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THE FOUNDATION FOR SCIENCE AND TECHNOLOGY

COUNCIL

THE FOUNDATION FOR SCIENCE AND TECHNOLOGY

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Simplification call for collaboration

Government needs to simplify the plethora of schemes aiming to facilitate business-industry research collaboration across all disciplines, according to a new review published by Professor Dame Ann Dowling DBE FREng FRS, President of the Royal Academy of Engineering.

The report was commissioned by the Department for Business, Innovation and Skills (BIS) and compiled after regional meetings, workshops and over 210 written submissions of evidence from both academia and industry.

In it, Dame Ann says the complexity of the existing support mechanisms creates frustration and confusion and means the UK is not reaping the full potential of its opportunity to connect businesses - both domestic and international - with the excellent research being done in UK universities.

There are two approaches to streamlining the system, according to Dame Ann: reducing the overall number of schemes or simplifying the interface between the user and the scheme. She recommends that Government does both.

www.raeng.org.uk/policy/dowling-review

The Foundation will be holding a debate on the Dowling Report in the autumn.

Education pathway for apprentices

The Catalyst Fund set up by the Higher Education Funding Council for England (HEFCE) is supporting the University of Sheffield's Advanced Manufacturing Research Centre to develop a new education pathway for apprentices to continue their studies through foundation, bachelor and masters level.

The fund commits up to £45 million annually. This money aims to drive innovation in the HE sector, enhance excellence and efficiency in Higher Education, and support innovative solutions. Funded projects will normally be collaborative, bringing together support from other partners including business, universities and colleges, and other public agencies.

Science is vital for improved productivity

Productivity is the single most important determinant of average living standards and is tightly linked to the differences in wages across countries, according to a plan published jointly by the Treasury and the Department of Business, Innovation and Skills (BIS). "In every member country of the Organisation for Economic Co-operation and Development (OECD) where average wages are above UK levels, productivity is also higher," it continues.

The plan, entitled *Fixing the foundations: creating a more prosperous nation*, is a response to the recent slowdown of productivity growth in the UK and to the long-standing gap compared to other countries. "The drivers of productivity are well understood: a dynamic, open enterprising economy supported by long-term public and private investment in infrastructure, skills and science," it says.

The plan recognises that the science base is a vital national asset. It argues that the UK needs new ideas that are used as widely as possible. In order to help achieve this, the Government will deliver on its science capital commitment, investing £6.9 billion in the UK's research infrastructure up to 2021. It will ensure the UK science has a focus on those areas with greatest potential, from genetics to quantum technology, and has asked Sir Paul Nurse to lead an independent review on how best to make these strategic choices. It will look for opportunities to develop the UK's network of Catapult centres for commercialising technology. It will also support universities in collaborating with industry and commercialising research, responding to Professor Dame Ann Dowling's review.

www.gov.uk/government/publications/fixing-the-foundations-creating-a-more-prosperous-nation

Government promotes 'One Nation' science

The Government is to take a new approach to research funding, one which in the words of Science Minister Jo Johnson, "promotes and protects our reputation for world-class science, and also drives growth and raises productivity for the whole of the UK".

Speaking at the University of Sheffield's Advanced Manufacturing Research Centre, the minister noted that "at present, 46% of public investment in research goes to the Golden Triangle. This reflects the strength of internationally-renowned universities in London, Oxford and Cambridge."

He added, though, that "other parts of the country have proven research excellence in their universities and [we have to] ensure we fund excellence wherever it is found in order to realise the productivity gains that we have seen in the Golden Triangle". The Government will therefore "recognise and reward excellent research proposals that reflect local strengths and leverage local funds".

https://www.gov.uk/government/speeches/one-nation-science

Funders review public attitudes to research

The top 15 funders of publicly funded research in the UK, including the Royal Society, the Wellcome Trust and Research Councils UK, are working together in a consortium to review the current state of public engagement with research within higher education, research institutes and clinical settings across the UK.

The consortium has commissioned a research company to carry out an attitudinal survey of researchers, and those working in a public engagement-enabler role, along with in-depth phone interviews.

The work will focus on developing a robust evidence base around the understanding of, and participation in, public engagement with research. The survey will build on the Royal Society Survey of factors affecting science communication from 2006, to ascertain changes in the sector since then and to provide a benchmark for future developments. It will include all academic disciplines with a view to highlighting the importance of public engagement and learning how to overcome barriers to it.

www.royalsociety.org/news/2015/06/public-engagement-survey

Science and technology in a successful economy

Patrick Jenkin

In my role as Chairman of the Foundation from 1997 to 2006, I had the great privilege of leading it during a revival of public interest in science and technology. 'Science and Society' was the title given to an enquiry by the House of Lords Select Committee on Science and Technology, one which I was honoured to Chair.

I am not a scientist, but as a layman I have never doubted the importance of scientific research – and of its translation into industrial and commercial applications for the economy of the UK. I have been flattered to have been told that many people regard Science and Society as one of the more important reports by Parliament in the last two decades.

Last month's general election outcome astonished most of the media as well as many political pundits, few of whom had remotely contemplated an overall Conservative majority in the House of Commons. There has been some criticism of how little science figured in the campaigns of the parties and in the welter of comment that has followed. So I have written this editorial in the form of a letter to the Chancellor of the Exchequer, the Right Honourable George Osborne MP.

Dear Chancellor,

"The election victory and your return to No 11 Downing Street have given you the opportunity to reaffirm the Government's commitment to scientific research and innovation. The former Minister for Science, the Rt Hon David Willetts, made a huge contribution in these areas and I for one hope that his voice will continue to be heard in the councils of the nation. Not the least of his successes was in persuading the Treasury, early in the last Government, of the case for supporting scientific research. In the emergency Budget of 2010, the programme was substantially protected from the severe public expenditure cuts that had become essential to restore the UK's finances to health.

"In your second 2015 Budget on 8 July you singled out productivity as the great economic challenge in ensuring that Britain becomes the most prosperous major economy in the world by the 2030s. The purpose of this letter is to underline the cardinal importance of sustaining and indeed enhancing the UK's programme of scientific research and innovation, despite the further cuts that are necessary in public expenditure.

"In the foreword to the paper that you and the Business Secretary published on 10 July, entitled *Fixing the foundations: Creating a more prosperous nation*[1], you note that the drivers of productivity are 'a dynamic, open enterprising economy supported by long-term public and private investment in infrastructure, skills and science'.

"It is widely recognised and applauded that the UK has a record of scientific achievement second only to that of the USA. It is because of this that our universities attract able scientists and engineers from all over the world.

"The Royal Society and other national academies[2] have been making a case for Government and business to spend 2 per cent of GDP on scientific research and innovation. May I suggest to you that it is *imperative* that the Government listens to that case and responds appropriately?

"There is, too, another point that needs to be made: the UK has for many years recognised the value of the so-called Haldane Principle – namely, that the actual programmes for research and innovation should primarily be determined by the scientific community itself, and not by Ministers. Of course governments will have their priorities but again, in my view, the balance between top-down prioritisation by Ministers and allowing the research community to identify what should be supported must be sustained. One of my quarrels with the scientific activities of the EU is that neither the Commission nor the European Parliament appear to pay any regard to this principle. I note that this is one of the challenges you address in your paper on productivity and you refer to the review that Sir Paul Nurse is currently undertaking on the work of the Research Councils.

"The Haldane Principle depends upon continuing public support for science and scientific research. Indeed, it was the central theme of my Science and Society report[3] that there needs to be a continuing and expanding effort by the scientific community to engage with the public in order to secure that support. Engagement was our key recommendation and this involves, of course, a dialogue. I have been delighted, as have many others, by the significant efforts most scientific bodies and

The Rt Hon the Lord Jenkin of Roding retired from the role of President of The Foundation for Science and Technology at the AGM in May. Prior to that, he was the Foundation's Chairman from 1997-2006. Patrick Jenkin was elected Member of Parliament for Wanstead and Woodford in 1964 and he remained an MP until 1987 when he was appointed to the House of Lords. He was Secretary of State for Social Services from 1979-81, for Industry from 1981-83, and for the Environment from 83-85. He served as a member of the House of Lords Science and Technology Select Committee and during that time chaired the enquiry into Science and Society that reported in 2000.

The current Chairman of the Foundation, The Earl of Selborne, thanks his predecessor The Rt Hon the Lord Jenkin of Roding for his service as Chairman and President of the Foundation on his retirement at the AGM this year.

many thousands of individual scientists and engineers have been making to realise that key recommendation. I hope you and other Ministers will continue to support those efforts.

"There are other important policy issues. One of the most urgent is that the success of our research base and of our research achievements should be translated – creating products and services which are marketed across the world. Innovate UK and its support of the network of Catapult centres must continue to be promoted and supported by the Government.

"Another challenge is to increase the supply of people with STEM skills – Science, Technology, Engineering and Mathematics. It is a matter of dismay that, despite the efforts of Ministers and of many in engineering, the proportion of students entering university to read STEM subjects has remained almost constant over the last decade. The UK must redouble its efforts to improve the ratio. It is particularly important that there should be more women who are attracted to careers in engineering. They are very prominent in medicine and other biosciences; this now needs to spread to physics and other scientific disciplines.

"There is too, I believe, a need to rebuild the relationship between science and Parliament. I joined the Parliamentary & Scientific Committee as soon as I entered the House of Commons in 1964: I soon found myself debating issues in the House where science was relevant. In several of my appointments, both on the Opposition Front Bench and in Government, I found the meetings of that Committee a very useful source of inspiration, information and guidance. I was also able to establish relationships with individual scientists and engineers, some of which have endured for many years.

"When I was elected President of the 'P&Sci' a few years ago, I was disappointed by the relatively few members of the Commons who attended our meetings – there were usually more peers than MPs. It has long been recognised in scientific circles that few people with real scientific experience get elected to the House of Commons. In contrast, though, the current system for the appointment of peers to the House of Lords ensures that those benches contain some of the most distinguished scientists and engineers in the country.

"In my view, there needs to be a much greater awareness by elected Parliamentarians of the huge importance to our nation's future of the scientific research and innovation undertaken in the universities and in industry, much of it inspired and financed by the Research Councils. Of course, the Select Committees on Science and Technology in both Houses do very valuable work and this is to be applauded. Yet there is no doubt that the work of the Parliamentary and Scientific Committee and of the other All-Party Groups covering specialist scientific subjects must spread their influence more widely in both Houses.

"Before I end, Chancellor, may I say a few words about The Foundation for Science and Technology? A former Chief Scientific Adviser, Sir David King FRS, told me after a particularly successful evening's debate, that if the Foundation did not exist, it would have to be invented! Our role in promoting debate among our influential audiences about a huge range of scientific, engineering and medical research policy questions remains as important as ever.

"Our Chief Executive, Dr Dougal Goodman OBE FREng, has been very successful in persuading Ministers to take part in these debates and make key speeches to the Foundation's audiences. David Willetts was a regular speaker; Dougal has invited his successor, Jo Johnson MP, to participate and indeed hopes many other new Ministers will agree to speak at debates. David assured me that he found his frequent attendances at our events among the most valuable engagements he undertook.

"The Budget statement spells out priorities for continuing the process of restoring the UK economy to a proper balance between spending on public services, cutting taxation, and the promotion of economic growth. The Plan for Productivity makes the connection, rightly in my view, that the creation and application of new ideas is critical for long-run productivity growth. With continued support from Government, I am confident that our universities, colleges and businesses will play their full part in delivering the increase we all seek."

Yours ever, Patrick Jenkin ❑

1. Fixing the foundations: Creating a more prosperous nation www.gov.uk/government/publications/fixing-the-foundations-creating-a-more-prosperous-nation
2. Making the UK the best place for research and innovation www.raeng.org.uk/news/news-releases/2015/february/making-the-uk-the-best-place-to-do-research-and-in
3. Science and Society, Select Committee Report www.publications.parliament.uk/pa/ld199900/ldselect/ldsctech/38/3801.htm

The recent Ebola outbreak in West Africa raised a number of serious questions about the way in which national and international communities respond to such epidemics. A meeting of the Foundation on 25 March 2015 considered some of the lessons that could be learned.

An integrated campaign around a focussed target

Christopher Whitty

SUMMARY

- Ebola is probably the most serious new infectious threat since the emergence of HIV.
- Panic threatened to disrupt an effective response.
- A decision was made to take a single, strategic focus: to get R_0 below 1.
- Healthcare workers bore the brunt of the disease.
- The systematic UK response, across the whole of Government, the Wellcome Trust and also NGOs, was crucial.

Much of the damage that Ebola has done to poor people around the world has been due to panic. The damage is quite disproportionate to the number of people who have died from it. Indeed, many of those who died in the Ebola outbreak did not perish directly from Ebola but rather because health services broke down.

This epidemic started in December 2013 and there was a justifiable gap before it was first picked up. There was then a period between April and August 2014 when it was being discussed but little happened. This was a serious failure of the international public health system in a number of ways. It is important not to point the finger at individuals, but institutions need to look seriously at this failure.

One of the problems we have currently about the Ebola epidemic is that some people are drawing conclusions because it fits their narrative. As an example, some are saying the problem was insufficient surveillance in Sierra Leone. In reality, the disease was identified as Ebola in West Africa at an early stage. The challenge lay in the correct interpretation of the epidemiology, the division of responsibility between several multilateral agencies and insufficient international will to assist in tackling transmission mechanisms.

We must draw the correct conclusions about aspects that did not go so well.

By August 2014 there was a wide realisation, not just in the countries involved but also in the World Health Organisation (WHO), the UK and the USA, that this outbreak was potentially catastrophic for the region. The disease was compounding up: in many of the countries affected, the number of cases was doubling around every 30 days. Although the numbers were quite small at this stage, the compounding effect threatened very serious numbers indeed. They were guaranteed to overwhelm local health services.

Once a response started, however, many things were well done and we can learn some positive lessons. The UK took a lead responsibility to support the government of Sierra Leone. There was a very good interaction between all the relevant UK Government Departments. There was also a good link-up with the academic community. The Wellcome Trust took a major leadership role, as did the Medical Research Council (MRC). Then there was the extraordinary courage of doctors, nurses and administrators from this country who engaged in something that was not their fight and involved considerable personal risk. It should also be remembered, however, that the heaviest burden, by a long way, fell on West African doctors and nurses and a large number died.

