty of its evaluation and the unproven nature of the proposed methodology the Society proposed that the 'impact' weighting should be 10-15 per cent at most.

Another area of importance to the Society's membership is the independence of scientific advice to Government. In a submission to the House of Commons Science and Technology Select Committee the Society recognised that ministers take account of factors other than scientific advice when reaching a decision, but argued that clear and proactive communication of these factors to the relevant scientific advisory committee, and to the public, is essential to preserve mutual respect and trust. It also urged that the induction process for new ministers should include discussion of the 'Statement of Principles for the Treatment of Independent Scientific Advice' included in the Select Committee's consultation.

great deal from membership of 'Phys Soc' and still do. Like many other learned societies, it gave me the opportunity to present, defend and publish my work to leaders in the field, attend specialist symposia as well as broader meetings, gain funds to travel to overseas conferences, identify mentors and collaborators and to learn of some of the many skills needed to succeed in an academic career in science.

My own PhD students are often at a loss as to which society to join. Some trained as physiologists, some as molecular biologists, some are clinicians and others come from mathematics backgrounds. All undertake research which demands interdisciplinary work and varied skills. The research areas do not always link automatically with a specific learned society.

In an inter-disciplinary age, the creation of the Society will allow for more effective and efficient working relationships between member organisations, stronger support for individuals who are members and new opportunities for training, as well as dissemination of discoveries in biology and interaction with representative bodies of other areas of science and technology. It will also provide a platform for the promotion of biology as an attractive career.

A continuing drive towards even more interdisciplinary (or even non-disciplinary) research might reasonably be accused of creating "Jacks of all trades, but masters of none". Thus, many scientists will still wish to maintain a close alliance with their own discipline and learned society. Some of the learned societies provide valuable professional qualifications and accreditation and there will always be a need for highly specialised knowledge and advice.

These are good reasons to maintain the structure of existing learned societies – but within the integrated framework provided by the Society of Biology. The learned societies are here to stay for the foreseeable future. The challenge is to ensure that they work effectively and efficiently with each other and with the larger bodies to support and promote science in its widest sense and particularly in the policy framework within which it takes place.

The Society of Biology: www.societyofbiology.org

The Christmas Reception of the Foundation for Science and Technology on 9 December 2009 provided an opportunity to explore the cross-party support for science and research.

The importance of science

The Christmas Reception of the Foundation for Science and Technology provides an annual opportunity for a more informal discussion about the topics of the day. Last December, the Shadow Minister for Universities and Skills, Conservative MP David Willetts, was invited to outline his party's perspective on science policy.

Mr Willetts said that the Conservatives, like the Labour Government believed strongly in the importance of research and science. He particularly endorsed the drive that Lord Sainsbury had shown and the initiatives that the Minister had introduced. He highlighted the emphasis on dealing with global problems such as climate change and poverty. David Willetts was particularly concerned about demographic changes and the divergence between ageing and young populations.

He shared the view that the Haldane principles on funding for research should be followed, and the dual structure for funding maintained. However, he expressed doubts about some features of the new REF (Research Excellence Framework), in particular the factor for impact. How was this to be measured, he asked? Would, for example, the 'research' that led to the MMR debacle be rewarded for impact?

The Shadow Minister was also concerned that industrial policy and scientific research funding should not be too closely linked. It was not evident, he said, that there was a linear process whereby scientific research went in at one end and commercial success came out from the other. Moreover, it was dangerous to formalise too rigidly the relationships between universities and business. At the same time universities should beware of spinning off companies too soon.

Mr Willetts was particularly concerned to break down barriers between research and commercial success. Areas which could be explored included the greater use of tax credits, problems caused by delays in getting intellectual property rights because of peer review, the legal framework on patents and also the institutional overlap caused by differing standards. Mr Willetts attached particular importance to effective clustering of businesses and institutions.

On education generally, he shared the Government's emphasis on getting more students to study Science, Technology, Engineering and Mathematics (STEM) subjects, getting more scientists into teaching and giving pupils better career advice. He added that James Dyson was reviewing these issues for the Conservative Party.

Responding, Professor Alan Thorpe, Chair of the RCUK Executive Group and Chief Executive of the Natural Environment Research Council (NERC), welcomed Mr Willett's support for continued investment in research. The UK is, he argued, a centre of excellence: we need to celebrate this and make clear the impact that good research has on social and economic problems. But there is a long time interval between research and final impact, which is why we need a sustained pattern of funding.

We need to measure impact both quantitatively and qualitatively, he noted. The Research Councils have strong links to business both here in the UK and internationally. Research is crucial for a sustainable world and national economy and a successful society.

Sir Anthony Cleaver, Chairman of EngineeringUK, also welcomed Mr Willett's comments, especially about the consensus across the political divide. He wished to emphasise the importance of collaboration between businesses, universities and the Government. It was particularly important in addressing the likely shortfall of engineers at technician level as well as at higher levels (he noted the demographic decline in 18-24 year olds). Of course, getting more pupils to do STEM subjects was vital, but that should be seen as a way of encouraging apprenticeships as well as university entries. He hoped the engineering diploma, for which 6,000 pupils were already studying, would continue. ☐

A special meeting of the Foundation for Science and Technology on 12 March 2010 honoured the achievement of a number of famous names in aviation and space travel.

Enthusing the next generation

The first and, to the present day, the last human beings ever to set foot on another world were among the special guests at a meeting of the Foundation for Science and Technology held at the Royal Society in early March. Captain Neil Armstrong and Captain Gene Cernan were joined by Jim Lovell, the Captain of Apollo 13, as well as Bob Gilliland, the first man to fly the world's fastest airplane, the SR-71 Blackbird, and General Steve Ritchie a fighter ace of the Vietnam War. They spoke of their experiences and gave their thoughts about the US space and aviation programmes across the decades. David Hartman, the former first host of the Good Morning America TV show, 'anchored' the panel discussion.

For the invited audience of more than 200 people, this was literally the opportunity of a lifetime – only 12 men have ever walked on the Moon. From the moment that Neil Armstrong took his "giant leap for Mankind" to the day that Gene Cernan lifted off from the lunar surface to rejoin the command module of Apollo 17 was less than four years. Armstrong set foot on the moon on 21 July 1969, Cernan left it on 14 December 1972.

Steve Ritchie and Bob Gilliland explained how the space programme grew out of the aviation research programme which had resulted in aircraft such as the F-104 *Starfighter* flown by General Ritchie in combat – the aircraft still holds the low-level speed record for an aircraft more than 40 years later – and the SR-71, a strategic reconnaissance aircraft capable of flying at Mach 3. Ritchie highlighted the rapid progress in military technology – the air-to-air missiles on his aircraft had a strike rate of little more than 10 per cent. Yet the Vietnam War introduced technologies which have become standard today, such as the first laser-guided bombs.

For many of the audience it was the experience of the three astronauts which was the focus of interest. They recalled how the impetus for the space programme had come from the Cold War. The launch of the Sputnik satellite by the Soviet Union had acted as a wake-up call to the USA. So on 25 May 1961, President Kennedy issued a challenge to the whole country. He said: "I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the earth."

Neil Armstrong, the first man on the Moon (left), and Gene Cernan, to date the last to walk on the Moon. Photo © Michael Cockerham.

This was a huge challenge. To achieve it, three successive space programmes were instigated, as Captain Lovell explained. The first was the Mercury programme, which was concerned with actually getting a manned craft to the edge of space and the astronaut safely back to earth. The second was the Gemini programme which was designed to test whether human beings could live and work in space. It also developed the techniques of space walks and docking manoeuvres.

With the benefit of these lessons, Apollo then took men to the Moon and back.

All three astronauts had flown in space as part of the Gemini programme. Jim Lovell quipped how he wished he had paid more attention to Newtonian mechanics before he had flown – the astronauts had been shown some of Newton's original manuscripts held at the Royal Society. He said that on the space walks, when he turned a wrench to tighten a bolt "the wrench turned me!" making it difficult to keep his footing. His co-pilot could also feel the "equal and opposite reaction" to everything Lovell was doing on the exterior of the craft.

The three discussed the pressure on everyone involved in the space programme to deliver before the end of the decade, with just a couple of months between launches at one stage. Technological progress was being pushed at an enormous rate. Yet, as we all know today – they achieved it.

Jim Lovell raised an interesting hypothetical question. The oxygen tank that exploded on Apollo 13 had originally been intended for Apollo 10. What would have been the consequences for the lunar landing programme if the accident had happened to the flight *before* the scheduled moon landing mission, he wondered.

When asked about the need for future manned exploration, Gene Cernan said that the space programme had created many technologies that were in everyday use and that space exploration had more than repaid the financial investment. Jim Lovell felt there was a balance to be struck between manned and unmanned flights – he noted that the Hubble telescope had needed human beings to actually visit it to correct the problems with it.

Neil Armstrong recalled that when they were flying to the Moon some 40 years ago, everyone thought that humans would be walking on Mars within decades.

They were agreed that the space programme had changed humanity's perception about their place in the universe – we are all on a spaceship called Earth with finite resources.

A significant number in the audience were school or university students who were not even born when these events were played out. Yet when the formal session ended, everyone immediately rose to their feet to give the astronauts and aviators a standing ovation. For everyone, it had been a very special occasion. ☐

Should the Government pay as much attention to engineering advice as it does to scientific advice? The question was debated at a meeting of the Foundation for Science and Technology on 7 July 2009.

Turning ideas into reality

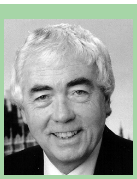
Phil Willis

The Commons Select Committee on Innovation, Universities, Science and Skills (IUSS) with its huge remit – innovation, universities, science and skills – chose engineering as the subject of its first major inquiry because engineering will be a crucial tool as we tackle some of the largest challenges ever to face humanity. Engineering will be central to our ability to deal with issues such as climate change, energy security, food security and water supply.

The recession has highlighted the importance of engineering to the UK's economic health. The economic downturn reminds us of the value of industries that build *things* rather than simply profits, and that provide employment opportunities on national scale. As Lord Mandelson aptly put it: "If you really want to change the world, choose a career in engineering: I mean *real* engineering, not financial engineering." Engineering makes up between a quarter and a third of our GDP, through sectors such as construction, manufacturing, mining and quarrying and electricity, gas and water.

In addition to economic challenges, the UK has a huge future works programme which relies upon a significant body of engineering expertise. This programme includes projects that are truly vast in scale: the 2012 Olympics; the planned Crossrail line for London with an estimated economic benefit of at least £36 billion for the UK; the £45 billion 'building schools for the future' programme; and plans to build 240,000 new homes every year until 2016.

In order to match the predicted growth in jobs, the UK needs to increase the number of graduates with Science, Technology, Engineering and Mathematics (STEM) degrees from 13 per cent to around 25 per cent. This will rely on getting young people interested in these subjects from a much younger age, and providing vastly improved careers advice to shape their subject choices early on.



Phil Willis MP is Chair of the House of Commons Select Committee on Science and Technology and was also Chair of its predecessor the Select Committee on Innovation, Universities, Science and Skills (IUSS). He started his career in education where he became a headmaster. At Westminster, he was appointed Shadow Secretary of State for Education and Skills in 1999, retaining the post until 2005 when he was appointed Chairman of the Select Committee.

Energy

The development of the UK's energy sources also poses key challenges for the engineering industry. These include: the development of new nuclear power stations; the decommissioning of existing nuclear power facilities and nuclear waste disposal; the development of the UK's energy generation infrastructure, including renewable energy; and the mitigation of the effects of climate change such as building flood defences.

Another concern is the 'Valley of Death', that gap which separates university spin-off companies from their goal of becoming commercially viable large employers, and which stubbornly resists our attempts to build bridges across it.

In this inquiry, we were also concerned that many employers were struggling to recruit engineers. Many complained that there were too few high quality engineers and that they were leaving engineering to find money in the financial sector.

The inquiry

The inquiry, *Engineering – turning ideas into reality*, was very thorough; the Committee received nearly 400 written submissions, held 13 evidence sessions and interviewed 86 witnesses. We could not possibly cover all of engineering: it is just too big. We decided instead to take a case study approach, exploring the issues through the 'lenses' of nuclear engineering, plastic electronics, geo-engineering and engineering in Government.

The Government's enthusiasm for nuclear power raises questions about the country's capacity to deliver a new generation of power stations. There are significant skills shortages that could affect plans to bring new plants online by 2020. According to the UK Commission for Employment and Skills *Ambition 2020* report, for low, intermediate and high level skills the UK is currently 17th, 18th and 12th respectively among OECD countries. This is predicted to drop to 23rd, 21st and 10th by 2020. This turn of events will affect every sector in the UK, but particularly growing areas like engineering. We concluded that a 'master roadmap' is needed for all major engineering projects, including nuclear new build.

The plastic electronics case study highlighted the potential opportunity afforded to the UK through the support of emerging, innovative industries. Hailed as a disruptive technology, the UK research base in this area is world-class. However, while the pioneering research into Plastic Electronics took place in Cambridge, the factory opened in Dresden. We were concerned that the UK is likely to miss out on the economic return associated with translating the findings of research into commercialised technologies. So we have called for a serious revision of the structures used to support the growth of fledgling industries.

The discussion of geo-engineering research really highlighted the global nature of many engineering challenges. The committee considered the implications for policy-making of a new engineering discipline. It became clear that, if the Government is to be an informed actor in the development of any future international policy relating to geo-engineering, it is essential that the views of the science, engineering and social science communities be seen as complementary sources of expertise, and their advice actively sought and considered.

The final case study went further and demonstrated that engineering advice and scientific advice offer different things, and that this should be recognised in the policy process. We found that Government, in key policy areas of several departments, does not have sufficient in-house engineering expertise to act as an intelligent customer. Engineering advice is frequently not sought early enough during policy formulation. We were shocked to discover that engineering advice had been lacking in the formulation of policies as important and diverse as eco-towns, renewable energy and large IT projects.

The Government responded to our report just last month. And it is fair to say that it was generally very positive. The Government agreed with our suggestion that 'roadmaps' are needed for all major engineering projects. They agreed that more could be done to stimulate innovation through Government procurement. They agreed that it would be sensible to make policy considerations for a plan B for tackling climate change – geo-engineering – just in case plan A fails. The Government also agreed on the need for more generalist engineers and that there should be a clearer understanding of who does what in terms of skills provision.

The Government also agreed with some of our suggestions on engineering in Government. It agreed that there needs to be a better understanding of the expertise that we have currently in the civil service. We should recruit more experts into the science and engineering fast stream, distribute them more widely and provide real opportunities in career progression while retaining specialist skills. And they agreed that links between the public and private sector need to be strengthened through secondments.

Disagreements

So, fundamentally, the Government agreed that engineering advice in policy making is absolutely crucial. Unfortunately, they disagreed with us on how to maximise efforts and put engineering at the heart of Government policy. At present, science and engineering advice is located with the Government Office for Science in the Department for Business, Innovation & Skills (BIS). In our view:

- GO-Science should be placed properly in the heart of Government: in the Cabinet Office;
- the Government should have a Chief Engineer to coordinate cross-departmental engineering programmes;
- every Government department should have a Chief Scientific Adviser, a Chief Engineering Adviser, or both.

Unfortunately, the Government said no to all three of these proposals.

Next steps

The response from the engineering community to the report has been very positive, and it was widely welcomed for identifying many of the issues that cause engineering to be under-represented and under-valued.

So what is next? We recommended that the Royal Academy of Engineering should continue the outstanding coordinative role that it took for the engineering community during our inquiry. We also suggested that the Academy should be the first port of call for the Government when it is seeking engineering advice. The Academy is keen to live up to our challenge.

We need to raise our game in order to make sure that UK engineering is successful, so that UK plc can be successful. As a wise engineer once said: "The most important thing is to keep the most important thing the most important thing." ☐

Select Committee report:
www.publications.parliament.uk/pa/cm200809/cmselect/cmdius/50/50i.pdf

Building on success

John Browne

The recession has been good for developing engineering skills, while turbulent for the world economy. Even as the Select Committee was going about its business, admissions to most engineering courses at UK universities were rising significantly – up to 15 per cent in the case of civil engineering. The value of an engineering degree remains appreciated well beyond the profession – not least for its systems approach which can be applied in the City as much as in engineering design. Nonetheless, 89 per cent of employed engineering and technology graduates still go into engineering roles.

