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THE FOUNDATION FOR SCIENCE AND TECHNOLOGY

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www.foundation.org.uk carries reports on all Foundation meetings.

New ministerial appointments

Greg Clark has been appointed the Minister for Universities and Science at the recent cabinet reshuffle. He takes over from David Willetts who has left the Government.

Mr Clark has been Conservative MP for Tunbridge Wells since 2005. He retains his former responsibilities in the Cabinet Office as Minister for Cities. He has a doctorate in economics from the London School of Economics.

Speaking to businessmen at the Farnborough Air Show shortly after his appointment, Mr Clark said there would be "long term continuity and confidence in policy" and that his brief was to continue the "excellent work" of his predecessor.

George Freeman, MP for Mid-Norfolk and an Associate Member of the Council of the Foundation for Science and Technology, has been appointed Life Sciences Minister. The role is a joint one between the Department of Health and the Department for Business, Innovation and Skills. Mr Freeman was Government Life Science Adviser from 2011-13 and helped coordinate the Prime Minister's Life Science Strategy in 2011.

Transforming the education system

All students should study science and mathematics until age 18 as part of a new baccalaureate according a report, *Vision for science and mathematics education*, published by the Royal Society.

The Government should create new baccalaureate-style frameworks that place emphasis on vocational and academic learning across a broad range of subjects to 18, the study says. It sets out a roadmap for radically transforming our education systems, with particular focus on mathematics and science, over the next 20 years.

The report, which has been written by a committee including scientists, education experts, teachers and a former Secretary of State for Education, also calls for:

- the status of teaching to be raised and for increased support for subject-specific professional development;
- new post-16 courses and qualifications in mathematics, science, engineering and technology to engage students who are studying arts and humanities subjects;
- new, independent, expert bodies in England and Wales to set curriculum and assessment, providing stability, increasing innovation and bringing to an end the turmoil that teachers currently suffer from as a result of constant changes.

Tackling antimicrobial resistance

The Prime Minister has commissioned a wide reaching independent review, led by the internationally renowned economist Jim O'Neill and co-funded and hosted by the world's second largest medical research foundation, the Wellcome Trust, to explore the economic issues surrounding antimicrobial resistance (AMR).

The review will set out a plan for encouraging and accelerating the discovery and development of new generations of antibiotics, and will examine:

- the development, use and regulatory environment of antimicrobials, especially antibiotics, and explore how to make investment in new antibiotics more attractive to pharmaceutical companies and other funding bodies;
- the balance between effective and sustainable incentives for investment, and the need to conserve antimicrobial drugs so they remain effective for as long as possible;
- how governments and other funders can stimulate investment in new antimicrobials and timeframes and mechanisms for implementation;
- increasing international cooperation and support for action by the international community, including much closer working with low and middle income countries on this issue.

Mr O'Neill will work independently of Government, and will have full freedom to approach the issues and the evidence as he sees fit. He will work with international experts covering all aspects of the AMR pipeline and associated economic issues to identify a range of proposals that can form the basis of a new, strengthened global effort.

In a separate development, antibiotics has also been chosen as the theme of the £10 million Longitude Prize. The challenge will be to create a cost-effective, accurate, rapid and easy-to-use test for bacterial infections that will allow health professionals worldwide to administer the right antibiotics at the right time.

www.longitudeprize.org

• See page 25 of this issue.

Buildings and infrastructure 'ill-prepared for changing climate'

The resilience of transport networks, homes, hospitals and water supplies in England need to be enhanced to counter the more frequent and severe flooding and heatwaves that can be expected in future. This is the key finding of a new report by the Government's official adviser on preparing for climate change.

The Adaptation Sub-Committee of the Committee on Climate Change is calling for a new building standard to be introduced to prevent an increase in the number of premature deaths that could result from homes and buildings overheating. Premature deaths from overheating could triple to 7,000 per year by the 2050s, says the Committee, as average temperatures rise and combined with an ageing and more vulnerable population. Extreme temperatures during severe heatwaves could have an even greater impact on people's health and well-being.

The Committee found that new homes are being designed for yesterday's climate, and not with the health impacts of higher temperatures in mind. One-fifth of homes could already be overheating, even in a cool summer. Forthcoming research from Cambridge University will also conclude that 90 per cent of hospital wards are of a type prone to overheating, even in today's climate, said the CCC.

The Committee is recommending that cost-effective solutions, such as improved ventilation, tinted windows, and external insulation, should begin to be installed in new and existing homes, hospitals and care homes to limit the health impacts of higher temperatures.

www.theccc.org.uk/publication/managing-climate-risks-to-well-being-and-the-economy-asc-progress-report-2014

Investment 'good for the economy'

A new independent report for the Campaign for Science and Engineering (CaSE) shows that investing public money in science and engineering is good for the economy. *The Economic Significance of the UK Science Base* examines the economic impact of public investment in the UK science base.

The study looks in detail at the relationship between public funding of science and engineering and three levels of economic activity: total factor productivity growth in industries; ability of universities to attract external income; and interaction between individual researchers and the wider economy.

The report shows that, at the level of industries, universities and individual researchers, public investment in science and engineering leads to economic growth.

http://sciencecampaign.org.uk/UKScienceBase.pdf

Science and technology are transforming our world. But what is the role of the Arts and social sciences? And how can these different disciplines interact and support each other?

Working together for the good of humanity

Nick Stern

Professor Nicholas Stern (Lord Stern of Brentford) is President of the British Academy and one of the UK's leading economists, specialising in the economics of public policy and in development economics. As head of the Government Economic Service, he led the ground-breaking Stern Review on the economics of climate change, published in 2006, which has had great influence around the world. He has been Chief Economist of the EBRD and of the World Bank, Second Permanent Secretary and Head of Government Economic Service in the UK, and has served as adviser to governments, businesses and NGOs in many countries. Since 2007 Lord Stern has been the IG Patel Professor of Economics and Government, and Chair of the Grantham Research Institute on Climate Change and the Environment at the London School of Economics and Political Science. He was elected a Fellow of the Royal Society earlier this year.

Science, engineering and medicine are vital drivers of human progress and we must celebrate and nurture them. The British Academy stands shoulder-to-shoulder with our fellow national academies – the Royal Society, the Royal Academy of Engineering and the Academy of Medical Sciences – in delivering a shared narrative on the importance of all parts of this country's research and science base. Last autumn the academies' joint document, *Fuelling Prosperity*[1], made a powerful case to the Government for continued investment in all areas of academic research. It is only by ensuring that science, engineering, medicine, humanities and social science researchers continue to work together, and by recognising the vital contribution each of these subjects make to our society, that we will be able to face the challenges that lie ahead.

Science, engineering and medicine are vital drivers of human progress and we must celebrate and nurture them. Without the humanities and social sciences, however, we can never find effective responses to the issues that confront us. The knowledge and expertise they provide are founded in analysis and insights of what constitutes social and cultural well-being and how these are shaped; the drivers of a modern knowledge and service-based economy, the basic elements of the UK's contribution, place and reputation in the world.

From history to psychology, economics to law, literature to philosophy and languages to archaeology, the humanities and social sciences help us understand what it means to be human, how to make sense of our lives and understand the choices we make and, above all, how we interact with one another in communities and across nations.

The humanities and social sciences infuse our economy and our public and cultural life in a myriad of ways. They play a vital role in bringing new ideas to the fore and pushing politics and public debate forward, helping both to understand and create the kind of world we want. This involves participation, contribution and prosperity. But these subjects are also about challenge and questioning: sometimes being awkward, always demanding rigour and honesty, often forcing ethical issues and choices into the open.

The UK is at a crossroads on many key issues – constitutionally, economically, environmentally – and on the role of the state. There are core issues to be tackled and crucial decisions to be made across all these dimensions, including tough decisions for public spending. Evidence-based and thought-through responses are required and this, in turn, requires expertise from humanities and social science. These are the subjects that can help us understand the choices that confront us as a society and as human individuals, and how best to respond.

Many of our responses will require new ways of doing things; innovations in how we work, make choices and communicate. The younger generation, in particular, appears to be much less politically engaged than many of its predecessors. It is our responsibility to help create an intellectual environment where they feel moved to contribute their ideas, commitments and inspirations.

Overarching

For me, the British Academy has two overarching goals: first, fostering excellence, by providing the resources, time and space to generate new research, with a special emphasis on supporting early career scholars; and second, putting our subjects to work – showing what they can do. These twin goals are mutually supportive. We can demonstrate that we are an outstanding investment – not just public but also philanthropic – in what really matters, and in the future of the UK and the world more generally.

One of the greatest questions we face as a society – and as part of an increasingly interdependent world – is to decide what we mean by prosperity and how it can be

fostered. Earlier this year the Academy offered an example of that question by launching our multimedia project *Prospering Wisely*[2], using a booklet, videos and a specially created website. We set out to demonstrate that a rounded understanding of 'prosperity', and indeed prosperity itself, is deeply dependent on the contributions of the humanities and social sciences.

Prospering Wisely included video interviews with a range of Academy Fellows – a deliberate and I think powerful way of going beyond assertion, which brought to life some of the practical ways in which we can see knowledge and insights which grow from our disciplines feeding into our national life.

As I said in my introduction to Prospering Wisely, the humanities and social sciences "encompass all of the elements that make for a good life and a healthy society". Those who work in the humanities and social sciences know that our disciplines are valuable in themselves, that learning and scholarship are intrinsic goods. But we also understand the contribution they make as vital drivers of human progress. They provide the rigorous scrutiny and insights, the ideas and the long-term thinking that can – and do – have a profound influence on our social and cultural well-being, on our place and reputation in the world, and on and in the communities we live in.

A society without thriving social sciences and humanities risks achieving at best only an arid kind of prosperity, far less rich than our creative human culture deserves – and at worst confusion, apathy, decline and conflict.

A community of scholarship

A crucial challenge for the British Academy in the coming years is to continue to represent and speak for the interests of the community of scholarship which makes all these contributions possible, and which sometimes feels threatened, unloved and vulnerable. The Academy's 900 UK Fellows embody and represent the very best of academic life in the humanities and social sciences.

We focus, rightly, on excellence, as we must, but we must never forget that that excellence rests on the fact that our disciplines are taught and researched by more than 60,000 academic staff across the country and studied each year by around one million UK undergraduates, 60 per cent of all postgraduates and some 250,000 international students. That structure not only delivers excellence at its pinnacle; it also delivers vast wealth into the UK economy and, equally importantly, contributes to all those non-financial aspects that make for prosperity. The more challenging the political and economic climate becomes, the more important that these economic basics be understood.

The British Academy Debates, launched earlier this year, have been well received. These large-scale public discussions around the country seek to demonstrate the humanities and social sciences 'at work' – using a grouped series of events to examine and illuminate some of today's most difficult questions and toughest human and policy challenges.

In the first series of debates, leading academics and other public figures put their research to work in the discussion of some of the key challenges and opportunities posed by the steadily ageing population, and on the way demolished some popular nostrums and stereotypes. The events attracted substantial audiences in London, Sheffield and Edinburgh, with many more watching the online recordings, and with a further 'spin-off' event at the Hay Festival in May, where the Academy has now established an annual presence.

Complex challenges

We need these debates for two reasons. First, because of the sheer scale, complexity and urgency of the challenges we are facing, as societies, as economies, and as individuals. Second, it is central to Academy's role to demonstrate that the humanities and social sciences provide not only real intrinsic value in themselves, but great public value and utility. Research, scholarship and expertise in our disciplines illuminate human dilemmas and explain how economies, cultures and communities function. They help make the complex intelligible, and help us understand human values and possibilities.

The British Academy Debates can make an important contribution to discussion of these challenges. They can help provide a new kind of national conversation. Further series of Debates have now been planned and will focus on immigration (this coming autumn in Birmingham, Liverpool and London) and on Well-being and Public Policy (in early 2015 in Manchester, Cardiff and London).

Like Prospering Wisely, the Debates are a way of fostering an intellectual atmosphere in which the contributions of our disciplines to international and national life are recognised. At the same time the insights they provide stand alongside and are integrated with those of science, engineering and medicine.

The kind of economy the UK now has, and shares with more and more of the developed world, depends on the creativity, knowledge and skills that come from social science and the humanities, just as it needs capital resources and equipment. These skills promote growth that can renew and adapt – by driving innovation, by challenging, questioning and by offering up new ideas. More than three-quarters of the UK economy is now in services, with a constant need for people with knowledge and skills in critical analysis, problem solving, negotiation and communication, teaching and listening, and speaking other languages. The very skills that training in the humanities and social sciences provide.

Intertwined

Finally, let me emphasise that nothing I am saying about working to ensure that the public value of the humanities and social sciences is better understood should be taken as implying any kind of false competitiveness with science, technology, engineering and medicine. They are intertwined and mutually supportive. □

1. https://royalsociety.org/policy/publications/2013/fuelling-prosperity

2. http://www.britac.ac.uk/prosperingwisely

This topic formed the theme of Lord Stern's address to the Fellows of the British Academy at their Annual General Meeting on 17 July 2014. He will take part in 'Tackling the Great Challenges of the 21st Century' with Sir Paul Nurse at the Royal Society on 28 October.

The UK is a maritime nation with a long history of oceanographic research. How can it maintain that leading edge into the future? The question was debated at a meeting of the Foundation on 10 March 2014.

Connectivity - the glue that drives innovation

Ralph Rayner

Ocean technology has come a very long way in just over half a century, roughly the period since the Moon landing in 1969. That was a perfect example of the way in which a clear and audacious goal inspired a whole generation to achieve something extraordinary. The Apollo Mission certainly inspired my generation. How iconic that view of the Earth from the Moon has become. It really has taught us that the Earth is 'Planet Ocean'.

Another source of inspiration for me was the career of Auguste Piccard in the early days of atmospheric and ocean exploration, and, in particular, the descent of the bathyscaphe *Trieste* to the bottom of the Challenger Deep in 1960. Now, more than 50 years on from the Trieste, Jim Cameron's dive in the *Deep Sea Challenger* is inspiring another generation to dream about ocean science and technology. This time the message will reach an even bigger audience with a *National Geographic* film about the dive as well as the publicity surrounding the event itself.

Innovation has been an important part of the journey over the past half century. Innovation does not always require sophisticated technology; a perfect example is the humble shipping container which has had a profound impact on maritime transport but required no great technological advances for its realisation. Equally, innovation is not always about a new product, it can just as easily be a business process which reduces costs or provides a new route to market. For example, iTunes, where a range of different technologies came together, made possible a new route to market and completely transformed an entire industry.

Innovation is certainly not a linear process. In reality it is extremely complex, involving many feedback loops and connections, dipping in and out of research and different spheres of knowledge while connecting a novel idea or solution with a potential market. This complex process has many potential points of failure.

Professor Ralph Rayner is Sector Director, Energy and Environment, for the BMT Group, the Chairman of Sonardyne International and a Professorial Research Fellow at the London School of Economics. He is also an adviser to the United States National Oceanic and Atmospheric Administration (NOAA) and serves as a Trustee of Plymouth Marine Laboratory.

The innovation process is about new ideas and designs with connectivity playing a key part in their generation. In the 19th century, innovation was often characterised as the activity of the lone inventor, although it could be argued that even the greatest of these individuals were building on the knowledge of many others. The 20th century was a century of corporate innovation with large numbers of participants working together, often within a single organisation, to realise new products and services.

In the 21st century we are seeing the emergence of 'open innovation' involving many different, networked organisations and individuals, connecting many different disciplines and sectors.

The concept was put quite succinctly by Steve Jobs: "Creativity is just connecting things." 'Just' may be a rather diminutive term for such a complex process, but that is essentially what the process is about.

To be sustainable and to grow, any business needs a lot of new ideas and, returning to Steve Jobs, the key trick in business is picking the ideas with the best chance of success and discarding the rest. In my experience, companies do not fail as a result of a lack of good ideas, they fail because of an inability to adequately concentrate on just a few carefully-chosen nuggets which will ensure their future sustainability and growth. Jobs also recognised the complexity of the innovation process and the fact that you have to create markets as well as just responding to immediate customer needs.

Government has an important role to play in creating an environment that encourages turning knowledge into value. Historically, interventions in the process have concentrated on translating basic research into applied research and development, but more recently governments have begun to recognise that the other stages in the innovation process are equally prone to failure; especially in smaller organisations that lack the critical infrastructure needed to

DISCUSSION

The bigger picture

Seeing marine science as an area where different disciplines meet, rather than one in its own right, may be more productive for the sector in the long term. It may be better to talk of the underlying fields of sensor technology, materials science, autonomous systems and so on. There is also value in taking a wider rather than narrower perspective, and a distinct cultural value in talking of the need for global care of the oceans, rather than focussing too much on more local issues. This could be made highly motivational for young people. The multi-disciplinary nature of marine science also enables old barriers between disciplines to be broken down.

effectively take a good idea to market.