The R_0 strategy

A decision was reached in the UK, jointly with the civil and military responders in Sierra Leone, to take a single, strategic focus: to get R_0 below 1. R_0 is a very simple concept. If R_0 is 1, then on

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One of the problems we have currently about the Ebola epidemic is that some people are drawing conclusions because it fits their narrative.

Local burials involve washing and touching the bodies. Burying somebody safely is fairly easy, medically: the difficulty lies in doing it in a way that is socially acceptable to the family.

average one person gives a disease to one other individual and the disease is stable in the population: it flatlines. Above 1, it keeps compounding up. Below 1, it will die out.

R_0 was between 1 and 2 in August. Our view was that this would continue increasing to the point where it overwhelmed everything and the health service would then fail. So the priority was to get R_0 below 1. We decided to do this by supporting the government of Sierra Leone in four ways.

There were two forms of transmission that were crucial in previous epidemics – hospital transmission and burials – due to people touching bodies which were highly infectious. This is very different from, say, flu. So the first target was to reduce transmission in hospitals, while the second was to make burials safe.

Local burials involve washing and touching the bodies. Burying somebody safely is fairly easy, medically: the difficulty lies in doing it in a way that is socially acceptable to the family. We also discovered that this is not just about the burial itself. There was a great tradition of senior people being surrounded by their friends and family on their death bed. Crucial insights were put forward by anthropologists and we were very fortunate to have that support; integrating anthropological sciences with epidemiology for epidemics was one of the things we can learn positively from.

New methods needed

Another priority was to reduce transmission in the community. In previous Ebola epidemics there has been some transmission out of healthcare settings and burials, but this has been small enough in numbers that the sufferers could be located – everyone who had been contacted could then be tracked and isolated. Here, the numbers were far too large for this strategy to work and new methods had to be found.

We needed to shorten the interval between first symptoms (when people become infectious) and the point at which they either died or recovered. People were very afraid, though – and with reason – to come to healthcare centres. In addition, Ebola's early stages are just like any other infection: fever, headache, feeling generally unwell, maybe with some diarrhoea. That is the same as malaria, flu, dysentery and many other conditions. Most people in the poor areas of Sierra Leone would get such illnesses several times a year, so it would not be possible to isolate everyone with these symptoms.

How to bring those people to isolation? It could not be through active case-finding; there were just too many of them. Some method had to found where people were incentivised to come and be isolated – i.e. passive case-finding. That may sound a trivial undertaking, but it was very difficult indeed. The decision was made to establish community care centres – isolation facilities for sick people out in the community. The idea was to reduce the distance people had to travel in order to access care. It is too early to be sure how successful this was and we need to learn from the successes and failures of this approach.

Finally, there were a number of measures designed to increase 'social distancing' – making people less liable to congregate and come into contact with others. Some were uncontentious: people do not shake hands in Sierra Leone at the moment. Others clearly came at a cost to society: closing schools, closing transport, closing markets, cancelling Christmas celebrations. The impact on Sierra Leone of six months of no education for any child in the country was certainly not trivial. It is not clear what impact these measures had on the disease, but we implemented them anyway; we need to learn whether we over-engineered this.

Healthcare

Healthcare workers bore the brunt of the disease. One of the lessons we need to test is whether Ebola epidemics could be halted almost before they have taken off if healthcare workers can be protected by, say, a vaccine.

The courage of healthcare workers who went into this environment was very considerable.

Nigeria, Mali and Senegal managed, with some warning, to control the Ebola epidemic extraordinarily quickly. There was a great deal of panic about how this was going to roll across the UK and USA. Yet these are three African countries, with challenged healthcare systems, which were able to kill off the epidemic very quickly by identifying the early cases and isolating them.

In responding to the epidemic in the main countries, the biggest problem was that there was an overwhelming need to respond fast before the epidemic got to uncontrollable levels, but if half-trained healthcare workers were thrown into poorly designed and half-built

environments, many of them would die. That was the stark reality and there was a serious tension between the need for speed and the need for safety. Initial incidence of Ebola in healthcare workers indicated that roughly 10% per person year of healthcare workers would catch Ebola and over 70% at that stage would die.

Training and building

So there was a significant period of training and building. The result was, therefore, that between the beginning of August and the time medical intervention started to make an impact, infection levels kept rising – as we knew they would. That was the planning assumption, but there was enormous pressure from the media, local politicians and others to "do something".

The modelling really helped because it was clear that R_0, the key metric, was steadily going down even as the numbers went up. So this was a very, very difficult period and the way we got through it provides some of the more positive lessons.

R_0 modelling was extremely important for day-to-day operations. A decision was made only to support operations and research that would help get R_0 below 1. So support was provided to modelling, anthropology, vaccines and diagnostics as these were considered critical to the central mission. Clinical trials were not carried out, because the capacity to do both simultaneously was just not there. The Wellcome Trust took a great leadership role in this area.

That stance was relaxed later, once it became clear that R_0 was below 1, but we were very focussed in our first period of intervention. However, speaking as a scientist, I believe the clinical research that was carried out was far too slow. I am not talking about vaccines here, but the clinical response around simple but essential questions like "what works in fluids", "what works in antibiotics". This was very disappointing, particularly from the UK which has some of the best clinical researchers in the world who are very good at working in tropical and low-resource environments.

Lessons learned

There are lessons to be drawn from things that went well and that is important: the courage of the volunteers, both African and international, was quite extraordinary. These were people who had not been planning to take part, they were not in uniformed services, yet they were prepared to put their lives seriously at risk to deal with a global public health problem for people they had never met before and never would again.

The integration of different sciences – epidemiology, modelling, anthropology, water and sanitation, as well as clinical sciences – was excellent, particularly in terms of the UK response.

The systematic UK response, across the whole of Government, the Wellcome Trust and also NGOs, was crucial. The clear, strategic focus on one thing – R_0 – was the right thing to do: I am confident there would have been a muddled response otherwise. The armed forces did a heroic job in terms of integrating around epidemiology and working with their Sierra Leone colleagues, who are also fantastic.

The Safe Burial Teams were a great success and worked really well. The integration of different sciences – epidemiology, modelling, anthropology, water and sanitation, as well as clinical sciences – was excellent, particularly in terms of the UK response.

Rapid vaccine response

I also think it was extraordinary that Ebola vaccines got through Phase 1 studies so quickly. Once the world had woken up to the fact that there was a problem, it worked at a phenomenally rapid speed.

Some things went considerably less well. The major issue was the delay from April to August 2014: no one would dispute that. The questions are then "why?" and "what do we do about it?" With the benefit of hindsight, the fact that Ebola vaccines were not through the Phase 1, early clinical, safety studies and on the shelf was a mistake. We need to make sure that this does not happen again.

In some countries, although not Sierra Leone nor the UK, hysteria was allowed to trump public health, with some very regrettable results.

Finally we need to be careful not to draw lessons from Ebola for subsequent epidemics that may have very different characteristics. If the virus had been airborne; if R_0 were significantly higher; if (like influenza) the risk from dead bodies was much smaller, then the methods used here would have had very different results. Some lessons, like the failure to respond early enough, are generic to any major epidemic, some will be specific to diseases similar to Ebola. ❐

Speaking as a scientist, I believe the clinical response around simple but essential questions like "what works in fluids", "what works in antibiotics" was far too slow.

Learning the lessons of the Ebola outbreak

Ripley Ballou

Dr W. Ripley Ballou is Vice President and Head, Clinical Research and Translational Science, Vaccine Discovery and Development at GSK Vaccines. Previously he served as Deputy Director for Vaccines, Infectious Diseases Development and Global Health at the Bill & Melinda Gates Foundation. He is an expert in vaccine development and has worked in this field for more than 25 years.

SUMMARY

- New ways of working together are needed.
- The Ebola outbreak shows what can be done.
- Modelling is useful but not definitive.
- Governments must provide risk mitigation for the industry.
- We must seize the opportunity that is presented to us.

GSK was not working on an Ebola vaccine before May 2013 when it acquired Okairos, a small Italian/Swiss biotech firm which happened to be working with the US National Institutes of Health (NIH) on a vaccine candidate. A series of studies in non-human primates suggested that a single dose of the vaccine could completely protect such animals from a lethal challenge.

Prior to August 2014, the World Health Organisation (WHO) had no policy on the potential use of experimental or licensed vaccines to control Ebola outbreaks. In August 2014, when the public health emergency was recognised, the situation changed: WHO and industry entered into a dialogue about how to accelerate the development of vaccines that were in advanced preclinical development.

The power of partnership

The creation and development of an effective Ebola vaccine could not have been achieved by industry alone. In August, when WHO declared the Ebola health emergency, we were asked what was needed to accelerate vaccine development. We already had a draft plan: if we got the go-ahead, we generally knew what we could do and in what timeframe. In a matter of days, we were able to put forward a plan to run a series of clinical trials. There was a tremendous response from the US Food and Drugs Administration (FDA).

The original NIH timetable was to submit an Investigational New Drug (IND) application in December with the first trial to start in March 2015. In fact, the IND was submitted on 1 September and it was reviewed in 48 hours – that has never happened before in my experience. So that allowed the first clinical trial to start in early September at the NIH.

The NIH were able to supply vaccine vials to Oxford to start studies which could then be expanded to Geneva. We also sent the vaccine to Mali so that we could get data from West Africa.

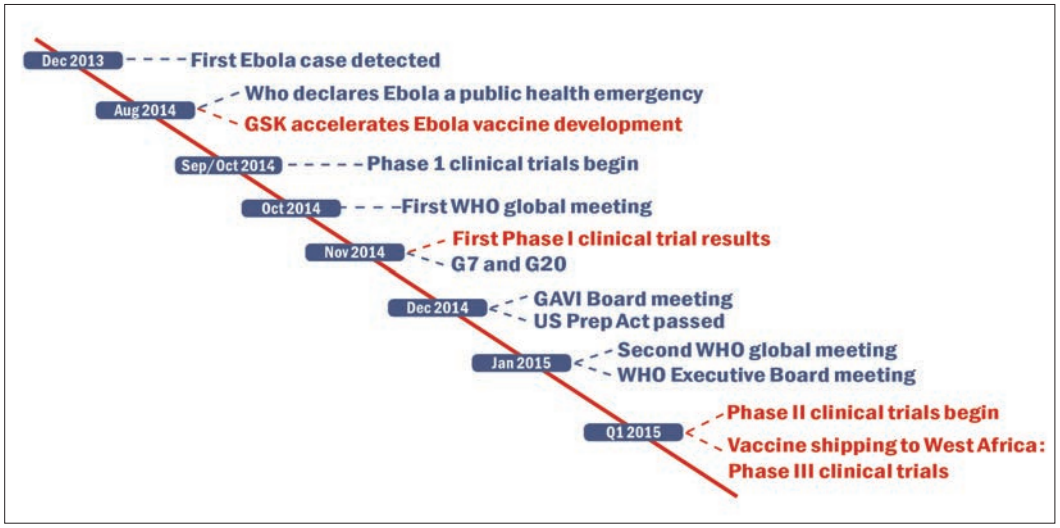
By November, we had assembled initial safety data and the immune responses we were seeing were very promising. In fact, by the first week in January, it was possible to say: "This is the dose for the Phase 3 protocols." The process to develop the protocols included work with the NIH, Centres for Disease Control and Prevention (CDC) as well as WHO. In parallel, a range of people that were working on other projects were asked instead to focus on learning how to make this Ebola vaccine. This was a new platform technology for GSK, with 175 people who are still working on how to make large numbers of these doses. This is what it took to be able to go to Liberia and start a Phase 3 trial in the first week of February.

A process that normally takes up to 10 years was achieved in a few months, precisely because of partnership working. By tapping into existing networks of scientists, investigators, funders, the Wellcome Trust, DFID, MRC, we were able to accelerate the programme. With the help of WHO we were able to engage national regulators to get the necessary approvals. Going through the national regulatory agencies in developing countries is very time-consuming. Yet here the approvals were gained in a matter of weeks.

That provides a very positive message that we can improve on traditional, accepted ways of doing things.

Problems with predictions

Modelling predictions can have a downside. A presentation was given at an early meeting of stakeholders, including industry representatives from different countries as well as agencies such as WHO and regulators. The message was, essentially: "If it goes the way we are seeing, we are talking about the depopulation of West Africa by April 2015". It was incredibly sobering.



Timeline for GSK Ebola vaccine development

Yet while this certainly focussed the discussion, I am not sure that it was the best context for rational decision-making and planning. This scenario contributed to a sense of desperation which I believe impeded normal scientific debate, especially around study designs. In particular, there was a huge push-back against the idea of randomised control trials of vaccines. The regulators pleaded that such trials were the only way to know if these vaccines were going to work. Yet there was tremendous resistance and, in fact, two of the three phased trials currently under way are not randomised control trials.

The perils of promises

At that meeting, participants were encouraged to share company projections on when vaccine supplies might become available and these were considered confidential information. Given that GSK had not made one dose of the vaccine at that time, this required high-risk projections of the numbers of doses that that could be delivered if everything went perfectly, projecting forward more than a year. These predictions were provided, in confidence, to WHO. Yet within 24 hours they were published in *Science*, which put tremendous pressure on our organisation in terms of being able to deliver on our promises.

At the same meeting there were several analyses of the complexity of both regulatory and liability issues. The UK government argued for some relief from liability for producers and distributors of the vaccines. High-level talks have been held with governments on the issues of loss mitigation, not only due to the diversion of resources to fight Ebola, but also indemnification against claims that might be brought by trial participants (given the very early stage of the Ebola programme and the development aspects of the vaccine itself).

We continue to invest without a concrete mitigation plan in place. We have had to acquire expensive supplementary trial insurance using our own resources.

The US government has the Public Readiness and Emergency Preparedness Act (PREPA) and it is essential that governments in general provide the necessary incentives to allow industry to step in during future emergencies. There was a collective failure of global governance as the scale and the nature of this humanitarian crisis unfolded.

By remaining fully focussed on the traditional pillars of case identification, case isolation and contract tracing, the wrong signals were sent to industry. Consider what could have been done if we had had a six-month head-start. Stronger surveillance and detection systems, coupled with better coordination and decision-making, could go a long way to being better prepared for the next Public Health Emergency of International Concern – PHEIC.