In the UK today, about 13 per cent of GDP comes from manufacturing. This has dropped from 31 per cent in 1977 but the whole nature of business and industry (and what is measured as 'manufacturing') has changed in that time. Indeed, the actual value of manufacturing output has continued to rise while the sector has changed; so despite the shockwaves of recession, the underlying strengths of the sector are firm.

The Lord Browne of Madingley FREng FRS is President of The Royal Academy of Engineering. He was appointed Group Chief Executive of the BP Group in 1995. Following the merger with Amoco, he was Group Chief Executive of the combined group until 2007. He is a Managing Director of Riverstone Holdings, Chairman of the Cambridge Judge Business School, Past President of the British Association for the Advancement of Science (now the British Science Association) and Emeritus Chairman of the Advisory Board of the Stanford Graduate School of Business.

In terms of 'value added', UK manufacturing still lies sixth in the world rankings – just behind Italy and ahead of France. The industry is two and a half times as big as 50 years ago. This is because we have concentrated on the high-technology and high-value areas in engineering while traditional heavy industries have declined.

Engineering has never been confined to heavy industry, though. It has always underpinned construction, but it also pervades sectors as diverse as aerospace and defence, electronic and electrical equipment, biotech and telecoms; as well as leisure and the media. There are few companies listed in the FTSE 100 index that do not rely on engineering in some form: the Tesco Clubcard owes as much to engineering thinking and software as it does to business innovation.

The UK remains strong in important areas:

- the iconic Watercube in Beijing, shown on televisions around the world during the Olympics, was designed by Arup, a global company based in London;

- the UK contributes about a third of the total value of the Airbus A380 via the wings and engines. In fact, the UK accounts for over 13 per cent of total global turnover in aerospace;
- the UK defence and security industry punches well above its weight with a 30 per cent share of the global market.

At the individual level, the UK competes strongly in the new industries and wins on a global basis. Mike Lynch, a Fellow of the Royal Academy of Engineering and founder of Autonomy Corporation – now a FTSE 100 company – showed what could be done.

We can draw a number of conclusions from this:

- engineering in the UK is in good health, providing a firm base for going forward;
- UK engineering is seen as an exemplar around the world, even in countries like Japan and China. We have intellectual credit where it matters;
- this worldwide reputation makes the UK an attractive place for global companies to do their R&D – Microsoft in Cambridge, Sharp in Oxford, and so on;
- diversity is the key.

Engineering and science

The Committee's inquiry was into 'Engineering', not 'Science'. Yet from my perspective, both are essential parts of an innovation spectrum. Engineering has two faces, much like the Roman god Janus. One faces the sciences, the other faces commerce and finance. Engineering understands both and translates between the two.

It deploys the fruits of science in creating the products and services with which commerce can create wealth. At the same time it translates the needs of commerce into research opportunities.

Engineers, in short, are concerned with 'practice'. Engineering is about solving the world's great 21st century challenges:

- providing practical solutions to climate change and energy needs;
- providing infrastructure of many kinds to defeat the underlying causes of poverty;
- aiding improvements to health and wellbeing.

Lord Darzi, Health Minister from 2007 to 2009 and Honorary Fellow of the Royal Academy of Engineering, is himself an ardent enthusiast for what engineering can do for medicine. This helped him become a world leader in micro-surgery.

Engaging with Government

One important result of the Committee's inquiry is its suggestion that Government has much to gain by closer collaboration with engineering. Engineers are taught to think in terms of systems, to be pragmatic, to think of delivery in the real world. They also understand project management. Those skills are needed in Government now as never before, as the Committee and Government both acknowledge.

The Royal Academy of Engineering, together with the engineering institutions, now has a close working relationship with John Beddington and his team of Departmental Chief Scientific Advisers. As an engineering community, we are helping to provide expert advice on topics as diverse as critical infrastructure resilience and global water security. Looking forward, we expect to bring this engineering advice to an ever-increasing range of policies and Government objectives. I take it as a huge vote of confidence that the engineering community was asked to contribute to the Severn Tidal Power study at an early stage, providing valuable advice on what could lead to a £20 billion project. This is probably the largest engineering project the UK will have ever seen.

Good scientific advice does not exist in a vacuum and neither does engineering advice. Good policy needs both and should not pay too much attention to the boundaries between them. They are complementary.

The Committee's report recognises the breadth and diversity of the engineering profession. Our rich history has left us the legacy of 36 professional engineering institutions, all providing for separate constituencies – similar to many other professions with a long history. There have been calls for rationalisation and if we were starting with a clean slate we almost certainly would not structure the profession as it is now. However, I see no profit in pursuing that course in the short term. I am glad the report accepts the shape of the profession we currently have. What is far more important is that we work together, speak with a unified voice, and provide a coherent source of advice to both Government and the public.

The Academy fully accepts the Committee's recommendation that it should take forward and formalise its leadership role so that the community can communicate – and coordinate – more effectively. A unified voice of engineering is important in helping Government in its policy development and deployment, but is critical to our relationship with society in general.

Today there are great opportunities for engineering to play a part in a UK and global economic recovery – not least in low-carbon developments. The base already exists in this country. A low-carbon revolution, especially in the waters off our coasts, is a prize to be won. It is time for the Government, UK businesses and engineering to work together on reaching this goal. □

At the forefront of the global market

Dick Olver

Despite the widespread tendency to regard the UK as primarily a services-based economy, engineering remains at the heart of our current and future economic performance. What is more, as the Select Committee's report recognises, engineering is pivotal not just to our economy, but to the very fabric of our society. The downturn has not changed the vital importance of engineering one iota. Indeed, most people do not realise that UK manufacturing industry contributes more to the country's GDP than the financial services sector.

What is more, the importance of engineering to the UK will increase in coming years, with engineers at the front line in meeting the critical challenges now facing mankind. Only through world-class engineering can the UK and the world hope to halt the deterioration of our ecosystems, and navigate our societies towards sustainable development.

In the years to come, the search for alternative and sustainable sources of energy, water and food, will demand new skills and technologies, as well as a greater number of qualified engineers. These shifts bring UK industry a real opportu-

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nity for world leadership. I agree with the Select Committee that, to make the most of this opportunity, we will need a 'clear and sustained' national strategy for engineering.

Today, we are looking at a complete restructuring of the British economy with, for example, the rise of lower-carbon industries and technologies. As the Select Committee says in its report, while the current economic crisis creates short-term challenges for UK engineering it also opens up massive longer-term opportunities.

To compete successfully through and beyond this global recession, UK engineering and manufacturing now need to focus on where and how we can compete most effectively in the global market. Yet how can we do that, when statistics show that it can be up to 20 times cheaper to produce goods in China or India than in the UK? Well, the key to future economic success is not about cornering the market in manufacturing, but in talent and Intellectual Property. This is why the Chinese are trying to build educational institutions to rival Oxford and Harvard. It is also why India and China want to keep more of their top graduates at home, instead of seeing them migrate to the West.

Competitive advantage

The UK has competitive advantage over many other countries in the race to be a leader in Intellectual Property and innovative talent. We are already a world-leading exporter of high-tech goods and continue to outperform many of our competitors in the developed world. In 2006, 25 per cent of the goods exported from the UK were classified as high-tech, compared to 22 per cent from the USA, 15 per cent from France and 11 per cent from Germany. What is more, we have a highly educated workforce, and our economy is underpinned by a global business culture, infrastructure and relationships. Our legal system is admired and applied worldwide to support business contracts and protect intellectual property. We also have a history of entrepreneurial growth and innovation, plus a high-tech infrastructure base.

Perhaps most importantly, we have a history of achieving great things without significant resources or a large population: in other words, a history of winning worldwide purely through know-how. This is our real competitive advantage!

Future success could come in areas of technology where the UK has already set the pace, ranging from pharmaceuticals to unmanned aircraft, from silicon design to geo-engineering and from fuel cells to plastic electronics. It could also come on the new frontiers, such as: information and communication technology; cyber security and the opportunities created by the new security industry sector; biotechnology; new sources of energy; and nanotechnology. In every case, the key differentiator for success is high value-add, not low manufacturing costs.

However, as the Inquiry report rightly points out, UK engineering does face real challenges, most notably a shortage of the skills needed to sustain world leadership. To sustain the role of engineering and science as the driving-force behind the UK economy, we need to ensure that world class scientists, engineers and technicians are developed through the UK education system. Currently, however, demand for these skilled people far outstrips supply. Closing this gap requires not just change in the educational system, but in society's view of engineers and engineering.

True, we must work collectively both to encourage the successful study of Science, Technology, Engineering and Mathematics (STEM subjects). But we must also confront the deeper social issue that ours is an economy and society where engineering has long been undervalued. To attract our brightest people into STEM-related careers, we need to build far deeper and wider understanding, recognition and support for the achievements of the science and engineering communities, highlighting their attractiveness as a career choice for the most capable people.

Diversity

What is more, the engineering industry's skills gap is not purely due to external factors. We also need to take a long, hard look at ourselves. For example, one glaring reason for the skills shortage is the lack of diversity among qualified engineers. The Select Committee highlights that women account for only 2 per cent of engineering apprentices, and only 14 per cent of engineering graduates — compared with over 60 per cent in other subjects.

Equally alarming is the statistic that only 4 per cent of engineering apprentices come from ethnic minority backgrounds. Put simply, the UK engineering industry is missing out on a massive amount of talent, as well as failing to reflect the diversity of UK society.

As well as training more qualified engineers, attention also needs to be given further down the skills hierarchy. In 2006, the Leitch Report presented a gloomy assessment of skills in the UK workplace, with one employee in five facing problems of basic literacy and numeracy. It went on to recommend tough improvement targets to ensure the UK remains globally competitive.

As we in the UK seek to improve our skills base, the good news is that we have three key strengths to draw on.

The first is a growing commitment to engineering skills in the partnership between Government, industry and education. A good example of this is the creation of the UK Commission for Employment and Skills, an employer-led organisation that will help drive Government skills policy and funding. A further positive collaborative development is the revitalisation of the UK's apprenticeship system. There are now a quarter of a million apprenticeships a year.

The UK's second strength is the world-class engineering research in our universities. The December 2008 Research Assessment Exercise (RAE) rated between 15 and 20 per cent of our university engineering-related research as 'world leading'. However, we could do even more if we followed President Obama's example in the USA and made investment in critical emerging technologies part of our economic stimulus package, positioning research as a 'once in a generation opportunity' to strengthen our future capabilities.

The UK's third strength is an increasing focus on engaging school-age pupils with STEM careers.

What do these efforts mean for the UK? We are at our strongest when competing not on price, but on innovative value-add. In the future, with the right skills in place, we can pinpoint where and how we can apply this edge most effectively in the global market.

And, at the risk of talking up my own business, one of those areas where we can compete and indeed already have a proven world-class presence is in the aerospace, security and defence sector.

Aerospace and defence

This is an industry that we must not take for granted. In the Committee's report and the Government's response, we do appreciate the focus on specialist disciplines such as plastic engineering, geo-engineering and nuclear engineering. However, nothing is said about aerospace and defence. This is both surprising and disappointing.

It goes without saying that this industry is core to our country's armed forces, and to UK's ability to defend its national security and strategic interests. But its importance goes much further and deeper.

The industry is a major high-value contributor to the UK economy, creating thousands of jobs directly and in its supply chain, and achieving consistent success in export markets. In addition, the industry supports and fosters skills and innovation: BAE Systems is the UK's largest employer of qualified engineers. It is also an industry that is actively seeking our new opportunities. For example, in recent years it has begun to take the lead in the fast-growing global market for electronic security and personal identity services. World-class science, technology and engineering capabilities will be critical for maintaining and growing that lead.

Summary

In my view, our country depends on a strong and vibrant engineering sector as much as ever. Industry is committed to working in partnership with Government and the education system to build and sustain the world-class skills and research base that will keep our engineering businesses globally competitive. We believe there is a powerful argument for a Government-led national engineering strategy to ensure engineering is given the priority it needs and deserves. □

The Government has formally responded to the report. Lord Drayson, Minister for Science and Innovation at the Department for Business, Innovation and Skills (BIS), reflected on the discussion that took place at the Foundation's meeting.

A need for reliable and authoritative advice

Paul Drayson

The Lord Drayson of Kensington is Minister of State for Science and Innovation jointly at the Department for Business Innovation and Skills (BIS) and the Ministry of Defence (MoD). After completing a PhD in robotics, he successfully grew a biotechnology company, Powderject Pharmaceuticals, into a leading manufacturer of vaccines. On his appointment he was invited to attend Cabinet meetings and to participate in the National Economic Council. He chairs a Cabinet Committee focussing on science and innovation across Government .

The Government welcomes the Committee's report and its support for the UK's world class engineering base. Our response shows that there is agreement with the Committee's views – for example, our explicit acknowledgement that engineering advice is key to good policy and delivery in a huge range of areas, from tidal power to medicine. We also value the focus provided by the Royal Academy of Engineering in acting as a conduit for advice to Government from the engineering community. I should also say how helpful it has been over recent years for the engineering institutions to work more closely together to produce coordinated and coherent advice: what we need in Government is reliable and authoritative advice that we can use to make decisions.

I was very pleased to learn that overall the discussion during the Foundation's meeting was so positive and constructive. That said, we do need to guard against slipping back – the engineering community must continue to work together (and at times with the science community) to provide the coherent advice Government needs. In this context, I remain convinced that it is more helpful to see science and engineering as a continuum of knowledge rather than separate worlds. It will also be important to focus the community's energies on providing advice on the key challenges we face nationally and internationally, and to avoid being distracted by minor issues of process and structure.

In tackling the seemingly eternal problem of the perceived status of engineers in the UK, I think it is important for the key players to focus on the contributions they can make; in particular, for both academics and employers to redouble their efforts to dispel the negative mythology about engineering. We need to get the message out to young people making decisions about their futures that engineering is a singularly rewarding field offering intellectual stimulation and challenge, as well as hugely interesting and rewarding professional career prospects – suitable for both men and women.

It is also important not to confuse the rising generations of potential engineers (and scientists) by arguing too strongly for one branch of engineering over another, or even for engineering over science. Most people who pursue careers in engineering (and science) will wind up working in multi-disciplinary teams where success will depend on the effective contributions of people from different disciplines. I believe that these approaches offer the best prospect of attracting more of the brightest and best in the country to pursue engineering qualifications and careers.

I look forward to reading the committee's next report on *Putting Science and Engineering at the heart of Government Policy* – and in due course to the Foundation's deliberations on the Government's response to it. □

Government response to IUSS Committee report: www.publications.parliament.uk/pa/cm200809/cmselect/cmdius/759/759.pdf

As the UK exits recession, what will drive the recovery? The role of science and innovation partnerships was considered at a meeting of the Foundation held at Queen's University Belfast on 7 October 2009.

The key partnerships to deliver innovation

Peter Gregson

The Secretary General of the Commonwealth, and now Chancellor of Queen's, Kamalesh Sharma, describes knowledge as "the currency of the 21st century". That idea is at the heart of this debate.

At the outset, I would like to draw attention to two features of the economy in Northern Ireland. First, it is led by small- to medium-sized enterprises (SMEs), with the emphasis on small: 99 per cent of companies in this part of the island employ fewer than 50 people. Second, the industrial structure is different from the rest of the UK – we have much less in the way of business services but more in education, manufacturing, retail, construction, public administration, agriculture and health.

In Northern Ireland we face four key challenges:

- rebalancing the economy through private sector growth and public administration reform;
- maintaining and developing our strong manufacturing base;
- addressing new and emerging markets such as information technology and personalised medicine;
- building a strong, value-added agrifood sector with a continuing emphasis on exports.

The key partners are universities, business and Government. They must work together to develop a cycle of innovation. In a perfect world, universities would create and disseminate knowledge, businesses would generate wealth and thereby improve quality of life, and Government would create an environment that encourages business and sustains universities. However, we do not live in a perfect world; moreover, the rug has been pulled out from under our feet by the global recession.