Another important role of governments is as the 'customer' for new products and services – creating the initial market pull that takes the product or service to critical mass. Ocean science and technology businesses in the UK have watched with some envy the role that the US Government has played in acting as a customer for American businesses. It has led to the USA dominating key segments of the ocean technology market.

Of course the most important role for Government lies in creating motivated and informed talent to feed the translation of knowledge into value. It plays a pivotal role in supporting the education of the next generation.

The so-called 'Valley of Death' is usually portrayed as a gulf lying between basic research and its translation to applied research and development. This is not the only 'Valley of Death' in the translation process and it is probably not the most important. Equally challenging are the transitions between: a good idea and a product or service; a developed product and the means of producing it; the means of production and the creation of market awareness; as well as between market awareness on the one hand and effective sales delivery and support infrastructure on the other. Great ideas can fail at any of these hurdles – and frequently do.

In conclusion

A key role of Government is supporting high-quality, fundamental research and doing so in ways that avoid the pitfalls of trying to fund only the research that might generate economic value. The history of scientific research is littered with examples of research perceived to have no practical value, but which turned out to change the world.

Another role for Government is to help businesses (and especially smaller businesses) to successfully navigate the various 'Valleys of Death'.

Knowledge derived from research often drives innovation which is far from its origins: think of computers or advanced materials as examples. This is especially true of the marine sector which lacks the investment of many other sectors such as medicine or aerospace. Many great innovations in marine science and technology have been driven by strengthening cross-disciplinary and cross-sectoral communication – many more innovations are possible if we work at fostering these interfaces and unconventional partnerships.

I firmly believe that many of the most significant future innovations in ocean science and technology will come from making these connections stronger – by bringing together what is happening in fields as diverse as medical sensing, optical communications, nanotechnology, low-power microelectronics and computing, to name but a few.

Finally, I want to re-emphasise the themes of education and outreach – especially to the next generation. Whether we are in Government, civil society, research or industry, we all have a part to play in inspiring, educating and mentoring the next generation of scientists and technologists. ☐

The contribution of marine science and technology to the economy

Ed Hill

At school we are taught that the ocean covers 70 per cent of the Earth's surface, but we are not taught how pervasive the impact of the ocean is upon us: for example, the oxygen in every second breath a human takes is produced by marine plankton. And so much about the oceans is still unknown: the Census of Marine Life Programme from 2000 to 2010 found that in every sample from below 3km depth in the ocean, one in two specimens came from a yet undescribed species.

The oceans also hold the key to some of the major issues of our age. These are just a few:

- where in the ocean is the excess heat in the Earth's system going?
- can the ocean continue to absorb excess carbon dioxide?
- what are the limits to ecosystem resilience in response to warming, acidification and de-oxygenation of the ocean?
- what are the 100 million or so viruses in every teaspoon of sea water doing in the Earth's system?
- is the ocean heat conveyor-belt slowing down?

Humanity

The relationship between humanity and the sea can be summarised under three broad categories: we draw resources from the sea; the sea presents risks and hazards to us; and our impact on the marine environment potentially limits the ability to extract future resources.

There are business opportunities associated with each of these areas, whether through exploration and mapping, exploitation of resources, or through understanding and managing the risks and opportunities that the marine environment presents.

For the UK, the ocean is of vital national interest. Our own marine area is three times the size of the land. It encompasses coastal regions, continental shelves, ocean margins and deep sea provinces. There are potentially enormous resources here, but we also have a responsibility to steward this environment.

An area of the Earth approximately equivalent to its entire land surface lies beyond the national jurisdiction of any country (a global commons) and is, therefore, subject to international regulation. The UK has always been a leading player in international ocean governance. However, a continuing leadership role will have to be supported by a presence in the deep ocean, underpinned with practical, sound science.

Looking at the overseas territories of the UK, about 32 times the area of the land surface is submarine real estate and the UK is responsible for two of the largest marine protected areas in the world's oceans.

The economy

The ocean also plays an important role in our economy. A report from Oxford Economics[1] has estimated that about £35 billion of gross value added to the UK economy comes from the marine sector;

everything from oil and gas through to some of the small industries supporting the service sector, including maritime consultancy. Other figures suggest that this is an under-estimate and the real contribution could be anything up to 4 per cent of total UK output, with just short of one million jobs and about 5,000 companies generating £9.2 billion for the Exchequer.

A recent international comparative analysis by the Council of Canadian Academies shows the quality of UK marine science to be world-class (comparable with leaders like Germany and the USA). The UK spends about £170 million per year on marine science: Defra, Marine Scotland and NERC fund 80 per cent of all public marine science in this country.

Marine science in the UK is both competitive and collaborative. For example, nearly 90 per cent of the National Oceanography Centre's publications have an international co-author, so the UK is very strongly connected internationally.

In addition, it has world-class research infrastructure. In the last decade some £120 million of capital investment has been allocated to two new research ships. The country does not have the largest oceanographic fleet in the world but it has vessels capable of going anywhere in the world and in the deepest waters. Tonne for tonne, it can be argued that this is the most advanced research vessel fleet in the world.

What does that mean in practice? Well, in 2013, British scientists were responsible for the discovery of the deepest, hottest, hydrothermal vents in the Cayman Trough. Not only was this a fantastic discovery in its own right, but the way in which it was done was important – it was an international collaborative programme. The area was first mapped by a ship with a multi-beam echo-sounder, the vents were then 'sniffed out' by an autonomous robot submarine, the research vessel subsequently went back in and used a deep sea, remotely-operated vehicle to sample the vent site – so a combination of technologies made this discovery possible.

Something thought impossible to do 15 years ago, but now a reality, is long-term monitoring of the Atlantic Ocean part of the global thermohaline circulation; revealing for the first time the truly unexpected variability in the circulation which controls the climate of NW Europe.

Science and innovation

The UK has a healthy innovation system: about 30 universities have marine science strengths, there is a major national research institution and a number of other specialist institutions involved in the translation pathway from science to application. A number of intermediate information providers draw on this science base, working with industry and with key agencies in the public sector.

There are a number of significant clusters of marine science and industry activity. A particularly noticeable grouping exists in the south east of England, around the Southampton, Solent, Portsmouth axis, drawing on a range of expertise such as the Southampton Marine and Maritime Institute.

The Marine Industries Liaison Group (part of the UK Marine Science Coordination Committee) undertook some work last year to survey the state of the marine industries. The first conclusion was that it was actually a time of confidence for UK businesses – they were all anticipating growth and an increase in exports. However, there was a perception of common needs between public sector and private consumers of marine science, for things like seabed and habitat mapping, for long-term marine monitoring, for instrumentation.

The importance of fundamental discovery science was recognised, but there was a greater focus on the need for strategic, applied science. Looking toward the future, there was a general feeling that development of the sector, including the science, was planned over too short a timeframe. Much greater collaboration and dialogue was needed between the public and private sectors, both providers and users of the science.

Marine science is having an impact on business in several ways. One is through the provision of advice to Government. In 2009, as a result of scientific advice on seafloor geology and sediment processes, the UK claimed 2,000,000 km^2 of extra submarine real estate, which adds considerable natural resources for the future.

Marine modelling and observations are dramatically improving skills at forecasting climate and seasonal weather, with an associated impact on economic sectors sensitive to seasonal weather (e.g. agriculture, transport, retail, energy, health). A whole host of other services, from specialist consultancy to industry, sharing of facilities, formation of information hubs and clusters, networks, the provision of skills, technology transfer (for example on sensors and platforms), the accessibility of data and data products – all these and more are having quantifiable impacts on business.

The inevitable question, though, is: "Is this enough and can we do more?"

Emerging areas

There are a number of emerging areas which have been identified by the business community. There are some immediate issues, such as the question of scientific evidence on oil and gas decommissioning, through problems with ballast water, anti-fouling and the really serious matter of underwater noise.

There is a great deal of innovation on

Professor Ed Hill OBE is Executive Director of the National Oceanography Centre. NOC has research centres in Southampton and Liverpool and operates two ocean-going research vessels. Professor Hill is a member of the Executive Board of the Natural Environment Research Council (NERC), the parent body of NOC, and is also a Professor of Oceanography at the University of Southampton. A Physical Oceanographer by training, his research experience is in continental shelf sea processes, especially density driven flows such as frontal jets and dense water cascades.

DISCUSSION

Valuing academic excellence

Does the traditional way of valuing academic success really provide a useful metric for advances in the marine sector? The conventional measure of value - publish or perish - may still work in a number of academic areas but it is less suited to the nature of much marine exploration and technological innovation where impact on the economy and on the commercial world are often more important. It could be to the disadvantage of many marine technologists that promotion and tenure still largely rest on the publication record. On the other hand, the bedrock of academic excellence remains the ability of peers to access and critique work through reputable journals.

marine autonomous monitoring systems and sensors. This could be worth €4 billion a year in Europe alone. Further ahead, there could be opportunities in unconventional hydrocarbons and deep-sea mining.

We have, in the UK, all of the key elements of a success story: from a world-class science and engineering base; through a leading role in many aspects of marine autonomous systems (and the micro-sensors required to do this); a high reputation for leading in international marine standards; a dynamic small- and medium-sized enterprise (SME) sector capable of developing and building – and also operating for clients – this kind of technology. In addition, we have a number of major global players in the offshore sector, as well as a UK-based supply chain and an oil and gas sector with many transferable skills and access to global markets.

While we have all the elements, the challenge is to join them all together!

Marine businesses have been calling for a strengthening of the research ecosystem to ensure that the basic science base remains healthy and at the same time we are effective in translating research through innovation.

Then there is the issue of following through on large research and capital investments – in the UK we do not always provide the resource support to maintain these investments. For example, we need to nurture the marine innovation clusters which have begun to develop.

There needs to be a strategic, longer-term, rounded view of the opportunities. The community – including researchers, Government and industry – has to stand back and horizon-scan. A commitment to map the remaining 80 per cent of the UK's underwater space would be a clear and unambiguous sign of intent.

Ironically, one of the biggest barriers to progress in this area is psychological: many of our traditional images about the relationship between Britain and the sea harp back to our history. They are, essentially, backward-looking. It is time that Britain reinvented and reinvigorated its relationship with the sea. Yes, it is part of our history but it is also very much part of our future, one filled with exciting opportunities.

1. Oxford Economics (2013) The economic impact of the marine and maritime sector on the UK in 2011/12.

A time of challenge and opportunity

Rick Spinrad

There is a hackneyed old adage that the USA and the UK are two nations separated by a common language. I would say instead that our respective research communities are in fact linked closely together by some common issues and challenges. Many of these actually go beyond the marine sciences, although plenty of examples can also be found within this discipline.

The HMS *Challenger* expedition in 1874 is a good place to start when examining the progress of marine science. The late 19th century was when research began to grow into the dynamic enterprise that we see today. The Challenger expedition was really about discovery and the quest for knowledge: there was an awareness that there were so many things still to be understood.

Moving forward in time, the Integrated Undersea Surveillance System (IUSS) – SURTASS was the ship-based version – was used during the Cold War to monitor the Soviet fleet. This programme was set up by US Navy Admirals who went to Cambridge, Massachusetts, with a great deal of money, in order to find the best researchers and ask them to build a system that would detect submarines. This was built in less than two years: how many operational systems of that magnitude are developed today (from inception to operation) in two years? It was a very different kind of research environment.

When I worked in the Office for Naval Research in the 1980s, it supported the best research, no matter what the field (ultimately, of course, the expectation was that it would have some value for the US Navy). The National Science Foundation also awarded funding purely on scientific merit – the best proposal, the most fascinating science.

As time went on, though, the NSF came under more and more pressure from Congress to justify its support for projects. In one presidential election, the question was even asked: "Why is the US Government studying the DNA of grizzly bears? Are we concerned about paternity suits in the woods by bears?" The NSF progressively added more and more requirements for 'broader impacts' to its funding criteria. How does a particular research project result in societal benefit? How does that research result in commercialisable products? This is not a trend that is particular to the USA, it is universal. The requirement for an immediate and quantifiable return on investment (ROI) is increasing.

Another general trend is that technological innovation is being driven by sectors outside of the science community. When I worked for the US Navy, we had MilSpec – Military Specification. An acoustic system for marine technological applications had to meet the military (in this case the Navy) specification. Today's products have to meet Microsoft or Apple standards or any one of thousands of sector-specific requirements. So the market is now driving the pace of innovation (and, consequently, the pace of scientific research) much more than Government.

This entails the development of a new set of paradigms. There will be a mingling of public and private funding. Right now, in the USA that would be illegal. Even if public and private objectives are the same, the money cannot be spent in the same way. Compare that with Finland where it can be difficult to identify any separation between the public sector and the private sector in many investments made there. This is likely to be the pattern of the

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future.

There will be more crowd-sourcing and citizen science. Initiatives like Kickstarter allow anyone with an idea to seek support from individuals via the web. Kickstarter has been around for about three years and was originally used by people starting up a tie-dyed T-shirt business or the like. But I had a faculty member walk into my office about six months ago and say "I want to put my proposed research up on Kickstarter. What are our policies for crowd-source sponsored research?"

Citizen science is another excellent idea. Bob Ballard has done some wonderful undersea exploration work and while working with NOAA he said, "I want to make undersea exploration available to the world." At that point, he wanted to provide web access, in real time, to his next undersea exploration. Furthermore, he wanted to allow researchers from all over the world to actually drive the remotely-operated vehicle. Using the same software used in public voting on TV shows, he could allow people to choose: "Should the remotely-operated vehicle (ROV) go over there and look at that black smoker, or go over there and look at that sea star?" It really is an interesting example of citizen science.

Open-source technology is a new concept where the proprietary approach to software and technology is dissolving. Groups like Open ROV (which incidentally is a crowd-sourced group) makes all of its technology openly available. The conventional idea of protecting intellectual property is being by-passed. Making an impact in the market is going to involve getting people to use your technology instead of wasting time trying to patent and protect the individual property. The reason: well, because by the time you do that, it will be out of date.

Then there is 'commoditised education and training'. There is a metric in the USA called the Six-Year Graduation Rate – the number of students that attain an advanced degree within six years of starting at college. Well, the rate is dropping or remaining flat at many universities in the States. Formerly, students would go to college, get a degree and then be guaranteed a job or a place at graduate school. Now, the economy has changed and students are saying: "I need these courses, I need that accreditation, I need that certificate, but the degree – no, I don't need the degree."

So, how are we training students to prepare for commoditised education and training? Ad hoc networks of scientists and technologists are already collaborating across international or disciplinary boundaries. It is just as easy for a researcher in Oregon to work with a colleague in Southampton as it is to work with someone just down the road. The technology today means that it is not necessary to be based in geographic clusters for many projects.

The 'research by the pound' concept sits alongside commoditised education and training. When the Deep Water Horizon blow-out occurred four years ago in the Gulf of Mexico, researchers were not focussing on a general understanding of ecosystem dynamics in an oil spill, but rather challenges like the best predictive model for the loop current, how oil is entrained in the loop current and how dispersants act – and people were willing to pay whatever it took to get this research done. I call that 'by the pound' research because it does not necessarily advance understanding, but it helps to solve particular problems.

The US Government currently uses very detailed and prescriptive specifications in its funding calls. Yet look at the story behind the (private sector) dive project by James Cameron in the Mariana Trench and there is a different model. The basic development concept was subject to adaptive management, accompanied by a great deal of very creative thinking, together with just the amount of testing and evaluation needed to solve problems. In fact, it was executed in a way that was totally foreign to the way governments support development.

Will academic research become increasingly beholden to industry? When I arrived at Oregon State University four years ago, just two per cent of our research profile was supported by industry. Today that has risen to 12 per cent. Part of that was due to necessity – the Federal Government is reducing its investment, so universities are turning to private industry and foundations. However, there is a price to be paid in that it means a move towards 'research by the pound', commoditising research. The focus shifts towards return on investment and away from the advancement of knowledge.

The peer-review system is under strain. All researchers are spending more and more time engaged in the peer-review process. In the past there was a willingness to tolerate risk in research; today, though, the community is less risk-tolerant and as a result research is reviewed with ever greater scrutiny.