Prepare or perish

Over the last decade the world has encountered a series of global health emergencies for which we were unprepared: H5N1, SARS, H1N1, MERS and now Ebola. All of these threats have one thing in common; they are zoonotic diseases that jump from animal reservoirs to humans. There are many more that we know about and perhaps many that we do not.

We have an opportunity to make a change because of the focus created by Ebola. It will, however, take vision, political leadership and a rethinking of how we address this class of infectious disease threats. We must seize this opportunity. □

By remaining fully focussed on the traditional pillars of case identification, case isolation and contract tracing, the wrong signals were sent to industry.

A view from the frontline

Oliver Johnson

Dr Oliver Johnson OBE is Programme Director of the King's Sierra Leone Partnership. He is based in Freetown, Sierra Leone. He leads a long-term institutional partnership between King's Health Partners and key health institutions in Sierra Leone, including the Connaught Hospital and the College of Medicine & Allied Health Sciences. He was awarded an OBE in the Queen's Birthday Honours in 2015 for his services in the fight against Ebola.

SUMMARY

- There is a need to reform the World Health Organisation.
- We must learn how to respond more quickly to emergencies.
- Military intervention was required due to the scale of the crisis, but they did not play the role many of us anticipated.
- Planning should be more local; this would speed the response.
- More public health practitioners are still needed out in the field.

I have been in Sierra Leone for over two years, so before the first case of Ebola emerged. One of the things I want to emphasise is that, particularly from the UK Government side, the effort was extraordinary. The work people put in, the energy, the passion and humanity and the risks they took were exemplary.

The outbreak can usefully be divided into three phases. The first is from March to July 2014 – the build-up. The second goes from August to December – where there was, frankly, a meltdown. The third phase, from December to the present day and beyond, is the stage where we are beating the epidemic.

When the first case was identified in Guinea in March 2014, the Ministry of Health organised a meeting of all the stakeholders – WHO, MSF, Kings, DFID – within the first week. So, very early on, all of the different partners came together in Sierra Leone to discuss this outbreak and start talking about it. We did not manage to build any early momentum. Indeed, there was a sense early on that Sierra Leone had escaped the outbreak. There was a real under-investment early on.

The government split its response into a number of pillars. Being on the clinical side, we went to meetings organised for the case management pillar. It was soon clear that the total resource consisted of King's Sierra Leone Partnership (KSLP), an Italian surgical NGO called Emergency, a small British paediatric charity called Welbodi Partnership and a little bit of input from Médecins Sans Frontières (MSF) – and we had to prepare 17 government hospitals for the outbreak of this disease.

It was notable that the World Health Organisation (WHO) was not at the case management meetings. One of the key lessons from this crisis is that, while people are saying we need to do more to address the issues at WHO, they are not saying it strongly enough!

Quite early on, in early June, MSF said that the epidemic was out of control. Immediately afterwards, the MSF country director was roundly criticised by a Minister. The Minister and the WHO country representative at the meeting were agreed that the situation was under control. That was the consistent message early on and highlights limitations in detecting emerging threats and responding to them quickly.

There was clearly a political dimension to the WHO declaring an international state of emergency. There was also a disconnect between the African region WHO and the global organisation. There were people on the ground emailing headquarters saying "this is really bad", but it was not acknowledged at the international level.

Furthermore, WHO is very under-resourced and has very few experts to deploy in many areas. WHO budgets have consistently been cut over the years and it is critical to invest in the organisation now.

A meltdown

The second stage was a meltdown at the hospitals, where there were huge numbers of health worker infections and suspected Ebola cases queuing outside the gates. This was avoidable. It was not until late August that the Department for International Development (DFID) started talking about funding clinical teams like us, although they did move quickly at this stage. Indeed, DFID was prepared to go the extra mile to find a way to release funding, to find a way of making things work. However, next time there is a similar situation, the response needs to be much quicker.

Another important aspect was the support of the Foreign Office. The level of attention British Nationals received, and the real warmth we got, were exactly what anyone would hope for.

In one episode a few months ago, Connaught Hospital ran out of water because the pipe had been cut. We had an Ebola unit with 10 positive patients in it and no water to make chlorine. I

The Newton unit set up by the King's Sierra Leone Partnership to treat Ebola patients

What happens when NGOs cannot or will not accept the money to do things that we consider to be a priority?

called Kate Airey, the Deputy High Commissioner, who was at this point in the National Ebola Response. She mobilised the Sierra Leone Army to get water down to us. Time and again, public servants stepped in with support.

From August to November we were facing meltdown. In one rural health post, the number of patients rose from eight to 18 in just a week. The staff too were showing symptoms from contact with previous patients. Patients were sleeping outside and receiving no care. That was typical of what was happening across the country in August and September.

In the Connaught Hospital in Freetown, a unit was set up in just four hours and cost about $400. We took over a ward and put up some plastic sheeting. There were nine beds here and we set it up in one night. That unit has seen over 1,000 patients, of which over 750 have tested positive for Ebola. It had to be done safely – and it was, safely and quickly.

The overall response to the crisis could have been quicker, which would have seen a lot more beds open sooner, reducing transmission and helping patients in need. Coordination was very important but extremely challenging. In Freetown there was no treatment centre for months. During August, every patient who tested positive had to be put into an ambulance and then sent maybe five hours to Kenema or eight hours to Kailahun.

Connaught had 16 beds. Macauley Street and Newton were two other units that KSLP had set up which were similar to Connaught. The Military had 10 beds and there were 10 at Lakka. That was the total number of treatment beds in Sierra Leone at that time.

In addition, there were probably 100 patients in their homes. We put up a white board with every patient awaiting collection on it. It might say 'one suspected case quarantined in a house with 19 other relatives. Unable to isolate this patient'. We knew that transmission was taking place just because we just could not get them into a bed.

Why were there so few beds? Why was it so difficult to get them set up? I think there had been a huge reliance on MSF and when they reached capacity we were stuck.

Delivering a response

When the DFID response began in August, they were so supportive. But when they assembled all the NGOs in a room and asked 'what can you do to open beds?' there was silence. None of the NGOs wanted to engage: it was a complete market failure.

Faced with an international health security threat but a lack of engagement from private aid agencies, the solution was, essentially, to nationalise the effort. The army was sent in, DFID became directly involved in operational issues like dead body management and organising lab sample transport systems, UKMED was set up to deploy health workers from the NHS.

If we are going to have a system where the British people and the British Government rely on NGOs to do our work, what happens when they cannot or will not accept the money to do things that we consider to be a priority?

KSLP had called for British military intervention. On 10 October the President of MSF stated that the military was the only organisation that could be deployed in the numbers needed. Bear

King's introduced the concept of throughput that we know from the NHS – that bed capacity is not just about bed numbers but also about turnaround times.

in mind that MSF tries to be completely independent: it is very rare for them to call for military intervention.

The path that UK military intervention took was different from initial expectations though, focussing on logistics and control rather than putting military medical personnel out in the field (which is what was most needed and what we were hoping for). The British Council building became the Freetown command centre. In a large hall, the British military worked with the Sierra Leone National Ebola Response Centre and other partners such as AGI and KSLP to set up command and control groups for all aspects of the response, from quarantining and surveillance to lab sample transport and ambulances – and the whole thing ran like clockwork.

The British response was well joined-up internally. The High Commissioner, the Brigadier, and the Head of DFID all met every night in a military-style briefing setting.

The risk of such an approach however was to establish a separate command centre from the government. Every night there was a briefing at the UK Government site and a briefing at the UN's site. Being so joined-up internally can make it difficult to join up with other parts of the overall response and this became a significant challenge and source of tension.

The British military ran a treatment centre at Kerry Town and the health workers there gave a huge amount of security to British health workers on the front line. They were also able to treat some Sierra Leone nationals working in British-run treatment centres.

I believe the facilities could have been up and running more quickly though, if more of the planning had been done in Freetown rather than in the UK. To put this in perspective, Kerry Town was first planned as a site on 12 August, but it did not admit a patient until 5 November. On the other hand, we were asked by the government to consider opening a unit at Lumley Hospital on 24 October and, by working locally, the first patients were admitted on 31 October.

Personal protective equipment

Personal protective equipment (PPE) was a hugely contentious issue. What is the right PPE to wear, what is safe? It might have been better to make some decisions in the field. Debating it all at length in the UK added to the delay.

One thing that KSLP introduced that worked really well was the concept of throughput that we know from the NHS – that bed capacity is not just about bed numbers but also about turnaround times. A league table of treatment centres and holding units in Freetown was created, recording the time taken from a patient arriving to getting out again (if they were negative) or getting to a treatment centre (if they were positive). I spoke to a surgeon from a hospital which initially came bottom of the table, who told me: "I was so ashamed, but we went back and had a meeting because we couldn't stay bottom of the list and we worked out what we could do to move forwards and speed up."

The final stage

The final stage was the long 'last mile' that started in late December with the increase from just 200 beds to about 900 beds, with treatment centres opening that could absorb all the cases out in the community, allowing us very quickly to bring numbers right down. Now the challenge is not about numbers of beds, but traditional outbreak control.

There is currently much better epidemiology and outbreak control in the response. Yet while this has definitely improved, it is still not as surgical as it needs to be. There are still occasions where patients test positive and a week later a phone call says 'there has been some exposure' – how can a week pass in making that kind of analysis?

Public Health England has enormous expertise in outbreak control in the UK. While it has deployed resources in Sierra Leone laboratories, it has not been effectively deployed in public health and outbreak control. We need to rethink about how it is led or resourced so that we can deploy good public health practitioners in the field because right now that is what is needed.

FURTHER INFORMATION

British Red Cross www.redcross.org.uk
Centres for Disease Control and Prevention
www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa
Ebola virus: UK Government response
www.gov.uk/government/topical-events/ebola-virus-government-response
Department of Health
www.gov.uk/government/organisations/department-of-health
Department for International Development
www.gov.uk/government/organisations/department-for-international-development
Foreign and Commonwealth Office
www.gov.uk/government/organisations/foreign-commonwealth-office
GlaxoSmithKline (GSK) www.gsk.com
King's Sierra Leone Partnership www.kslp.org.uk
London School of Hygiene and Tropical Medicine www.lshtm.ac.uk
Medical Research Council www.mrc.ac.uk
Médecins Sans Frontières www.msf.org
Public Health England
www.gov.uk/government/organisations/public-health-england

Research is not my area but I do wonder if we were asking the right research questions. How effective are the existing treatments? Some of the basic questions have not been answered yet. Take the ongoing debate about Loperamide. Does it reduce diarrhoea and therefore increase survival or does it cause more infection and therefore decrease survival? A simple study early on could have answered that question and it could have been carried out in the field.

One success story is the development of a rapid diagnostic test. There are a number under development – one was invented and developed by the British Government and has been field-tested. It had a 100% detection rate for Ebola.

There are 10,000 of these tests already in Sierra Leone. However, they are not currently being used because they have not been released and supported by the UK Government. Yet these sorts of rapid diagnostic test are critical. How can we break the logjam and save lives?

Many people have died due to the Ebola outbreak even though they did not have the disease. Women in labour could not get a Caesarean. Children have not been immunised for measles, people have stopped their HIV or TB treatment for months and months.

Now that the outbreak is under control, countries now need to invest in the future of their health systems – it is essential. ❐

The debate

Following the formal presentations, there was a debate.

There was broad consensus that the UK has responded well – and in concert – to the crisis once the public health emergency had been called. There was no evidence that the humanitarian response has distracted from support to crises in other regions (such as Syria). On the other hand contributors agreed on the need to learn the lessons from the delayed international response to the outbreak.

A number argued that WHO needs reform. It was successful at galvanising support from member countries once the public health emergency had been declared. Yet the fault lines in its structure and resourcing have long been apparent to member states. The problems with the organisation are political, not technical. It is for member states to take the lead on reform, but a new UN organisation is not the answer.

There were lessons for governments around the world in this; and there were lessons, too, for governments in the region. The heroes in West Africa were at the bottom or the middle of the social scale. There were some, at the top of these societies, who should be ashamed of their response. There was, inevitably, a risk that this would not be addressed honestly.

Some NGOs had been slow to step up to the crisis on the ground in Sierra Leone. Their reluctance stems from lack of experience in such situations and consequent risk aversion.

The role of industry in developing new vaccines quickly and manufacturing at scale was noted. The unprecedented speed of the trials process and the new regulatory approach have lessons for bringing other new medicines and technologies to market.

An effective command and control process is an early priority in such an outbreak: treatment facilities, protective equipment and clinical processes and protocols are vital.

There was considerable debate and discussion about effective community engagement: is the use of anthropologists a legitimate substitute for direct engagement with local people? Do local communities become effectively engaged in local prevention measures?

The difficulties were acknowledged. Families had protected victims. Smuggling of infected people occurred. The outbreak had occurred in populous regions with porous borders.

The UK domestic response was exemplary: from the public health and prevention perspective, through NHS frontline preparedness to the specialist treatment given to returning, infected health workers. Impressively, national communications had been based on public health science; and the Chief Medical Officer's early public warning that we should expect a handful of cases had been powerful in setting the right tone and avoiding an hysterical response.

Throughout the discussion tribute was paid to the heroism of West African and international workers who had led the response to the outbreak on the ground. The global health system had been challenged by this outbreak, as had governments and individual organisations. There had also been genuine successes. Much remains to be done and lessons still have to be learned.

An effective command and control process is an early priority in such an outbreak.

Ministers have to make tough policy choices. In many cases, the decision involves a value judgement. Yet they need to be supported by evidence. How can decision-makers ensure that scientific and value judgements are given their proper weight? The issue was debated at a meeting of The Foundation for Science and Technology on 20 May 2015.

Bridging the gap between scientific and value judgements

Mark Walport

Sir Mark Walport FRS FMedSci is Government Chief Scientific Adviser at the Government Office for Science. Previously, he was Director of the Wellcome Trust, which is a global charitable foundation dedicated to achieving improvements in human and animal health by supporting the brightest minds. Before joining the Trust he was Professor of Medicine and Head of the Division of Medicine at Imperial College London. Sir Mark is Co-chair of the Prime Minister's Council for Science and Technology.

SUMMARY

- Innovation created the modern world we live in. However, innovation also poses new risks.
- Innovation is needed to deal with the threats we currently face.
- To have a sensible discussion about risk, terms need to be clearly defined.
- Scientific and values-based arguments must be distinguished from one another.
- Politicians are elected to reconcile scientific and value-based issues.