Maximising resources

The recession has had three main impacts: a decrease in funds for investment; a shrinking of markets; and fiercer competition. For universities and businesses, the decrease in funds has meant

Professor Peter Gregson FREng is President and Vice-Chancellor, Queen's University Belfast. He is committed to seeing Queen's develop as a broadly based, research-driven university and has led it to membership of the Russell Group of UK universities and to THE Entrepreneurial University of the Year Award 2009.

an increase in partnership-working and collaboration as a way of maximising our use of existing resources. For example, the White Rose University Consortium draws together the universities of Leeds, Sheffield and York, and works very effectively with Yorkshire Forward, their Regional Development Agency.

Here at Queen's University Belfast, we have worked closely with Invest NI to develop many business-university collaborations including the outstandingly successful Northern Ireland Centre for Entrepreneurship which provides entrepreneurship education within the curriculum for all undergraduate students. A related partnership with Trinity College Dublin and University College Dublin will change the nature of graduate education across the three universities and help to embed innovation in the postgraduate curriculum.

Business partnerships also increase. Some businesses will embark on joint marketing and development programmes; others will go further still and explore joint ventures and mergers. In Northern Ireland, a joint venture between Rolls Royce and Goodrich led to the formation of Aero Engine Controls. This gives Rolls Royce an in-house capability – control of aero engines – that had hitherto been part of their supply chain. Incidentally, this example also shows how recession concentrates supply chains.

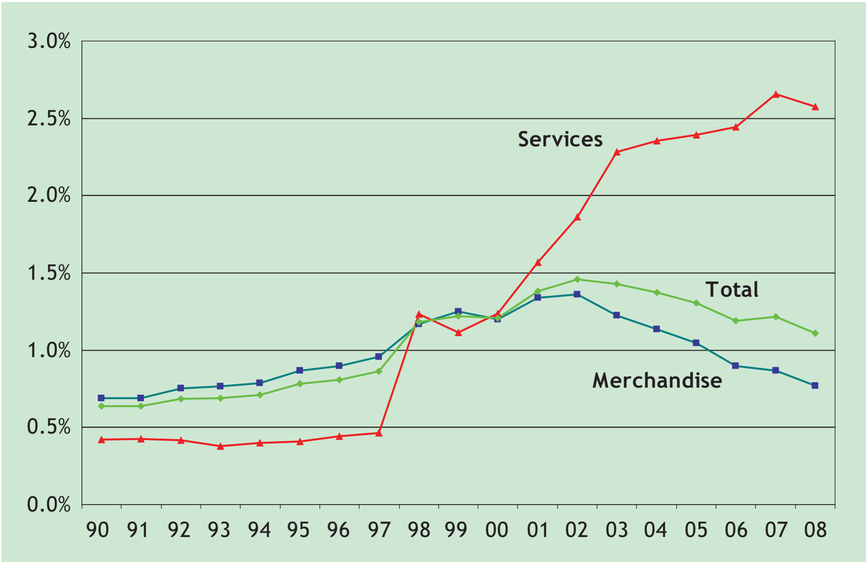
Governments in Belfast and Dublin have been very active in supporting partnerships and collaborations; examples include the Department for Employment and Learning All-island Research Programme, the Higher Education Authority Programme for Research in Third Level Institutions and the Science Foundation Ireland Centres for Science, Engineering and Technology.

Shrinking markets and fiercer competition mean that we must use knowledge to improve our products and services, and so enable us to move up the value chain and increase the range and size of our markets. Business is very adept at accessing new knowledge, as exemplified by the Queen's Ionic Liquids Laboratory in the School of Chemistry and Chemical Engineering, which is supported by Petronas. Another example is the recently launched Queen's-Seagate University Technology Centre. Both of these follow the model set by the Rolls Royce University Technology Centres, which are perhaps the best exemplars in this field.

For their part, universities work hard to improve communication and increase interaction with industry and business. Universities are also involved in spinning out their own technologies. Andor Technology, which was floated on the London Stock Exchange's Alternative Investment Market (AIM) nearly four years ago, and Kainos are just two of the spin-off companies from Queen's. Our spin-out companies now contribute over £100 million into the Northern Ireland economy every year, and provide more than 1,000 high value jobs.

The Government has also stepped up to the plate. We, in Northern Ireland, were the beneficiaries of a very creative project, the Special Programme for University Research. This project underpinned the remarkable development of our Centre for Cancer Research & Cell Biology and our unique Sonic Arts Research Centre.

Furthermore, Queen's University Belfast has been selected to lead one of the two Innovation and Knowledge Centres in the UK, supported by the Engineering and Physical Sciences Research Council and the Technology Strategy Board. The contract for our Centre for Secure



Ireland's share of world trade.

Information Technologies is the largest research investment ever awarded to Northern Ireland. It will enable us to attract more talent to Queen's and ensure the future of our companies in this important field.

Partnership in practice

I would like to conclude with an example from medicine that illustrates how the three key partners in Northern Ireland — Government, business and universities — can collaborate to make the innovation cycle work. First, the Department of Health, Social Services and Public Safety invested £80 million to build a new Cancer Care Centre at Belfast City Hospital. This was a core element of a major programme of change and development in cancer services across Northern Ireland.

Second, Queen's University Belfast, together with support from the Government, invested £25 million in the Queen's Centre for Cancer Research & Cell Biology. The centre now contains 300 international clinical scientists who are committed to the highest quality of research excellence. It is the only unit in the world to be recognised as a centre of excellence by both the National Cancer Institute in the USA and Cancer Research UK.

The third, and most important, investment came from the business community; the Almac Group has invested £200 million to support new work in the fields of drug discovery and personalised medicine. The university's work in cancer research, cell biology, analytical chemistry, biomedical informatics and medicinal chemistry is aligned with Almac's businesses – diagnostics, sciences, clinical services, clinical technologies and pharma services. Is it sustainable? In this case, I believe it is, because we have business, Government and university working together, and further joint investments are being discussed and will surely follow.

Universities are in a pivotal position to support business-led science and innovation partnerships. If knowledge is the currency of the 21st century, then science and innovation partnerships could be the banking system of the future. However, much will depend on the lead from business. ☐

Finding the right niche

Eoin O'Driscoll

Over the past two decades Ireland, with its favourable tax regime, has attracted high-growth US companies in ICT (information and communications technology), pharmaceuticals and internationally-traded services. This foreign direct investment resulted in a large expansion of exports and Ireland joined the top rank of countries in terms of GDP per capita.

The dramatic growth in exports helped to fuel a consumer and construction boom, which was then further accelerated by cheap credit and reckless lending. During the boom, energy costs, professional fees, wages and salaries all rose at a rate far above that of our trading partners and we lost our international competitiveness. Government spending grew rapidly, funded by a surge in transaction-based taxes. When the international credit crisis struck, credit tightened, transactions stopped and tax receipts collapsed. The gap between spending and taxes widened and we are now faced with a very large hole in Government finances.

Eoin O'Driscoll is Chairman of Forfás, Ireland's National Policy Advisory Board, and Managing Director of Aderra. He is on the board of a number of private software and telecommunications companies and is Director of the Trinity College Institute of Neuroscience as well as a member of the National Executive Council of the Irish Business and Employers Confederation. In 2004 he chaired the Enterprise Strategy Review Group.

What do we do now?

First, we must cut our costs. This is necessary to allow us to survive, but it is not sufficient to allow us to thrive. As a small, open economy we can only thrive if we have export-led growth. Achieving this growth in a highly competitive globalised world will present challenges. We now face more intense competition and our 'temporary monopoly' in attracting mobile foreign direct investment is no longer a sustainable strategy for economic growth. To thrive in the new competitive landscape we must create new 'temporary monopolies' to replace the tax-based one – the source of our growth in exports.

We need to create temporary monopolies based on knowledge and intellec-

DISCUSSION

Small- and medium-sized enterprises

Speakers observed that individuals developing successful but relatively small businesses were often content to stay in a comfort zone, continuing with an agreeable lifestyle and retaining personal control. A speaker from the SME sector responded that once such a business became too prominent, it was regarded by bigger corporate players as potential prey. On the other hand, an entrepreneur with experience of American as well as European business observed that developments in Silicon Valley and elsewhere pointed to the overall benefits of an 'exit strategy'.

tual property (intellectual property rights are in reality state-enforced temporary monopolies). As a small, open economy we must focus on niche areas where we can develop and exploit comparative advantage. A well-educated workforce, a strong base of leading high tech companies as well as recent investments in science technology and innovation all position Ireland to build comparative advantage based on knowledge.

We should select niche areas that play to our strengths and that capitalise on our existing investments. We can build comparative advantage by using our excellent natural resources in the areas of wind and wave. We have a growing applied research base in 'green tech' with strong centres of excellence such as the Tyndall Institute, ERC at UCD and the Marine Energy Research Centre in Cork. We are now putting in place the necessary piloting and prototyping infrastructure such as SmartBay Galway, which carries out work on oceanographic monitoring, to allow us to take advantage of the enormous natural resource we have on our doorstep.

We can build comparative advantage in niche areas based on our research capability. Ireland has strong research capability in photonics and optics and we are now creating leading companies in these fields, such as Intune and SensL. We can also build comparative advantage based on collaboration and interdisciplinary research. As home to 13 of the top 15 pharmaceutical companies, 15 of the world's top medical device companies, eight of the 10 top ICT companies, with world-class food and agribusinesses, we are well positioned to seize opportunities based on the convergence of ICT and biotechnology.

In these and other niche knowledge areas, we can achieve growth by developing and delivering goods and services that provide value for customers in international markets. As a relatively high-wage economy, we will never compete on the basis of cost – we must compete on the basis of value. Thriving is about creating unique and sustainable competitive positions; it is about knowing and understanding customer needs; it is then about using knowledge, skills and expertise to satisfy those needs in a superior, differentiated way so that we can extract a premium for the products and services that we provide. Only by doing this can we avoid a race to the bottom.

Science Foundation Ireland, the Irish Research Council for Science Engineering and Technology and the Programme for Research in Third Level Institutions, have transformed the research landscape at Irish universities. We now need to build on this to position Ireland to compete based on knowledge. Merely providing a manufacturing base for the ideas of others will not sustain our ambition for growth.

Meeting customer needs

To provide value for customers, organisations need to satisfy real customer needs. Here we need to invest in understanding the dynamics of markets – how to interpret customer requirements and how to satisfy them with innovative products and services.

This kind of approach is exemplified by Apple. They recognised that customers wanted easy access to their music anywhere and at any time, and they responded with the iPod. This product is an excellent example of the innovative use of existing technology. Apple took standard electronic components – memory, a display and some plastics, and created a new product which cost less than $150 to manufacture but could be sold for $300. Apple identified a customer need and satisfied that need in a superior way.

A lesser-known example is that of Keenan Brothers, a small Irish company. They sell mixer wagons, which are attached to tractors and are used to mix and distribute cattle feed. Keenan Brothers have approximately 15,000 customers worldwide. They manufacture the mixer wagons but create value by selling them as part of an innovative nutrition solution to world-leading farmers. They discovered that their customers wanted nutrition solutions that would produce higher milk yields and better beef quality. So they integrated nutritionists into their sales force and established a technology advisory board that included a professor of animal genetics, a professor of animal nutrition and a professor of mechanical engineering. Keenan Brothers is now a leader in their field, shipping to over 50 countries. As a company, they understood their customers' needs and sought the help of universities to create innovative technology that met those needs in a superior, differentiated way.

Integrating research with the market

To foster entrepreneurship and innovation in niche knowledge areas we must find ways to integrate research with the market. This is not a linear process but one that requires complex interactions between those who produce ideas and those who commercialise them. Peter Day, business correspondent with the BBC, speaking at a Science Foundation Ireland conference last year, summed up the process of innovation well when he said: "It's from the friction developed by the real world rubbing up against a clever brain that can see the goods and services people need." We need to foster this friction through more applied research and by increasing the mobility of our researchers so that they rotate in and out of industry. Without this we are unlikely to get the full economic benefits of our investment in research.

Writing in 1947, Frederick Terman, Dean of Engineering at Stanford University, said: "A strong and independent industry must, however, develop its own intellectual resources of science and technology, for industry activity that depends upon imported brains and second-hand ideas cannot hope to be more than a vassal that pays tribute to its overlords and is permanently condemned to an inferior competitive position." His message to California is relevant to Ireland today.

In the Republic of Ireland we now have an opportunity to build on the progress we achieved through foreign investment by taking responsibility for our own destiny and using knowledge as the way forward. If we do this, we can build on our success in manufacturing and internationally-traded services to develop new niche knowledge areas based on science and technology. ☐

Building joined-up support for innovation

Iain Gray

The Technology Strategy Board (TSB) is an organisation of 96 people with a total of over 1,200 years of business experience. The TSB is not just a funding agency; it is an innovation agency that brings together different funding mechanisms through partnerships and networks. Our motto, 'Connect and catalyse', sums it up: we connect businesses with other businesses, businesses with academia and businesses with Government.

Although we are a publicly-funded body sponsored by the Department for Business, Innovation and Skills (BIS), we understand the needs of business and the decision-making processes that have been taking place in businesses around the UK over the past 12 months.

We were set up with a budget of £1 billion over a three-year period. We distribute funding but are also involved in a range of other activities. We support the full spectrum of businesses, from manufacturing through to healthcare, information communication technology, the creative industries and the financial services sector. We also support all sizes of business, from large multinational corporations through SMEs (small to medium enterprises) and down to micro-businesses employing five to 10 people.

Growing the businesses of tomorrow

One of our roles is to examine initiatives which ensure that large corporations keep their research and development base in the UK. We want to identify emerging technologies and grow them into the businesses of tomorrow. We are also looking for ways to support SMEs. Over 65 per cent of the funds that we distribute go to SMEs.

However, we receive many requests for funds and we must make choices. To do so we ask a number of questions. Is there a market for the product or service? Is the UK ready to exploit that market? Will the product or service be available within a timescale that will ensure the business benefits from it? Can the Technology Strategy Board make a difference? Those are our key criteria.

Over the past 12 months we have had to make some particularly difficult choices. Our first priority was to focus on low-carbon and ultra-low-carbon vehicles, low-impact buildings and 'green' manufacturing. Our second priority was the digital economy, with a focus on bringing together the creative industries and the electronics sector. Our third priority has been healthcare, in particular stem cell and regenerative medicine.

Iain Gray FREng is Chief Executive of the Technology Strategy Board. Prior to taking up this post he was Managing Director and General Manager of Airbus UK, whose Bristol operation he joined when it was still part of British Aerospace. He is a Fellow of the Royal Aeronautical Society and was awarded its Gold Medal in 2007.

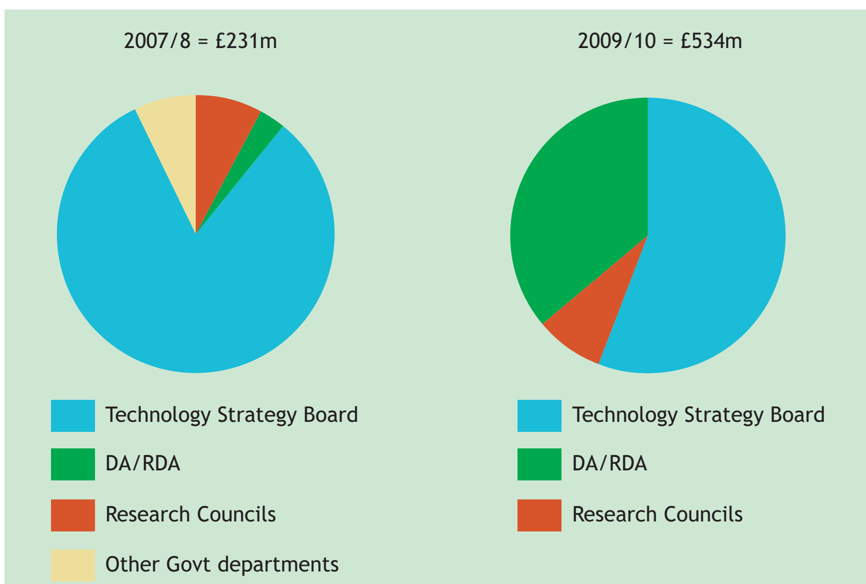
We secured an additional £50 million of funding over a two-year period, part of which is being used to support the development of low-carbon vehicles and a low-carbon vehicle demonstrator programme. We also fund work into low-impact buildings, including £10 million for a competition to retrofit older buildings with new 'green' technology. Digital Britain received £10 million and we are responsible for managing the UK Digital Test Bed. Finally, we distributed £11 million to healthcare and £30 million to high-value manufacturing. Much of our investment is matched on a 50:50 basis by the private sector.