One piece of good news is that the physical location of the research will be less important. There will be much more virtual research, with collaboration via tele-working and tele-conferencing. Following Bob Ballard's exercise, there was for a period of time in the US Office of Ocean Exploration a programme which allowed research to be conducted from a ship with access to experts from everywhere. An ROV could be put over the side to explore an area of the ocean that nobody had seen before, then thousands of researchers from all over the world could be given real-time access and could decide what exactly the ROV should examine. So place is becoming much less important.

Finally, what becomes of exploration, monitoring and observation? It is increasingly seen as a 'nice to have' rather than as an essential part of research. Yet, this is the era of big data and from big data a lot can be learned about the environment. It is, though, increasingly difficult to justify sustained investment in this area.

I will conclude with the comment that the way we address these new paradigms, the way we get to the future, is through engaged debate, but with the person on the street, with the politician, with the business person, with the public in general, not just the research community. ☐

DISCUSSION

Fundamental and goal-driven research

Fundamental research provides the essential intellectual foundation for future, goal-driven technological innovation. This often draws on the results of past research. The history of science shows, though, how hard it is to predict in advance the outcome of basic research or for that matter the often surprising directions in which it can lead. The amount of spend - and luck - are often the most important determinants of research coming up with interesting results. So the choice should lie in picking the race, not the winner. Unlike fundamental research, technological innovation can be directed to specific ends, particularly where there is a need to circumvent a barrier to a new product or process. Here it is possible to pick likely winners and target limited funds more effectively.

The control of tuberculosis infection in cattle in the UK has become highly controversial. How can the science help to identify the most effective options for Government? The matter was discussed at a meeting of the Foundation for Science and Technology on 2 April 2014.

A farmer's perspective

Adam Quinney

Tuberculosis (TB) is a life-threatening disease that affects both animals and humans. Bovine TB was first recognised as a significant problem during the Victorian era when TB in humans was linked with drinking milk from infected animals. By the 1930s, around 40 per cent of cattle were infected and about 2,500 people were dying each year as a result of contracting TB from cows.

A tuberculin skin test for cattle was developed in the 1930s and in 1935 the Government introduced the voluntary Attested Herd Scheme. Pasteurisation of milk was also introduced in 1935. Although these early steps went some way toward reducing the effects of bovine TB, it remained a serious problem until the 1950s, when tuberculin skin testing of cattle became compulsory. Within 10 years bovine TB was largely eradicated, except in the southwest of England where a couple of stubborn pockets remained.

Badger populations

Bovine TB affects a number of animal species, notably badgers. It can be passed from badgers to cattle, as well as between cattle. The *Badgers Act* of 1973 protected badgers and, from then on, their numbers began to grow. This was followed by a rise in the numbers of cattle becoming infected with TB. In the 1980s, fewer than 500 cattle per year had been slaughtered because of TB infection. By the late 1990s, this number had grown to 4,000-5,000 cattle per year, and in 2012 the number slaughtered reached 26,500. The slaughter of these cattle costs farmers and the country a great deal of money. Although demand for beef is increasing worldwide, UK beef production has actually fallen. Bovine TB is now estimated to be costing the UK economy £100 million per year.

Despite the rise in infection rates, many politicians took little interest in the problem. Attempts to reduce TB infection from badgers by culling were fraught with difficulties. The Randomised Badger Culling Trial (RBCT), which ran from 1998 to 2005, concluded that large-scale culling was not cost-effective, with an average reduction of 16 per cent over the nine years. Farmers have found this conclusion difficult to understand as the reduction in the cull area after the badger cull was just over 40 per cent.

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The pilot badger cull trials in Somerset and Gloucestershire (2013) are due to run for four years, to see if free shooting could be an option. However, they are complex and costly for farmers, who are being asked to pay for the culling. This can sometimes amount to as much as £2,000 on a farm where there were only 12 badgers. There was also a perception among farmers that the official conclusions from the previous trials were partly based on public distaste for culling, which itself stemmed from the public's limited understanding of the issue. It is pertinent to note that since the RBCT made its report, cattle prices have doubled. Therefore culling may now be more cost-effective than indicated in that study.

The public's view of badger culling was largely negative. This seems to be based on the erroneous belief that farmers are against vaccination and would like to cull all the badgers in the country. This has only served to polarise the debate. I think most farmers would support badger vaccination in areas where the risk of bovine TB in badgers is low. However, it is unlikely that badger vaccination alone will control TB in higher-risk areas: in some of these areas, more than half (55 per cent) of badgers are infected. In these areas, other measures will be needed.

Reducing bovine TB in the future

In the future, a vaccine for cattle might provide a solution. We need trials to find out whether such a vaccine would work in all cattle or only in young cattle, whether the immunity conferred would be passed on, and whether this is a measure that would work everywhere in the country. Another initiative that needs to be explored is that of post-movement testing of cattle (as an addition to the present pre-movement test) to stop the spread of TB from High Risk Areas to Low Risk Areas, especially in breeding cattle.

There is no silver bullet for bovine TB and the solution might be very different in different areas of the country. What works in Devon may not work in Cumbria. We need to explore a range of solutions.

Defra needs to work in genuine partnership with farmers. Farmers need to be confident that their economic and practical problems are understood and that the information they are given is accurate and consistent.

DISCUSSION

Defra engagement with farmers and the public

Farmers' lack of trust and confidence in Defra is a major obstacle to progress. Farmers are mistrustful of Defra's motives and see it as being heavily influenced by wildlife enthusiasts. Defra's actions sometimes seem to polarise issues. A key task should be to educate the public, starting in schools, about the importance of cattle herds to the UK economy and how TB can be controlled while still preserving wildlife. No solution will work without partnership between Government and the agricultural community.

The impact of slaughtering on farmers, their families and their staff needs to be appreciated. This is a personal tragedy for many UK farmers. I visited one young farmer on the Cornwall/Devon border last year. He was exactly the type of person we want to see in farming – in his mid-30s, university trained, and keen to invest in his farm to improve the welfare of the animals and increase productivity.

To this end he had borrowed £750,000 and was working hard to meet the needs of the market in order to enable him to reduce his repayments. The farm had been in his family for generations. He had had a closed herd since 1996, he had no immediate neighbours and was separated from neighbouring farms by roads and arable fields.

After TB testing last autumn he lost 90 cows, and on further testing in February he lost another 60. This man was weeping, not only because of the financial loss, but because his hopes and desires and plans were disappearing and he thought he would lose the farm that had been in his family for so long.

It is crucial that this problem is tackled effectively – cattle numbers have already dropped from 16 million to 10 million, and this is a significant loss to the UK's export trade. We need an independent body to oversee bovine TB control. It should have representation from all stakeholders and a proper budget with which to investigate various methods of control in badgers and cattle, trial new vaccines and develop an effective long-term plan. ☐

Culling versus vaccination

Rosie Woodroffe

TB is a huge problem, for both beef and dairy farmers, and badgers are part of this problem. As evidence has accumulated on the badger's role, it has become more and more apparent that badgers' ecology and behaviour have important impacts on the spread of infection. Developing an effective solution demands an understanding of these features of badger biology.

Professor Rosie Woodroffe is a Senior Research Fellow at the Institute of Zoology, Zoological Society of London. She was a member of the team that designed and oversaw the Randomised Badger Culling Trial, which investigated the spread of tuberculosis between badgers and cattle between 1998 and 2007, and remains actively involved in research on this issue.

Culling

Culling changes the behaviour of badgers. If left undisturbed, badgers live in stable groups within a limited territory. Each badger group defends its territory and the groups can be packed quite tightly together. The badgers within the groups tend not to wander beyond their defended territory and it is rare for them to move between territories. Hence if there is TB infection in a territory it tends to remain within that territory without spreading. This is a very stable pattern of disease. The key point is: if the group is left undisturbed, its behaviour works to slow the spread of disease.

When culling is carried out, it reduces the number of badgers but it also introduces disturbance that changes the behaviour of the badgers. They start to range more widely, territories are no longer defended so fiercely, and home ranges begin to overlap. This increases the opportunity for disease transmission between badgers. It also means that each badger is likely to come into contact with more cattle herds. The key point is: if the group is disturbed by culling, its behaviour works to hasten the spread of disease.

In short, badger culling has two opposing consequences: it reduces the number of badgers, which should reduce the transmission of disease, but each badger is more infectious, which can increase transmission of disease. After culling, a higher proportion of badgers are infected and each badger ranges more widely, creating opportunities to come into contact with more herds of cattle. Working out the balance between these positive and negative impacts of badger culling is a complex process.

Widespread proactive culling – as done in the Randomised Badger Culling Trial – reduced badger numbers by about 70 per cent and led to relatively less TB in cattle inside the culled areas. Conversely, reactive culling, in which there was localised culling of badgers, reduced badger density by about 30 per cent but increased TB risk to cattle significantly. On the land immediately outside the proactive culling area, we saw a small reduction in badger density, a change in badger behaviour, and more TB in cattle.

In summary, large-scale culling greatly reduces badger numbers but increases the proportion of badgers with TB and causes the badgers to range more widely. This results in a reduction in bovine TB within the culling area but an increase outside the culling area. Small-scale culling reduces badger numbers to a lesser extent and increases TB in both badgers and cattle.

Vaccination

Vaccination can be a powerful tool for wildlife disease control – for example it has eradicated fox rabies across much of western Europe. Although TB is a very different disease, badger vaccination is still promising. We have an injectable

DISCUSSION

Is badger control a political or a scientific decision?

A consensus was reached that the eventual decision on what control measure to implement will be a political one. The role of public opinion and its influence on politicians should not be underestimated. People dislike the idea of killing badgers and the welfare of badgers is a legitimate concern. Furthermore, the reasons behind the increase in badger population are not understood and more research, such as tagging studies to measure badger habits, is needed. Better understanding of badger behaviour may yield other ways of containing bovine TB. There is also the wider issue of the countryside and the importance of tourism and recreation as sources of income. The sight of dead badgers does not improve the allure of the countryside.

vaccination for badgers that is available now. This vaccine reduces the risk of individual vaccinated badgers later testing positive for TB, and it also greatly reduces the risk of infection in unvaccinated cubs within the same group. Because vaccination leaves the badgers' territorial structure intact, this natural brake on disease spread can be augmented by vaccination.

Which is best?

Culling and vaccination operate by different mechanisms. In principle, either of them could have the potential to control a wildlife disease. Population structure is a very important factor in disease transmission. Because culling alters the structure of badger populations in ways that accelerate TB transmission, this approach is risky: it can increase disease risks to cattle rather than reducing them.

By contrast, the effectiveness of vaccination might be enhanced by the fact that it does not disturb the behaviour of the badger population, thus restricting the number of susceptible hosts that each infected badger is interacting with and lowering the target needed to be reached in order to have a controlling impact. The effect of badger vaccination on cattle TB is untested but merits investigation.

The cost of large-scale culling has been variously estimated at around £300 to £2,500 per square kilometre, plus £4,400 for policing. The cost of vaccination is around £1,330 to £4,000 per square metre. So vaccination is likely to be cheaper than culling.

To conclude, badger vaccination is likely to be cheaper than culling. It is unlikely to cause harm and that makes it a less risky option than culling. Vaccination has the potential to reduce disease within badger populations and hence reduce transmission to cattle, but this potential needs to be explored. ☐

The current status of the fight against bovine TB

Miles Parker

Although over-reliance on statistics can be dangerous, two key measures can be used to provide a good picture of the current status of bovine TB in the UK. They are prevalence (the number of animals infected at any one time) and incidence (the number of new cases that occur over a period). The national monthly tuberculosis statistics between 1996 and 2014 show a rise in both prevalence and incidence.

Prevalence rates spiked in 2001-2002 when foot and mouth disease halted testing for bovine TB. Rates rose to levels not seen before, and have never returned to their pre-2001 levels. However, with the exception of the southwest, the rate of incidence (new cases) is slowing down. It is still too early to say whether overall prevalence is decreasing.

The slowing down in the incidence rate may be a result of a series of measures that have been taken over recent years, including zero tolerance of test avoidance. The severity of the measures taken has increased throughout this period. However, it is important to note that there is a time lag between the introduction of new measures and their effect on incidence. This time lag can be as much as 10 years.

Despite the reduction in the number of new cases, there is no reason for complacency. Maps show a steady spread of bovine TB from 1986 through to 2010, mainly from the southwest in a northerly and easterly direction. When these maps are compared with a map of the national herd, it becomes clear that TB is spreading throughout the herd. The concern is to avoid a situation in which the occurrence of TB in cattle exactly maps the distribution of the national herd.

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In addition, there has been a steady decline in the size of the national herd, which has been decreasing by about 90,000 cattle per year. This decline is not related to the presence of TB. It reflects increasing competitiveness in the industry and changes in market conditions. If it continues, though (and it is a big 'if') we shall have lost about half of our national herd by 2035.

During this decline in cattle numbers, there have been attempts to regulate the badger population. Surveys of badger setts in England and Wales were conducted in the mid-1980s and again from 2010. The results suggest that the number of badger groups – which is not the same as the badger population – has increased by between 70 and 105 per cent. This rise in the number of badger groups is significant and needs to inform any measures we take to control bovine TB.

Our knowledge of the epidemiology of badgers and bovine TB has improved over recent years, and the evidence suggests that transmission of TB from badgers to cattle is relatively inefficient. One report indicates that only around 6-9 per cent of bovine TB is the result of direct transmission from badgers; however that 6-9 per cent triggers the much more efficient cattle-to-cattle transmission, which is responsible for 50 per cent of cases. More analysis is needed to substantiate these conclusions.

Currently we have five options for the management and control of bovine TB:

- containment;
- intensive testing;
- biosecurity;
- vaccination;
- wildlife control.

Containment

For the purposes of containment England is divided into three epidemiological areas. The high-risk or endemic areas begin in Cornwall in the southwest and extend as far as Staffordshire. The 'edge' areas immediately to the east of this extend roughly from Hampshire up to Nottinghamshire. The remaining areas to the north and east are low-risk, low-incidence areas.

Each of these areas now has a different management strategy. The high-risk areas are characterised by clusters and mini-outbreaks of TB, driven both by badger contact and by residual infection

DISCUSSION

Questions for future research

The focus of current research may be too narrow. For example, have there been studies about how the general health of herds affects their susceptibility to TB? What is the role of the vet? Has consideration been given to increasing the resistance of cattle to TB by selective breeding? Has account been taken of the great variation in types of TB in cattle? Do controls need to be more site-specific? Have we overlooked some other control option or subtlety in the ecosystem? More research is urgently needed, particularly into the transmission pathways of TB from badger to cattle and cattle to cattle, the development of better testing methods for TB in both cattle and badgers, and tagging systems to measure badger habits.

and cattle-to-cattle contact. In these areas, cross-infection between badgers is greatest and control of badger-to-badger transmission is an important factor. The strategy in these areas is to bear down on the disease by using all available measures.

In the 'edge' area the main strategy is to prevent geographical spread and reduce the incidence of new cases.

In the low-risk area the objective is to keep the disease out and to maintain official TB-free status.

Intensive testing

Intensive testing, coupled with slaughtering of cattle, is an important tool in reducing the spread of TB. Surveillance in slaughterhouses allows infection to be traced back to particular herds to identify where repeated TB breakouts are happening. Although intensive testing and slaughtering are important, they are not enough on their own. Around 30,000 cattle are slaughtered due to TB annually.

Biosecurity

Biosecurity relies on voluntary, risk-based cattle trading and farm-based risk assessment. It is very important that farmers are given more knowledge about the TB history of a herd that they are buying from. In this way, they can make decisions that will help to reduce the spread of TB through cattle movements.

In the future, it may be possible to identify and remove infected badgers or badger setts. Farmers may also be better able to reduce TB spread through husbandry measures, for example using the design of farm buildings to keep wildlife separate from cattle. However, our knowledge of the routes of cross-infection is incomplete. More work needs to be done in this area in order to provide farmers with accurate, evidence-based information.

Vaccination

The potential of vaccination is still being explored. At present the only available vaccine against TB is BCG. However, BCG is only about 60 per cent effective in the protection of uninfected animals and has no known effect on infected animals. It also interferes with the tuberculin skin test. There is work being done to develop a vaccine that does not affect the skin test, and on a test that can differentiate between infected and uninfected animals, known as the 'Diva test'.

However, it is not expected that such a vaccine will be available in the immediate future. It is likely to take another 10 years before there is a licensed cattle BCG.