The management of risk pervades the work of Government. Major issues of health, wellbeing, resilience and security depend to a greater or lesser degree on natural and man-made infrastructure.

The Government has a national risk register which is used to reduce or eliminate risk in the first place, then to mitigate those that remain, handle them effectively and finally clear up afterwards.

The assessment of risk is at the centre of the work of the Government Chief Scientific Adviser whose task is to provide advice on all aspects of science, engineering, technology and social science relevant to policy.

Innovation

Innovation is vital to the economy and to solving some of the future challenges society faces. However, innovation also inherently poses new risks.

The fact that the global population has reached more than 7 billion is essentially because of our ability to innovate. In the UK, innovations such as widespread electrification, improvements in healthcare, the ability to manufacture on a very large scale, and the capability to transport people and goods easily have made modern life possible.

Of course, the current global population level also creates its own challenges such as climate change and resource security. Innovation will be needed to meet these challenges and safeguard our futures.

It is clear that innovation is sometimes held back by poorly framed discussions about risk. In order to have a sensible debate, it is necessary first to be precise about the terminology we use. It is also important that all discussion participants are clear on the meaning and the types of arguments they are making.

It is clear that innovation is sometimes held back by poorly framed discussions about risk. In order to have a sensible debate, it is necessary first to be precise about the terminology we use.

Terminology

Hazard is all-too-often confused (and treated as synonymous) with risk.

Distinguishing between 'hazard' and 'risk' is extremely important. The world is full of hazards. The kitchen is full of them: bleach is not good to drink and so it is not sensible to store it in lemonade bottles. Electric toasters can burn.

Yet exposure can be reduced if knives are kept in drawers and the different vulnerabilities of family members are addressed by making sure that children, for example, are protected from plugging their fingers into toasters. Worthwhile conversations about risk cannot take place if different concepts are not carefully distinguished.

Threat is another common element of any such assessment but is usually applied to actions that humans do to one another.

Values

Different forms of innovation provoke different sorts of discussion about values.

High acceptance but who pays?

In one group are innovations where there is a high degree of public acceptance of the benefits. The pharmaceutical industries, producing drugs and vaccines, is a good example. Most people (but not all) accept that these are valuable because of their role in treating disease. Questions of values about innovation in this sector concern fairness and the matter of who pays. Take Ebola. It might have been possible to make vaccines more quickly, but there was a debate about who would pay for them. Discussions about values do concern innovation but they lie in the realm of fairness, equity and how they should be paid for.

Science meets values

In other areas of innovation, there is a straightforward confrontation between science and people's values. Modern maize bears little resemblance to its ancestor, the Central American teosinte plant. The change has occurred through uncontrolled breeding aimed at improving its use as a food stuff. There have been literally millions of genetic changes. Yet, people do not consider maize to be 'genetically modified food'. Change a single gene using a single nucleotide in a single position, though, then the plant acquires a new and mystical status as a genetically-modified organism (GMO).

Here, on the one hand, science – the genetic relationship between teosinte and maize – is well understood. On the other is the question of values: some people simply do not like the idea of human beings fiddling with nature. This is a value judgement. Members of society have values, often different values. Values differ between countries as well.

Unfortunately, discussions about science and values sometimes get confused and people who dislike GMOs on the basis of values may believe there is something intrinsically wrong with the science.

I believe it is very important that we distinguish between a scientific argument and a values discussion. It is my thesis that, in democratic societies, the politicians we elect must reconcile scientific and values issues.

My risk, your benefit

A third form of debate could be characterised as 'my risk, your benefit'. It can apply to innovation but equally to very large infrastructure projects. For example, a railway may thunder past someone's property at high speed, but the nearest station may be 50 miles away. Risk and benefit are not located in the same place. Similar arguments are involved with regard to geological disposal of nuclear waste, although here another form of values discussion intrudes as well – not only 'I have the facility in my vicinity, you get the benefit somewhere else', but also views about nuclear energy in general. Here there are also clear examples of how such values vary across Europe: France has a high degree of nuclear acceptance while Germany has decided to reduce its reliance on nuclear energy.

Discussions about science and values sometimes get confused. People who dislike GMOs on the basis of values may believe there is something intrinsically wrong with the science.

Unintended consequences

In some areas of innovation, science and values can become entangled as the full impact of an innovation is realised. Many people enthusiastically adopted mobile GPS devices: small, pocket-sized computers which can be used to make phone calls. Yet now there are all sorts of questions about the consequences of social networking, questions about privacy, about cyber security, issues about individual autonomy. The values discussions have arisen long after the technology itself had been widely adopted.

New challenges

In a few instances, it is possible to recognise – and reflect upon – the challenges in advance. So, drones bring potential opportunities as well as potential harm.

Another mistake that is often made is to frame questions about a technology in generic terms of being 'a good or a bad thing'. This is a ridiculous question. Going back to genetically modified organisms, the question should be in every case: 'What gene? What organism? For what purpose?'

To give a personal anecdote: soya beans are rather poor in sulphur-containing amino acids and so, some years ago, someone thought to make soya beans more nutritious by introducing a protein rich in these constituents. They found a methionine-rich protein in the Brazil nut that could be genetically engineered into soya beans. However, the result was to engineer the major Brazil nut allergen into the beans. Now, I have an ana-

Another mistake that is often made is to frame questions about a technology in generic terms of being 'a good or a bad thing'. This is ridiculous.

A further problem, which the Government has long been aware of, is that of encrusted regulation. It is very easy to add layer after layer to existing regulation: much harder to remove.

phylactic reaction to Brazil nuts, so this innovation would have made soya beans potentially lethal.

This is an example where a GMO can be a very dangerous product for a small number of people. In fact, this development was stopped.

The point here is that discussions about innovation need to be very specific in such cases if sensible decisions are to be made.

Regulation

There are also several types of regulatory challenge. The first is to ensure that systems are not too narrow in scope. Economic regulation is necessary where there is a monopoly provider or the market does not work effectively. Yet, regulation is not solely about price or competition. It is very important that our utilities, for example, have resilience built into them so they are capable of surviving future technological developments. R&D is needed in order to keep infrastructure up to date. The regulator must incentivise a resilient, secure and future-proof utility.

The second challenge is a difficult one which might be termed 'asymmetric incentives'. In a nutshell, if a regulator allows something to happen that does harm, then there is trouble. If, on the other hand, a regulator stops something that might have done good then the consequences may be rather small, if any. That constitutes an obvious incentive to be cautious. Now, unless regulators can be held to account for all of their decisions, then the danger is that asymmetric incentives will continue to distort regulation.

The third problem, which the Government has long been aware of, is that of encrusted regulation. It is very easy to add layer after layer to existing regulation: much harder to remove. That problem can be dealt with by will power!

One challenging area of regulation occurs where science meets values. One of the most successful examples in the UK concerns the technologies aimed at halting the transmission of mitochondrial diseases from carrier mothers to newborn children. People have very strong values-based, often religious-based, beliefs about embryo technologies.

The question then is 'Whose values trump whose?' The Human Fertilisation and Embryology Authority was set up at a time when stopping mitochondrial disease transmission in this way was not thought possible. The regulator has worked with technology as it has evolved. Furthermore, HFEA's structure has allowed it to conduct a conversation with the public and other stakeholders. Indeed, there was great deal of that discussion leading up to the (free) votes in both Houses of Parliament that enabled this therapy to proceed on a regulated basis.

Here, a clear distinction was made between science and values. At the end of the day the plurality of values was resolved by a democratic vote. Now, an interesting challenge for Europe is that while values differ within countries, they differ between countries as well. Embryo technologies are not very popular in countries such as Italy. Germany too, has difficulties because of its history. It may be that a solution will involve some kind of subsidiarity.

Providing advice

The role of the Science Adviser is to provide advice, of course, but also to recognise that the people who make tough policy decisions have to look at issues through different lenses. Take the climate debate. In surveys of the public, about three quarters are fairly or very concerned about climate change and believe the use of fossil fuels should be reduced.

A similar percentage are concerned about the UK becoming too dependent on energy from other countries (the energy security issue) and a similar percentage are concerned that electricity and gas will become unaffordable. That is the policy-makers' challenge – the trilemma of sustainable, secure and affordable energy. Once again this illustrates the challenge: clear discussion would make it easier for policymakers to make clear choices. □

The role of the Science Adviser is to provide advice, of course, but also to recognise that the people who make tough policy decisions have to look at issues through different lenses.

Policies can change as evidence evolves

Angela McLean

SUMMARY

- Restatements set out the evidence that everyone can agree upon.
- This clarifies what is relevant for debate
- Policy needs to reflect the evidence, not pre-empt it.
- Evidence-based policy needs robust evidence if it is to be effective.
- Policy needs to take uncertainty and changeability into account.
- A hallmark of evidence-based policy is that when the evidence changes the policy changes.

Restatements aim to create a document that both sides of an argument can agree to – and therefore do not need to argue about. The Oxford Martin School Evidence Restatements (a joint project with Professor Charles Godfray) can then focus on the unknown and the contentious. The word 'restatements' is borrowed from the legal field in which they restate existing common law into a series of principles. That is what our restatements are, a kind of 'bluffers guide'.

The process runs something like this. First we write an essay on the topic of interest and then hold what amounts to a day-long 'tutorial' with six to eight academics, drawn from across the spectrum of expert opinion. All members of this group are authors of the resulting article. During the course of that day, the first draft of the restatement is debated, paragraph by paragraph, rephrasing as necessary. Each paragraph is then labelled according to the type of underpinning evidence. One item might be based on data. Another might be an expert opinion or an extrapolation from data. The types of evidence are not necessarily ranked: the idea is to indicate to someone coming new to the field just what kind of evidence lies behind a particular statement.

The next step is to rewrite the restatement taking account of the group's advice. It is then sent out to around 50 stakeholders from all shades of opinion. What comes back are, roughly speaking, 50 peer reviews. These are often the results of enormous amounts of work put in by people critiquing what was said and pointing out things that were omitted. A further version is then drafted, which the authors then have to agree – and that is published as a journal article. The journal article consists of a short paper which just introduces the problem addressed, followed by the restatement which consists of a set of numbered paragraphs (the things we know) and then finally a long, annotated bibliography.

For a new civil servant with, say, a history degree who arrives in Defra and finds themselves in charge of neonicotinoids, this could be a useful way to access the literature very quickly. It provides an overview and enables the reader to find the papers that lie behind the evidence laid out.

Neonicotinoids

Taking as an example the debate surrounding neonicotinoid insecticides and pollinators leads to a consideration of what happens when there is new evidence.

The basic question is: under normal field operational conditions, are neonicotinoid insecticides responsible for the pollinator declines that we see?

Europe is currently under a moratorium on three neonicotinoid insecticide seed treatments. Using the process described earlier, an author group was established. The resulting report was published a year ago[1]. The overall conclusion was that, although it was possible to make bees very sick by feeding them high doses of neonicotinoids, the definitive experiment had not been done at that stage. There were 'semi-field' experiments in which bees were effectively made drunk on the neonicotinoids, put out in the field and, sure enough, could not find their way home. There were also two 'true field experiments' in which bees were placed next to fields treated with these insecticides – but these studies were very hard to interpret because of issues with replication and the placing of the exposed and control bees.

In late April 2015 Rundlöf *et al*[2] published a new study describing well-designed and carefully

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One of the important properties of good evidence-based policy is that it responds to changes in evidence.

analysed experiments in which bees were exposed to neonicotinoids under field conditions. There were eight replicates, and the replicates were far enough apart that the exposed bees and the control bees had different amounts of neonicotinoids in their pollen and nectar. In addition, this new paper considered bumblebees, solitary bees and honey bees.

It turns out that different types of bee have different levels of vulnerability. In the fields with the treatment, wild bee density was reduced, there was virtually no solitary bee nesting and bumblebee colony growth was greatly reduced. Particularly interesting, though, was the finding that there was no difference for honey bees between the treated versus the control field (which helps explain a lot of the previous literature).

However, there was a twist to the story which pointed to variable approaches to the presentation of summaries of scientific evidence. In April 2015 – and before the publication of new Swedish evidence – the European Academies Scientific Advisory Council had produced a paper[3] which very forcefully argued the case against neonicotinoids in a way which was difficult to comprehend prior to the publication of the Swedish study. Even in the light of the new study, some might find the phraseology of the EASAC summary surprisingly forceful given the underlying evidence base.

Policy changes

One of the important properties of good evidence-based policy is that it responds to changes in evidence. Experts can help policy makers by telling them what to watch for, what is likely to be the defining piece of information that could change well-informed opinions.

Good evidence-based policy has an evidence audit which would have a reference to uncertainty and a recognition that evidence can change.

There is a matching question about how to recognise policies that are sensibly grounded in value judgements, but that perhaps is a topic for another debate. □

1. Godfray C J, Blacquière T, Field L M, Hails R S, Petrokofsky G, Potts S G, Raine N E, Vanbergen A J, McLean A R (2014) A restatement of the natural science evidence base concerning neonicotinoid insecticides and insect pollinators *Proc Biol Sci.* 2014 Jul 7;281(1786). pii: 20140558. doi: 10.1098/rspb.2014.0558

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3. Neumann P (2015) Ecosystem services: Academies review insecticide harm. *Nature* 520, 157. doi:10.1038/520157a

Creating trust in the statistics that underpin decision-making

John Pullinger

In looking at the joining together of science and value judgements, an obvious question is: "Who is making the judgement?" Of course, it is people – ordinary people. The evidence used in making many everyday choices is not actually very robust, though. At a practical level, many judgements are based on very simple biology – a need to eat, an interest in sex, an aversion to pain. People are also driven by emotions and these are supported by values – whether spiritual values, a deeply-engrained way of thinking, or a whole host of other things. So, people are motivated by biology, by emotions and by values. Yet sometimes they also engage the rational side of the brain.

Scientists going into policy debates should not focus entirely on the science but also try to understand what is going on inside the other person's head as they try to interpret what we say.

Evolution has taught us all to spot patterns – children see animals in the clouds and we manage to escape predators because we can see a tiger in the grass more quickly. Approaching a problem via an ability already hard-wired into people gives a better chance of success.