Collaborative R&D

Through our collaborative research and development model, we engage with some 1,500 businesses. Our knowledge transfer network (KTN) model involves 57,000 businesses and our knowledge transfer partnership (KTP) model covers 1,000 businesses. Connecting business with business and creating consortia around business is a key part of what we do.

Brokering relationships between business and different Government departments is another important role for us. We have established relationships with chief scientific advisers, innovation teams and the people who control the budgets of different departments. We work with the Ministry of Defence, the Department of Health, the Department for Transport, the Department for Energy and Climate Change (DECC), as well as Communities and Local Government (CLG). We also have strong links with two new cross-functional offices: the Office of Life Sciences and the Office for Low Emission Vehicles. We also work with the research community and the Research Councils, and other organisations such as the Energy Technologies Institute and the British National Space Centre.

We use an innovation platform model to create a framework within which a particular challenge, for example introducing low-carbon demonstrator vehicles into the UK, is defined. From this framework we hang a number of initiatives that will help UK business. Together , these initiatives will make a real and sustained difference to our economy. ☐



Working with the public sector funding leverage'

The digital revolution is changing the way we work and play. Penetration of the web is very high in the UK but connection speeds are well below other nations. How can we bridge the gap? The topic was considered at a meeting of the Foundation on 14 October 2009.

The *Digital Britain* report

Dominic Morris

The final report of *Digital Britain* was presented to Parliament in June 2009 by the Departments for Business, Innovation and Skills (BIS) and Culture, Media and Sport (DCMS). It is one of the central policy commitments in the Government's *Building Britain's Future* plan and draft legislative programme.

In a way, the Digital Britain report was the first application of the 'new industry, new jobs' policy and 'industrial activism'. Other sectors, such as the lifesciences, low carbon and advanced manufacturing are similar and being given similar treatment.

The development, application and use of digital technology underpin nearly everything that takes place in the economy, from financial transactions in the City, to 90 percent of purchases on the high street. Fully £1 in every £5 is transacted through e-commerce. In medicine, the NHS has the largest data and communications system in Europe.

Digital Britain sought to provide a snapshot of a sector as we move from analogue to digital, or at least from one generation of digital technologies to the next.

Dominic Morris CBE is Strategic Director of the Digital Britain project, editor-in-chief of the *Digital Britain* White Paper and expert adviser on Digital Britain to ministers in the Departments for Business, Innovation and Skills (BIS) and Culture, Media and Sport (DCMS). Since 2001 he has been a director of communications for sector regulators, first at the Independent Television Commission and latterly the Office of Communications. He is a past private secretary to Margaret Thatcher and John Major.

Drivers

The process is being driven partly by the national transition in radio and TV. It is also driven by the availability of fixed line technologies where, despite fibre, a surprising amount of technology is still analogue or very much first generation digital.

Mobile is mostly now 3G, but is getting ready to move to Long Term Evolution (LTE). This is the next generation which will give relatively high-speed broadband 'on the move'. Five years ago, six times more voice than data was transmitted. This ratio will be reversed in two or three years.

We are seeing a growth in storage and processing power, and the 'death of distance'. One broadcaster used to transmit to many people; now, many transmit to many and broadcasting is participatory. There are thousands of blogs, tweets and You Tube clips. Anyone can be their own content provider. Public services are delivered online, so everyone must have access to suitable infrastructure.

Infrastructure

The Digital Britain report covered communications infrastructure. There has been a log-jam in mobile phone technology since about 2003-4, preventing future growth. However, we are now seeing demand for the first wholly-fixed network for more than 50 years.

Take-up of digital TV is about 92 percent, but we have to move radio from analogue to digital as well. The Australians are spending billions of dollars on high speed transport, communications networks and 'home on the move'. So are New Zealand, Scandinavia, France, the USA through President Obama's stimulus package, Japan, Korea, the rest of the Far East, and so on. In the words of the Cranberries band, "Everybody else is doing it, why can't we?"

The take-up of broadband is still only 60-65 percent. We are now moving from a point where it was an advantage to be connected to one where not having it is a social and economic disadvantage. That is economically inefficient and socially unjust. Yet getting people to realise that this is what they want is a challenge. We must make it available everywhere. At the moment, about 85 percent of houses in this country have download speeds necessary for viewing the iPlayer. Our ambition is to have iPlayer level, for everybody, by 2012. After that, the target is to ensure that about 90 percent of people have 40MB-plus speeds by 2016-17.

Delivery

Digital content will be delivered through economic models that are fundamentally different from those of infrastructure. We have begun to think about new models with lower production costs, aggregation and micro-payments.

All of those, however, require rights protection in order to succeed. We want to see a number of legitimate, low-cost businesses thriving in delivering downloads that consumers want and can get. They have to be able to compete, and so will need rights protection in order to work. There is also a further set of issues concerning consumer protection.

As far as institutional reform and security go, governance and power are shifting from the American founders of the Net to the European Union. Britain is taking its role in the International Internet Governance Forum.

We have got to be both smarter at delivery of services and smarter at procurement. Our aim is not just government on the web, but government of the web.

Engagement

Digital Britain was produced with a great deal of stakeholder engagement. We listened to many people and held Digital Britain 'unconferences' (an inelegant name but a means that saved the taxpayer money). There were no Government-funded biscuits, tea or hall hire. We just asked people to go and form themselves into communities of interest and tell us what they concluded.

While they did not come up with anything startling, neither did they respond on purely conventional issues. So this approach may be worth trying for other Government and public consultations.

Since the report, we have started working on the infrastructure. We have formed a company limited by guarantee; we have the directors' forum for getting the universal service out by 2012; we have the money. The infrastructure will provide us with next generation networks of some quality. The tender will, I hope, happen in spring 2010.

We identified many other issues in the report: challenges about personal identity, identity theft, high speed transport common infrastructures, and so on. These will be dealt with in the next Parliament. In the remainder of this Parliament, we have a Digital Economy Bill. The final third-generation access fund will be in the Finance Bill. Bar yet another core challenge, there will be a spectrum direction to the telecommunications regulator Ofcom, followed in 2010 by an auction of more spectrum than we have ever auctioned in one go – this will be for next generation mobile. We want to make progress with the digital radio upgrade plan.

And of course, there is a general election looming. So we have six months to get a lot done, then everything goes into the freezer for four or five months. After that, then we will see where we are. ☐

Digital Britain report: www.culture.gov.uk/what_we_do/broadcasting/6216.aspx

Digital Economy Bill: http://services.parliament.uk/bills/2009-10/digitaleconomy.html

DISCUSSION

Digital divide

A major theme in the discussion was the digital divide, and access to the web. Some speakers felt that the Government was not doing enough to ensure that rural areas (which could include areas close to urban areas where business and schools assumed there was web connection) were adequately provided with connections, but others warned against efforts to pressure people into demanding broadband before they were convinced of its value or understood its cost. At present there is a 'patchwork quilt' of accessibility; it is not essential for the Government to be solely responsible for joining up the edges. Part of the problem is the over-exuberant rhetoric that Government and others are using to trumpet the need and use of the web. It is not available everywhere and for every purpose. Politicians have to beware of sounding evangelistic, when the implementation may well fall short.

To be or not to be a digital Britain?

Wendy Hall

Let me start by saying it is so disappointing that this country is focussing 'Digital Britain' on telecoms and not people. I cannot believe that, for example, women are excluded (or rather they exclude themselves) from this debate because it is believed to be about telecoms.

My title is *To be or not to be a digital Britain*? because I am not sure that we are. My alternative title is *Where there is no vision, the people perish*. We do not have enough vision. What is our vision of the society we are trying to build in 10, 20 or 30 years? Have we had that discussion, not just in terms of technology, but what type of society our actions will lead us to? For example, are we going to include women?

We are falling behind. About one-third of Britons do not use the internet. The digital divide is clear to see: people from lower income, lower socio-economic groups, who are less educated, have less access. Age and physical and mental disabilities remain barriers as well.

Clearly, some traditional businesses will decline and change, but many reports note the number of jobs that could be created or obtained through next-generation broadband networks. There are more opportunities than threats. Among these is the opportunity for people to create and run businesses from home, so this is especially important for rural areas – they need faster access, not less, and I think that is something we need to stress again and again.

Dame Wendy Hall DBE FRS FREng is a Professor of Computer Science in the School of Electronics and Computer Science, University of Southampton, and President of the Association of Computer Machinery (ACM). She is a member of the Prime Minister's Council for Science and Technology and a member of the Scientific Council of the European Research Council. She was awarded the Anita Borg award for technical leadership in 2006 and the R&D Society's Duncan Davies Medal in 2009.
Photo: Robert Taylor Photography.

We have, of course, increased the access to the web through mobile broadband technology. We have the possibilities offered by dark fibre networks. The UK leads the way in the development of optical fibre technology and we really should be developing a proper strategy for a national fibre network.

There are latency issues with the use of satellites to provide broadband access, but this is the way many of our competitors will be introducing broadband to rural areas. The price of terrestrial wireless is falling very quickly, so let us think about hybrid solutions here.

Evolution of the web

I tend to think of the web in five year tranches. During the first five, those of us who played with it were surprised if the kinds of things we were trying to find were there. During the second five years (1999 to around 2004) we hoped we would find the things we were looking for. Now, we expect it. It is almost the case that you do not exist unless you are on the Web, or your organisation is on the Web.

Social networking and user-developed content is growing – MySpace, Facebook, podcasts, YouTube, blogs, Twitter. There are technology stories behind all of those and there are social stories behind why people use them: the human behaviour that drives people to use the new technologies.

The mobile web is driving the growth of all this. We are going to see new technologies of augmented reality where you will point your phone at a building or whatever and you will get information about it from the web.

These technologies are changing the world of business. Post-web businesses include Google, the reinvented BBC, Amazon, and eBay. Look what is happening to scholarly publishing with the open access movement! We also have iTunes, e-books and audio books. We will possibly have iMovie soon, certainly iLearn. All of this is going to be available to us while we are on the move. We will live in an amazing society.

We are about to reach Web 3.0, which will be about linked data. This will give us an environment where, when you ask a question, you will get an answer. There will be issues about whether you trust that answer, but it will be different from searching and finding documents that you then have to interpret as a user. It is very hard to imagine what the social impact of that will be, but it is going to be as profound as the first web. This new wave has begun. Take a look at data.gov.uk to see a prime example.

The amount of time we spend in a digital world (and the amount of information that exists in a digital world) will continue to grow, whether we are 'second-lifers' or not. Then there is the whole issue of our personal assets: digital memories for life. It is all about creating them, storing them, retrieving them, archiving them. At Southampton, we are working with neuroscientists to try and understand how this is going to work in relation to the way that our brains store our memories. The community is already achieving amazing breakthroughs with the MS SenseCam, which helps people with memory loss.

DISCUSSION

Women and sustainability

Speakers took up Dame Wendy's comment about women. The internet is often marketed so that it seems like 'toys for boys'. If there are cultural differences between men and women, then this must be addressed. Indeed security (in terms of privacy, fraud and unnecessary Government oversight) is a real problem, although individuals can help themselves, for example by frequently changing passwords. The internet is a major step towards sustainability. It is not carbon neutral, but it will enable increased economic activity and greater productivity, without adding significant operating or capital resources. Yet the more it becomes the bedrock of our lives, the greater the need for safeguards against breakdown from environmental and other catastrophes – such as floods and epidemics.

Going forward

Digital Britain is, or should be, about people. We need to think about the sorts of services we want to provide and what they are going to be used for. Rural communities and underprivileged areas need faster and better access, not less, otherwise we will drive people and businesses to the areas with the fastest access.

We need to think wireless and mobile, as they do in the developing world. We need to think the unimaginable. If we have power cuts in the future, it is not just the lights that will go out – we need to bear that in mind.

We should aim for an online community with the fastest speeds to connect to the internet anytime we want, and wherever we are. So I want to finish with the message that it cannot just be led by central Government and market forces. We have to help people to help themselves. Central Government should determine standards and provide national infrastructure, but the focus should be on community-driven or community-assisted deployment. That is what I would like the next Digital Britain report to look at.

We need to develop a national policy within which industry, schools, libraries, hospitals and other local services contribute to this effort. We should ask people what they are prepared to pay for before we levy the taxes. We should share best practice in how to make things happen at local level – what technology works best and is cheapest in specific circumstances. We should encourage the young (the people who know) to help the old and the physically disadvantaged to get online. We should make it sexy to be the person who donates a WiFi network or pays for the last few miles of the optical fibre network to reach a local community.

The motto of Digital Britain should be: online, anytime, anywhere, in a safe and secure environment. ☐

The role of the web in an 'evolutionary revolution'

Alfred Spector

As Niels Bohr famously said, "Prediction is very difficult, especially about the future." On the other hand, the future is actually at hand and we fail to see it. I think we can be rather confident of the implications of the rapid evolutionary change that we are seeing. We can let that guide us, as best we can, as we try to build up the internet and enable our society to benefit as much as possible.

What we saw with the web was the creation of a very powerful and simple base set of technologies. It was not an organisation that set out to aggregate all of the world's information and sell it at a very good price. It was a notion that a laboratory here, a university there, a government here, a private corporation or individual would store information and make it available.

A very simple way of addressing and accessing all of this stuff was also devised: HTTP. It was simple, but extensible. That actually allowed an enormous amount of information-sharing to occur. There is a tendency for all of us, as architects or as government agencies, to believe that the complex solutions that we come up with can work. Yet we may often conceive complex solutions that have within their very complexity the reason they will not succeed. What happened with the

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worldwide web was that, in a simple and semi-random way, we have arrived at a collection of innovations that collectively are an extraordinary accomplishment.

We have created a virtual library of Alexandria. We have created the search engine – which is a remarkable entity. We have allowed worldwide groups, with special interests in almost anything, to come together and to form a community, a market place, a self-education society and more

I am a strong believer in the Government's role in fostering the basic research that has led to this. We must continue to ensure that we remain leaders in the core technologies. As I think about digital Britain, or digital USA, a lot depends on whether we have the right talent pools. Why do relatively few people in our societies actually love computer science and technology as fields of study and employment? Across society, the numbers are much smaller than we would expect and it is quite surprising.

An 'evolutionary revolution'

Where is all this going? I think there will be an 'evolutionary revolution'. We are breaking down the barriers to communication and information. That is what I refer to as 'totally transparent processing'. This is having a tremendous impact on society.

Across the set of all human languages we will break down barriers. Google translates more than 40 languages. We have just introduced Welsh! We are supporting work on a small language in New Zealand, spoken by the original inhabitants. This will open up the English language corpus, or the Chinese corpus, or the Japanese corpus, or the German corpus or the Spanish, to an under-served population in New Zealand.

Look at the effect this could have on communication. Our President was clearly trying to communicate with the Arab world during his Presidential campaign and early radio addresses. We can provide transcriptions of the speeches and translations of those transcriptions – from audio to text and text to another language. Those are the kinds of fluidities that I envision.

We will also break down barriers across different modalities: text, image, audio, 3-D models, maps and the like. We will be able to move easily across all of these different kinds of data elements. An image will help us find another image. Text can help us find images. Videos will help us find other videos. We will communicate in different ways. We will convert one form into another, automatically. Couple voice recognition technologies with Google's translation capabilities and one has interactive translation which is quite usable by travellers. Again, as we (Google and the broader community) are already doing these things in isolation, I have no doubt they will blend together into a coherent fabric that fundamentally changes the accessibility of information and revolutionises communication.