At the same time, research is being carried out to develop vaccines for badgers, and there is now an injectable badger vaccine that is licensed and available for use. Although there is limited experience of its use in the field, it has the potential to be a useful tool. From a practical perspective, the most desirable type of badger vaccine would be an oral vaccine, but this is likely to be at least five years away, and it is not at present clear whether such a vaccine can be produced at all.

Wildlife control

There is evidence from the Randomised Badger Control Trial that, if carried out in a widespread, coordinated and efficient way over a sustained period of time, removal of badgers can reduce the incidence of TB in cattle. In areas of the world where TB control has been addressed, control of a wildlife reservoir, where it existed, has been an important factor. As mentioned earlier, although badger-to-cattle transmission of TB is not very efficient, indirectly badgers may be causing up to 50 per cent of cattle infections in high-risk areas.

The need to control wildlife is supported by evidence from Ireland with respect to badgers, New Zealand in possums, Australia in the feral buffalo, the USA in the white-tailed deer and Spain in the wild boar. There are lessons from these countries for us. ❐

Clarifying points of agreement and disagreement

Chris Gaskell

Bovine tuberculosis a very complex and serious problem, no one disputes that. The evidence base upon which policy makers have to work is a mixture of natural science evidence, social science evidence, economic evidence and politics. Those evidence bases are incomplete: we cannot, as the scientists providing the evidence base, point to clear and unequivocal evidence in many of the areas under debate.

Just to underline this, it is noteworthy that the policy in England changed from not-culling to culling at exactly the same time as the Welsh policy changed from culling to not-culling, on exactly the same evidence base. So clearly there is an issue here.

In 2011, I was part of a group asked to review the natural science evidence base for the Welsh Government. In doing so we came to appreciate the problems of the policy maker, particularly in terms of how robust the evidence was. In reporting back to the Minister, we drew up a scheme to look at the evidence and categorise it under four main headings.

The first would include matters where there was a consensus about an evidence base – in other words a minister or policy maker could be confident about it.

The second was where there was a

general consensus of expert opinion. In other words there was not robust, controlled experimental work to support the evidence base, but actually most scientists would be confident in offering this advice.

Then there was an area where the support was less robust – there was majority support for something, but no real evidence base, just a deal of common sense.

Finally, there was a category where there was some support but no real evidence. The views were not supported by the majority but were probably worthy of further consideration.

Basic premises

So that led us to draw up a few basic premises which I think are worth restating. The first is that TB is a major problem in cattle and badgers, in Wales in our case, but also in certain regions of England, but not in Scotland.

The eradication of bovine TB in cattle will require the simultaneous use of a range of measures: there is no 'silver bullet'. That is disappointing for scientists because we may not be able to determine which particular measure is most effective because the solution will have to involve a mix of approaches.

The measures will vary by geographical area and, by implication, according to the degree of severity or prevalence of disease. There may well be particular epidemiological issues in different areas as well.

There is a general consensus, supported by an evidence base, that cattle-to-cattle transference is crucially important. Some will argue about the relative importance compared to badger-to-cattle transference, but cattle-to-cattle remains a fundamental issue, explicitly made by the Randomised Badger Culling Trial report in 2007.

There is also a general consensus, based on an evidence base, that there is an association between bovine TB in badgers and in cattle in those areas where it is endemic in both species – nobody contests that.

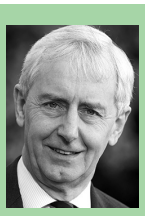
There is, crucially, an evidence base that culling badgers will make a difference to the incidence, or the increase in prevalence, of the disease in cattle. The Randomised Badger Culling Trial showed that the number of cattle outbreaks can be reduced by culling badgers – there is a debate about whether that is enough and whether it is sustainable, but there is an evidence base for this reduction.

There is evidence that there is benefit from reducing contact between cattle and badgers. Where prevalence is high in badgers there is more likely to be transference, although it is not a straightforward relationship.

There is also evidence, based on laboratory and some field trials, that vaccination of badgers will make a difference to immunity in the badger population. There is no evidence that this will affect the incidence in cattle, but common sense suggests it would.

In the report to the Welsh Government, we went on to talk about the vaccination of cattle against TB. We also made the point that the social science evidence base is as important as the natural science evidence base in any policy. To control and eradicate the disease in cattle, all parties have to be committed to the policy, and that includes the farming population. So the confidence of the farming population in the chosen measures is hugely important. However, the social and economic evidence base is incomplete.

Finally, we concluded that, notwithstanding all the scientific evidence, this would ultimately be a political decision.



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Issues

So, what are the points of agreement and disagreement on this issue? Well, we agree that:

- badgers and cattle infect each other and themselves;
- infection in wildlife reservoirs has to be controlled if eradication is to be achieved;
- measures to reduce cattle-to-cattle infection are important in the control and eradication of the disease;
- the culling of badgers, carried out to certain criteria, will reduce the incidence of herd breakdown due to bovine TB;
- vaccination of badgers will reduce disease and probably infection, but this may take a long time;
- in certain parts of the country at least, cattle vaccination is one of the medium-term measures that we need to examine closely;
- eradication will require a collection of measures and it will be difficult to identify which will have the major impact.

But we do not agree on some other things. There is no agreement, for example, on how best to control disease and infection in the wildlife reservoir. There is the nub of the issue for the policy makers – whether to vaccinate, as in Wales, or to cull which is the current policy in England.

People also disagree on how Draconian to be in controlling cattle-to-cattle transmission. There seems to be an appetite for risk-based trading. Farmers want to play their part in disease eradication, but they need to be confident that the measures they are being asked to implement will deliver. The social science about the farming community is important.

There are also further questions to be answered. Are the measures being applied to cattle bespoke enough for the region or even the farm under consideration? If different areas of the country require different measures, there is a strong argument that some of those individual measures should be even more bespoke and targeted. As a veterinary surgeon I believe that the local vet, properly informed and properly equipped, is one of the key players in advising an individual farmer about TB control on his farm.

There is an urgent need to determine whether – and how – we could deploy a licensed cattle vaccine.

Biosecurity measures need to be revisited to see if these are stringent enough as part of the protection of our cattle herd from badgers.

Then I think scientists and policymakers need to step back and take a fresh look at the issue. Are we sure we are not missing something important? Are we convinced there is nothing else that might have an impact? Are there other farming or husbandry practices that are having unintended consequences? What is the impact of maize growing, for example? What is the cause of the badger population explosion? Should we be talking about badger population control at all? □

With the United Nations forecasting that the world will need to increase food production by 40 per cent in the next 15 years, what are the most effective ways of achieving this? And what part can the UK play? These questions were discussed at a meeting of the Foundation on 21 May 2014.

A strategy for the future of UK agriculture

George Freeman

Within 30 years the world will need to double food production on the same amount of land, but with half as much water and energy. The science of how to produce more food from less is an area where the UK can play a leading role. For the last two or three decades, though, we have treated agriculture not so much as a prime economic asset, a key industry, but as a very important arm of hedgerow and countryside management. That has now changed.

The Coalition Government has set out a series of ambitious, industrial strategies for sectors it has identified as key to long-term economic growth for this country: the life sciences, aerospace and digital technology and a number of others.

The final strategy to be announced was Agri-tech[1]: Government has recognised this as a key industry. That is not just for its importance in producing more food – important though that is – but as a source of technologies, intellectual property transfer and global trade.

Agriculture and manufacturing

British farming is the largest part of our manufacturing sector. It makes a vast contribution to the UK economy. However, productivity is not rising and if we are to be a crucible of innovation and help the world tackle the grand challenge of feeding itself then we need rising productivity. In addition, given the extraordinary rises in commodity prices, we need to be able to produce more from less.

Those rises are for various reasons including climate change, which is altering global geography and the geography of crop production. There is pressure on water supply due to population growth and conflicting demands on land use. Scratch beneath the surface of many of the geo-political hotspots around the world and there is a food or water or land shortage.

The Agri-tech Strategy is not just about GM and plant science, it is also concerned with satellite-guided equipment, precision farming, engineering, informatics, smart phones, low chemical use and accurate 21st century farming.

George Freeman MP is Member of Parliament for Mid-Norfolk and was asked by the Universities and Science Minister to take the lead in the political drive to develop the Agri-tech Strategy. He was elected to Parliament in May 2010. He has written and spoken widely on the potential of Britain's science and innovation economy to unlock huge trade and inward investment opportunities in fast emerging global markets. In July 2014, he was appointed Minister for Life Sciences.

While the Government spent £450 million in 2011-12 on agricultural R&D, no single agency was responsible for this spend: it was divided across 21 different bodies and there was no central strategy. The science base, brilliant though it is, had become cut-off from the progressive parts of the farming industry. There was no integrated strategy, vision or business plan for accessing and exploiting global markets.

Yet by attracting investment into our science base it would be possible to generate more IP and technology spin-outs which would drive up the competitiveness and productivity of British farming. That in turn could be used to tap into emerging markets and so help to grow our global sales and our own broader life-sciences clusters.

Integration

In order to do all these things, the Agri-tech Strategy was launched in July 2013. At its heart was the aim of integrating three pillars: science and innovation; supply chains; and the global markets we want to engage with.

The Science and Innovation pillar is not just about deep science within the laboratory, but also about close-to-market technology. That has to connect to the supply chain – from the lonely Hebridean sheep farmer right up to our global brands. And then, finally, there is the link to the global markets that have the capacity to invest in our science. Crucially, among the emerging markets are those serving people who, within 20 or 30 years, will have developed a more Western style of life, with aspirations to live and eat more like us as well.

Three years ago I met the Minister for Food Security from Qatar whose office has a budget of billions of pounds. When I asked him how much of that would be allocated to the UK he told me: "Nothing. Nobody has been to tell me what is available." Inward investment is as important as exports. It has to be a two-way flow.

A blueprint for success

What might success look like? Critically,

DISCUSSION

Research and innovation

While a great deal of research and innovation is being carried out by major international agricultural engineering companies such as Ford or John Deere, there is very little being done in this sector by smaller UK manufacturers. New technologies such as robotics, data mining, new materials, engine performance improvement and satellite positioning could all help to improve productivity and are often led by smaller firms. Equally important is the design and manufacture of food processing equipment, in which there is definitely room for an expansion of UK capacity.

this is not a strategy just for Ministers, the Department of Business, Innovation and Skills (BIS) and the National Farmers Union (NFU). It needs to embrace all the relevant parties, including our huge research and science base and the global 'ag-bio' companies (initially on the 80/20 rule that the biggest 20 per cent have the capital and the expertise to drive this strategy, with the rest following).

The food industry is a highly competitive sector, often operating on very tight margins. It does, though, invest in its own R&D and may be able to help guide this process and ensure investment is directed to the right areas.

The non-profit organisations, both big and small, have a crucial role to play as well.

The programme

The strategy is built around four specific activities. The first strand is the Agri-tech Catalyst Fund which is modelled on the Biomedical Catalyst established within the Life Sciences Strategy. Anyone wanting to develop a technology or an innovation that helps to produce more from less, is eligible for support if the work is to be carried out here in the UK. It is not venture capital – the Government does not take equity in the business – all that is required from the applicant is to draw up a business plan to pull in matched funding and demonstrate a protectable asset. Bids are open and the first funds have been allocated.

Already, five specialist venture capitalists have been to see me and discussed opening an office here in the UK with the vision of building a cluster here to help drive the sector.

Second, the Treasury has allocated £90 million to invest in a series of agricultural innovation hubs. These will be places where the deep science expertise that exists in our great research institutes can be brought out into the field. So they are both virtual and physical. These will be places which British farmers can visit to witness world-class innovation relevant to them. The centres will also link into the agricultural colleges and agricultural societies so that county shows are not just a celebration of 18th century progress, but of 21st century innovation – and young people will be inspired by this world-class industry.

The first of these centres will focus on agricultural informatics in order to try and establish a global lead for the UK in this field, which applies big data to modern farming. Importantly, these hubs and centres will be industry-led.

One of the most exciting clusters is in Norwich. It has world-class programmes in plant science and environmental technology – the clean-tech technologies and the nutritional work at the Norfolk and Norwich Hospital for example. Elsewhere, Harper Adams is creating a cluster in robotics and engineering while there is exciting work taking place in animal science in Scotland.

The third is the Institute of Agricultural Metrics. Around the world there is a fast-growing sector concerned with the application of data and information in 21st century agriculture. This helps to drive policy, but also commercial applications. There are already companies in the UK aggregating the agronomic data and our vision is to create a centre of excellence. If Britain can take the lead here, then it can remain at the forefront for the coming decades.

The last major project centres on Emerging Markets. The Department for International Development (DFID) has put £10 million into a catalyst fund for technology transfer. We want to demonstrate to the public that British agriculture, science and innovation are not just vehicles to maximise profit in the British supply chain, but can help the world feed itself.

Inspiring a generation

The real key to success will be to inspire a new generation, not just of business leaders but also of technologists, of designers, of technicians and of employees on the farm. Our farm workers are already hugely skilled but they are going to become even more expert and professional as the sector embraces new technologies.

In a connected world, regulation too spans national boundaries. However, as we focus on global markets, it is becoming apparent that the EU is an increasingly unhelpful jurisdiction in which to do agriculture and innovation. The Government has sent out a very strong message on GM and on the application of genetics more broadly in agriculture. In the review of our relationship with the EU, the UK may have to look to repatriate agricultural biotechnology jurisdiction: if Europe wants to return to the Dark Ages, the UK will not be locked in too. A better outcome of course would be for Europe to become a progressive crucible, a driver – as it was in the Enlightenment – for science and technology in agriculture.

The Government has taken a lead in this area by setting out the Strategy. It has put money on the table and it is now absolutely crucial that the industry steps forward. There is a huge opportunity for industry with these centres and the Catalyst programmes.

We also have an opportunity as a nation to take the lead in metrics. One way of starting that process is by hosting a global conference on the subject in Britain and using that as a launchpad for the Institute of Agricultural Metrics.

Most important of all is communicating to the public that 21st century agriculture is something to be excited about; that Britain is leading the drive for clean, green, modern farming systems that will produce more from less. People can be proud again of what British science, engineering and innovation is doing in the agricultural sector. □

1. **www.gov.uk/government/publications/uk-agricultural-technologies-strategy**

Taking a consistent approach to Government procurement

Peter Bonfield

The British Food Plan is a cross-Government project looking at the public sector's role in creating a healthier population among school children, hospital patients, people in prison, our military and armed forces, local workers in local authorities, etc, through its procurement practices. The other element looks at how to do this is in a way that supports an economically healthier and vibrant farming food supply chain in this country and how that feeds into issues such as food security, jobs, employment and the rural economies.

Procurement, of course, is about

money – influencing how it is spent provides an opportunity to encourage innovation and create better outcomes. It was a key part of my role at the Olympic Delivery Authority.

About a year and a half ago, I was asked by the Government to lead an independent review of forests and woodlands. This followed a controversy over the proposed sell-off of publically-owned estate. Work carried out by a panel led by the Bishop of Liverpool highlighted two issues in particular. One was that forests and woodlands were too reliant on Government grants and did not have enough economic vitality (employment, growth). This in turn was impacting on the quality of the woodlands: there was less access and less biodiversity.

Rather than write a thick report making recommendations that no-one would take any notice of, I wanted to get on and try to fix the problems. So we spent six months on it and called it 'Grown in Britain'. We made it into a cause: creating a sustainable future for our forests and woodlands. The trick is to put real economic sustainability first. It was finished in October 2013 and has since blossomed. It has generated hundreds of millions of pounds of investment from the private sector. We now have more than 20 million people in the country who are active in woodlands and I included at the end of the report a very small paragraph which described the "wouldn't it be nice ifs…"

I have since been invited back to see the Secretary of State for the Environment and asked to apply some of these insights to food. I am truly independent: I have no knowledge of food and no knowledge of farming. I do have some knowledge of Government procurement and how to make it work.

The context

To add some disturbing context: in the UK, one million old people are malnourished and 3 million people in total are malnourished – indeed, 25 per cent of hospital admissions involve malnourishment. People who are malnourished take longer to get better and their wounds take longer to heal.

The learning ability of school children is materially impacted by what they eat. On cognitive tests children who have a good breakfast have twice the learning capacity than those who do not have a meal. UK citizens are getting increasingly obese – especially children – and that condition will follow them through life and create all sorts of issues. As a nation, we need to address that.