Life is a lottery and those who are well-placed to play the odds tend to come out on top. Evolution has given an advantage to those who are good at gaming, which is just a very layman's way of assessing risk.

Almost any survey shows great antipathy among British people to numbers. Some Royal Statistical Society surveys suggest this aversion runs quite deep. Yet, present people with numbers and they just take to them. Inflation figures – everyone is interested. There is a seductive power about the language statisticians speak.

SUMMARY

- Judgements are made by people who have values as well as analytical capabilities.
- The post of National Statistician was created to help policy makers distinguish between rival claims.
- A trusted intermediary is necessary for rational, public debate involving statistics.
- In order for such an intermediary to operate effectively, a framework needs to be established.
- Ultimately, there needs to be a better understanding of statistics at all levels and particularly in political decision-making.

The other quality scientists have is scepticism – it is almost a defining characteristic. When presented with scientific evidence, our own scepticism and humility can win friends – and that is a very powerful message.

The National Statistician

The history of the post that I hold now is enlightening. It was created by Winston Churchill in 1941. In the darkest days of the war, all the key players in the War Cabinet were presenting evidence on why he should give more support to the Army or the Navy or the Air Force. Now, he had no way of choosing between these competing demands. My post was created out of the confusion caused by people arguing from different numbers. He needed an independent, trusted starting point to enable rational discussion, debate and argument in a world where there is always uncertainty.

The level of uncertainty today is probably higher than in 1941. Why? Well, there are several reasons. First, most of the evidence submitted to policy makers comes from someone with an axe to grind.

In my previous role as Librarian in the House of Commons, I had to provide evidence for debates. Every day, people would come to my office with wonderful research. I would often respond by pointing out that this or that piece of research would come to those conclusions because of who commissioned it. That was not always obvious to those knocking at my door!

The evidence submitted was rarely impartial. So, how to judge who to trust? The amount of information is just too much to take in – there is information overload. How to filter it?

There is a daily temptation to leap to false conclusions. Those reports that disturb me most are the ones about clusters, for example, of cancer cases: all the media rush to this little 'village of death' and suddenly there is a view that something ghastly must be going on. Yet in nearly every case, it is just a random effect.

More generally, extremes of any kind are amplified. The finding that is the most odd seems to be the one that must be right and must, therefore, influence behaviour. I have been involved in some surveys looking at public perception of different features of our society and they are quite alarming. One study in 2013 showed that people think there are more than twice as many immigrants in the country as there are in reality. Or 25 times as many underage teenage pregnancies, 35 times as much benefit fraud, etc.

Is it any wonder that public opinion is so skewed? Some kind of trusted intermediary, that can have a voice which trumps all this nonsense, seems to me to be the key to proper, rational debate.

How to restore trust

For that trusted intermediary to operate securely, there needs to be a framework in place.

First, we need better evidence. We must invest in the science base when the world is changing so quickly. There are lots of new things to discover, lots of new applications to put into action.

Second, professional scientists who are in positions to influence decisions need support. The legislation that established the post of National Statistician only dates from 2007, but it became necessary because of a crisis of trust. It sets out a statutory code of practice for statisticians working in Government that gives us authority over the form, content and timing of all the statistical releases.

During the general election period we were the only part of Government that had authority to continue with its public-facing role. That was very important – the public still needed to know what was happening to crime, immigration, jobs and the economy. Frameworks that protect the voice of the professional are crucial in all scientific disciplines.

John Pullinger CB is the UK's National Statistician, Head of the Government Statistical Service (GSS) and Chief Executive of the UK Statistics Authority. He was the project manager for the creation of the Office for National Statistics (ONS) and was the policy lead on the development of the Government Statistical Service. He served as the 14th Librarian to the House of Commons before returning to the GSS in his current role. He is a past President of the Royal Statistical Society.

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Third, scientists need to spend time with decision-makers. Their world is not an academic, scientific place; rather, it is a very messy place with all sorts of other things going on. One of my team was seconded to the BBC for a few months recently. Her one-sentence observation when I spoke to her was really interesting: she said "There are so many simple things we could do that would make it much easier for the BBC to report what is going on." So I am looking forward to making just those simple changes that do not cost anything, but which enable us to be heard more clearly. We need to understand the public policy process better.

The fourth and final element of this framework is education. Education does not just refer to schools and the universities, I am specifically thinking about decision-makers. A survey of MPs' statistical literacy shows it to be much the same as that of the general public. Given the choices they need to make, investing in the education of MPs (indeed the whole of the decision-making apparatus, including civil servants, ministerial advisers, etc) is really important. If they are not educated about statistics, they will not understand some of these basic questions that we take for granted.

If the head is going to temper the inclinations of the heart in the decision-making process, it must become easier for people making decisions to understand, accept and use the evidence that we create. They will then be able to make much better decisions; and that will benefit us all. ❐

The debate

Following the formal presentations, a number of issues were raised in the debate.

Complex problems where science and values meet require resolution through the democratic process, not least in terms of mediating and weighing different propositions on values. Such decisions are often taken under considerable pressure of time, under pressures from vested interests, under political constraints based on voter expectations, and in circumstances where the scientific evidence is genuinely uncertain. Evidence coming to Ministers – whether on science or on values – is rarely of a uniform view. Often the difficulty is how much weight to give to minority opinions on both sides of the equation.

There may be a cacophony of voices from the science base, too. A vital job for scientists in Whitehall is to integrate and make sense of those voices, which was why papers such as the 'restatements' are so valuable. The increasing emphasis on transparency is not a magic bullet. Transparency increases the need for informed scientific analysis to turn raw data into evidence. This process must be unbiased, usable and – crucially – trustworthy.

There is clear evidence that Ministers do take scientific advice seriously and that guidelines on the use of data and evidence are having an impact. The UK is well served in that respect. Encouragingly, too, a stronger horizon-scanning function is being developed within Government to ensure that regulatory functions are adapted and aligned to changes in technology and in the use of the evidence base.

That does not mean that all Governmental decisions are grounded in evidence, or reviewed and changed in the light of new evidence. The debate over badger culling was cited as an example. In circumstances where there is genuine scientific uncertainty (such as the risk of transfer of BSE to humans) scientists should resist pressure to make estimates which could only have a speculative element, as they may be seen as having scientific validity.

For scientists providing advice at a political level, there are lessons to be learned. On the one hand, they must remember and understand the context in which advice may be put. On the other, they if they do not know the answer to a question they should not be tempted to offer one.

Too often the interplay between science and values is misread. Arguments that are really grounded in judgements about values are disguised as scientific arguments, or else they use evidence selectively to justify a values-based proposition.

Arguments that are really grounded in judgements about values are disguised as scientific arguments, or else they use evidence selectively to justify a values-based proposition.

Judgements related to values can be legitimate within the decision-making process. The social sciences have a significant role in providing and analysing evidence-based values. The UK is a pluralist society; and decisions need to take account of evidence relating to values. ❐

Government Ministers regularly cite the Haldane Principle without always defining how they are interpreting it. How to achieve the right balance between Ministers' priorities for research and those of bodies like the Research Councils was debated at a meeting of the Foundation on 3 June 2015.

The Haldane Principle – an historical perspective

Peter Hennessy

SUMMARY

- In 1918, a committee chaired by Richard Haldane published the Report of the Machinery of Government Committee.
- The report concluded that the allocation of research funds should be decided by researchers rather than the State. This became known as the 'Haldane Principle'.
- The Haldane Report led to the creation of independent Research Councils, the first being the Medical Research Council .
- The value of the Haldane framework can be seen in the excellence of UK science.
- The current drive towards impact statements and performance indicators should not be permitted to undermine a principle that has proved so beneficial.

I have been a fan of R B Haldane for about 30 years – ever since I read his fabled *Report of the Machinery of Government Committee*[1], published by the Ministry of Reconstruction in 1918. Throughout this report, Haldane made observations on the State's relationship with scientific and technological research.

The essence of Haldane's view is captured in this sentence from his report: "We have come to the conclusion … that in the sphere of civil Government the duty of investigation and thought, as preliminary to action, might with great advantage be more definitely recognised."

With typical British understatement, Haldane expressed a principle that still resonates today: the application of thought to ruling.

Haldane's principle has served as a gold standard aspiration, not only in science and technology but also in arts, humanities and social sciences.

Other points that remain relevant are:

- The need to keep in mind 'the pursuit of new truth';
- The disbursement of public money on science should 'operate without close or habitual reference to the administrative requirements of any Department';
- Departments need 'to know where the rightful boundaries of their own Intelligence and Research Work are to be drawn' and to beware 'laying down in advance a series of precepts'.

1964

Haldane's principle was invoked again in 1964 by Lord Hailsham (who had been Minister of Science in the Conservative Government) when he attacked the new Labour Government's plans for a Ministry of Technology. He told the House of Commons: "Ever since 1915 it has been considered axiomatic that responsibility for industrial research and development is better exercised in conjunction with research in the medical, agricultural and other fields on what I have called the Haldane Principle through an independent council of industrialists, scientists and other eminent persons and not directly by a Government Department itself."

In other words, patronage – whether by the State, the Research Councils or by private sources – needs to be applied with flair and imagination and viewed as intellectual risk capital.

2014

The Haldane Principle was once again supported in a full statement by the Coalition Government in December 2014. In *Our plan for growth: science and innovation*[2] the Government stated: "It is not the job of a strategy for science and innovation

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Patronage – whether by the State, the Research Councils or by private sources – needs to be applied with flair and imagination.

Governments and Whitehall Departments have an insatiable appetite for performance indicators, which simply do not fit the life of the mind.

that will last for 10 years to specify in detail the scientific questions to be answered. And when it comes to fundamental research it remains the case that those at the 'coalface' of research are best placed to identify the key questions and opportunities to achieve knowledge. However, many of the 'grand challenges' for society, the ultimate customer for research, are obvious." These challenges are listed as low carbon sources, energy storage, the use of scarce resources, as well as improving human, animal and plant health.

The future

Governments and Whitehall Departments crave order, tidiness and predictability. They also have an insatiable appetite for performance indicators, several of which simply do not fit the life of the mind. The growing preoccupation of the Research Excellence Framework with 'impact' has produced a proliferation of 'Potemkin villages' in our universities, built solely to satisfy the Higher Education Funding Council for England (HEFCE) and the Treasury.

The Haldane Principle has supplied a fruitful means of reconciling the differences between researchers' and scholars' love of the mess and uncertainty from which speculation and new knowledge emerge, with Government's love of order and predictability. It has served the country well, enabling us to harness the yield of independent thinkers in our universities and research establishments.

The Haldane Principle provides a distinctive way of conducting the relationship between Government and science that has enabled the UK to punch above its weight in the international science arena. It is to be hoped that the current drive towards impact statements and performance indicators will not undermine a principle that has proved so beneficial. □

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Adapting Haldane for the 21st century

Martin Rees

The Lord Rees of Ludlow OM Kt FRS is Astronomer Royal. He was formerly Master of Trinity College Cambridge and President of the Royal Society. Lord Rees has had a distinguished career as a theoretical astronomer and science communicator. He has authored many thought-provoking books, including *Our final century: will civilisation survive the twenty-first century?*

Science impinges on more and more aspects of our lives. Because it is substantially funded from the public purse, it is only right that the Government, on behalf of the public, has some form of oversight. The question is one of degree: how much control should it wield over research priorities?

Fostering academic excellence

Much of our public research spending goes to our universities. Traditionally, in return for teaching, university faculty can devote part of their time to research in fields of their own choice. This system ensures that our universities attract the best talent. When academics extol 'free-wheeling' research, where they choose their research topics themselves, they are sometimes accused of arrogance and disregard for their obligations to the public. However, significant advances in research are more likely to be achieved by people who are committed to – even obsessed with – the research problem they are tackling.

If you ask scientists what they are working on, you will seldom receive an inspirational reply such as 'seeking to cure cancer' or ' understanding the universe'. Scientists focus on a tiny piece of the puzzle; they tackle something that seems tractable. They are not ducking the big problems – rather, they are using their expertise to judge which approach is likely to pay off best. They know that science is unpredictable, diffuse and long-term. For example, the inventors of lasers in the 1960s used ideas that Einstein had developed 40 years earlier, and the lasers they invented were in turn developed into tools used in eye surgery and the manufacture of DVDs. The Haldane Principle provides the best framework for attracting committed individuals and supporting them properly.

SUMMARY

- By allowing researchers to choose their own research topics, the Haldane Principle provides the best overall framework for supporting individuals.
- Younger researchers fare less well under the Haldane Principle, because research allocations are governed by academics and the interests of older researchers can dominate decisions.
- There is a danger that funding is inflexible and centred on the south, preventing balanced regional development.
- There needs to be a high-level, transparent, independent advisory body to advise on strategic investment and national capability.
- Scientific research has intrinsic value, over and above its ability to generate spin-offs.

It is crucial to foster the translation of new research findings into social or commercial benefits. That is why the research universities are doubly valuable. In addition to their own research, they keep a discerning watch on what is happening elsewhere in the world. They can seize on good ideas from anywhere and run with them. So it is in the UK's interests to foster academic excellence right across the board – even in areas where we cannot claim to be world leaders.

Funding for younger researchers

Applying the Haldane Principle unchecked, though, risks inducing trends that are misaligned with what is best for the long-term health of our research system. The first concerns the age at which researchers receive funding. The self-interest of older researchers could dominate decisions if research funding allocations are governed by academics. We are seeing this today in both the USA and the UK.

A recent American report that looked at the career patterns of biomedical scientists found that the proportion of grant-holders aged under 36 has fallen from 16% in 1980 to 3% today. The proportion of those aged over 60 has risen even more dramatically. The mean age when researchers get their first grant is now 43.

There is a similar trend in the UK, and it augurs badly. Some people will become researchers regardless of funding. Yet a world-class university cannot survive on these alone. It must attract ambitious young people with flexible talent – the kind who aspire to achieve something by the time they are 30.

Regional funding

Another risk of the Haldane Principle involves not young and old, but north and south – when the interests and credentials of the 'Golden Triangle' (London-Oxford-Cambridge) are at odds with the regional pump-priming policy. Many feel the Government should override Haldane in the interests of balanced regional development.