It is clear we will also break down barriers caused by artificial technical or form-factor distinctions between different devices. Already, the capabilities of cell phones and computers are merging rapidly. Televisions are moving towards fluid internet access. There will be many more consumer appliances, including health care devices, with easy access to the capabilities I have mentioned.

And finally, I think the barriers to the use of different bodies of information (such as web documents, the deep web data that underlies what we usually see, blogs, geographical data, books) will disappear. While some data are clearly private and confidential (like our healthcare records) and others are clearly public (like road networks), access should be fluid but with due regard to matters of privacy and user-control.

Fostering the future

It is impossible to choose 'top-down' winning strategies, in my opinion. I am head of research at Google but I cannot do it and a private company has many advantages over societies due to its smaller scale and clarity of objectives. Google prefers, wherever possible, a 'bottom-up' approach in helping this evolution occur.

We must ensure that there are minimal barriers to network service creation. Ubiquitous, high-performance communication is a clear enabler, so anything that facilitates this is desirable, providing and ensuring that there are not barriers to fast experimentation – and failure.

It is very important that we accept that things will fail. Could we have predicted Twitter? Who wants to listen to a few lines about how good the food is at the Royal Society tonight? I, personally, do not think anyone wants to know that – that would have been my conclusion if someone had asked a few years ago. Yet Twitter has been successful. So, we do not know what is going to succeed; nor do we know what is going to fail.

There are many opportunities. As computer scientists we now have the opportunity to create amazing interfaces to systems and 'mass customise' these to particular uses and particular individuals. We will have virtually unlimited data and processing. There is no question that this will happen. There are some very interesting issues about making sure we do the processing with great efficiency, with very good, green computing technologies, but this is feasible.

Computers will appear to have understanding. We will see this, increasingly, as a partnership between ourselves and our computers: computers learning from us while we learn from the computers. I will not go into this further, but I will offer the term 'hybrid intelligence' to be provocative.

With the ability to gather data all the time and store it at mass levels, science will change. For example, you can scan the universe and look for differences over time. What are those differences? What astronomical events are occurring? It is very difficult to see them, but if you just scan everything and essentially subtract images from each other to highlight changes, this will have enormous implications in astronomy.

As we measure almost everything, we can optimise societal systems in ways that are really enormous and valuable – in healthcare, for example.

There are challenges: for example, computer security and cyber warfare. But there are really no limits. We are not talking about physics: the laws of Newton and Einstein do not apply to logic. Let's put in place the simple building blocks, starting with education and communication infrastructures, so we foster this bottom-up path to a world with vastly more information and communication. ☐

The future of broadcasting in a digital Britain

Erik Huggers

Erik Huggers is Director, Future Media and Technology, at the BBC. He is responsible for the BBC's output over the internet, interactive TV and mobile services. He also holds responsibility for managing the BBC's Broadcast and Enterprise Technology portfolio, Information and Archives, and he leads the BBC's Research and Innovation activities. Erik joined the BBC from Microsoft, where he worked across a wide variety of industry-changing digital media initiatives.

The BBC absolutely welcomes *Digital Britain*. There is only one issue where we differ from its conclusions and that is the proposal to top-slice the BBC's licence fee. However, I will leave that aside for now and focus on other topics.

We believe in the value of a digital Britain. Our *Delivering Creative Futures* strategy is about getting ready for the digital age. We are going to go completely digital.

Now that sounds very simple, but if you think about it, thousands and thousands of people using a corporate network, using commodity computing technologies, using cameras and recorders that shoot straight to memory – this is a complete cultural shift. We think that these investments will unlock, on the one hand, great new creative output which will help us deliver our public purposes. On the other hand, we think it will help us deliver great efficiencies because all of these technologies are becoming very affordable.

But a digital Britain is not only a great thing for the BBC. We also think it is a great thing for all public institutions. It is great for audiences. It is great for the consumer. Having access to all that information, all those services, can only be a good thing.

However, I do not think Digital Britain goes far enough. The Korean Communication Commission's fantastic broadband capability had nothing to do with government intervention. The government worked hand-in-glove with the commercial sector and put rules and regulations in place that allowed the private sector to invest and build these networks. South Korea currently provides around 100Mb per second to the home, but is going to upgrade its networks to 1Gb per second to the home, and 100Mb per second for wireless, in 2012. In the light of that, you have to wonder what is going on here, and whether our ambitions are too low.

Growth of internet services

At the beginning of October 2009, for the first time in the UK, the total value of internet advertising surpassed television advertising. It is not going to look back – it is only going to continue to grow.

One in six of our audiences currently do not watch television in the traditional, linear way any more; they (particularly younger audiences) watch it on iPlayer. We have between five and six million users per week using BBC iPlayer. Each of those users consumes around 60 minutes per week of long-form video. They consume around 160 minutes per user per week of radio. That growth has increased from nothing in December 2007 to a level where we are now the world's largest flash-streaming service other than YouTube.

We are hosting the Olympics in 2012. When I think about our capability to deliver media to the nation and to the world, I get very worried. The BBC, as one of the host broadcasters, has the rights to all the video and for the first time we want to make everything available to all audiences. I have sleepless nights over that. To tell you the truth, we had big worries when Andy Murray made it into the semi-finals at Wimbledon. It was only the semi-finals, but he nearly took our corporate network down! So you have to wonder what happens if a Brit makes it to the finals at Wimbledon in 2010!

Another challenge on the horizon is this: you may be paying for flat-rate broadband services as a consumer, but if after 5.30pm you click on some video which you want to see at a particular quality level, you may find the ISP has decided to throttle down your bandwidth and give you a much lower quality experience. This is called traffic-shaping, and there is clear evidence that ISPs are actively traffic-shaping the BBC's distribution capabilities on the web. Ofcom regulates and allows this as long as it is called traffic-shaping, network management, or some such thing. But we need to create transparency so that consumers know this is happening and can decide to pay more for quality of service, or else we have to find other ways to deal with it.

The 'digital divide' is another problem area. The BBC and other broadcasters, media and entertainment companies can play a major role here, educating consumers but also making great services available that allow consumers to see the value of being online.

Current projects

We believe that, currently, BBC web services and most people's web services are consumed on PC and mobile devices. The last piece in the jigsaw is the living room. At what point are we going to be able to deliver the richness of the web to the living room? In partnership with BT, ITV and Channel 5 (and there are others who are very interested) [*since this talk was given Channel 4, Talk Talk Group and Arquiva have also joined the partnership*], we are looking at an opportunity to bring the world of the web to the masses in an open-standards based way, from which the consumer will benefit greatly. This project, entitled Canvas has the potential to democratise access to the living room.

Today, if you want your services in the living room, you either need to have access to spectrum (which is difficult) or access to capital (to build out your cable network or satellite network). With Project Canvas bringing the internet to the living room, any small corporation can start to build services and applications and get them there. We hope this will spawn a whole new industry, in the same way that Apple achieved with the iPhone and the App Store. We think that Canvas has the same capability for the living room. ☐

The space between science and politics

Geoffrey Boulton

I shall speak from the perspective of a natural scientist, for whom the term 'politics' in my title refers to something all citizens of a democratic society are engaged in: the business of making choices – which is not just the role of professional politicians.

There is a strong scientific basis for the view that the climate is changing, and there is evidence that the strongest driver for much of the most recent change is the accumulation of anthropogenic greenhouse gases in the atmosphere, together with deforestation. Although there are large uncertainties associated with this view, and it has been increasingly challenged in the last year or so, I believe that the balance of evidence still favours it. Although, contrary to popular myth, science rarely if ever gives unequivocal answers, the immensely serious potential for what has been called 'dangerous climate change' still demands a serious and energetic response, notwithstanding the uncertainties.

Can we, as a species, adapt our behaviour to minimise potentially serious risks, even though they may lie beyond the next electoral cycle, or must we wait until those risks become reality?

The Royal Society of Edinburgh has launched a major inquiry on facing up to climate change led by Professor David Sugden[1]. It is a risk-based approach, with two principal objectives. The first is to map the ground between where we now stand and where we will need to be to achieve the emissions reduction targets agreed by the Scottish Parliament. The second is to engage our fellow citizens in finding ways to create awareness of the risk and to discuss how we should respond to it.

Even though significant climate change seems distant from us, it is important to recognise that elsewhere major change is happening now. On a recent visit to Scotland, the President of the Inuit Federation, representing Greenland and Northern Canada, commented that he was very weary of people who talk about future climate change and of armchair sceptics. Change, for him, is happening now, and it is destroying his communities.

Professor Geoffrey Boulton OBE FRS FRSE is General Secretary of The Royal Society of Edinburgh and a member of the Prime Minister's Council for Science and Technology. He is Regius Professor of Geology and Mineralogy Emeritus and former Vice Principal of the University of Edinburgh. He has served on a number of UK and international scientific bodies, including the Council of the Royal Society.

Communicating

One of the principal problems of transmitting scientific information in the public domain is that most of us in our everyday lives think of cause and effect in simple terms – here is a cause, there is the effect. Part of the climate system behaves like that, such that if the concentration of atmospheric greenhouse gases increases significantly, some very basic physics and chemistry will determine the long term direction of average global climate change. The short term and geographic patterns of change however are determined by turbulent phenomena. On these scales, the climate system is a complex phenomenon in the technical meaning of the term. It involves a series of interacting processes such that if the system is externally perturbed, for example by adding more CO_2 to the atmosphere, it is not self-evident what the short-term outcomes will be.

Transmitting such a message in the public domain is extremely difficult. Scientists have too often given the public simple stories – and sometimes those simple stories have, in a sense, turned round and bitten us back. It was H L Mencken who said, "For every complex problem there is always a simple solution that is neat, plausible and wrong." It is an adage that we would do well to remember.

Because of its complexity, computational models are a basic tool in understanding the climate system. The model is a 'black box' into which we put our current understanding of the physics, chemistry and biology of the climate system. We then perturb the 'black box' (the model) and the behaviour that results is often unexpected. When someone asks why the system behaves like that, there is no simple answer.

One of the things that we hear from those who strongly doubt climate change is: "Of course, they are only models." It is a shame that we use that word 'models', but we should say to them and our fellow citizens that we use models to predict the future every day. Other complex, coupled computational models are used daily to forecast the amount and structure of steel, glass and concrete needed in major buildings to minimise cost and maximise long-term stability, and in designing aeroplanes optimally to minimise material and cost while maximising safety. Those who tell us that models which attempt to predict the future are airy-fairy are wrong. We are all of us familiar with their results, every day.

Strategies

So what should our mitigation strategy be, particularly in relation to the decarbonisation of energy? The objectives need to be very clearly spelt out by Government. They should be: to meet emissions targets (which are now enshrined in law); to minimise cost (because we do not want to undermine the effectiveness of our industry or the cost to individual citizens); and to maximise energy security.

An ideal policy would set these objectives out in such a way as to give confidence to companies that want to invest. It would have long-term economic instruments which both force and reward change – so that an efficient company with clever technology can meet emissions targets at lower cost than competitors, and thereby thrive.

Ideally, energy suppliers would have the freedom to utilise whatever technology they wished. We need the largest transmission and supply network, linked into Europe if possible: the idea that Scotland needs to have its own isolated energy system would have been ridiculed by one of its most famous sons, Adam Smith.

It would be a mistake however to have an emissions strategy without an adaptation strategy, and there is an emerging strategy for Scotland. But do we need one when the direct risk from climate change to Scotland may be small? While the direct risk may indeed be small, it is also important to recognise that the secondary effects on Scotland of climate changes elsewhere could be very large. If, for example, the South East Asia monsoon, a major control on agricultural fertility in Asia, were progressively to weaken, the economic implications would be enormous and Scotland would not be left unscathed. Rises in food and energy prices, migration and conflict, are all secondary effects being considered by politicians as well as security and military organisation worldwide.

The way we look at such possibilities is important. Some claim that they have zero or low probability. But even those who regard them to be of high probability need to think in terms that are not alarmist. Martin Luther King did not say: "I have a nightmare", but "I have a dream." He spoke about his vision of an honest, lawful, harmonious, multi-racial society. It seems to me that our vision has to be to live within an Earth which has finite resources, in a way that is sustainable for the long-term future. It is not just a question of changing what we do, it is also a question of changing how we think. ☐

1. www.rse.org.uk/enquiries/climate_change/index.htm

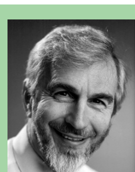
DISCUSSION

Public understanding

There has been a failure to bridge the gap between emissions reduction objectives and public understanding. Why is it that we have not had a mature discussion based on probabilities and risks? After all, assessing risk and probabilities is part of our daily lives - as when we cross the road ahead of the traffic. Businesses cannot survive or thrive unless they are continually assessing risk and making decisions about incurring costs or developing new products. Perhaps the failure is due partly to a lack of understanding of complex science and scientific methods; partly the long term and seemingly abstract nature of the issues.

The impact of climate change on Scotland

John Mitchell



Professor John Mitchell OBE FRS is Director of Climate Science at The Met Office. He joined the organisation in 1973 after completing a PhD in atomic physics at Belfast. He has spent most of his career seeking to understand and predict climate change, apart from two short spells as a forecaster. In 2002, he became Chief Scientist and in 2006 moved to his current post.

I am going to look at three issues: the basic science of climate change (to help people address some of the sceptical arguments); some of the global results; and regional predictions, particularly for Scotland.

Basic science

There is a tendency among people who believe in climate change to demonise the sceptics; I do not think that is helpful – after all, scepticism is the foundation of science. What really annoys me, though, is when sceptics do not do their homework. Figure 1 shows the concentration of carbon dioxide over the last several hundred thousand years – in fact that curve has now been extended back to over 600,000 years. On the far side you can see the scale. Those ice-age cycles (which are what these are) show the limits of CO_2. Today we are almost at 390ppm. That is well outside of the range over the last several hundred thousand years, and it is also a much faster rate of change. I do not think that is natural.

The greenhouse effect is very simple; greenhouse gases absorb long-wave radiation, trapping the radiation that is emitted from the Earth and bringing it back down again. Increase greenhouse gases and you are bound to have a warming effect. With the simple, classical physics of radiation theory, you can calculate what change in radiative heating is due to a doubling of CO_2 and, with simple school physics, you can work out that – without any other changes – you would get a 1°C increase in temperature. Now, in a warmer atmosphere there is a greater weight of water vapour (the main greenhouse gas) and that gives a strong, positive feedback, increasing the warming further.

The sceptics have also attacked the data record, but there are actually three independent sets of observations: the land surface temperature dataset; the sea surface temperature dataset; and the marine air temperature dataset.

Modelling

We took existing climate models and tried to simulate what the climate would look like without greenhouse gases. The main natural factors we did include were volcanoes and changes in the output of the sun. We know there have been three major eruptions over the last 50 years and that there has been little change in solar activity over the last 30 years so, not surprisingly, when you include only these factors you see very little change in temperature in recent decades.

Adding in the effect of increasing greenhouse gases and the effect of other atmospheric constituents such as aerosols, you get a much better fit. This is some of the evidence why you need greenhouse gases to explain what has happened in the past.

People will often say that "it's only a model", but the model we use in Met Office climate modelling is a version of the weather forecast model. It is based on the laws of classical physics. It is tested against past climate. There are a number of tests which give us confidence in the model, but our main confidence rests on the physical principles upon which it is built. These are well-tested and physically-based models. Nevertheless there are some small scale processes which cannot be modelled explicitly (for example, clouds) and these contribute to the 'factor of two' uncertainty – the predictions for the future for a given scenario are generally uncertain by a factor of two (i.e. over ±30%) by the end of this century.

There is a degree of uncertainty due to the different emissions scenarios. The other major source of uncertainty is due to the fact that climate varies naturally – which is what the sceptics keep reminding us. And that variability can be significant, which means when you are looking for an indication of climate change, you can be looking for a small signal against a very noisy background.