Dr Peter Bonfield OBE FREng is Chair of Defra's British Food Plan and Chief Executive of the BRE Group. His focus as BRE's Chief Executive is to drive innovation and improve sustainability across all sectors. He believes that research has a key role to play in this, providing the evidence base that underpins successful delivery. He was on part-time secondment to the Olympic Delivery Authority (ODA) from 2006 until 2012, where he co-created the sustainable development strategy for the Olympics and supported its delivery.

A substantial proportion of all the food that is given in hospitals is wasted. In a time of austerity and efficiency in Government spending, that cannot be right. Recent studies show that overall 30 per cent of all the food that is bought is wasted. How can that be allowed to happen?

Looking at the rural communities where much of our food is produced, how can we get more money into those communities to help them create jobs, wealth and local employment?

Agriculture – including food – is the largest manufacturing sector in the country. Government purchasing is responsible for about 7 per cent of all food service sales, which includes schools, hospitals, prisons, local authorities, central Government, etc. It is relatively small part of the total but overall, it can be used to influence how people think, how people feel, how people behave and how the private sector behaves. The British Food Plan has been working with some of the big retailers because by working together we can create a bigger impact.

Is it possible to get a range of organisations to buy in a balanced way (taking into account price, quality and other factors) in a way that gives best value per pound and delivers the required outcomes? Where is the evidence? Well, it is the Olympics.

Lessons

What are the lessons to be learned from that experience? First, employing people and organisations that are responsible in how they employ their own people is essential. Making sure that products are sourced in the right way (in terms of provenance, embodied impacts, etc) is a part of the process too.

When we adopted this approach at the Olympics, most people said it would not work and everybody thought it would cost more. In reality, though, responsible companies do what they say they are going to do. In construction, that really helps because the amount of rework is much reduced.

Take concrete, for example. It is grey, comes in liquid or solid forms, it helps build things. At the Olympics, six international companies competed to supply concrete. The embodied impacts of materials is one of the measures we used in assessing bids, and so it was one area where they competed to make a difference. They reduced the embodied impacts by substituting cement (which is very high-impact, a tonne of CO_2 emitted for every tonne of product) with waste materials. This reduced environmental impacts and cut cost – in that way less money is spent but there is a better outcome.

By being less prescriptive about the product but, instead, measuring bids against the balanced scorecard of factors, there is room allowed for innovation and better outcomes.

The British Food Plan

That was the evidence that inspired the British Food Plan. The programme then had to devise its own balanced business scorecard for food and catering in the public sector. That involved identifying the array of costs and other factors that

DISCUSSION

Demonstrating best practice

Demonstration farms are crucial if farmers are to learn how to apply good science on their own farms. The variability of production on farms is very wide; much of this is due to insufficient knowledge of the management of soil conditions, as well as actual farming practices. Few know how to use water economically and restrict energy use. The demonstration farms will bring all aspects of farming together, so as to improve the economics of the sector, and play a major role in helping farmers produce healthier, quality food.

must be considered when we buy food for school children, for hospital food, or prisons. Then it has to be implemented across Government – either mandating or strongly encouraging its use.

The current plethora of guidance, rules, standards and other regulations is confusing. It needs to be tidied up, made more coherent and consistent – made simpler and easier, in fact. There are some key issues like quality assurance: it is essential that the food is what it claims to be and that it comes from where it says.

The scheme needs to be piloted because people will come up with lots of reasons why it may not work – just as they did with the Olympics. Now, while we recognise that some elements of the programme are stronger than others, it is important to test the ideas, gather evidence and learn how to make it work efficiently and effectively. And we should do this in partnership – the private sector, the public sector, suppliers, farmers, the NFU, etc – learning together just as happened with the Games.

There is nothing online about the plan. Rather than raising expectations too early, we just got on with making it work. Once the practice is established, an online presence will be created – again, just like we did on the Olympics – where people who want to buy or sell can find out more.

The key to all of this is innovation; some in agri-tech but some also in practical areas to make the British supply chain more competitive.

The culture

Another insight taken from the Olympic experience is the need to transform the culture in which this all occurs. As with Grown in Britain, too, if everyone adopts a common vision and puts aside day-to-day competition in order to reach the goal, great things can be achieved. A positive critical culture enables participants to identify problems and then put their energy into fixing them, rather than just listing why they are not working. It may be private sector driven, but it is public sector enabled – there is a regulatory element, but primarily it is the public sector enabling innovation, rather than prescribing or blocking.

The vision is long-term and involves: the setting up of a number of groups; establishing momentum and critical mass; and the description of clear measures of success.

Pilots have so far been set up in prisons, schools and hospitals, with the process being driven through Local Enterprise Partnerships (LEPs). The Mayor of London is running a competition in two borough. Then there are working groups, looking at how we enable innovation.

The report was published on 21 July. What was achieved is remarkable in that Government departments are now aligned on how to buy in a consistent way that will deliver the outcomes we are seeking. □

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/332756/food-plan-july-2014.pdf

Ensuring food for the future

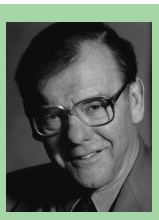
Christopher Haskins

In 1945 my father would be happy to harvest two acres a day and he would have 10 people in the field to achieve that. My son is disappointed if he, with his two sons, does not manage 50 acres in a day. The increase in agricultural productivity in my lifetime has been spectacular.

However, far more change took place between 1814 and 1914 than took place between 1914 and 2014. The Reverend Malthus wrote his prophecies of doom in the 1780s yet by 1928 the Malthusian Society had shut down! In 18th century England, starvation was a real possibility. By 1928, starvation was a thing of the past in this country.

There were three groups at work here:

- scientists – biologists, botanists, chemists, people like Sir John Law who invented artificial fertilisers;
- agricultural engineers – who I think played a greater part than the scientists. They include people in companies like John Deere, McCormack, Ford and Ferguson;
- farmers themselves – in the 19th century, particularly in North America, farm structures changed to enable the farmers to raise the collateral to invest in technologies and the new sciences.



The Lord Haskins is a crossbench Peer in the House of Lords. He is a former Chairman of Northern Foods and Express Dairies, and is Chair of the Humber Local Enterprise Partnership. He is a former Board member of Yorkshire Forward Regional Development Agency, and has a wealth of experience in regional development and regeneration.

Latterly, in the UK, one of the drivers was necessity. Britain did not learn the lessons of the First World War when the country was threatened by starvation. In the Second World War, it did learn and, as a result, Government incentivised food production, irrespective of cost and to a large extent irrespective of side-effects. Production has slowed down over recent years, though. The food mountains across Europe changed the view of the EU and incentives were introduced to cut production rather than increase it. Food imports into this country have risen over the past 30 years. Self-sufficiency has reduced from about 70 per cent to around 60 per cent.

Changes to regulation and farming practice have affected yield. My farm produced four tonnes of wheat per acre in 1984, but only in two other years since then. Botanists may talk about yield increases of one per cent per annum, yet that would mean total yield had risen by 30 per cent over recent decades – in fact, it has not gone up at all. There are, though, a few areas where productivity is increasing such as intensive livestock production.

Priorities for the future

Looking forward, it is vital to help the farmers of the developing world produce more for themselves. This can be achieved through knowledge transfer, mainly via technology and science which is well-established. That is not easy because it requires a huge transformation of farm structures in the developing world. There will be fewer – but bigger – farms, just as happened in the 19th century in Europe. The process is already happening in China and India and must be managed rather than resisted.

New technologies and science will be needed and that is where the British

research centres come in. They represent a huge resource but one which will primarily benefit people outside of this country, particularly as they develop technologies to cope with challenges such as climate change.

In this country, the biggest opportunities are for mechanical engineering and computing. Precision farming is spectacularly exciting. Satellite positioning will enable farmers to use far fewer inputs than they do at the moment, getting better yields.

Robotics offer a technological breakthrough in food manufacturing. Marks & Spencer used to employ 5,000 people putting sandwiches together. Robotics will take over this type of task in the next 20 years and the impact on our society will be dramatic.

One of the big priorities for scientists today is to deal with the unintended, negative consequences of scientific development in previous years. A number of the technologies which were seen to be good 30 years ago are now regarded as flawed. Plants are becoming more resilient and resistant to sprays and chemicals, animals are more resistant to antibiotics. Addressing these issues is a huge priority for the farming world.

Waste

Waste is another challenge. It can be divided into two categories. First, there is the waste created in the developing world from food which never gets out of the fields – whether because farmers have not got the technology, the resources, the machinery to cultivate and harvest it in time or, most importantly, to store it. There is too little infrastructure to take it from farms to places to be stored and sold.

In the developed world, the waste of food is obscene: some 30 per cent of the food bought in our shops never gets eaten. We order too much, we eat too much, we throw away far too much – often through ignorance because we do not know how to make yesterday's meal into another for today. People of my generation would make the Sunday joint last through till Tuesday at least. Now if a joint is not finished on Sunday it is thrown away.

So wastage occurs because of ignorance, indulgence or neurosis. Sell-by dates have become a licence for people to get concerned about themselves. Most shelf-lives are not necessary because food tends to tell you if it is wrong!

Waste in restaurants, supermarkets and factories is also far too high and that is because of bad scheduling. Supermarkets order too much from suppliers and then cancel it. Suppliers have to second-guess the supermarkets, making product ahead of time and then finding they have over-produced: the consequence is vast quantities of waste. Perfectly good food is rejected by the supermarkets since customers will not take it off the shelves because of blemishes.

Huge progress has been made on scheduling of food through the system over the past 40 years – but there is so much more to be done. As soon as a customer buys a product in a store, at that moment that information should be transmitted back to the factory so that an order can be created six days ahead. The supply chain can then react to customer behaviour.

Another issue concerns food-related health problems. The real issue is that people eat too much and do not take enough exercise. The number of calories people actually consume has halved in the last 100 years, but lifestyles have become much more sedentary. The reduction in exercise is much greater than the reduction in calorie intake – we need to cut the calories more.

Potential crises

What can governments do to tackle possible food crises in the future? First of all, reduce barriers to food trade across the world. There are still far too many and food is a particularly sensitive issue. I am a director of a company that exports pigs for breeding to China. The regulatory obstacles faced in moving a high-quality live animal to a country like China are nightmarish. A priority for governments all over the world is to make food move more freely from the areas with surpluses to the areas with shortages. There is a balance to be found between, on the one hand, promoting responsible, science-led regulation and, on the other, outlawing practices which might seriously endanger people. But a lot of public trust in the industry has been jeopardised due to issues like BSE and GM.

Finally, there is an astounding variability of performance in this sector. The difference between a well-run farm and a badly-run farm is enormous. In any other industry those badly-run farms would go to the wall. In this industry, they carry on. This is partly because land values are so high and there is a cushion, partly because people think farming is a way of life rather than a business. There is a large number of structural issues in UK farming which need to be put right. ☐

Dr Stephen Axford, Head of the Agri-tech Industrial Strategy, joined the panel after the formal presentations. In his introductory remarks, he said:

From discussions within the Agri-tech community and through talking to retailers, food processors and manufacturers, there seems to be a real appreciation of the potential for the private sector to invest in their own research and in skills and training.

There is also a realisation that it is time to think in a far more collaborative way about common challenges and an awareness that much research can be done in a pre-competitive environment. Getting together and investigating, for example, the ability of a potato to resist blight, will benefit the entire industry, and the UK economy, as well as the individual businesses involved.

The Technology Strategy Board has opened a funding call for the Informatics Centre which is a core part of this strategy. We expect to make announcements about the other centres or 'hubs' later in the year.

The Government is delivering this programme at pace. The Agri-tech Catalyst is already in operation with money being allocated. Innovation is being supported across a spectrum from basic science through to business behaviours.

The societal and health impacts of this strategy are also potentially massive. For example, more effective production of better foods could have an enormous influence on disease. Obesity rates are going up, not just in this country, but also in other parts of the world such as Asia, with the associated susceptibility to diabetes and so on.

We must not focus solely on a parochial, domestic environment. British science can make an impact on the wider world. While it can help to drive increased trade, UK technology can also pioneer solutions to global challenges: the planet is not large enough to sustain agricultural production for a rising population with current methods. We have to sell more 'intelligent' foods, future-foods even, into some of the markets. There is no reason why the UK should not be the global leader in this area.

The UK and China are both heavilycommitted to research and innovation. A meeting of the Foundation on 11 June 2014 looked at how collaborations and partnerships could be increased.

Identifying the opportunities for collaboration

Tony Cheetham

The Royal Society has a number of Memoranda of Understanding (MOUs) with international organisations, including the Chinese Academy of Sciences. One of the themes of our International Strategy is the development of stronger links with the emerging economic powers, and in particular China, India and Brazil. Official visits to China began in 1961.

There are many conceptions and misconceptions about science in China and they affect people's views on whether we should collaborate scientifically. One which is frequently heard is that Chinese scientists excel at execution, but are weaker at discovery and innovation. It is also widely believed in companies that intellectual property is not well protected there. There have been concerns about plagiarism and falsification in Chinese science. Then, finally, there is a view that maybe Chinese universities are not comparable with British ones. Each of these issues is discussed below.

Discovery science

Is discovery science weak in China? Well, the volume of publications from China is second only to the USA now. But what about the quality?

Science is arguably the world's leading scientific journal and is published by the American Association for the Advancement of Science. In 2000, there were five times as many papers from the UK as from China, now it is 1.5 times – the trend is clear. It can be seen in fields such as physics, biotechnology and chemistry.

There is clear evidence of convergence on quality at the top end of Chinese and British science. Everyone expects, of course, that China will overtake us in the near future, although there remain significant differences from field to field.

Does the work have any impact? Citations to *Chemical Communications*, a leading chemical journal published by the Royal Society of Chemistry, is shown in Figure 1. China is clearly having a much greater impact than in the past in many of the world's leading scientific journals. Chinese science is now in the Premier League in footballing terms. The future trend is absolutely clear.

Professor Tony Cheetham FRS is Treasurer and Vice-President of the Royal Society. He was Professor in the Materials Department of the University of California at Santa Barbara from 1991 until 2007. In 1992 he took up the Directorship of the new Materials Research Laboratory. In 2004, he became the Director of the new-created International Center for Materials Research at Santa Barbara, and then in 2007 moved to Cambridge to become the Goldsmiths' Professor of Materials Science.

There is a large volume of great science being done by China. This is good for the global scientific endeavour and it is a good thing for mankind as well.

Table 1 shows the number of joint publications from different countries with China. The UK is in second place behind the USA – ahead of Japan, Germany, Australia and France. Analysing the figures according to the field of research, they are dominated by engineering in the broader sense, followed by physics and chemistry, and then biochemistry and molecular biology: there are around four times as many engineering papers as life science contributions.

Intellectual property

Then there is the difficult issue of intellectual property. There is a certain apprehension among many companies about the ability to operate effectively in China while safeguarding their IP. Things have improved a great deal but there have been recent instances in the life sciences and pharmaceutical areas that have given cause for concern. This affects our ability to engage totally with China on technologies that are close to the market.

For an academic, this is less of an issue. If people listen to our talks or read our papers and have even better ideas, well that is the way that science works after all.

Plagiarism and fraud in scientific publishing are problems everywhere. It may be more of a problem in China than in most places as a consequence of the manner in which the Chinese system rewards scientists for publishing papers in high impact journals, and large numbers of them. In China, there is a strong correlation between where you publish, how much you publish, and your salary or academic post. To a certain extent this is true everywhere, but it is the heavy reliance on impact factors that can lead to undesirable results. I know from personal experience with my co-workers that impact

DISCUSSION

A change in attitude

There needs to be a change in attitude in our education system, from schools through to universities. Universities need a new approach both to Chinese students studying in this country (who could form an important alumni base for the future) as well as establishing a more effective UK academic presence in China. A longer term view is necessary; and much more effort has to go into developing a deeper and wider understanding of Chinese culture (and better language skills) on the part of students and researchers, for many of whom China remains a cultural 'blind spot'. Existing UK expertise in these areas - as in the School of African and Oriental Studies - could be exploited more effectively.