Be that as it may, and despite the trend towards concentration, it is crucial to retain enough flexibility to allow excellence to sprout and bloom anywhere. For example, Leicester University is world-class in genetics and in space science; Dundee in bioscience. None of this was planned. Outstanding young researchers in these fields happened to have jobs there and had the enterprise to build up major groups. The system that prevailed in the 1970s and 1980s allowed this. It is important that selectivity should not be so harsh that emergent opportunities like this get choked off.

Choosing research priorities

Third, there is the question of favoured funding for priority or strategic subjects. Clearly, the selection of priorities needs expert input, but equally clearly it involves wider criteria than scientific excellence alone. Some academics are uneasy about this because they want all funds to be allocated to the best science as judged by peer review.

Yet there is a counter-argument: the total public resources for research, and the matching and follow-up by private sector, will be bigger if the money is boosting topics of obvious timeliness and societal benefit. Ring-fenced research funding has provided predictable, although shrinking, support for scientists. If ring-fenced funds are perceived by politicians to be supporting scientists unconcerned with a wider agenda, they are unlikely to be increased and opportunities will be lost.

Until 20 years ago, the Advisory Board for the Research Councils, which had independent members, apportioned research funds. This board was abolished in 1993 and replaced by a single Director General for the Research Councils. This role encompasses broader responsibilities, thereby diluting the ability of the Director General to address strategic priorities. Currently there

Many feel the Government should override Haldane in the interests of balanced regional development. But it is crucial to retain flexibility to allow excellence to sprout and bloom anywhere.

It is a cultural deprivation to be unaware of Darwinism, DNA and the basic chain of events that led to the emergence of the cosmos, life and our biosphere.

is no senior scientist from outside the civil service in this role. This is a serious deficiency.

There needs to be a high-level, transparent and independent science strategy advisory body that would include representatives from Research Councils UK, the Council for Science and Technology, research-intensive Government Departments and the wider scientific, business and charitable communities. Its primary role would be to advise the Department for Business, Innovation and Skills (BIS) on strategic investment and national capability. It would also need to advise on how to deal with expanding areas such as energy research, data analytics, robotics and genomics.

The American model

In many ways, science policy well is handled well in the UK. Compared with the USA, the interface with Government is closer, the respect for evidence is stronger and the rapport between scientists and legislators is certainly better. But there are things we can learn from the Americans.

Often the advice that is needed for a funding decision requires a wider range of expertise than a Departmental chief scientist and in-house staff can provide. The USA has the National Research Council, which is publicly funded but controlled by their national academies, and operates at arm's length from government departments. It produces reports on technical and policy issues. It also produces, after wide community discussion, regular reviews that recommend priorities in fields such as space science. These reviews carry weight in congressional committees.

The USA also has a very distinctive group known as the JASON advisory group (named after the hero in Greek mythology, famous for his quest for the Golden Fleece). The JASON group is composed of top-rank scientists and was founded in the 1960s with support from the Pentagon.

In the early days it was largely made up of physicists, but now includes scientists from other fields. It is funded by the US Department of Defense but chooses its own members. They spend about six weeks together in the summer, with other meetings during the year.

The sociology and 'chemistry' of such a group has not been fully replicated anywhere else. Perhaps, though, we should try to create a similar type of group in the UK, not for the military but in civilian areas, for example under the remit of the Department of Energy and Climate Change (DECC), the Department of Food and Rural Affairs (Defra), or the Department of Transport. The challenge would be to assemble a group of top-ranked scientists who enjoy cross-disciplinary discourse and debating a range of ideas. They would need to be able to dedicate substantial time to it and address the kind of problems that play to their strengths.

The European model

In its own way the European Union has a Haldane principle. The European Research Council gives grants to outstanding individuals and has a respected record for its quality of peer review. There is well-managed European collaboration, epitomised by CERN in Geneva which is the world's leading laboratory in particle physics.

Similarly, the European Southern Observatory and the European Space Agency have world-beating facilities and projects. They are independent of the EU with a separate oversight structure. These capital-intensive sciences are not typical of research, of course, but they're good portents – they show that Europe can match the USA if we optimise a European research community. Even 'small sciences' may achieve higher peaks of excellence if they involve more than one nation.

The intrinsic value of scholarship

Although our paymasters focus on the spin-offs from scientific research, let us not forget its intrinsic value. It is a cultural deprivation to be unaware of Darwinism, DNA and the basic chain of events that led to the emergence of the cosmos, life and our biosphere. Indeed, science is the most universal culture, shared by all nations and all faiths.

Although we often think of spin-offs as emerging from science and technology, this is not always the case. Two of the most valuable pieces of intellectual property to come out of Oxford did not come from scientists or engineers, but from professors of renaissance literature and of Anglo-Saxon. I refer of course to C S Lewis and J R R Tolkien, whose works now earn billions of pounds for the creative industries.

These two distinguished scholars, who were both archetypical old-style Oxford dons, would surely feel like disaffected aliens in today's world with its Research Excellence Framework, line management and audit culture. Their values were the traditional ones: commitment to an institution, and to scholarship and learning for their own sakes. Whatever happens, let us hope these ideals will not become extinct – they would certainly have resonated with Lord Haldane himself. ❐

Balancing good science with good government

David Willetts

SUMMARY

- Government ministers should not be involved in decisions about the funding of individual projects or choosing researchers.
- There is a role for Government Ministers in identifying overall strategic research priorities.
- Government ministers are also necessary to ensure the UK's participation in large international collaborations and in politically sensitive research areas.
- New technologies need public support to succeed.
- We need to encourage younger researchers by ensuring that peer-review is not age-based.

In December 2010 the Department for Business, Innovation and Skills (BIS) published a statement on the Haldane Principle as an annex to its report *The allocation of science and research funding 2011/12 to 2014/15: investing in world-class science and research*[1].

The statement set out a clear definition of the Haldane Principle: "The Haldane Principle means that decisions on individual research proposals are best taken by researchers themselves through peer review." In practice this means that although Ministers have a legitimate role in decisions that involve long-term, large-scale commitments of national significance, they do not have a role in making decisions about which individual project should be funded or which researchers should receive funding.

Identifying strategic research priorities

Ministers must ultimately decide, with the help of external advice, on the overall size of the funding for science and research and its distribution between the Research Councils, the national academies and Higher Education research funding. Among the challenges they face is the need to identify key national strategic priorities for Research Councils without crowding out other areas of their missions.

In the department's policy paper from February 2013 – *2010 to 2015 government policy: industrial strategy*[2] – we identified eight areas of technology as strategic priorities: big data, satellites, robots and other autonomous systems, synthetic biology, regenerative medicine, agricultural technologies, advanced materials and energy storage.

Supporting long-term international collaborations

Ministerial support is vital to make long-term decisions about international collaborations such as the Large Hadron Collider project at CERN. More recently, the Square Kilometre Array, which has been at the centre of some fraught discussion about where the headquarters should be located, needed the involvement of ministers and politicians.

There is also the inevitable 'horse-trading', often with other governments, that requires a minister to negotiate a deal. An example of this is our involvement with the European Space Agency, in which we negotiated to achieve the best deal for the UK.

Projects with political sensitivity also need political involvement. An example of this is the British Antarctic Survey, which has a dual mission that also concerns Britain's activity in the South Atlantic and harks back to the circumstances of the Falklands War.

The pursuit of excellence

We must be dedicated to the pursuit of excellence regardless of location. There is a very understandable argument for expanding capacity and ensuring that we do not end up with all our research funding in the Golden Triangle. I think there is also an argument for a distinct and specifically identified capacity building budget in particular locations, although that might have to done outside the Haldane Principle for the main science budget.

The Rt Hon David Willetts was Minister for Universities and Science from May 2010 to July 2014. He served as the MP for Havant from 1992 until 2015. He also worked at HM Treasury, the Number 10 Policy Unit, and as Paymaster General. He is the author of *The Pinch: how the baby boomers took their children's future – and why they should give it back*, published in 2010.

There is a very understandable argument for expanding capacity and ensuring that we do not end up with all our research funding in the Golden Triangle.

HALDANE PRINCIPLE DEFINITIONS

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Scientists can be so excited by their scientific and technological advances that they can run ahead of public opinion and fail to gain public support. There have been some unhappy experiences over the past 20 years because of this, for example with genetically modified food.

Peer review should be vibrant and lively, and this may not mean review by one's own age cohort.

Public opinion

That provides some idea of the areas where there are legitimate decisions to be taken by Ministers about, for example, ethical and regulatory frameworks. There is a wider argument, though, which is that scientists can be so excited by their scientific and technological advances that they can run ahead of public opinion and fail to gain public support. There have been some unhappy experiences over the past 20 years because of this, for example with genetically modified food. Fracking is in danger of going the same way. Without wider cultural and political support, these kinds of programmes simply cannot be maintained. Another area, driverless cars (which falls within one of the eight great technologies), still need a great deal of work to achieve acceptance by the public. This is another instance of technology moving faster than attitudes and general culture.

Giving the younger generation a chance

I would like to throw down a challenge to the science community in the area of peer review. Peer review should be vibrant and lively, and this may not mean review by one's own age cohort – literally one's peers. Distinguished 50-something scientists may be familiar with the problems and issues that other 50-something scientists are thinking about. However, if they are not switched on to what 30-something scientists are concerned with, then peer review, as envisaged by the scientific community, may not deliver opportunities for younger researchers.

In Britain it is very important that we have principal investigators in their 30s getting research grants. We have to ensure that the younger generation has its chance.

I believe that the UK should be enabled to engage in world-class science in all fields. I hope that funding constraints do not place that under threat or exert new strains on the Haldane Principle. □

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A response

Professor Jane Elliott, Chief Executive of the Economic and Social Research Council (ESRC), gave a response to the speakers' presentations before the general discussion began.

The Haldane Principle has helped to create a very strong science and university sector in the UK over the past century. Will it continue to serve us as well in the future? I think everyone would agree that politicians should not be involved in awarding individual grants. Yet we also acknowledge the need for political backing to enable very large capital projects to get off the ground. The difficulty lies in the grey area between these two, and that is where we need to focus some of the debate.

One proposal has been to create a broader advisory board to oversee research funding. How would such an advisory board fit with the existing structures of our individual Research Councils? Each of these councils already has a broad mix of people of very high calibre, who are by no means all scientists or academics.

In terms of funding for research, the Economic and Social Research Council (ESRC) received 420 applications last year and were only able to make 53 awards. This was not because of the calibre of the applications. Of those that scored 7 or more out of 10, we were only able to fund 32%.

Similarly, the Engineering and Physical Sciences Research Council (EPSRC) is only able to fund about 6,000 out of 10,000 really excellent academics who apply to it for support.

Certainly we should support excellence, but we do have to think about where we prioritise, given that we cannot fund all of the excellent research we would like to.

The debate

Following the formal presentations, a number of issues were raised in the debate.

Some argued that the Haldane Principle is only relevant to a small proportion of research expenditure in the UK – that which is channelled to Higher Education institutions and Research Councils through the dual-support system.

The push towards the alternative Rothschild contractor/customer model for Government-funded research in the 1970s resulted in money being diverted from Research Councils to Government Departments. With less stringent allocation principles, research budgets subsequently suffered from cuts (apart from Defence and Health).

The physical sciences are more dependent on Research Council funding than the biomedical sciences which benefit from a number of other sources (such as the Wellcome Trust) where the Haldane Principle does not apply.

It is uncertain whether the Haldane Principle has the ability to cater to the growing need for collaborative and interdisciplinary research. Research Council studentships, for example, are becoming too linked to the 'eight great technologies' at the expense of blue-sky missions.

In the end, who has responsibility for overseeing the quality of relations between Government and science? Perhaps this lies (or should rest) with Parliament, and tribute was paid to the work of the Parliamentary Select Committees.

Is the autonomy of Higher Education institutions really under threat? While this will always be a concern, there is evidence to the contrary, such as the reduced influence of those who were founding sponsors of the new universities.

Is peer review as effective as it should be? There are concerns about age bias and these may be valid. It is vital to ensure that reviews are undertaken by people still active in research.

Aligning priorities

Sometimes, other factors may either aid or disadvantage research priorities. The British Antarctic Survey is an interesting example of an area where political and scientific priorities point in the same direction, to mutual advantage.

Overall, the consensus was that the Haldane Principle has served the nation well in the research areas where it applies and that it is as relevant to the 21st century as it has been to the 20th. However, its detailed formulation may need to be adjusted over the years to take account of external circumstances.

In the end, who has responsibility for overseeing the quality of relations between Government and science? Perhaps this lies (or should rest) with Parliament.

How can the tension be resolved between resource extraction and environmental protection? In this, the 50th anniversary year of the Natural Environment Research Council (NERC), a special celebratory meeting of the Foundation on 23 June 2015 considered the challenge.

The challenge of environmental research

Duncan Wingham

Professor Duncan Wingham is chief executive of the Natural Environment Research Council (NERC). He was appointed to a chair in the Department of Space & Climate Physics in 1996 and was head of the Department of Earth Sciences at University College London from 2005-2010. He was founder and director of the NERC Centre for Polar Observation & Modelling (CPOM) which discovered the widespread loss in mass from the West Antarctic Ice Sheet and identified its origin in accelerated ocean melting. He was chairman of the NERC Science & Innovation Strategy Board (SISB) and from 2000-2012 was the lead investigator of the European Space Agency's CryoSat and CryoSat-2 satellite missions.

SUMMARY

- Environmental science is becoming ever more important globally.
- There is an urgent need to understand how the environment supports human wellbeing.
- A Research Council's role is to provide the information and advice upon which people can make decisions.
- Our understanding of the environment has increased dramatically over the past 50 years.
- Independent scientific advice has had an enormous impact on environmental policy.

Eighteen months ago, the bi-annual survey from the Department of Business, Innovation and Skills (BIS) on UK science excellence placed environmental science in first place in the UK for field-weighted impact. Per pound invested, the UK came top in the world. That is a nice position for a chief executive of a Research Council focussed on the environment to find himself in! Across the world, though, there is an increasing interest in environmental science, not just among our established scientific competitors, but in many others too, such as South Korea and China.

The message I took from the report was the ever-growing importance – in policy, society and business – of environmental science.

There are many other signs of this growing attention. The post-2015 millennial goals, now under discussion at the UN, differ from the millennial goals in their explicit recognition that the desire of much of the world's population to enjoy living standards we take for granted may place unsustainable demands on the environment.