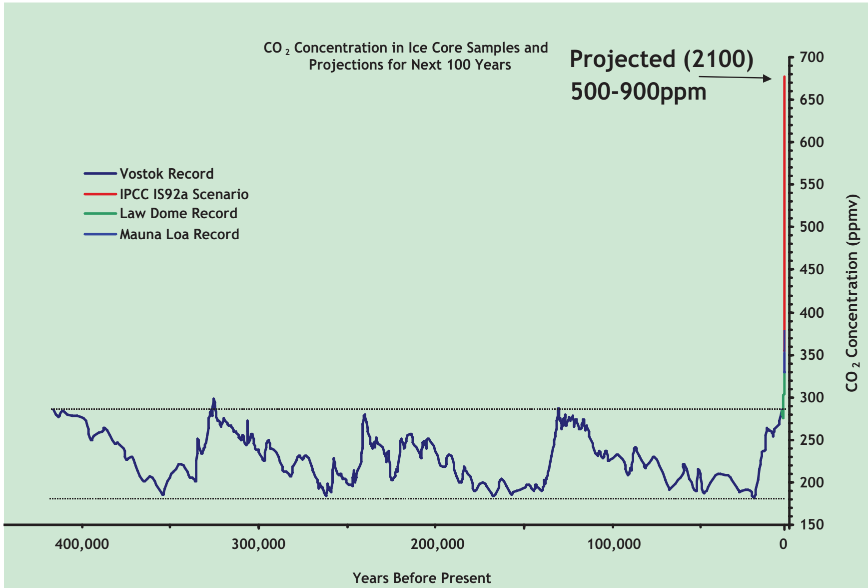


Figure 1. Current and projected CO_2 concentrations exceed those of the last 400,000 years. Based on Figure 6.3 of *Climate Change 2007; The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Report on Climate Change*. S Solomon *et al*, IPCC 2007.

Degree of change

Even a global temperature change of 2°C is quite substantial. It may not sound much to the man on the street. Yet the summer of 2003 represented an anomaly of about 1.5 to 2°C. In Paris, between 30,000 and 40,000 people died of heat-related deaths in the summer of 2003.

For many, though, the global prediction is not of particular interest – if you are in Edinburgh, you want to know what is going to happen there and that is a much more difficult scientific problem.

In 2002 we used a single model for the UK climate, so we had one estimate of the likely change. The last assessment from the Intergovernmental Panel on Climate Change (IPCC) employed something like 19 global models and, because there is uncertainty in models, they gave a range of estimates. For the 2009 scenario, we produced a probabilistic distribution of change.

Another difficulty we have at present is that the global models have a grid of about 300km which is pretty large – there is only one grid square for Scotland – so we have also run some of these models again at high resolution (about 25km) to get the regional detail.

Now let us be very clear on this: this does not mean that these projections are accurate to this particular resolution, given there are even uncertainties at the global level. It does take account of the effect of the mountains, coastlines and so forth, so it is adding in some regional information.

Under the approach we have taken, we have probabilities that measure how strongly different outcomes for climate change are supported by current evidence.

Just to give you an idea of what happens over Scotland, on a medium emissions scenario, temperature increase in 30-40 years time would be well above the 2°C that we saw in 2003. It is likely to be generally wetter in winter and drier in summer. For sea level, the central forecast is for a change of about 20cm by 2050, 25cm by 2080 and 30cm by the end of the century.

A big problem was a lack of computer time. We would have liked to run global models with a resolution of about 20km: that would have allowed us to resolve the weather systems that really affect the British Isles. That would have taken up to 4,000 times more computing.

There are a number of sources of uncertainty, particularly at the regional scale, hence the need for a probabilistic approach. The UK scenarios that we have released account for all the known sources of uncertainty in future directions. Yet, models still have systematic errors – that is a 'known unknown' that we cannot do anything about. ☐

What business needs to know about climate change

Andrew Dlugolecki

I am going to look at issues that businesses need to take into account when they are considering climate change. But why should we worry in Scotland? From some of the advice I have heard, Edinburgh in 2080 will be similar to Bordeaux now! Why not buy some land for your children or grandchildren and set up some vineyards for them?

Let's start with facts. I looked at the Central England Temperature Record from 1659 to 1899 and determined the temperature of a hot month on a 10 year event period, a 20 year event and 100 year event. Then I looked at what has been happening in the 20th century. The frequency is changing rapidly, particularly for the '100 year events'. By the beginning of the 20th century these were occurring once every 80 years, but now it has come down to every 12.5 years. The shrinkage is very fast for extreme events.

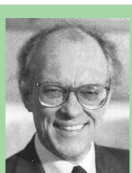
Looking forward, the 100 year summer will happen once every three years by the 2040s. That may sound great – being warmer – but it also means drought; and in winter there will be bigger and wetter storms.

Another problem is that events come unevenly. Statistics from the British Insurance Association show a huge peak in weather-related claims in 1990. There were four storms within a month then. Not only that, these events are reaching new intensities. And there are impacts beyond the immediate costs. Munich Re statistics show global losses of around $180 billion in 2005 (which included hurricanes Katrina and Rita), but economists

DISCUSSION

Models

Models can tell us what *can* happen, but not what *will* happen at specific times and places. Understanding can be improved if the discussion centres - as is generally the case with business decisions - on the upside and downside of options; together with an appreciation that we must have contingency planning to deal with extreme events in particular circumstances and areas - the sort of analysis undertaken in the Lloyd's of London insurance market.



Dr Andrew Dlugolecki is a board member of the Adaptation Sub-Committee of the Committee on Climate Change. He worked for 27 years in the Aviva insurance group. As a representative of the British insurance industry, he began to work on the issue of global warming from 1987 onwards. He has been the lead author and editor of work on the impact of climate change on financial services for the Defra, the EU and the IPCC.

believe that real losses were nearer $450 billion because of the damage to the oil and gas industry and the repercussions for the global economy. Nor do the Munich Re data include the long-term disruption to New Orleans. We may now be entering a situation where the costs go well beyond anything that we have seen before, or that we were insuring against.

Further, we are not just affected by what happens in Britain. China is an increasingly vital part of the supply chain. If you go home you will find many things made in China. However, insurance surveys suggest the Chinese are more concerned with running factories and getting things built, while attention to risk management in terms of floods and storms is very low.

SME preparedness

A survey carried out by the British Insurance Brokers Association within the last couple of years looked at businesses of up to 250 employees – between 95 and 99 per cent of British enterprises. Between 26 and 41 per cent said that if their site was closed it would take them more than a month to recover. Very, very few have plans for uninsured events – they just hope insurance will take care of it, basically. Why? Well, some 75 per cent of the larger enterprises said planning would take too much time. For smaller businesses it is more about cost and that they do not know where to start.

The Met Office did a review of how much of Britain's turnover was affected by the weather and came out with a figure of something like £10 billion annually. It is remarkable how often companies use the weather to excuse poor results, especially 'too wet' excuses. Here is a sample of some that I found. One used it because their food business stopped doing very well; a second because beer sales were down; a third because they were not selling clothes; while another said people did not want to buy tents. They cited the weather as a significant factor but were not doing anything to manage that exposure.

Yet some people are taking action. In Australia, which is becoming seriously affected by climate change, water is recognised as a vital resource and so they are using recycled water to clean machinery and to irrigate golf courses.

Retailers are turning to non-seasonal goods. In garden centres it is quite difficult to find the plants because there is so much else there – furniture, trinkets, clothes, winter leisure.

Carbon

Moving to carbon, the change needed over the next 20 years is as big as moving from the horse to the internal combustion engine. Enormous changes will be needed in Scotland, in Britain and in the rest of the world.

There are a number of reasons why the change will happen. The first is regulation. The EU Emissions Trading Scheme was a start. The Energy Performance of Buildings Directive (EPBD) requires that every retrofit or upgrade of a major building has to take account of energy efficiency. In the UK, the CRC Energy Efficiency Scheme is a revenue-neutral measure which will reward efficient companies and penalise less-efficient companies.

The second is the Carbon Disclosure Project. The biggest 3,000 companies in the world are being asked what they are doing about climate change. The project is backed by 475 investors who control $55 trillion dollars of assets. In its analysis, the members of the FTSE100 come top, globally, in grappling with this issue. The Global 500, the biggest 500 companies in the world (which include many of the FTSE100), are pretty good in terms of their response to the questionnaire that is sent out annually – but the FTSE250 is significantly worse in terms of its reporting and planning for emissions. So there is clearly work to be done, even for quite large companies.

The third element is public opinion; this is definitely beginning to change and having an effect on the way companies are viewed. Then there is litigation. UK Financial Investments, the company set up to administer taxpayers' investments in RBS and Lloyds Banking Group, has been doing its job in a very 'arms-length', non environmentally-aware fashion. A court action was launched in October, not against RBS but against UKFI, arguing that as a major investor it should be adopting the same best practice as every other institutional investor in respect of financing fossil fuels.

An analysis by the Carbon Trust of 'value at risk' from climate change shows the electricity sector has a great deal at risk, as has the logistics sector (they are using petrol all the time), so sectors are affected differently. Yet within each sector there is the same dynamic: some companies are more efficient, and different customer profiles make them more or less exposed to climate change.

The whole business sector needs to think about climate change and in particular the impacts (not just in Scotland or the UK, but around the world), the way that customers are going to behave in the future and carbon reduction. ☐

DISCUSSION

Agriculture

Some 20 per cent of carbon emissions come from agriculture. What will be the impact of increased flooding on agriculture and drainage systems? How will landscape adapt? Can we switch from existing crops to new ones quickly enough? What will be the effect on the landscape generally? In short, has the effect of climate change on the natural environment been adequately considered?

An effective national infrastructure is essential for any developed economy. The issues facing the UK in ensuring a functioning infrastructure in the 21st century were discussed at a meeting of the Foundation on 11 November 2009.

A national infrastructure for the 21st century

Mark Walport

Sir Mark Walport FMedSci is Director of the Wellcome Trust and a member of the Prime Minister's Council for Science and Technology (CST). He is a founder Fellow of the Academy of Medical Sciences and an Honorary Member of the American Association of Physicians. He chaired the team that produced the CST report *A National Infrastructure for the 21st Century*.

You might well ask why a medic should be involved in producing a report on infrastructure. Well, what separates the developed from the developing world — and with it the health prospects of the populations in developed and developing countries — is the infrastructure associated with water. Separating the water we drink from the water we excrete has been one of the most important advances in public health, but it is something that we all take for granted.

We forget it is there until it stops working; when it does, though, the potential to live as an advanced society falls away very rapidly. We saw how critical the supply lines were, for example, during the tanker driver strikes. In a very short time, if fuel does not get to the petrol stations it does not get to transport systems and the supermarkets run out of food: we live with 'just in time' supply lines which are crucially dependent on infrastructure.

Keeping the infrastructure up-to-date is fundamental to an advanced economy. In a world where companies can decide to locate pretty much anywhere, an important factor in the decision-making process is whether the infrastructure will support their activities. If we get this wrong it will have catastrophic consequences for the UK economy.

The infrastructure is also important if we are to take our response to climate change seriously, which is likely to mean coping with more frequent extreme weather events. It is also vital for promoting social inclusion — for instance, access to the Internet is going to be extremely important, especially for young people, in terms of whether they are 'inside' or 'outside' society.

Decisions

Decisions that we make about infrastructure will determine how and where we live in the future. If, for example, we decide that it is too expensive to get fast broadband access to the more remote parts of the countryside, it will determine people's choice as to where they live. How we distribute infrastructure and transport systems will determine how people choose to live. It is integral to much of social and Government policy.

In the report on national infrastructure for the Council for Science and Technology (CST), we put a 'traffic light' measure of risk against each of the major infrastructures. Much of our infrastructure is aging and there are concerns too about lack of capacity.

Then there is the question of resilience: our ability to respond to major, unpredictable, external events. Critical in this respect is the interdependence of different parts of the infrastructure network. For example, if the electricity supply fails then the likelihood is that the gas supply will fail too. Almost all our infrastructure is critically interdependent, yet there has been a tendency to view them — and to regulate them — as individual 'silos'.

The other issue relating to complexity is fragmentation. We have infrastructures that are divided functionally by region or by company and which create their own issues about interconnectedness. Interdependence has not been taken sufficiently into account.

Recommendations

That, then, is the background to how we found the major issues in the national infrastructure. Our recommendations, briefly summarised, were as follows.

First, there is fragmentation, both geographically and within Government – one department is responsible for one bit of infrastructure and another department is responsible for another: unless they talk to one another it will not work. Someone, somewhere in Government must be accountable for national infrastructure.

If we want to get investment from the private sector in infrastructure, then there needs to be a consistent and long-term view. Why would a company choose to make an enormous investment if it is likely to be adversely affected by a policy decision made a few years down the line? Whilst some policy change is inevitable, we need some kind of certainty and direction in the planning for national

DISCUSSION

Engaging the public

The case for urgent investment in infrastructure renewal is hampered by a lack of understanding by the public of the importance of the infrastructure and the consequences of failure. As a result politicians, inevitably focused on five-year electoral cycles, are not pressured by voters into developing the necessary long-term policies. Certain events such as the floods of 2007 have alerted the public to specific problems, but there is still little understanding of interconnectivity or the scale of the investment needed to minimise risk. The media has a role to play, but is not interested unless there is a significant individual failure, in which case they only look for someone to blame.

DISCUSSION

Tangible benefits

There has been too much emphasis on very large-scale projects. Individuals find it difficult to see how they will benefit from such grand schemes: it would help if there were more, smaller schemes with local impact. We need to develop pressure groups for infrastructure investment in the same way that environmentalists built pressure groups for the environment. The public might react more positively if it understood that we were seeking to enable individuals to maintain an acceptable standard of life for the future, rather than seeking to avoid a vaguely-defined catastrophe.

infrastructure if it is to attract adequate investment.

Second, we need 'joined-up' Government. There must be much more recognition of the issues of interconnectivity and resilience, much more sharing of data. The *Planning Act* should be implemented in a way that allows essential projects to be given the green light. We may be seeing the start of a shift in emphasis with the announcements about nuclear power, but it is extremely difficult to move forward on these national infrastructure projects if planning is such a battle.

Third, on resilience and interconnectivity. There needs to be a clear understanding of where the points of weakness are. We need to know what is likely to flood and what is not, where the interconnections are and we need to deal with conflicts arising between the strategic and the legislative framework. There must also be much more modelling and understanding of the human factors.

Fourth, regulatory regimes. Regulation in recent years has predominantly been economic, aiming to get the most for the lowest price. That tends to drive out capacity and reduce resilience. The regulators have tended to function in individual silos, but they need to work with one another, to stimulate R&D and innovation, and to think about the interdependencies in the systems they serve.

Fifth, we need to do the research. Research has been driven out of some areas of national infrastructure, but we need to be in a position to respond as infrastructure is planned for the future. For that, we need research and innovation to develop modern systems.

There is serious concern about skills. Recruitment is affected by the fall in the number of engineers. Nuclear research took a serious hit, there were research problems in the water industry and, if we are going to have a system that is fit for purpose, then we need a research workforce. It is up to the people who are going to develop the infrastructures to provide the 'pull'. The industries involved have to say what that 'pull' mechanism is so that young people can listen and understand what is available to them if they go into these branches of engineering.

Finally, it should not be forgotten that we must also think about interconnectedness and the security of our infrastructure in relation to the outside world. Although we are an island, we are connected to Europe in many different ways. We depend on shipping for the transport of many of our goods; we depend on many foreign sources for our energy — these are all national security issues. ☐

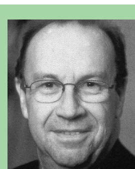
The Council for Science and Technology report is available at: www.cst.gov.uk/reports/files/national-infrastructure-report.pdf

How to modernise our ageing infrastructure

Brian Collins

We were a world leader 150 years ago in developing water, waste, urban and long-distance rail and, more latterly, road systems. We benefitted from that early investment but although a first-mover in many of those technologies, we chose not to do much about replacement. We did, however, expand our motorway systems and nuclear power and, in particular, North Sea oil and gas.