Collaboration between China and ...	Joint publications 2000-2013
USA	160,611
UK	47,204
Japan	43,112
Germany	29,277
Australia	28,899
Canada	27,495
France	17,785

Table 1. International collaboration

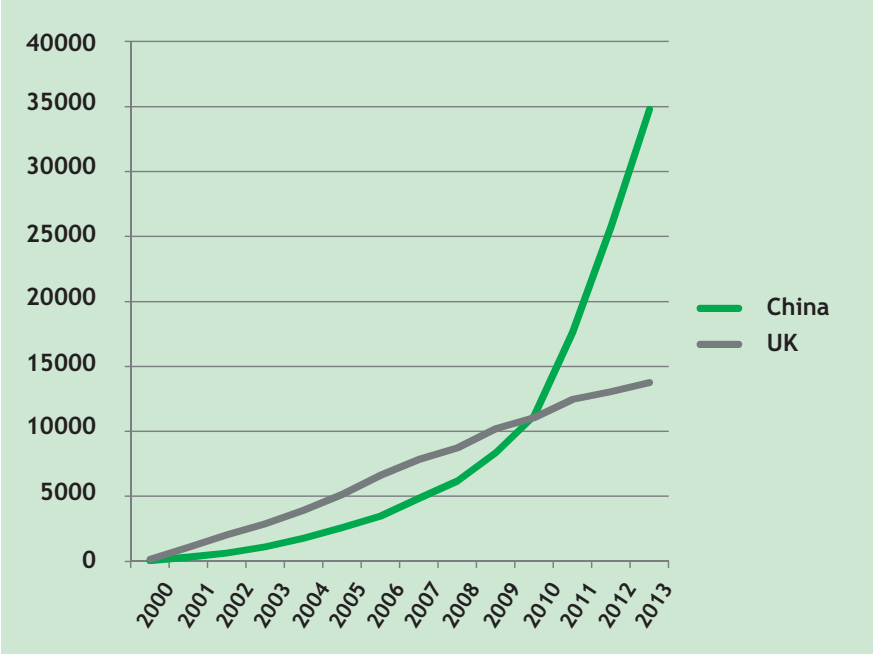


Figure 1. Citation data from Chemical Communications (RSC).

factors are used very widely for assessing researchers in China. The Royal Society has signed the San Francisco Declaration, which discourages the use of impact factors for the assessment of individuals.

While IP and other issues cannot be swept under the carpet, things are getting better. For example, the advent of big data and electronic screening of submissions means that it is becoming much more difficult to get away with plagiarism or publishing multiple copies of the same paper.

Chinese universities

A large proportion of the best science in China is carried out in the Institutes of the Chinese Academy of Sciences. There are about 100 of these and they are separate from the universities. They have no counterparts in Britain, so comparisons are not possible.

China operates more like Germany where the Max Planck Society dominates research in many respects, with its large network of high-powered centres. That having been said, there are a number of universities that are strong at research, such as Peking University and Fudan, as well as the CAS University of Science and Technology. A number of British universities have instigated exchange programmes with them and we are in a very strong position: English is after all our native language and there is a preference for native English-speaking collaborators and even faculty.

The Leiden ranking of universities looks simply at research output and the rankings are based upon citations per paper. It is normalised per paper for the comparison of different institutions. It is also normalised for differences between fields. Life sciences papers are cited much more than chemistry, which in turn is more than physics and engineering, for example. The ranking takes account of that.

On the latest ranking, the top Chinese university was Fudan, at number 96 in physical sciences. It was slightly ahead of Edinburgh and Durham, which were 107 and 108 – so that puts the numbers into context. Tsinghua University was 142, only just behind Sheffield and Bath. Comparing that with other countries, the top Indian university was the Indian Institute of Science in Bangalore which was 288 – no-one would regard the IISc Bangalore as being anything other than a premier research institution! China is much stronger in some fields than others. In the life sciences, for example, the top university was Tsinghua at 208.

Britain and China

Is Britain well-placed to respond to the growth in Chinese science? The first point to note is that there is a massive mismatch between the number of Chinese students studying here and the number of Britons who are studying in China. In 2012, about 46,000 Chinese students arrived in the UK to study, so at any given time there may be 135-140,000 here. The number going from the UK to China in the same year was about 4,000. That puts us well behind France, which had 8,400 students, and Germany at 6,300.

Now the figure for Chinese students in Britain does not include all the people who come here for post-docs, so the mismatch is even greater at that level. There are visa issues at the post-doctoral level in Britain and so the first choice for many is to go to the USA.

For the future, we need a workforce that is well-informed about the strengths and weaknesses of China and familiar with Chinese culture. Only then can we really truly make the best of working with our Chinese colleagues.

Academic collaborations with China are highly desirable because China has developed into one of the leading scientific nations in the world. From the Royal

Society's point of view, this is a top priority: we want to engage.

There is already a great deal of collaboration between the UK and China. Most of it is supported by the National Natural Science Foundation of China (NSFC) or the Chinese Academy of Sciences. However, the recently announced Newton Fund[1] will increase the support from the UK.

The most important message is that more young British scientists need to experience China and to see first hand the opportunities for scientific collaboration in this huge country.

Politically and economically, the UK should not underestimate the soft power of scientific engagement, which has historically been so important in our engagement with Russia, South Africa, Argentina – and now China.

Yet this is not something that can be undertaken by email. Face-to-face interactions are extremely important when dealing with China, so it is vital to get 'feet on the ground' and spend time there in order to make the most of the opportunities.

1. www.gov.uk/government/publications/newton-fund-building-science-and-innovation-capacity-in-developing-countries/newton-fund-building-science-and-innovation-capacity-in-developing-countries

A view from China

Michael Kwok

Arup is a trust-owned global consulting company of planners, engineers, designers, project managers and consultants. It has over 11,000 staff spread across 90 offices in 35 countries. More than a quarter are based in China; over 2,200 in Hong Kong and more than 800 staff in the mainland.

Research and innovation have a long history in Arup – they are key components of our business. We connect with our clients, collaborators and academics through a focus on new thinking and through developing new skills and techniques in order to satisfy our future business needs. Innovation helps us stay ahead of the competition

China has the potential to provide us with a strong platform for further innovation, drawing on its scale, speed, hunger, drive, a demand for innovation and an endless supply of human resources and talents. Not only do we want to capture the vast China markets, but in time we hope to move significant elements of our value chains into China in order to support Arup's global business.

Let me give you an example of the scale and speed at which the Chinese economy is progressing. Arup's very first project in China was the Hilton Hotel in Shanghai. At 145 metres it was one of the tallest buildings in China 30 years ago. We devised a composite concrete core and steel frame system: this was its first use in China, but since then it has become the industry standard. We have built taller and taller buildings as time has gone on, with more complex engineering techniques.

All this has happened in the wake of the economic miracle that China has created in the last 20 years. The country has had an average annual growth of 10 per cent in GDP over the past three decades. China has now overtaken the USA as the largest construction market in the world. The main driver of that activity is urbanisation.

Michael Kwok is a Director of Arup and Head of its Shanghai Office. He has taken charge of a number of major Arup projects in China, including the National Stadium (the Bird's Nest), the CCTV New Headquarters Building, and the Beijing Capital International Airport Terminal 3. He set up the Arup offices in Shanghai, Beijing, Wuhan and Chongqing, and he is responsible for developing Arup's business and operations in mainland China.

In 1978, more than 80 per cent of the Chinese population were living in rural areas and in 1990 the figure was still around 74 per cent. By 2012, 52.6 per cent of the nation was living in the cities: in 34 years, more than 400 million people have moved from the countryside to the cities. The rate of urbanisation – at an average of 1 per cent per year – is likely to continue for the next 16 years. This means an extra 13 million new city dwellers every year over that period. That amounts to the population of a city like Plymouth moving every week. The numbers are just staggering.

Urbanisation is an important aspect of Chinese government policy for economic growth. Urbanisation and a rise in per capita income go hand in hand and this means hundreds of millions of Chinese will be entering the middle class.

It is recognised that domestic consumption will take over from Government investment and exports as the main driver of economic growth. Debate is intensifying on how to focus innovation to cope with the speed and scale of change. Basically we are talking about innovating for 1.3 billion people.

However, 30 years of growth and development have brought major environmental problems in their wake. Consequently, there are ambitious targets for China to reduce carbon intensity, both at national and city levels. There is a strong demand for innovative solutions that will curb emissions while at the same time maintaining economic growth,

DISCUSSION

A two-way flow

The UK should put more emphasis on multi-disciplinary approaches: through the Research Councils, Academies and the Learned Societies it is well placed to do so. The UK also has a strong historical record on urbanisation upon which to draw, including the fact that London - unusually in advanced Western countries - is still expanding. Collaborations should flow in both directions, engaging partners in academia and in commerce while exploiting new paradigms such as the Catapult Centres. It is important not to see collaboration as solely what we can do for the Chinese market. We need to learn from China and to encourage Chinese expertise and investment into the UK.

so that the trajectory of urbanisation can continue. Such solutions will be applicable to many parts of the world.

There are many green technology initiatives to help achieve the ambitious carbon reduction targets, including: renewable energy, low-carbon automotive, green building and the gradual implementation of Smart Grids.

One of the most important and effective programmes has been in transport. Take urban metro as an example: in 1995 there were only four lines running in three cities in China. By 2013 there were 55 lines in 17 cities. By 2015 there will be over 87 lines in 25 cities.

The Beijing Changxindian Eco-City is a project for which Arup was engaged to provide conceptual and detailed regulatory planning for a site of 5 square kilometres in the south west of Beijing. For the first time, low carbon and other environmental targets were incorporated into the statutory planning requirements.

The project combined a strong, bottom-up drive from the developer who saw the business case with a top-down drive from local government and policy support. We started the project in 2010 and the first phase was completed in 2013. The project has been recognised as a successful demonstration of sustainable development which is likely to be replicated, adapted and further improved in other parts of China.

Research and innovation

In undertaking research and innovation collaboration in China, we normally carry out 'road-mapping' exercises to identify short term and long term drivers and business opportunities. We then work out priorities for research and the likely resource needs.

In China, on a day-to-day basis we are pushed by the technical challenges and at the same time we are pulled by the business need to stay ahead of the game. Like many other organisations, we have limited funding and resources (particularly for research), so we have to set priorities. Where the research has a high priority, Arup provides full funding; for other research topics where we have shared interests with others, we will provide match-funding or jointly apply for external support.

Very often innovation can also be achieved through project collaboration. The National Swimming Centre in Beijing – or the Water Cube as it is better known – was a project with very strong research aspects. There were many design elements that were ground-breaking and the first of their kind. The project, from concept to completion, was the result of a multi-disciplinary collaboration between Arup and the architects, the local design studio and the contractor.

There are also other means of knowledge-sharing with academia, such as technical forums with partnership universities and lectures or technical visits for students. Maintaining good relationships and connections with partnership universities helps to align shared interests and to attract the best students to join Arup.

We do explore a wide range of research activities with our strategic partners and often formalise agreements with a Memorandum of Understanding, which is a very effective way to align interests in China.

For example, we are working with the University of Zhengzhou to identify a programme which will allow Henan Provence to complete its industrial restructuring by 2020, incorporating decarbonisation and clean air strategies.

With the South China University of Technology we have been reviewing the current business frameworks for Smart Cities and determining how this can feed into the Smart Guangzhou project, proposing a revised future business framework with challenges and timelines.

Arup has been working with partners including the London School of Hygiene and Tropical Medicine, UCL and Peking University, on a project funded through the EU's Seventh Framework Programme. In this we have been jointly developing methods to quantify the positive and negative impacts on health and wellbeing of greenhouse gas reduction strategies in urban areas of Europe, China and India.

While all this joint activity is very positive there are, of course, also challenges involved with research work in China. The country's research and development funding structure can be divided into Government-led and non-Government-led research. Government-led activities are typically assigned with good resources – they are high profile, strategic projects which impact on policy and industrial development. This is, of course, just the type of research activity in which we are very keen to be involved. However, although we have a good relationship with the Government, our experience in bidding for this type of work indicates that the balance seems to tip a little more in preference towards Chinese organisations.

There are, though, an increasing number of Government-led, international collaborative research activities in China and we hope, in time, more weight will be given to global insight and international technical expertise. ☐

The risks and opportunities of partnership

Robin Grimes

What are the drivers for research? Well, the answer is likely to depend on one's background and experience. As a physical scientist who has spent his entire career either with industry or with academia, in engineering and science, I see the world in a very specific way. I am aware that social scientists, for example, will see things differently.

In the same way, the answers we come to in Britain, whether as physical or social scientists, are likely to be different from those of another culture on the other side of the world, even though there will be a substantial overlap. While we hold a large number of research drivers in common, getting our relationship right with China is about understanding and appreciating – as well as actually enjoying – those differences.

There has been a startling increase in the sums China has invested in research over the last decade and a half. In terms of the scientific literature, that investment is reflected in the increasing number of published papers from China. The USA has always maintained first place in terms of published papers but China is projected to overtake it in the next year or so.

Risks to the UK

If China becomes the pre-eminent nation for research, the risks to the UK of not collaborating will be substantial. China will become the largest science nation, not only

for output but also investment. Research in science, engineering, medicine, is a long term game and we have to engage over that long term. Otherwise, the UK faces losing not only the status of being at the intellectual 'top table', but commercial opportunity as well.

In addition, there would be a loss of influence. There are a number of areas where the UK wants to influence the global agenda. Climate change, air quality and water are among the environmental issues that come to mind immediately but there are other areas that really matter to us here as well such as, in healthcare for example, the dementia challenge, antimicrobial resistance, food safety, etc – the list goes on and thus the risks of not being engaged are significant.

What do we mean by 'research'? My background is in the basic science area which is perhaps the more traditional understanding of the term. But a great deal of research is now taking place in the commercial space where it is directed to achieving specific market-related goals. It involves turning ideas into commercial opportunities. I believe that, particularly in our collaboration with China, this will be absolutely key – finding ways to bridge what is often termed 'the valley of death'.

Commercial risks

Exploiting that research is bound up with questions of intellectual property rights. And here many firms perceive significant commercial risks. However, this is now becoming a priority for reform in China itself, being driven by domestic Chinese stakeholders who can see the benefits of protection for trademarks, copyrights and patents. Patents are actually only part of the issue. Infringement of trademarks can result in loss of market share, as well as loss of reputation. Perhaps even more important than these problems is the issue of knowhow. It is the seepage of knowhow from companies which is more damaging than anything else.

Then there are threats from cyber espionage. Another area of concern is potential selective enforcement of regulations. Dual-use of technologies could be particularly difficult. There are real potential problems if more than one product or technology is being brought together, and the difficulties multiply if the technologies originate in more than one country.

So it would be foolish to deny that there remain difficult issues for organisations seeking to collaborate with Chinese counterparts. These will have to be addressed over the coming years.

Professor Robin Grimes FREng is Chief Scientific Adviser at the Foreign and Commonwealth Office. He is currently Professor of Materials Physics at Imperial College, where he directs a research group that predicts the properties and performance of materials for energy applications. Professor Grimes has advised the House of Lords Science and Technology Committee's inquiry into nuclear research requirements, and was part of the Scientific Advisory Group for Emergencies (SAGE) which provided official advice on the 2011 Fukushima disaster.

Of course, different sectors bring with them their own unique challenges. In space, for example, there is a great deal of discussion in the literature about the dual-use of technologies, particularly with satellites. But innovation is not just about hardware, it applies to business models as well. There are many businesses in the UK offering opportunities to use satellites, to provide data, to provide analysis, and those growing areas for collaboration are perhaps less problematic.

China is rapidly catching the rest of the world in aerospace and much of that has been as a consequence of joint ventures, with product development taking place in both partner countries. What will happen when Chinese aerospace companies move to the UK? That is going to be an interesting paradigm.

The life sciences are different again. There is a huge market opportunity for rapid commercialisation in China. It is an area which also demands a particularly long-term perspective.

So, different areas have different demands and different research paradigms. What is the future of research going to look like? There are a number of models: university research groups, entrepreneur-driven projects (although entrepreneurship in the West is not the same as in China), corporate laboratories and national laboratories. Although the last two are less common now in the West than they used to be, in the life sciences at least the pendulum may be swinging back.

Today in the UK, to help accelerate the translation of research into practice, there are the Technology Strategy Board driven Catapult centres. Each focusses on a different area: high-value manufacturing, future cities, digital economy, cell therapy, satellite applications and more to come.

All these paradigms create places for people – those with the ideas and others with the ability to turn them into products – to come together. We need to be doing that with international partners too. We need to attract our collaborators in China to come to the UK and use these innovation centres. Once we have created the joint products, the next question is then: "Where do we want to manufacture them?"

UK universities currently attract a large number of Chinese students – is this going to decrease suddenly as China develops its own? I do not believe that is likely. Chinese students will continue to come to the UK and it is not just students but also academics. There are 3,000 Chinese academics in British universities at the moment and others in industry and commerce. Yet there are only about 4,500 British students in China and most are on short term study courses of a few weeks, rather than three-year doctorates.