There is another message contained in these goals, too. It is that the question of resource extraction versus environmental protection is out of date. There is very little of the 'natural' world left. The terrestrial land surface is now almost completely given over to production. Global chemical cycles, of nitrogen for example, have been altered out of all recognition. The issue is no longer one of preservation: it is to address the issue of how the environment aids the pursuit of human wellbeing.

The role of a Research Council here is not to judge, it is to inform. The actual decision what to do about that information is not a scientific one. This is not to underestimate the impact of independent, objective advice. There are many examples of that impact in the 50 years that NERC has existed.

Everyone is familiar with the discovery of the ozone hole. Yet while it is associated with Antarctica, it is the northern hemisphere where depletion would have the greatest impact on people and agriculture. A recent paper showed that without the Montreal Protocol, UV radiation in northern Europe would be 10% higher than today. There are concerns over air quality in the UK today but it is easy to overlook how much the situation has improved. It is a telling statistic that in the 1980s, the sulphur content of the air in the Outer Hebrides was higher than it is in central London today. The story of acid rain and its impact on the UK and continental environment was instrumental in our cleaning up our energy production act.

Finally, 18 months ago, there was a high wind, wave and tide event just as large as the 1953 event that caused widespread devastation on the east coast of the UK and in the Low Countries. This time, however, it went largely unnoticed – save perhaps as a tourist attraction. This is a testament to the understanding – born of NERC-funded work and then outwards through the Met Office and beyond – in forming our coastal defences and their emergency response strategies.

Independent, objective advice has had a tremendous effect on UK policy, no more so than on concerns about the environment.

Resources or environment?

In 1964, when the present Research Councils were coming into being, there was a proposal to create a 'Natural Resources Research Council'. The emergence instead of the Natural Environment Research Council was, even then, recognition of the tension between benefiting from the environment and the demands being made upon it.

We have become familiar with the concept of a 'safe' limit on CO_2 in the atmosphere – to which NERC and the UK have made enormous contributions. Yet questions remain on issues where we have much less insight. Is there a minimum safe level of biodiversity, or a maximum demand on soils and water, for example? And then in terms of wider engagement, what economic framework do we use to judge the choices that will command wide agreement?

I have no doubt that NERC, along with its sister councils, will have its work cut out for the next 50 years, just as it has in the past 50. □

Questions remain on issues where we have much less insight. Is there a minimum safe level of biodiversity, or a maximum demand on soils and water, for example?

The business of the environment

Simon Pollard

Professor Simon Pollard is Pro-Vice-Chancellor for the School of Energy, Environment and Agrifood at Cranfield University. An expert in risk science and practice, his work has influenced the practice of risk management and policy within Government, among its regulatory agencies and within the international water utility sector.

SUMMARY

- We are reframing the debate on resource extraction and environmental protection.
- Absolute decoupling of economic growth from environmental impact is widely accepted as vital.
- Transdisciplinary and applied skills are needed to manage the green economy.
- Big data will play a large part in identifying opportunities and mitigating risks.

Can we resolve the inherent tension between resource extraction (for economic activity) and environmental protection (for the protection of natural capital)? I offer three responses:

1. Advanced economies now recognise a 'green economy' as a prime contributor to economic recovery, or full blown growth. In response we are reframing the environmental sciences, in part, in light of business needs.
2. There is now wide recognition that 'absolute decoupling' of growth from impact is a necessity and so new business models, most of which have been in the wings for some time, are being explored with vigour – one model is the 'circular economy' in which material flows are of two types, 'biological nutrients', designed to re-enter the environment safely, and 'technical nutrients', which are designed to circulate at high quality without entering the environment.
3. These changes, when set in the context of economic need – building cities that are resilient to shock, analysing resource flows through global supply chains, and deploying ecological principles for engineered systems – are generating exciting opportunities for business, which is in need of professionals with the requisite skills who think this way.

Context

The annual global amount of materials extracted, harvested and consumed stands at just over 60 billion metric tonnes and is expected to rise to 100 billion metric tonnes by 2030. Eighty per cent of these materials are construction minerals, biomass and fossil fuel. The total materials requirement of all economies relies on domestic and imported materials, that carry additional embedded burdens – carbon, water, public health, security risk, are examples. Further, the degree of 'lock-in' within the global economy is substantial in terms of trade and technology, so unplanned disruption of the system in the interests of 'sustainability' would be naïve.

Resource extraction tracks economic growth, and growth is ultimately constrained by the economic availability of resource stocks (reserves). The seminal work on 'limits to growth' was undertaken by the Systems Dynamics Group at the Sloan School, MIT, in the early 1970s. Using a scenario approach – the World3 model – they compared the 'number of earths' required to support human activity (including the absorption of wastes) with humanity's ecological footprint, and projected this forward in time. In short, we are now in 'overshoot' – our needs have exceeded the resources available and so we must examine how we can continue to develop and support societies by decoupling growth from its impact.

How severe a decoupling show we pursue? Economists speak about decoupling that happens 'relatively' (degradation continues, but at a lesser

rate to growth, pursued by the OECD since 1980) and 'absolutely' (degradation is truly stemmed, while development continues). We talk of 'resource productivity' (doing more for less) in order to secure absolute decoupling – indeed this is an enormous opportunity for clean technology innovation, if we want to take it. The debate on decoupling is at the stage where the aim is now to stimulate a green economy with targeted interventions that avoid the uncertainties of wholesale disruptive change to the industrial economy. This approach is being adopted by many voices and strategies – from the deep ecology (radical, revolutionary, act now) movement to a more transitional approach. One of these strategies is that of a circular economy – an economy that is, by intent, purposefully restorative.

The green economy

It is worth reviewing the breadth of issues that the environmental sciences are expected to address within the business sector. Companies have to manage: increased expectations on environmental governance; a growing demand to perform beyond basic legal compliance; the expectations of self-regulation, sharing more risk and cost; global value chains vulnerable to occasional shocks; and the rise of codified ethical standards.

Business leaders in the 21st century are expected to articulate the sustainability agenda through a tough filter of business reality because the agenda has become a main board item, with growing calls for the routine disclosure of environmental performance.

There is enormous business opportunity in all this. The international water sector, for example, is under considerable pressure. It is being required to reduce the energy costs of shifting water and so is seeking to revolutionise wastewater treatment and turn conventional unit processes into a manufacturing facility for phosphorus and nitrogen recovery. Biogas from digested sewage is being used to power on-site plant. These pressures can be viewed equally as business opportunities to drive innovation.

Governments talk increasing of a green economy. Advanced economies are becoming interested in the low-carbon environmental goods and services sector because of the prospects for growth, jobs, export, scale-up and the skills opportunity. The Department for Business, Innovation and Skills (BIS) estimates the global green economy to be a £3.4 trillion market, growing at about 4% per annum. The UK is the world's sixth largest supplier, with 3.7% of the global market share supporting just under a million jobs in the UK alone.

With all the information now available, we need to train the next generation of 'resilience managers' to tease out insights from systems and data.

New business models

So what are the strategies for reducing the tension between resource extraction and environmental impact? These depend on whether one opts for 'evolution' or 'revolution'; for transitional or disruptive change. The needs are to secure value (business) and well-being (society) through less impact while at the same time restoring the environment. In policy terms, this is about articulating the future we want (UN) or living well within our limits (EU). It would be folly to assume one strategy will deliver all the outcomes we seek, so we need to work with a palette of responses. Hence the need for an in-depth understanding of what different business models can deliver.

The linear paradigm of 'make, use, dispose' from the 1950s must now be considered unhelpful. Even a thermodynamic view of resource extraction, manufacture, product use, and resource recovery (adopted in the late 1970s after the last energy crisis) does not deal easily with systems and their interconnectedness.

Any new paradigm needs to focus on societal development, be uplifting (for societal buy-in) and value-centric to be recognisable to business. It must also generate jobs, well-being and value while restoring the environment. The circular economy is one such paradigm. It has its roots in the work of Fritz Schumacher, Walter Stahl and David Pearce. Reinvigorated by the Ellen Macarthur Foundation and others, with analytical insight from McKinsey and Company, it brings together the industrial and ecosystem in a new practical way. Here, the business of the environment is writ large – integrating applied environmental science and technology and aligning these with the economic needs of the industrial system.

The circular economy is purposefully restorative by design, and one in which material flows are of two types: biological nutrients, designed to re-enter the biosphere safely, and technical 'nutrients' (product components and assemblies that feed the industrial system), designed to circulate at high quality without entering the environment. The focus is on maintaining the value of system components – a sequence of cascades for capturing their value is deployed. Reports by McKinsey and Company highlight a combined annual trillion dollar opportunity (globally) in net material cost savings through transition to circular economy. This process is driven by factors such as increased design for re-use, new or enhanced recovery mod-

els, and the introduction of access instead of ownership models that promote greater circularity.

Skills and big data

Recent audits of the skills required to address these needs show a rising need for modelling, multidisciplinary thinking and translational science. We are certainly not short of data, information and evidence. The question for a systems approach is, can we generate meaningful insight from it that instils a sense of collective urgency to address these challenges? Cranfield's recent success in this regard relates to risk and big data – recognising the enhanced systems understanding that the analysis of large volumes of data might yield. To achieve that goal, a new generation of risk analysts needs to be trained in order to design mitigation strategies and seize opportunities that will emerge.

We are forging a new forward-looking, value-centric, business-focussed literacy within the environmental sciences; one that can challenge and work with business. Along with other disciplines, environmental scientists are moving apace, reframing much of what we have done with a new resonance for industry and focussed on the enormous opportunities that the future will bring. □

Further reading materials on this subject can be found in the event summary on www.foundation.org.uk

Balancing resource extraction and environmental protection

Ron Oxburgh

SUMMARY

- There is an urgent need to better understand how environmental systems work.
- Impacts are not always easy to see and science can help explain these mechanisms.
- Environmental regulation must be honest in both intent and application.
- Governments and commerce have a responsibility to understand the environmental implications of what they do.
- Research institutes have a vital role in helping everyone – government, business, regulators and the public – understand our environment better.

The world's population was 2 billion in 1927; today it has reached more than 7 billion. That is an explosive rate of growth which cannot be sustained by any species. Human beings represent a very significant mass of the species living on Earth and make enormous intrusions into the space – in every sense – of the other species living on this planet.

The challenge is to extract the resources we need and manage the abundant waste we produce without destroying the wider environment upon which humanity depends. It is often not appreciated that a huge range of other organisms like bumblebees, birds, frogs, etc, are all part of an organic web each with a distinctive role in the environment.

The Treasury now has a Committee on Natural Capital, chaired by Dieter Helm. The idea is to put some comparative measure, in this case a cash value, on the natural assets around us – the woods, the streams, particular populations of animals, insects. Then if some 'development' is being considered, the value to be gained can be compared against the environmental loss being incurred.

There is a real need to better understand how environmental systems work. Some things that we do may have relatively little impact, while some which seem trivial to us could have devastating effects. The consequences of human activity can be felt at different scales – local, regional and global. People are well aware if a wood is being destroyed when a new road is being built. It is fairly easy for people to make a link between mining and the environment. At a higher scale the connection is less obvious. Over-extraction of water may affect communities some distance away and may not be apparent to the people doing it.

At the global scale the consequences are even more difficult to see. The effects of greenhouse gases on the atmosphere were – literally – invisible until a significant amount of scientific research had been done. Similarly with ocean acidification which is arguably at least as important an issue as greenhouse gases in the atmosphere: again careful scientific observation was required to make the connection clear.

So, often it is only at a local level that the links are conspicuous.

The Lord Oxburgh FRS HonFREng is a former Head of the Department of Earth Sciences in Cambridge, Rector of Imperial College, London, Chief Scientific Adviser at the Ministry of Defence and Chairman of Shell. He has served as the Chair of the House of Lords Select Committee on Science and Technology. He is an adviser to the Government of Singapore and a member of the Singapore Advisory Committee on Science and Technology.

Acid rain

Acid rain caused a great deal of damage to the forests of Scandinavia. There was die-back on a very large scale and this came to public notice in the years after the Second World War. The suggestion was made that this was due to emissions from UK power stations, particularly the SO_2 but also NOx. Initially, this was resisted by the interested parties, but a great deal of detailed work (including a report from the Royal Society) confirmed that this was the correct conclusion.

The consequence was that the UK introduced a regulatory regime which has subsequently been extended to other parts of the world. Power stations were required to install scrubbers to take the NOx and SOx out of their emissions. This had the consequence that the problem was pretty much solved. This was a really good example of science-based regulation which enabled us to live somewhat better with nature.

Oil sands

The extraction of oil from oil or tar sands is an extremely emotive issue in many parts of the world. This is open-cast mining of impure bitumen, which has a lot of sand and grit in it that has to be disaggregated. The separated bitumen then has to be hydrogenated in order to produce oil.

This means of producing fuel is roughly twice as energy-intensive as conventional oil production, so it is expensive. In addition, Canada has a very strict and progressively-tightening regulatory regime, with post-production restoration as a legal requirement.

Yet, another element to the mix concerns the right to a livelihood of the indigenous people. The working of the oil sands has transformed the lives of the local people – the Cree. When I visited them, they told me that this was the best thing that had ever happened to them since they lost the fur industry on which they had previously depended. They now run the catering, they run the transport and the security for the operations: most of the non-technical aspects of these operations are carried out by local people.

The Arctic

Those two previous situations have been regulated quite effectively. Let us now look at the Arctic. The decline in summer ice has made the High Arctic accessible for a whole range of commercial activities that were unthinkable previously. Exploration for hydrocarbons is probably the most controversial currently. There are probably significant hydrocarbon concentrations worth exploring and the pressures for commercial exploitation arise partly from governments and partly from business competitiveness. There is a reason to go there from a commercial point of view!

My concern is that the Arctic has only very recently become accessible and our understanding of the way the environmental systems work in the Arctic is still rudimentary. I do not believe we know enough yet to operate there safely.

Most of the High Arctic resource lies within the sovereign territories of the main littoral states, primarily Canada and Russia, but Norway, Greenland and the USA also have an interest. However, the regulatory regime will vary country by country and based on an incomplete scientific understanding.

Shale gas

It is not clear if the shale gas industry will ever succeed in this country. Public opinion is strongly negative due to some rather poor early commercial practice in the USA. There remains, however, a substantial UK resource and indeed NERC research played an important part in demonstrating its existence.