Then, in the 1980s, we initiated infrastructure privatisation, which meant that choices were made by the market within a new regulatory framework. Regulation was largely sector-by-sector, with little attention paid to how the various utilities and networks interacted – and there was nobody taking an over-arching view. Private sector partnerships and Private Finance Initiative (PFI) deals were put in place. Now 65 per cent of expenditure on infrastructure is private, 29 per cent public and only 6 per cent is Public-Private Partnership (PPP) — a small percentage in spite of what we hear about the importance of PPP (Figure 1). The net result of this complicated arrangement is that it is not clear how much we are spending on maintenance and renewal at a time when much of the privatised infrastructure is ageing and in need of more investment.



Professor Brian Collins FREng FIET is Chief Scientific Adviser for the Department of Business, Innovation and Skills (BIS) and for the Department for Transport (DfT). He is also Professor of Information Systems at the Defence College of Management and Technology, Cranfield University. His research centres on information management using next generation information and communication technology.

The Council for Science and Technology's report has raised more questions than answers. Some are matters of policy, some relate to research, and some are questions of analysis. I will highlight those that I think are the most important.

First, the science. The fundamental scientific questions are to understand how infrastructure works on the national scale, and how to relate it to the socio-economic conditions and technical problems that we face. The reality is that with elections every five years, the administration can change political complexion several times in the lifetime of many projects, whereas many international competitors — like Singapore — can plan for decades ahead knowing that there will be stability.

It is important to be able to plan ahead. Yet it is also possible to become locked into a technology that has become

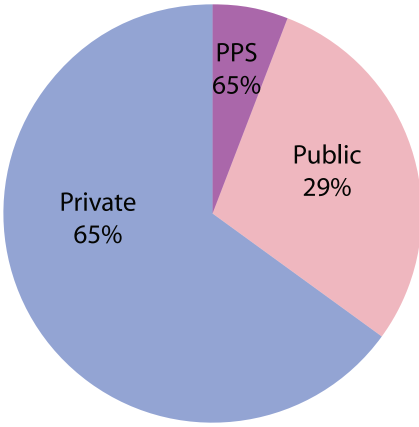


Figure 1. Investment in UK infrastructure

outdated, so we need to be aware of how to use new technologies, such as plastic electronics, as they become practicable.

Then there is engineering. We need to learn how to engineer resilience into these systems, and if we are to gain public acceptance for the investment required, we need to deliver a quality service and to explain the economic benefits of proper investment.

Have we done engineering at that scale? Not in recent years — the Olympic site is probably the largest project currently under way, but even that is not on the scale that we are talking about for the future. We have — or at least had — the expertise and it has contributed to massive civil engineering projects abroad, in the Middle East and China for instance: perhaps now we have to work out how to transfer that knowledge back into the UK to modernise our own infrastructure.

There has been little systems analysis of the interconnectivity between our infrastructure networks. The linkage between these elements is largely unregulated and often a matter of bilateral contracts, all of which cause us to have systemic failure points within our complex set of infrastructural components. Cascade failure could result from these omissions, as it did in New Orleans, where there was a clear failure to appreciate these linkages.

Where are the skilled professionals who are going to do the work? And if you want a balance between energy security and other things, how do we go about doing it? Who makes the decision where the right balance points are and how long-term can we make them so that investment (by private industry, in particular, or even better, foreign industry) occurs in the right place at the right time?

Importantly, we need to decide on the role of Government, both central and local. Many important infrastructure facilities are locally optimised — and therefore the vulnerabilities are localised. For example we cluster port, oil and energy installations around river estuaries, all vulnerable to sea level change.

Finally, how dangerous is the 'do nothing' option? We could continue to drift through the situation we currently find ourselves, and continue to fix things as they break. How dangerous, really, is that? That is the baseline model and if we are advocating greater spending, or doing things more systematically, then we need to know where we are starting from and just how bad it will be if we do nothing. ☐

Maintaining the national infrastructure

Tim Broyd

Halcrow is a UK-based engineering design consultancy. About half of our 8,000 staff work overseas and we are heavily involved in work on major infrastructure projects — including the High Speed 1 Channel Tunnel rail link, the St Petersburg flood barrier and utilities for Yas Island, location of the Abu Dhabi Formula One Grand Prix. Here in the UK, Halcrow works with the Highways Agency managing the transport infrastructure in several regions. Our work demonstrates how large-scale investment in modern infrastructure can be completed on time and on budget.

Professor Tim Broyd FREng is Group Technology Director for the Halcrow Group. He recently founded a national centre for construction innovation and excellence in Scotland, is the founding Chair of the Institution of Civil Engineers Policy Panel, and is a Visiting Professor at both the University of Reading and the University of Dundee.

Each year the Institution of Civil Engineers (ICE), where I chair the Policy Panel, issues what we call a 'State of the Nation' report, compiled by experts drawn from across ICE's membership. The purpose of this and our other occasional reports is to stimulate debate and to highlight the actions that civil engineers believe need to be taken to improve the nation's infrastructure.

Recent reports have covered capacity and skills within the industry, transport policy, flood hazards and carbon capture and storage. Most recently, in summer 2009, the topic was the defence of critical infrastructure[1].

In recent years our critical infrastructure network has faced a number of threats — from the attack on the London transport system in 2005, to the floods of summer 2007 and indeed heavy snow in winter. The ICE report examines how we deal with such challenges and how we can prevent major events bringing the country to a halt.

The communications network is vital for the functionality of the critical infrastructure, but this falls outside of the ICE's main area of expertise: there are others more able to consider it. For the purposes of our report, the goal of defending critical infrastructure was seen as the water, energy, waste and transport systems.

The report identified three main threats: system failure, climate change and terrorism.

System failure

System failure is particularly relevant to the energy sector, where we must ensure that we have the necessary generating capacity to meet our needs, together with a national grid that is flexible enough to manage the changing electricity energy mix. In May 2009 many homes and businesses suffered blackouts when the Sizewell B nuclear reactor in Suffolk and Longannet coal-fired power station in Fife unexpectedly stopped working within minutes of one another. This was followed by the failure of several other generating units later that day.

DISCUSSION

Creating a favourable environment

It should be feasible to set up structures that will deliver the necessary improvements, making funding possible and promote the necessary skills. Investment in infrastructure needs to be made profitable for the private sector, and the successful PPPs show that it is possible to both safeguard the public interest and allow investors to make a return. In the present economic climate, the Government may need to allocate funding from the Treasury, no matter what comes from other sources, and build policy around that figure. On the other hand, the problem may now be so serious that one should start from what funding is necessary to improve the infrastructure and then the Treasury must meet any shortfall after accessing private investment.

The changing electricity generation mix in this country is eroding system flexibility, exposing us to the risk of more blackouts in the future. If this risk is to be managed effectively, operational and physical resilience need to be addressed within the incremental changes currently being made to energy transmission and distribution networks. The recent national policy statement on nuclear generation is a step in the right direction.

Climate change

Evidence submitted to the inquiry pointed to climate change as the greatest single threat to critical infrastructure. We are to expect less rainfall in summer, more in the winter and rising sea levels in the coming decades. We must ensure that critical infrastructure is defended from climate change.

The floods that caused the Mythe Water Treatment Works in Gloucestershire to fail in 2007 showed how a fault at a single piece of infrastructure can have huge repercussions across a whole region. Many water and sewage treatment plants, as well as electricity transmission and distribution assets were damaged or at risk. As serious as these failures were, it was the potentially disastrous near-misses that really exposed the dangerous weaknesses in our critical infrastructure network. Walham substation, serving 500,000 people in South Wales and Gloucestershire, as well as a number of Sheffield substations, came close to failure — events that would have endangered lives. Another alarming near-miss was at Ulley reservoir, near Rotherham, where a large dam was in danger of breaching. A breach would have caused loss of life as well as damage to the M1 motorway, to a major electricity sub-station and to the gas network connection to Sheffield.

Third, there is the ever-present threat of terrorism. The current terrorism level is 'severe', which means that an attack is considered 'highly likely'. Critical infrastructure asset owners and operators must maintain their vigilance.

The UK's infrastructure assets form an interdependent network. A single failure can cascade across the network rendering otherwise unaffected sectors inoperable. Yet the UK's current infrastructure defence system fails to recognise this vital interdependency.

The Centre for the Protection of National Infrastructure (CPNI) and the Natural Hazards team are there to cover terrorism and climate change, but systems failure is not currently being addressed. The report recommended that these issues could be addressed through the creation of an overview role, such as that given to the Environment Agency for flood defence. It would aim to assist Government in tackling the political short-termism which is so detrimental to protecting critical infrastructure.

The Planning Act

The Government has taken steps to address long-standing problems with the UK Securitas planning process. If properly implemented, the 2008 *Planning Act* can provide a more efficient planning system for nationally significant infrastructure projects. The legislation replaces eight consent regimes with a single one for major projects such as railways, ports, roads, airports, water and waste infrastructure. The Act also provides for the establishment of a new independent Infrastructure Planning Commission (IPC), to determine the detailed and technical merits of individual applications.

At present the Government takes no responsibility for the provision of reserve capacity, leaving its delivery to the market. Regulators have neither the remit nor the ability to incentivise asset owners to build reserve capacity into critical infrastructure assets. The regulatory system does not recognise interdependency or approach the critical infrastructure network as a whole. The Government should expand the remit of the regulators to address asset stewardship, as well as consumer interests. The regulators must be able to offer private asset owners some incentives to build reserve capacity into their infrastructure and should also be given the power to ensure that contingency planning is carried out by asset owners.

There are similarities between the ICE report and that of the Council for Science and Technology—published the next day. The ICE welcomes the announcement of the establishment of Infrastructure UK and looks forward to what will hopefully be a symbiotic and close relationship. We believe that Infrastructure UK must have the authority to coordinate activity in different areas of infrastructures and authority, rather than just be a meeting point between them.

Finally, how is all this to be paid for? A source of long-term financing is vital, supporting projects that will strengthen UK competitiveness and helping with the transition to a low-carbon economy. A National Infrastructure Investment Bank, initially capitalised by the Government and able to use the Government's credit rating to raise funds on international markets, could perhaps meet such a need. The presence of such a bank could help hold down the cost of capital across all infrastructure sectors.

1. www.ice.org.uk/knowledge/document_details.asp?Docu_id=2324&intPage=18&faculty

DISCUSSION

The skills shortage

Some participants thought the necessary skills were already available, as many young people are anxious to work in relevant areas, and we can access international skills; the problem is middle management, who still think traditionally and in silos. Others were more pessimistic: for example the programme for new nuclear stations may not be compatible with the timescale needed to produce trained nuclear engineers. But there is no doubt that all engaged in improving the infrastructure need to step up their activities.

Synthetic biology — a threat or an opportunity?

Richard Kitney

In both synthetic and systems biology, 25 April 1953 is very important. It is the date of the publication of the structure of the double helix by Jim Watson and Francis Crick in the journal *Nature*. Although there is no exact date when the biological revolution started, this is a good starting point. Almost 50 years later in 2001, another paper in *Nature*, this time with 50 authors, recorded the initial sequencing of the human genome. It is the initial sequencing of the human genome which represents a datum point in terms of the ability to develop synthetic biology.

Synthetic biology is a rapidly developing field so, as you might imagine, there are a number of definitions. The one that we tend to use is "designing and making biological parts and systems that do not exist in the natural world, using engineering principles".

People ask: "Why now?" Well, it is the bringing-together of a number of different factors. There is now high-speed DNA sequencing, the ability to synthesise DNA, widely available powerful computers, broadband networks to move data around, the internet itself and then, probably most importantly, the confluence of biology, engineering and physical science.

Synthetic biology comprises bio-nano technology, synthetic genomics and engineering, but social science and ethics are extremely important in this field as well.

Richard Kitney is Professor of Biomedical Systems Engineering, Department of Bioengineering, and Co-Director of the EPSRC Centre for Synthetic Biology and Innovation, as well as Director of the Graduate School of Engineering and Physical Science, Imperial College London. He was Chairman of The Royal Academy of Engineering's UK Focus for BioEngineering and recently chaired an inquiry by the Royal Academy of Engineering on Synthetic Biology.

Approaches to synthetic biology

I want to describe four approaches to synthetic biology – starting with 'bottom-up', moving to metabolic engineering, then talking about 'chassis' (which are different types of cells) and then moving to parts, devices and systems.

Let us start with 'bottom-up'. A year ago Craig Venter, together with some of his colleagues, published a paper in *Science*, which described the first sequencing and reconstruction of a bacterium M Genitalium. This particular bacterium comprises 583,000 base pairs, so it is quite small and what they did was first to sequence the M Genitalium genome; then they sent out the information to three companies (two in the USA and one in Germany). These companies resynthesised the genome in 'cassettes' which were reassembled into the whole genome.

For metabolic engineering, I will take the example of malaria. Artemisia is a substance which Chinese herbalists have known about for at least 1,000 years, but from a synthetic biology point of view the key interest is that in 1972 a Chinese scientist, Tu Youyou, managed to isolate artemesinin (the active ingredient in this particular form of treatment of malaria) from the annual wormwood plant. Jay Keasling, with his colleagues in Berkeley, re-engineered some of the metabolic pathways involved in the natural plant to create a starting point which begins with sugar and ends with artemesinin. It is now, if you like, a synthetic drug for treating malaria.

Biofuels is also a very big area. I was recently in Montreal where 500 biochemists and biotechnologists were presenting papers on industrial biofuels. Many people expect significant amounts of bio-diesel to be produced using synthetic biology techniques within the next three to four years.

What do we mean by 'chassis'? Well, we modify, at the moment, bacterial DNA. We place this in a cell (that is called a 'chassis') and we look at the response. These are the types of cells we use: E coli is probably the most popular in synthetic biology at the moment; there is yeast, of course; and other cells like B Subtilis are now becoming quite popular. These are the 'natural' chassis, but one of the common problems in synthetic biology is actually controlling the process because these are living environments. So other researchers are working on minimal cells, stripping down naturally-occurring cells and also creating artificial cells.

Now turning to parts, devices and systems: this is where you can apply the engineering principles of modularity, characterisation and standardisation to developing biological parts, biologically-based devices and, ultimately, biologically-based systems.

Systematic design

All of this revolves around systematic design. This is the basis for producing the standard parts, the standard devices and the standard systems. Some of the key factors here are abstraction, decoupling and standardisation – these are all engineering principles which are applied not only to synthetic biology but also to car and aircraft design.

Finally, the aim is to build a system on the basis of standard devices and standard parts. Modified bacterial DNA represents the 'parts'. The devices are collections of parts, but they are encoded into human-defined functions such as logic gates. Ultimately this will lead to the development of biologically-based systems which perform tasks familiar in engineering and physics, like counting and ultimately microprocessing, etc.

Standards are very important. The international community in this field is working very hard to achieve standardisation. The parts are stored typically in a registry. One of the most important registries is at MIT and we all feed parts into that registry.

In building molecules, we start off with software to create small sections of DNA code and these are assembled into DNA constructs – the device level. DNA error correction is carried out and then the whole thing is brought together into a large assembly. In fact we send off our DNA constructs, which we produce in the lab with software, to companies like GeneArt in Germany and we get DNA back via mail order.

Logic gates

We have recently been working on the development of biologically-based logic gates using a plant system which in fact infects the leaves of plants – it is called 'hrp' (hypersensitive response and pathogenicity) in its original form. There are two pathways which are stimulated simultaneously. However, what we did was to re-engineer this and separate out the pathways. That enabled us to produce an 'AND' gate. AND gates and NAND gates are the basis of all counters, all calculators in the electronics world – and now we have a stable AND gate. This will lead on to more sophisticated devices.

Finally, I just wanted to make the point that there are strong parallels here, in my opinion, with synthetic chemistry in the 19th century. One important discovery occurred in 1897 when Felix Hoffman, using synthetic chemistry techniques (which are not very different in concept from synthetic biology techniques) was able to produce aspirin for the Bayer company in Germany.

So, are we on the brink of a new industrial revolution? My view is that we are and this is incredibly important for the UK economy. ☐

Synthetic Biology: scope, applications and implications – report by the Royal Academy of Engineering. Available at: www.raeng.org.uk/news/publications/list/reports/Synthetic_biology.pdf

DISCUSSION

Open and candid debate

Scientists need to engage in open and candid debate with the public about the advantages that synthetic biology could bring - as well as the risks which might be involved. The history of the motor car is a good example of the readiness of the public to accept the benefits of new technology despite the attendant disadvantages, such as road deaths. Recent experience over GM has shown all too clearly the consequences of a failure by scientists to engage with the public about the risks and benefits.