Looking forward

So what kind of relationship should the UK have developed with China within the next couple of decades? There will certainly be a shift in the places where the research is carried out, with much more collaboration taking place around the globe.

Different research and collaboration models will enable more effective translation from the science, employing more diverse teams of researchers. Researchers are likely to become more itinerant, following the research opportunities across the globe.

New markets will emerge as people's aspirations continue to grow. The main drivers for research and development are likely to remain the same though.

The UK has to develop a smarter, more strategic approach to collaboration with China. That includes ensuring that our best people work with their best people. We need to attract Chinese innovators to come to the UK, not just for education but to work in British companies.

Education is changing and we should look at the possibility of joint degrees between UK and Chinese universities. Let us learn from our neighbours too; look at the way the Humboldt Foundation is setting up joint research institutions in China.

The long term aim must be to ensure that the UK is the 'partner of choice' for China. That is what this debate is really all about. ☐

Antimicrobial resistance (AMR) has been recognised as a global issue. A meeting of the Foundation for Science and Technology on 4 June 2014 looked at the scale of the challenge and possible solutions.

Confronting the threat of drug-resistant disease

Sally Davies

When I was practising as a haematologist, anti-microbial resistance or AMR (which takes in bacteria, fungi and viruses) was already an issue, but usually if one antibiotic was ineffective in a given instance, another was available. That is no longer always the case. The immediate challenge concerns bacteria, but the others are becoming resistant too. This was predicted in Fleming's Nobel Prize acceptance speech in 1945: this is Darwinian natural selection.

Antibiotics underpin so much of modern clinical practice: caesarean births, joint replacements, cancer therapy, transplants and the list goes on. Before the discovery of antibiotics, 43 per cent of people who contracted infections died. In the UK today, it is about 7 per cent. We do not want to return to those earlier times! Modern medicine as we know it would disappear. Indeed, one major European country recently had to shut down two of its bone marrow transplant units for a significant period of time because of antibiotic resistance.

And resistance becomes apparent very quickly (see Figure 1). While a couple of those antibiotics took 30 years to lose effectiveness, for most of them it was a decade or less.

Dame Sally Davies DBE FRS FMedSci is Chief Medical Officer for England and Chief Scientific Adviser at the Department of Health. Dame Sally is a haematologist with a research interest in sickle cell disease. She pioneered the centralisation of the £1 billion Department of Health research effort through the creation of the National Institute for Health Research.

Resistance doubles the death rate from infections. EU studies conservatively estimate 25,000 deaths a year – that is the same as deaths from road traffic accidents. A child dies every five minutes in South East Asia because they have an infection which is not treatable because of resistance.

It is a worldwide problem. A resistant *klebsiella pneumoniae* started off in North Carolina and within only a few years had spread all around the globe. A Swedish study of healthy young men going off travelling found that 25 per cent had drug-resistant bacteria in their guts when they returned.

This is not just an issue in human medicine: it affects animal welfare as well. I am told that farmed salmon in the USA have eaten their weight in antibiotics by the time they get to the fish counter. Scottish farmers tell me that theirs are, as in Scandinavia, individually vaccinated so very little antibiotic is used. But vets around the world use a lot. There are antibiotic-resistant bacteria in the seas of Antarctica, in the sea around Japan – they get into vegetables and agriculture, as well as wildlife. MRSA in domestic pets is transmitted to humans who then go into hospitals.

Food animals are a real issue. Globally, over 70 per cent of antibiotics are used in animals. There is some evidence linking over-use in the animal sector to resistance in humans but it is not conclusive. I cannot understand, though, why we have to prove that it is unsafe for humans to over-use antibiotics in animals (for growth promotion) before it stops, rather than for proponents to prove it is safe.

The message, then, is that we have all been abusing antibiotics – throughout the food chain and also patients and doctors. How many people want antibiotics to treat a sore throat – and how many GPs give in to such requests?

In the 1990s, this did not matter too much because if one antibiotic proved resistant there were others available. However, in recent decades antibiotic discovery has been diminishing – the last new class of such drugs dates from 1987. So what has gone wrong?'

The science is difficult, but not impenetrable. However, drug companies are disinvesting in anti-infectives. A major pharmaceutical company has closed its one site which majored on anti-infectives and plans to downsize anti-infectives as it relocates in the UK.

Part of the reason is the lack of incentives. A little profit on a drug that is taken every day, like a statin, a diabetes drug or a high blood pressure drug, will make much more money than an antibiotic which may only be used once in a person's lifetime. As Chief Medical Officer, I would

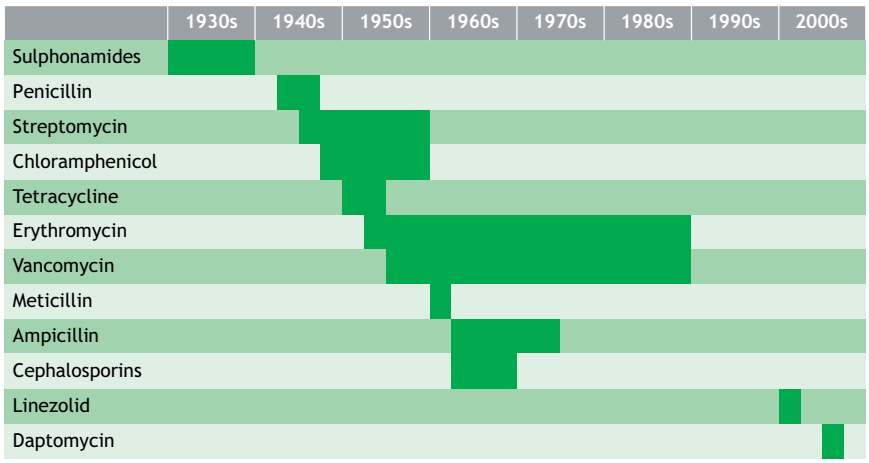


Figure 1. History of antibiotic resistance. Time from first clinical use to first clinical resistance.

DISCUSSION

A challenge for our times

The issue of anti-microbial resistance bears comparison with climate change: international in nature, not regarded as an immediate crisis and therefore lacking adequate institutional arrangements conducive to solutions. As with climate change, there is no simple single solution; AMR is a complex problem with multiple drives, for which a suite of solutions (tailored to the needs and situations in different countries) is required. Economics, social science and regulatory change as well imaginative and multi-disciplinary research will all play a part in finding a solution.

want to lock up any new antibiotic and only release it to save lives. So the tension between selling lots of product to make a profit versus the public health need of conserving drugs for emergencies becomes a problem. As a society, we will need to agree how to fund new antimicrobials, because they have to be paid for.

Meantime, the existing arsenal of drugs has to be conserved. The first step is to reduce infection, by making sure people 'catch it, bin it, kill it'. Something as simple as washing the hands is important. Yet during the 2009 pandemic, data gathered in one motorway service station showed that only one in three men washed their hands after they went to the loo – that is not the way to prevent infection.

It is possible to make a difference. Blood infections from the MRSA super-bug have fallen over the years. This has been achieved with obsessional cleanliness, infection control, hand-washing in hospital for staff and visitors, swabbing as patients arrive, treatment for carriers. There has been similar success with *Clostridium difficile*. This success now needs to be extended to other infections.

National and international initiatives

After the Chief Medical Officer's report of March 2013 was published, the Government decided to augment the five year antimicrobial resistance strategy. Six months later it was re-issued with seven areas of work. This is a cross-Government strategy, encompassing human, animal and agricultural science. It also covers all parts of the UK.

An expert committee which has specialists from both human and the animal sectors has been looking at signal-marker/drug combinations[1]. The five-year strategy will incorporate marker diseases. For example, gonorrhoea is looked after in specialist clinics in this country and 2 per cent of sufferers are now resistant to the last effective drug, *cephalosporin*. This disease is really unpleasant: it results in untreatable urethritis in men and in women it causes arthritis and infertility.

Internationally, 65 countries supported the UK's resolution at the World Health Assembly to develop a global action plan. It is almost unheard of to get that many countries signed up and the Foreign Office helped deliver that. Public Health England is working with laboratories in South Africa, Australia, New Zealand and Singapore under the Commonwealth umbrella. The National Institute for Health Research (NIHR) has funded work while the Medical Research Council (MRC) is leading an AMR Research Funders Forum and working internationally with the EU on a joint programming initiative in this area.

Finally, it would be much easier to better conserve antibiotics if we had rapid diagnostics: we would give antibiotics only when there are bacteria present. A rapid and cheap diagnostic would transform general practice management. I believe this is possible within five years – which is why it was put forward for the Longitude Prize*. □

1. https://www.gov.uk/government/publications/uk-amr-strategy-measuring-success

* Antibiotics has indeed been chosen as the theme of the Longitude Prize. See the Update page in this issue.

New approaches for an urgent problem

Jeremy Farrar

I was working as a junior doctor in London in the mid-1980s, at the start of the HIV epidemic. Most of us young doctors at that time had not worked in an era where an infection could not be routinely treated. Experiencing HIV, before anti-retroviral therapy came into being, was really life-changing for me. Individuals were dying of an untreatable condition. The thought of that situation recurring, but within the wider population, is terrifying.

There is a real possibility that such a catastrophe could occur in the coming years. Interestingly Alexander Fleming alerted the world to the possibility nearly 70 years ago in his Nobel Prize acceptance speech: "It is not difficult to make microbes resistant to penicillin in the laboratory by exposing them to concentrations not sufficient to kill them, and the same thing has occasionally happened in the body…"

Antimicrobial resistance is a reality; it is happening now in the UK. Statistics from the European Centre for Disease Prevention and Control estimated that 25,000 patients died from an infection caused by multidrug-resistant bacteria. In fact, the number is probably considerably higher as most cases are not diagnosed – we are still weak at diagnosing infections. The problem is truly global, so it must be tackled at that level: local or regional efforts will only have marginal benefit.

I believe we are currently in a 'honeymoon phase'. We have been part of an era where antimicrobial agents have been almost universally effective. They have tackled all types of bacteria affecting humans and animals, from young children and babies, through pregnant women, all the way to the end of life. Antimicrobial drugs – and this is a critical point – are not just the preserve of infectious disease specialists. It would be impossible to do routine surgery or treat patients with chemotherapy without access to antimicrobial agents.

We have misused (and not sufficiently valued) antibiotics over the last three or four decades. It was thought they would last forever.

Certain areas of medicine have been neglected, specifically microbiology and particularly microbiology and pharmacology joined together. Drug resistance cannot be dealt with in the isolated world of the microbiologist, or even that of the infectious diseases physician – it has to be tackled through

examining the way that drugs are used and how the microbe, the drug and the body interact. The lack of centres of excellence in pharmacology in the UK is a major problem in addressing this issue. Centres of excellence in microbiology must be re-established, but they have to be linked with pharmacology, chemistry and veterinary medicine, as well as industry and basic science.

The world is changing too. People are getting larger and yet we continue to use the same empiric drug doses that we have always used. Does the amount that was traditionally given to someone weighing 50/60kg work equally well on somebody who may be 120kg? The pharmaceutical community has not re-examined the pharmacological profile of many drugs, their penetration into critical sites of action or their use in combination therapy. Drug levels in the blood will only get us so far if the infection is in the brain or deep lung tissues. Until pharmacologists and microbiologists work together to revisit some of the chemical issues involved, I do not believe we can resolve these issues.

Then there is the question of abuse. GPs are often blamed for this, perhaps unfairly. Yet there are other areas of abuse too. In Africa and Asia and now increasingly in the West counterfeit drugs are becoming more and more common. Adequate regulation of the quality of drugs is absolutely critical. A tablet or injection with no antibiotic is terrible for the patient. For a population, a tablet or injection containing a small quantity of an antibiotic or antiviral can be even worse. Imagine a counterfeit market in anti-retroviral drugs which have 5-10 per cent of the necessary levels and what this may do for the development of drug resistance. An individual could perhaps take it for the rest of their life without knowing it was counterfeit, with it not delivering the desired effect and yet potentially encouraging the development of drug resistance.

The research agenda

The research agenda has to take centre stage. I want to pay tribute to the way this has been led by the Department of Health in the UK, but the funding agencies, including the MRC and Wellcome Trust, need to interact with the pharmaceutical industry (and across sectors, particularly agriculture and animal health) much more closely. There needs to be a pre-competitive stage where an open approach allows all targets to be assessed prior to the protection of intellectual property. Unless we get academics and industry together this logjam is not going to be removed.

Dr Jeremy Farrar FRCP FMedSci OBE is Director of the Wellcome Trust. He was previously at the Hospital for Tropical Diseases in Ho Chi Minh City, Vietnam, where he directed the Oxford University Clinical Research Unit. Over the 18 years of his tenure in Vietnam the unit grew to become a substantial centre for clinical and public health research with a science programme encompassing immunology, host and pathogen genetics, molecular biology, virology, and epidemiology.

There are also issues that relate more to social science and behaviour. There needs to be a change of behaviour in the way we seek advice and the way we seek antibiotics.

New economic models must be found. The current business model works very well for long term treatments like statins, or where the product has a high perceived value – as in oncology. However, those models will not work in an area where a drug might not be used, where it may be held back or only given to a patient for a very short period of time. This is where Government must play a role in providing the appropriate incentives for the development of new antimicrobials.

The scientific community also has to think outside of the box. There are areas of great potential which have not really excited much interest in the West yet. Phages – viruses that can kill bacteria – were studied in the old states of the Soviet Union. Yet they have been ignored more recently. We need to embrace insights that come from less conventional research. Antibodies as therapy in infectious diseases and targeted immune therapies are also areas worth further research.

Finally, the advent of antimicrobial resistance is one of the most powerful arguments for investment in future vaccines. Medical science will never stay ahead of infection – HIV, TB, malaria – if it only relies on pharmacology. At some point there will have to be vaccines for the big killer diseases.

The current pathway of regulation for new antimicrobial agents is far too difficult. Getting to the stage of proof of concept for a new agent takes too long. In addition, the use of combinations is not encouraged because of the way we regulate industry. Solutions will need action by Government, including the provision of incentives which really value this group of drugs.

International action

Our world is driven by many different imperatives, not just human health but also animal welfare, business considerations, etc. I am concerned about the World Health Organisation's ability to deliver what we need. Is a structure which was set up in the 1940s, with a different mandate and a different approach, still fit for purpose and able to deliver the cross-sectoral, intergovernmental, global solutions we need today?

The WHO's great strength is that it represents all governments, but this is also its greatest weakness. Nearly 200 countries have to agree and that often results in a totally watered-down set of principles. The International Health Regulations in principle are excellent as, if something happens in London today, it has to be reported immediately to the WHO. Yet we are now 20 months into Middle East Respiratory Syndrome (MERS) and its source is still unknown, it is not clear how many humans have been affected, the mortality rate is not clear and there is not a single systematic clinical study or randomised patient study. No vaccine is in late stage development.

We have been very lucky that this virus is only evolving slowly and has not spread like the related SARs virus did 10 years

DISCUSSION

Resources to tackle the challenge

When the HIV crisis appeared, there was a swift, energetic and concerted response to what was then an untreatable disease. An important factor contributing to the production of effective medication was the existence of a huge and relevant science base upon which to draw. The fight against AMR has no such advantage. Society will have to invest heavily to fill that void and it will need to incentivise those working in this area. Individuals and organisations are prepared to spend big money on insurance. Society should be prepared to spend good money on research to counter AMR as an insurance against a growth in the number and prevalence of untreatable diseases.

ago. We need a body with the ability to respond much more quickly to these rapidly emerging health issues whether that be the emergence of new infections or the emergence of drug resistance. Such a body needs to have global support but also needs real teeth to make the decisions that are critical in a rapidly changing environment. ❐

Taking practical steps to promote antimicrobial drug development

Patrick Vallance

The era of antibiotic drug discovery and development was really from 1930 to 1970 and the current decline started in the mid-1990s. The current challenges have been brought about by the convergence of several factors: a significant rise in the resistance of micro-organisms to antibiotics; a decrease in the number of large pharmaceutical companies working in this area; and a big drop in the number of approvals for new medicines, down from approximately 20 in 1980 to just one or two in the last couple of years.

The number of companies active in this field has reduced partly because of mergers, while the number of approvals for new medicines has decreased due to changes in regulatory procedures.

There has been a disproportionate reduction in antibiotic drug discovery and development over the past couple of decades. There are three main reasons.

First, the discovery and development process is difficult, but not impossible, and there are actions that could be taken in the area of early science to help with this.