Making biology easier to design

Pamela Silver

Why do we want to design biological systems? One reason is that if we can design a system it really does test our understanding of its components. What does biology do and what are the parallels to engineering? Biology is exquisitely sensitive – the olfactory system is capable of detecting single molecules. Biology is very efficient at transmitting specific signals. Biology is modular. The gene is the fundamental unit of biology, but we now know from the history of molecular biology that the gene is modular. Best of all, biology can self-replicate, so the vision of building machines that can duplicate themselves is at the core of synthetic biology.

Can we make biology easier and more predictable to engineer, though? In order to do so, we need DNA – rapid, inexpensive DNA. We have a lot of raw material to work with; new genomes are being sequenced daily. These are easily accessible, they are being deposited in the internet and so there is an information explosion. We just need to know what we want to do with it.

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DNA synthesis

The first gene was synthesised at MIT in the 1970s. It was tRNA, took Gobind Khorana many years, and he won the Nobel Prize. In the 1980s, one of my colleagues at Harvard, Steve Benner, was the first to synthesise a gene that encodes an enzyme. In the 1990s, with the advent of the Polymerase Chain Reactor (PCR) came the 'liberation of the genome' because if you know the sequence you are able to get any gene or any piece of DNA that you want.

That was the good news. The bad news was that you were limited to what nature gave you. You could mutate it, you could alter it a little bit, but you could not readily create large new genes. Today, though, we have the ability to make ever-longer pieces of DNA and to me this is really an important element of the future for young scientists. To me, the overarching goals of synthetic biology are:

- to make whole genomes or whole chromosomes for example;
- to design and redesign systems – what I call 'logical metabolic engineering';
- building life from scratch – making replicating systems from chemistry.

In order to make biology easier to design – which is the premise that I began with – we would like to have standardised parts. This will require knowing what measurements we need to make, the models and then, importantly, the point at which the experiment actually starts. What I would like to see is a student sit at a computer and then the next day get the DNA back and then the experiment starts – that would be much more fun that what we have now.

When I began I wanted to build biological computers. Suppose you have a cell that changes colour every time it divides: you know how old it is by its colour. It starts out green, and then the 'daughter' cell becomes blue and the new mother turns green. We made cells that can count to two! This is a lot harder than it seems.

Then we decided to make cells that could remember. When exposed to a particular chemical stimulus, certain cells can be made to change colour. A red signal indicates that they were exposed to the signal, and a sustained green signal indicates that the cells 'remembered' the past exposure.

We call these 'toy' systems. What can we do with these? Imagine a system where a cell exposed to something that turned it into a cancer cell, such as DNA damage, remembered that it had been exposed.

DISCUSSION

The role of NGOs

Non-Governmental Organisations (NGOs) need to properly understand the benefits of new technologies such as synthetic biology; the GM experience has shown the influence which these organisations can have on public opinion. Scientists need to be alert to the risks of losing their 'licence to practise'. The scientific community may find it advantageous to make greater use of professional public relations teams in managing the way its messages are conveyed to the public and to politicians.

We could track that cell in the tumour and we would know which ones were responding to drugs and which were not.

Bio-energy

No talk on synthetic biology is complete without mentioning bio-energy. Boosting the efficiency of fuel formation from micro-organisms is the major technological application of synthetic biology. The engineering of fuels is essentially a systems problem.

Rather than rely on maize or sugar cane, we can use light. There are micro-organisms that process light, so they can be used as the chassis. In fact we use the cyanobacterium which is responsible for about 50 per cent of all photosynthesis on Earth. The genome has been sequenced – we know quite a bit about it but not enough. Cells often 'compartmentalise' reactions to make them more efficient – cells in the human body do this, but even simple cyanobacteria do this.

We can produce bacteria that make various forms of carbon-based fuel, such as bio-diesel. We are also very interested in coupling the capture of sunlight directly to the production of hydrogen. Perhaps we could turn these into factories that would pump out chemicals or other fuels as well.

We decided to produce cells that would make sugar – sounds simple, right? The idea here is that when these cells are stressed they produce sucrose. But we have introduced, synthetically, an enzyme that can cleave the sucrose into glucose and fructose. Then we needed to get it out of the cell. So we took a 'transporter' from another organism and put it into these cells so that now they secrete sugar. They secrete glucose and can feed other cells that need glucose to live. Effectively we have created a symbiotic system that depends on light.

These are in principle the precursors of chloroplasts, which live in plant cells and give them energy. There are naturally-occurring photosynthetic animals – some sea slugs, for example. I proposed that we could take these photosynthetic microbes and introduce them into a non-photosynthetic cell. The cell would have to be clear so that the light could enter and in that way we could perhaps make photosynthetic animals – great for space travel! We chose a fish with the hope of producing the photosynthetic fish.

There are other commodities, like isoprene for example, that are made synthetically and their value is higher than biofuels. Companies could concentrate on producing these high-value commodities with biofuels as by-products. That is an intriguing concept. ☐

Social science sets the context

Nikolas Rose

Why should social scientists be involved in the development of synthetic biology, especially when synthetic biology is still at a very, very early stage in its development? Why should the EPSRC, when it funded our joint centre, have insisted that social scientists were involved right from the very beginning? It was because we now recognise that the development of technology does not happen in a vacuum, it always happens in a particular socio-political context. The socio-political context here in Europe and the UK is one in which there is a perception, by many, of a pervasive lack of trust – lack of trust in science, lack of trust in experts, lack of trust in politicians and regulators. There is a perceived lack of trust especially in areas where science and expertise touch things that are fundamental to people's everyday life (to their health and their security).

Many policy makers in this area therefore believe they must take their decisions in a climate of risk, a climate of anxiety and distrust. We all know that issues of risk and risk calculation are very, very hard to discuss rationally, especially when they are located in a media culture that veers between hype about scientific breakthroughs and anxiety about the damage that science may be doing to us.

Social scientists can contribute to this debate in many ways. First our evidence questions the view of the public as 'ignorant', 'irrational', 'mistrustful of science', 'swayed by media stories' and so on. Research on public attitudes to scientific developments shows that the public are not anti-science, they are not mistrustful *per se*. They can make distinctions between different kinds of scientist, they can make distinctions between what scientists do and what journalists report and they can make the distinction between those kinds of arguments that are made by scientists on the basis of their scientific research and the deployment of those arguments in political debate. In fact, it is probably a mistake to think of 'the public' – we should think of many different groups who have different attitudes to different kinds of science and medicine, based on their own beliefs and experiences. However one thing is rather consistent – sociological research shows that many people are particularly concerned where scientific developments are mixed with commercial developments.

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The two emerging technologies of nano-technology and synthetic biology have been accompanied by the almost obligatory involvement of social science, in part linked to this belief that public mistrust could undermine the tremendously exciting scientific and economic opportunities that these technologies promise. Even if the beliefs about mistrust are overstated, public debate over these emerging technologies is an opportunity to link democracy with technological development. It will also enable scientists themselves to enter into public dialogue about the opportunities and risks of their work. This debate has already started, and certain topics in synthetic biology have already emerged as of being of concern, both in the UK, in mainland Europe and in the United States. These are: bio-safety; bio-security; commercialisation; and what I will call, for the sake of argument, 'life itself'.

Bio-safety

One of the characteristics of living organisms is that they have the capacity to reproduce and in reproduction they mutate. Unintended consequences, the accidental release of these organisms and the way in which they might actually operate in living systems outside of the laboratory – all are major concerns in these debates.

Many years ago now, when artificial organisms were first being created, a voluntary and self-regulating system for governing their production was developed by the researchers at a famous conference at Asilomar in 1975. Since that time, in most countries, we have seen the emergence of robust regimes for regulating the conditions and the laboratories in which this work is undertaken. So current synthetic biologists are not working in a vacuum but I do think we need to be clear about the extent to which our current regulatory system for bio-safety is adequate to the new challenges of this technology.

Bio-security

Bio-security has been a major concern, especially in the USA. Some researchers there celebrate the idea of 'garage biology' where anybody sitting at their home computer, in a makeshift lab, can type in the genetic sequence of the organism that they want and then, one or two days later, receive it by mail order. It is actually not easy to distinguish the risks of benign activities from those that are malign in intention – many things developed for a very good reason can have damaging unintended consequences. However, while the idea of synthetically-produced pathogens wiping out vast swathes of the population has become quite popular in recent science fiction, I think it is misguided. Pathogens are actually quite hard to make into weapons, especially weapons of that can cause illness or death on a large scale. Nonetheless, this issue needs to be debated and addressed head-on.

Commercialisation

A commercial pathway needs to be developed for these products but, as I have already mentioned, many groups and individuals become concerned when commercial and scientific issues are mixed together. However, these issues are being addressed right at the very beginning of the development of synthetic biology. Partly because they have learned from earlier debates in genomics about 'patenting life', synthetic biologists are developing a very interesting approach to intellectual property – one which is based on 'open source' principles in which the basic biological properties are 'open source' but commercialisation can happen through patenting the products produced from publically available parts.

'Life itself'

One powerful view is that human beings *should not*, perhaps have *no right to*, create the organisms that evolution 'forgot'. Yet the idea of creating life *ab initio* is not driving the development of synthetic biology. Rather, we have the re-engineering of existing life – that is to say, most developments in synthetic biology work by 'hijacking' the properties of life to produce useful effects.

Nonetheless, the question of defining and delimiting what we can legitimately do to living organisms and what limits we should set to our endeavours in this area does seem to me to present a powerful challenge. We need to recognise, understand, debate and use responsibly the powers that we have for re-engineering organisms.

There are now very significant demands on researchers to show immediately that the work they are doing in basic science is translating into products. The demand to answer 'when will your work be in the clinic?', 'when will it be in the factory?' is there all the time when scientists get into public debate. While synthetic biology will have major consequences, to demand that scientists over-promise – that they say immediately what these will be – can be very harmful. Recently in Korea we saw how impossible expectations led to one team pretending that they had made advances in stem research which they had not actually achieved. I think we should try to lessen that translational pressure if we can.

Regulation

We have very good experience here in the UK in developing complex regulatory structures for biomedicine and biotechnology that have worked very well. The Warnock Report, for instance, on the regulation of research in reproductive biology, provided a stable environment, developed as a result of consultation and deliberation, that was accepted by almost everyone and widely respected by the scientists concerned This enabled basic research to happen, enabled the scientists to know what they could and could not do. This report also led to the establishment of the quasi-autonomous Human Fertilisation and Embryology Authority, which has produced a regulatory climate which enables the work to proceed, and has public confidence while ensuring both legitimacy, safety and good practice.

I think we could learn a great deal from such models about how to regulate this area. After all, none of us would be interested in the questions of synthetic biology if we did not have a real belief that in the future it will produce genuine public value as well as an innovation pathway that is extremely important for UK and international economies. But to make that happen is more than simply a technical or technological challenge – it is what one might term a 'socio-technical' challenge, and one that requires us to attend to the social practices, and the social pathways for innovation, at the same time as we encourage the basic research on which innovation must build. ☐

DISCUSSION

The potential for misuse

There is a potential for misuse of new knowledge emerging from synthetic biology research. However, some of the worst bioterrorism threats already exist (e.g. anthrax) and the fears have so far proved unwarranted. Moreover, it would be foolish for society to forego the benefits flowing from advances in technology just because of the potential dangers; it would be better to find ways of deterring bad people from doing bad things than to stop the creation of good things because bad people might misuse them.

Recent dinner/discussions organised by the Foundation for Science and Technology are listed below. Summaries of these and other events – as well as the presentations of the speakers – can be found on the Foundation website at: www.foundation.org.uk

The future strategy for high speed rail in the UK
17 March 2010

The Rt Hon the Lord Adonis, Secretary of State, Department for Transport
Iain Coucher, Chief Executive, Network Rail
Guillaume Pepy, Président, National Society of French Railways (SNCF) and Chairman, Eurostar
Terry Hill FREng, Chairman, Transport Markets, Arup

Astronauts speak to the next generation
12 March 2010

Captain Neil Armstrong, first man on the Moon
Captain Jim Lovell, Commander Apollo 13
Captain Gene Cernan, last man on the Moon
Bob Gilliland, Test Pilot
General Steve Ritchie, US Air Force fighter ace
David Hartman, former host Good Morning America

Christmas Reception
9 December 2009

Speaker — **David Willetts** MP for Havant and Shadow Minister for Universities and Skills
Respondents — **Professor Alan Thorpe**, Chair Research Councils UK and Chief Executive, Natural Environment Research Council
Sir Anthony Cleaver, Chairman, EngineeringUK

Synthetic Biology — a threat or an opportunity?
18 November 2009

Professor Richard Kitney OBE FREng, Professor of Biomedical Systems Engineering, Department of Bioengineering, Senior Dean and Director of the Graduate School of Engineering and Physical Science, Imperial College London
Professor Pamela A Silver, Director, Harvard University Graduate Program in Systems Biology, Department of Systems Biology, Harvard University
Professor Nikolas Rose, Director, BIOS Research Centre for the study of Bioscience, Biomedicine, Biotechnology and Society, London School of Economics and Politics

A national infrastructure for the 21st Century
11 November 2009

Sir Mark Walport FMedSci, Director, The Wellcome Trust and member of the Prime Minister's Council for Science and Technology
Professor Brian Collins FREng FIET, Chief Scientific Adviser, Department for Business, Innovation and Skills and Department for Transport
Professor Tim Broyd FREng, Group Technology Director, Halcrow Group and Chair, Policy Panel, Institution of Civil Engineers

The impact of climate change on Scotland
29 October 2009

Professor Geoffrey Boulton OBE FRS FRSE, General Secretary, The Royal Society of Edinburgh, and Member PM's Council for Science and Technology
Professor John Mitchell OBE FRS, Director Climate Science, The Met Office
Dr Andrew Dlugolecki, Visiting Fellow, Tyndall Centre, University of East Anglia and Chartered Insurance Institute

The Digital Britain Report - keeping up with the competition from other nations
14 October 2009

Dominic Morris CBE, Strategic Director, Digital Britain, Departments for Business, Innovation and Skills, and Culture, Media and Sport
Professor Dame Wendy Hall DBE FRS FREng, President, Association of Computer Machinery (ACM), School of Electronics and Computer Science, Southampton University
Dr Alfred Spector, Vice President, Research and Special Initiatives, Google
Erik Huggers, Director, Future Media and Technology, BBC

Beyond the recession - what can science and innovation partnerships do for you?
7 October 2009

Professor Peter Gregson FREng, President and Vice-Chancellor, Queen's University Belfast
Eoin O'Driscoll, Chairman, Forfás, Ireland's National Policy Advisory Board, and Managing Director, Aderra
Dr Iain Gray FREng, Chief Executive, Technology Strategy Board

Engineering: turning ideas into reality — the House of Commons Select Committee Inquiry
7 July 2009

Phil Willis MP, Chair, House of Commons Select Committee on Innovation, Universities, Science and Skills
The Lord Browne of Madingley FRS FREng, President, The Royal Academy of Engineering
Richard Olver FREng, Chairman, BAE Systems
The Rt Hon the Lord Drayson, Minister for Science and Innovation, Department for Business, Innovation and Skills (*note responding to the debate*)

The Future of Higher Education in England
17 June 2009

Sir Alan Langlands FRSE, Chief Executive, Higher Education Funding Council for England
Professor Michael Arthur FMedSci, Vice Chancellor, University of Leeds
Sir John Chisholm FREng, Chairman, QinetiQ and Chair, Medical Research Council

Financial models — key tools for risk analysis or the vector of global financial collapse?
10 June 2009

Professor John Kay FBA, Writer and Columnist for the *Financial Times*
Paul Sharma, Director, Wholesale Prudential Policy, Financial Services Authority
Professor David J. Hand FBA, President, The Royal Statistical Society and Head of Statistics, Imperial College London

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