Second, it is not easy to undertake the clinical trials needed to get an antibiotic approved – this is partly due to clinical complexity and partly to the regulatory regime.

Third, because of the restrictions on the prescribing of such medicines, there is little incentive to encourage companies to engage in such research – there is little opportunity for them to recover the costs of the significant levels of funding they put in to R&D programmes.

The science of AMR

How difficult is the science? Compared with other areas of drug development, antibiotics are roughly twice as difficult to take from the discovery of a candidate molecule through to regulatory approval (see Figure 1). For most new drugs, starting with 10 or 15 molecules that have got through to the pre-clinical stage, one of them will be approved on average for most areas. However the figure is closer to one in 30 for an antibiotic. Antibiotics discovery has a higher attrition rate than other areas.

Professor Patrick Vallance FRCP FMedSci is President, Pharmaceuticals R&D, at GSK. He is responsible for ensuring that GSK maintains a flow of potential new medicines through the R&D pipeline from early discovery through to approval. He has re-personalised GSK's Drug Discovery activities by setting up small, empowered teams, called Discovery Performance Units, to drive the success of potential new medicines in the pipeline. Prior to joining GSK from academia he led the Division of Medicine at University College London.

It is possible to find genes which are essential for the life of the microorganism, but while many antimicrobial targets can be identified it is hard to find good leads i.e. identifying chemicals which work against these targets. Between 1995 and 2001, GSK ran 70 so-called 'high throughput screens' (in which large numbers of compounds are screened to come up with a lead that might turn into a medicine). The success rate for antibiotics was only around 7 per cent (which appears similar to the success rate for other companies). In other therapy areas, the chance of ending up with a lead can be as high as 70-80 per cent.

It is particularly challenging to find leads against 'Gram-negative' bacteria, which represent a major problem at the moment. Gram-negatives can have up to three barriers to antibiotics – the outer membrane, the cell wall and the inner membrane – and furthermore they are extremely good at getting rid of chemicals. They live in toxic chemical environments; they are designed to kick chemicals out. It is incredibly difficult to get something into them that stays in.

A further constraint is the high level of an antimicrobial drug we need to get into the blood of somebody with an infection in order to kill bacteria. Because such massive amounts are being employed, there are much greater 'off-target effects'. That dramatically increases the potential failure rate due to potential toxicity at every stage of development – it is much higher than in other areas. It becomes very difficult to develop a medicine without it also being toxic.

Trials

Once the scientific problem of making a drug has been overcome, there remains the question of how to prove, in the clinic, that it is valuable. Clinical investigations in this field are very complex. The number of experienced clinical development teams that any company can budget for across all its therapy areas is limited. The fact that the antibiotic area is also a very small area of development means that there are even fewer clinical teams able to operate in this field. The industry needs to look more closely at how it makes the most efficient use of resources here.

Even if the right clinical research team is available and ready to do such studies, the number of hospitals set up to carry out

DISCUSSION

Human and animal regimes

The laxer regulatory environment for the use of antibiotics in animals, both as treatments and as productivity boosters, is indefensible. Much greater effort is needed to persuade vets and farmers and the food industry to be less profligate. Some may argue that the evidence of causal links of harm to humans is not yet conclusive. But the test required for drugs administered to humans is that they should be demonstrably safe. That test should apply also to the use of antibiotics in animals.

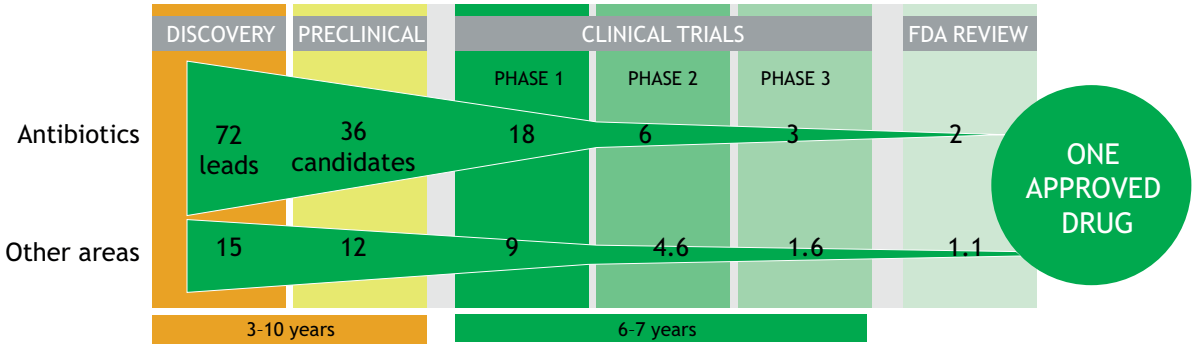


Figure 1. Drug development paths for antibiotics and other classes.

antibiotic trials is limited.

It is difficult to find the right investigators, it is difficult to identify the right patients, and it is difficult to get those trials actually done.

As an example: to test a drug on a resistant form of *Streptococcus pneumoniae*, around 1,000 patients would have to be signed up under the current arrangements in order to end up with 39 who are infected with the resistant strain. If a rapid and accurate diagnostic test was available it would reduce that number, then costs could also be dramatically reduced. Such a test would change not only clinical practice, but also the ability to make a new medicine.

Finally, on the clinical side there is the regulatory process. The application of standard regulatory processes to the assessment of an antibiotic adds a massive hurdle and a huge disincentive: hence it is very difficult to get any new AMR drug approved. The standard approach of the regulatory authorities is to do one thing at a time and to prove that thing works. A new approach is needed for antimicrobials.

It may be for example that a drug does not work well on its own, but it works very well (or needs to be used) in combination with other drugs. The current regulatory system is geared against that.

Having said that, the US Food and Drug Administration (FDA) and the European Regulatory Authorities (EMA) acknowledge this is a problem, and they are making efforts to make things easier.

Harmonisation

The pharmaceutical industry is the most regulated in the world. While the airline industry is also heavily regulated, there is one set of rules across the globe for the airline industry. We have multiple different sets of regulatory requirements at the national level for what is a global problem. So the harmonisation of the regulatory process is a key priority.

It is a major disincentive to have diversified regulatory processes. The regulators understand this and want to work towards some sort of harmonisation.

Another issue concerns return on investment. GSK has spent in the order of a billion dollars in the last nine years on antibiotic drug discovery and development. At some point, there has to be some accounting to our shareholders for that expenditure.

What does the practising clinician, or indeed a member of the public, want? Both want an antibiotic that is effective against these difficult bugs. But to help prevent the growth of resistance, they do not want it widely used. Furthermore, people do not like taking a long course of antibiotic treatment so if it is to be used, then it should be for a more appropriate course, which should normally be days rather than weeks. That causes a big problem for the developer.

One billion dollars has been spent to make a drug which no-one wants to use! The patent clock started ticking a long time ago and has now expired. A generic company can come along and copy it. Why would a company invest on that basis?

Society therefore has to come up with incentives to encourage companies to invest in this area and to see a return on that investment.

Current initiatives

There are however some interesting initiatives taking place. There are a number of potential new antimicrobials in the pipeline, although most of them are not new classes of drug and are in the early phase of clinical development, so many may not make it through to approval. Some new classes of antimicrobials are starting to enter companies' pipelines – with many of them arising from the laboratories of smaller companies who seek to partner with larger pharma companies for their development. But we do need to develop more.

There are new incentives in this field, particularly in the USA. Both the Biomedical Advanced Research and Development Authority (BARDA) and the Defense Threat Reduction Agency (DTRA) initiatives have provided significant sums of co-funding to support companies in their discovery and development of new antimicrobial drugs. The ability to 'piggy-back' antimicrobial research funding applications onto defence applications is providing an incentive.

The EU public-private partnership – the Innovative Medicines Initiative (IMI) – has a number of projects running across Europe under the 'New Drugs for Bad Bugs' programme. Collaborative research is taking place on how to stop bacteria kicking out drugs, as well as the development of new commercial models and the establishment of clinical trial networks. In the USA, the President's Council of Science and Technology (PCAST) has prepared a report on AMR which includes a recommendation to study the need for incentives and new commercial approaches for antibacterials. The UK government is committed to addressing the issue as part of its five-year strategic plan and other groups such as WHO, Chatham House and Brookings Institute are working and encouraging debate.

While it is true there are incentives needed at one end of the process, there are some things that can be done at the other end too, at the beginning. One is to move away from a traditional view of what constitutes a microbial target. There should be some attention given to other aspects of the process, including post-targets: how do humans respond to infections and can defences be boosted as a way of treating infections? Antibodies, vaccines and bacteriophages all offer new opportunities for fighting infection.

There is an opportunity in the UK to bring academics together with industry, perhaps through establishing a centre of excellence. That would allow interested groups to stay abreast of the latest developments, to set new targets and make it easier for companies to come in and make medicines.

There are a number of practical initiatives that could help us make the most of opportunities in the UK and I know that many in academia share that view. ☐

While the reality of anthropogenic climate change is acknowledged by the large majority of scientists, it is not universally accepted. A meeting of the Foundation for Science and Technology on 16 June 2014 provided a neutral venue in which both sides could engage in debate.

To act now or to wait?

Debate and disagreement about climate change continue in our society, even though a substantial majority of scientists and politicians agree with the Intergovernmental Panel on Climate Change (IPCC) that anthropogenic actions will be a major influence on the changes to climate which are forecast.

A special meeting of the Foundation, held at the request of Sir Mark Walport, the Government's Chief Scientific Adviser, brought together four individuals, each with substantial experience in the fields of science, politics and economics but representing different aspects of the debate. The speakers at the debate were: Sir Mark Walport; David Davies, MP for Monmouth; Professor Jim Skea, a member of Working Group III of the IPCC and of the Committee on Climate Change; and Peter Lilley, MP for Hitchin and Harpenden and a former Cabinet Minister.

Opening the debate, the Foundation Chairman, the Earl of Selborne, welcomed the opportunity to provide a neutral platform for both sides to come together. He expressed the hope that the debate would help to identify common ground between the speakers.

Climate change

While none of the participants doubted that climate change was happening, David Davies argued that natural variability in the earth's climate meant we could not be sure the current changes were due to human activity. Sir Mark Walport, on the other hand, citing the latest evidence compiled by the IPCC, stressed that greenhouse gas emissions from human activity – and in particular carbon dioxide and methane – were changing the concentration of greenhouse gases in the atmosphere and leading to a warming of the planet. While it is not possible to accurately predict the regional effects of that warming, most effects are likely to be negative.

It is, he said, vital to try to limit global greenhouse gas emissions in order to keep average global temperature rise to 2°C or less. For this, international agreement and action will be crucial.

Jim Skea noted that while more than 190 countries have signed up to the UN goal of keeping temperature increase below 2°C, achieving this target would mean cutting global emissions (compared to 2010 levels) by 40-70 per cent before the middle of the century. This would entail a change in global investment priorities away from fossil fuels towards other energy supply options and efficiency targets.

Climate change is a global problem and dealing with it is a common responsibility, he reminded the meeting.

The economic aspects

Peter Lilley focussed on the economic consequences flowing from policy choices on climate change. Drawing on his earlier experience as a development economist working in Africa, he told the meeting that his principal worry was the impact that 'prematurely decarbonising' the world economy would have on the poor, who spent a disproportionate amount of disposable income on energy.

All the speakers were in agreement that transparency about the data, the statistical methods and the models used was crucial for an informed and productive debate between the different interested parties in this debate.

In the discussion following the formal presentations, the value and forecasting accuracy of the available climate models – and the accuracy of the resulting forecasts – was discussed. Judging long term trends from time series with large short-term variability is challenging. However, the observation was made that the models are only part of the body of evidence for climate change catalogued by the IPCC and others. A reliance on small data sets or observations made over a short period is likely to confuse the picture; hence the aggregation by the IPCC of a wealth of observations from many different parts of the globe and over as long a timespan as possible.

In concluding, the speakers agreed to differ on whether Government should press ahead in the short term with adaptation or mitigation policies in response to climate change. However, one young member of the audience – and after all it is this generation that is likely to face the real impact of any change – urged the speakers to try to search out common ground. □

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

What is the right level of response to anthropogenic-induced climate change?

16 June 2014

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

Making the most of UK/China research and innovation partnerships

11 June 2014

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

Responding to the rapid increase of Antimicrobial Resistance (AMR) in organisms

4 June 2014

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

Delivering the Agri-tech Strategy - improving the quality and productivity of the UK food production and processing sectors

21 May 2014

George Freeman, MP for Mid-Norfolk, House of Commons
Dr Peter Bonfield OBE FREng, Independent Chair, British Food Plan, Defra and Chief Executive, BRE Group
Lord Haskins, Former Chairman Northern Foods, and House of Lords
Dr Stephen Axford, Head of Agri-tech Strategy (*panellist*)

Policy choices for the reduction of bovine tuberculosis (TB)

2 April 2014

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

Turning knowledge into value - adding value to the marine sector from research and innovation

10 March 2014

Professor Ralph Rayner, Sector Director Energy and Environment, BMT Group
Professor Ed Hill OBE, Executive Director, National Oceanography Centre
Professor Rick Spinrad, Chief Scientist, National Oceanic and Atmospheric Administration (NOAA), President-Elect, Marine Technology Society
Professor Richard Clegg, Managing Director, Lloyd's Register Foundation (*panellist*)

The challenge of communicating the uncertainty in risk estimates to decision makers

5 February 2014

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

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

27 November 2013

Dr James Smith CBE, Chairman, The Carbon Trust
Dr David Clarke FREng, Chief Executive, Energy Technologies Institute
Baroness Verma, Parliamentary Under-Secretary, Department for Energy and Climate Change
Sir David King KB ScD FRS HonFREng, Foreign Secretary's Special Representative for Climate Change, Foreign and Commonwealth Office (*round-table discussion*)
Ian Simm, Chief Executive, Impax Asset Management (*round-table discussion*)
Dr Bernie Bulkin, Director, Ludgate Investments Limited (*round-table discussion*)

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

13 November 2013

Sir John O'Reilly FREng, Director General, Knowledge and Innovation, Department for Business, Innovation and Skills
Ben Ritchie, Senior Investment Manager, Pan-European Equity, Aberdeen Asset Management
Professor Geoff Rodgers, Pro-Vice-Chancellor for Research, Brunel University

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

31 October 2013

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

Improving the career paths for MSc and PhD students, and postdocs

17 October 2013

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

Cyber security: how secure are UK organisations from cyber theft of IP?

16 October 2013

Chief Scientific Adviser, Centre for the Protection of National Infrastructure (CPNI)
Hugh Eaton OBE, National Security Director, Cisco UK
Professor John V McCanny CBE FRS FREng, Director, Institute of Electronics Communications and Information Technology, Queen's University Belfast

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

24 September 2013

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

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

10 July 2013

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

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

3 July 2013

Professor Colin Riordan FLSW, President and Vice-Chancellor, Cardiff University
Sir Leszek Borysiewicz FRS FRCP FMedSci FLSW, Vice-Chancellor, University of Cambridge
Sir Terry Matthews OBE FREng, Chairman, Wesley Clover
Edwina Hart MBE CStJ AM, Minister for Economy, Science and Transport, Welsh Government

Cities of the future - science, innovation and city management

19 June 2013

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

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

22 May 2013

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

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

16 April 2013

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

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

6 March 2013

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

Threats and opportunities - scientific challenges of the 21st Century

6 February 2013

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

Lecture (Science, Innovation and International Development) and Christmas Reception

5 December 2012

Professor Chris Whitty FMedSci FRCP FFPH, Chief Scientific Adviser, Department for International Development
Mme Geneviève Fioraso, Secretary of State for Higher Education and Research, Government of France (Professor Cyrille van Effenterre from the French Embassy spoke on behalf of the Minister)

The contribution of mid-sized companies to growth of the economy

26 November 2012

Dame Nancy Rothwell DBE FRS FMedSci, President and Vice-Chancellor, University of Manchester
Tera Allas, Director General for Economics, Strategy and Better Regulation, Department for Business, Innovation and Skills
Professor Luke Georghiou, Vice-President for Research and Innovation, University of Manchester
Richard Burslem, Site Director, Wallwork Heat Treatment Ltd

Delivering the industrial strategy - how can government promote growth?

14 November 2012

Sir John Parker GBE FREng, President, The Royal Academy of Engineering
Professor Alan Hughes, Director, Centre for Business Research, Judge Business School, University of Cambridge
The Rt Hon David Willetts MP, Minister of State for Universities and Science, Department for Business, Innovation and Skills

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