There is an opportunity here to establish a science-informed, effective regulatory regime and, in fact, it is already happening. It must be honest both in intent and application, though. There are examples in the USA where a regulatory regime was imposed which was so stringent that it made the regulated activity virtually impossible. Indeed, that was the intent of the lawyers and the politicians who introduced the regime. So that is what I mean by 'honest'. In addition, the regime must be fairly applied.

Here, there is a role for the British Geological Survey within NERC. There needs to be a systematic understanding of the natural infrastructure of the country – the geology, the hydrology, the ecosystems – and the results must be publicly available to all. The level of detail has to be sufficient to indicate specific commercial potential so that companies can decide if a resource is worth detailed evaluation and investment. There has to be sufficient detail to inform the development of appropriate regulation as well. And of course, further research will be needed in support of these functions. Obviously NERC does many other things as well, but in this particular context that is what is needed.

Appropriate regulation

Appropriate regulation is absolutely essential if we are to manage our impact on the environment and particularly in a world with more than 7 billion people. Regulation depends on understanding environmental processes and one size does not fit all. There is a question of scale and proportionality: different regulations

are needed to fit different environments.

Past disasters have partly come through ignorance – acid rain is a good example – and partly through wilful neglect. Governments and commerce have a responsibility to understand the environmental implications of what they do. In other words, serious environmental impact studies and the regulation must be clear, timely and fairly enforced. I believe this would be welcomed by industry. Most big companies want to do 'the right thing', but if competitors are not obliged to do the same, their competitiveness and profitability are reduced and their investors unhappy. That is why regulation must be enforced clearly and fairly.

Government research institutes such as NERC have a key role as independent advisers. □

A response

Professor Jane Francis, Director of the British Antarctic Survey, joined the panel and gave a response to the speakers' presentations before the general discussion began.

The British Antarctic Survey (BAS) is keenly aware of the tension between resource extraction and environmental protection. We are a research centre of NERC and have been considering how to work with industry. That is particularly pertinent in Antarctica, which has stringent environmental protection laws.

As well as working in the Antarctic. BAS is engaged both in the Arctic and north of 60° south, around the Falkland Islands and South Georgia. We focus on environmental stewardship to aid decisions about our engagement with industry. We use science as our focus to help our partners in environmental protection and cost avoidance.

Resource extraction includes fishing. Our scientists understand the science that contributes to the understanding of fish stocks around the Southern Ocean, their conservation and the impact on the fishing industry.

Our next big challenge concerns the Arctic. There is a major opportunity for UK science to work with industry to ensure environmental protection. Ideally, the science needs to be undertaken to understand fragile Arctic environments before industry is established there. This is an urgent challenge we need to address now.

The debate

Following the formal presentations, a number of issues were raised in the debate.

There are critical environmental problems for society to address – the challenge of determining how to use infrastructure more effectively, especially in the field of energy; how to cope with climate change, bearing in mind the particular responsibilities of industrial countries and more general problems of equity. Preparations for the forthcoming UN Framework Convention on Climate Change Conference of the Parties (UNFCCC COP) meeting in Paris in late 2015 have already highlighted differences of approach.

Science is critical in providing advice on all these issues. There is a conspicuous lack of scientists in Parliament, particularly the House of Commons, so the scientific case was not always made at the right level. The question remains how to assess the interests involved draw the right judgments: in some cases, the more local the circumstances, the more difficult the resolution. There is a need to engage the general public at an early stage and for organisations such as NERC to give genuinely independent advice. Assessments need to be more than just the consequences of new technologies: a good example is the impact of solar farms on former agricultural land.

Each part of the world had its problems, of course. In China, for example, tensions arise where a paramount need to maintain social stability delays intervention in longer term problems such as climate change. There are issues around the role of the Research Councils, coordination between them, and the part played by the international community generally. Non-Governmental Organisations (NGOs) serve a useful role in drawing attention to problems but not necessarily in finding solutions to them.

Somehow we have to make better use of the available science and assess the enormous risks that society now faces. There are also legal matters to take into account: how best to protect citizens and protect their assets? In spite of the work of the Research Councils, the role of science is not always sufficiently recognised. For example should there be a Chief Scientific Adviser reporting to the Governor of the Bank of England?

Sir David King, together with Lords Browne, Layard, O'Donnell, Rees, Stern and Turner, have published a report[1] arguing that a switch to renewables could be achieved much faster if there was a dramatic reduction of the unit cost of renewables. The concept behind this report was debated at a meeting of The Foundation for Science and Technology on 8 July 2015.

An Apollo programme for renewable cost reduction

David King

Sir David King ScD FRS HonFREng is the Foreign Secretary's Special Representative for Climate Change. He has been Head of the Department of Chemistry in the University of Cambridge, the Government's Chief Scientific Adviser and the first Director of the Smith School of Enterprise and the Environment at the University of Oxford.

SUMMARY

- There are substantial benefits to society from moving to a fossil-free energy system.
- The scientific community needs to be engaged in finding solutions to this challenge.
- Non-OECD energy demand is growing fast and will soon overtake OECD consumption.
- Renewables, energy storage and transmission systems are the technologies that need transformation.
- Involvement from governments around the world can deliver the necessary changes.

Energy security, health and prosperity are all benefits of moving on from the fossil-fuel age to the fossil-fuel-free period ahead of us.

The UK is committed to an 80% reduction in CO_2 emissions compared with 1990 – and 52% by 2028 (set by the Committee on Climate Change). We have already achieved a 29% reduction compared with 1990.

Society faces an enormous challenge in stabilising the climate. Yet the consequences of failure are massive. What I will be addressing here is the need for a global surge in RD&D activity for to provide the necessary impetus for the private sector to bring cheap, low CO_2 emissions energy into the market, for all countries.

Re-evaluating risk

As part of that, a new risk-analysis programme has been published. It starts from a different point of view from the Intergovernmental Panel on Climate Change (IPCC), one closer to the kind of approach that a Government Chief Scientific Adviser might take. So it does not deduce the probability of different outcomes if the CO_2 level should rise to 550ppm. Instead, it asks what a meeting of heads of state might see as the big risks and then works out their probabilities looking forward in time.

For example, the risk of crop failure in China is a function simply of rising temperatures. Even at relatively small rises, the probability of significant crop failure starts to increase. Significant crop failure occurring simultaneously in several parts of the world would lead to a major issue.

Alongside rises in temperature, there are other factors to take into account. The biggest rice paddy fields in the world are in Vietnam's Mekong Delta. They are very close to sea level. If this level rises, saline ingress becomes more and more likely, particularly with storms at sea.

So there is a risk of large-scale crop failure where the tipping point is very close to where we are now – the probability is going up.

We are using the best integrated analysis in the scientific domain. We did not reinvent any science, we simply looked at risk in a different way.

Tackling the problem

Looking at the region between the tropics, it is clear there is tremendous potential not just from solar energy, but from renewable energy in general. The challenge is to achieve cheap energy production that becomes competitive with fossil fuel energy – and it does not matter where.

As part of that, I would like to see a surge in activity that will be attractive to the scientific community and pull them in. After all, this is, I believe, the biggest challenge we face today. So we need a thrust in R&D activity towards carbon-free energy sources.

Energy demand

Today, primary energy demand is mainly from the USA, Europe and Japan. Looking forward to 2035, the International Energy Agency (IEA) predicts substantial growth in demand in the Asia-Pacific region. Further on, Africa becomes

the big growth area. The focus, therefore, lies in that region between the tropics. Why? Because these countries need to leapfrog into the new energy rather than focus on fossil energy.

So what are the implications for the Climate Summit in Paris in December? Well, quite simply we are off-track. The non-OECD countries have contributed far less in terms of emissions than the OECD countries up till now, but that is changing dramatically. The challenge that lies ahead is to meet that new energy demand without fossil fuels while at the same time the older economies transition away.

To improve the odds of staying within a 2°C increase in global temperature, cuts in emissions have to be made faster. And the longer the delay, the sharper the reduction later on and the more challenging that becomes, economically.

Delaying the transition means that large-scale energy infrastructure will eventually be retired before it has delivered its full operating life and that will be costly. However, if developed economies progressively retire plants as they come up to the end of their lifetime, replacing them with infrastructure fit for a post-2050 world, that will be a relatively cost-free way forward.

One of the surprising lessons of the past 25 years is the massive fall in the installation cost of photovoltaics (paralleled by a significant fall in the installation cost of wind turbines as well). The installed cost of PV has come down from $10 per watt in 1992 to half a dollar per watt today and the curve is still downward. Indeed, the fall has been so dramatic that it is now competing (in terms of installation costs alone) with coal-fired power everywhere in the world. Now, of course that is not the whole story because of the issues of intermittency and grid connections, but it is a very important part of the story.

Feed-in tariffs have driven costs down by creating cumulative capacity, a demand for renewable energy installation. But these have done nothing for energy storage, smart grids or interconnectors, and that is the missing piece of the puzzle.

Can radical technology innovation reduce the cost of supply? Yes, but support has to be targeted. Now the pillars of energy production in the future will be renewables, nuclear, and carbon capture and storage (CCS), which permits continued use of fossil fuel. These are supported by technologies serving all of them – storage, transmission and energy efficiency.

Note that energy storage serves nuclear energy as well as renewables. Nuclear power stations constantly produce electricity, whether demand is there or not. Energy storage provides the ability to store energy until it is needed.

There is a large potential market roll-out in Africa and India for small-scale distributed systems and also for storage in countrywide grids.

An international clean energy programme would need to focus attention on the key areas of renewables, storage and transmission. Developed to the right point, the system would be competitive with fossil fuels. Yet why continue to focus on renewables given the fall in cost? Well there is still enormous potential to drive it still further down with appropriate R&D. For example, PV is still very dependent on silicon; no alternative materials have yet appeared on the market. There is similar untapped potential for storage technologies and transmission.

A programme would need to be neither a G7 nor a G20, but commitment from governments. Although it will be a programme of RD&D, success will be measured in emissions reduction, not citations! I have proposed a 10-year programme, beginning in 2016, overseen by a commission. Each member government would nominate one commissioner. Supporting the commission would be a technical committee, including with people from industry (to keep the focus on market-facing solutions), as well as people from universities, from the political scene, and so on. A group of officials would distil a road map, identify what needs to be done and then work with research labs around the world. The International Energy Agency would be the ideal body to collaborate with to develop this road map and a plan would be to co-locate with the IEA.

Vital work

The work on energy storage technologies is absolutely vital. It is not just one energy storage technology that is going to win in the marketplace, though. Obviously batteries have a large part to play, but may not in the end may be the biggest player.

It is estimated that there are 620 million people in Africa who have no access to electricity. Most of them are in off-grid villages, and extending the grid to them is not cost-effective. Distributed, renewable energy with energy storage on micro-grids has to be the right way forward – in India as well. So there is a large potential market roll-out in Africa and India for small-scale distributed systems and also for storage in countrywide grids (tens of gigawatt hours).

There needs to be 14-hour storage for PV but there is an opportunity for seasonal storage too. This would compete with gas-fired turbines.

Demand surge could also be managed by large-scale energy storage facilities. So replacing gas-fired turbines in the future with energy storage would be one of the objectives.

These turbines can be used when there is a surge of power demand. But of course the surge could also be managed by large-scale energy storage facilities. So replacing gas-fired turbines in the future with energy storage would be one of the objectives.

Britain has a 90GW capacity today. That is seldom used: the average is 50GW. Gas-fired turbines are used to meet peak demand but it could be satisfied at much lower capacity with sufficient energy storage.

There is a big market for energy storage. A company would buy electricity when it is cheap (when it is surplus to immediate requirements) and sell it when it is in demand and more expensive. There is a real market incentive. A price of $100 or less per kilowatt hour of installation cost is based on replacing gas-fired turbines.

Among the 60 countries that I have visited in the past year and a half, there is considerable interest in international collaboration in this area. So far, there are only expressions of interest. The EU Commissioner for R&D is very interested. A number of EU member states, as well as the USA, Japan, Korea, Mexico, UAE, India, Brazil and China have also expressed interest. If those countries all sign up there is a real possibility of success.

We hope to announce statements of intent from participating countries before the Paris Conference in December this year. This will give the conference an understanding of how to achieve in practice a de-fossilisation of the global energy system.

The G7 Heads of Government made a commitment to decarbonise the global economy over the course of this century at their June 2015 meeting. So the G7 are taking this process forward, but not under their ownership. A number of countries that are not in G7 are also interested. □

1. A Global Apollo Programme to combat climate change. Centre for Economic Performance, London School of Economics and Politics http://cep.lse.ac.uk/pubs/download/special/Global_Apollo_Programme_Report.pdf

Making the most of opportunities

Bernie Bulkin

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SUMMARY

- It is essential to identify those technologies where a global effort will make a real difference.
- Progress needs to be speeded up through learning from earlier programmes.
- Electricity storage is crucial for the long term success of renewable technologies.
- Electronics can help create the best combination of technologies.
- We need to be clear on the merits of various 'renewables vs. fossil' stories.

There are several potential components in a viable decarbonisation agenda – renewables, nuclear, CCS, storage, transmission and efficiency. Is dramatic cost reduction at scale really amenable to a global coordinated effort and, if so, where are the best opportunities?

The Global Apollo Programme involves science, engineering, the scaling-up of manufacturing and a process of industrialisation. Not all of these are equally suited to a global programme in my view. It would be unusual if scientific breakthroughs could be orchestrated by a global co-ordinating body.

But where breakthroughs have occurred, the engineering challenges can be distributed, co-ordinated, and tackled in parallel, in order to make progress at pace. Yet, each renewable and storage technology is different, and has achieved its own particular state of development at this time. Therefore, it makes sense to consider each of them separately.

Solar

Solar panel costs have already dropped substantially. At small scales, solar competes with the retail (but not the wholesale) electricity price, whereas wind is competitive at the wholesale level. For much of the planet, solar power (when

the sun is shining) is already the cheapest form of electricity. In some places it can be 20% of the cost of fossil fuel-produced power. Where there is no electricity yet, solar may be the only way to provide power cheaply and quickly.

There are new PV panel materials that are at various stages of development and some may not succeed in the long term. Perovskites have received the most attention recently, but there is a very long way to go. If things proceed well, new materials may be commercially viable by the 2020s. A global programme may not be necessary because the demand for such materials is so strong, and the manufacturing base is so similar to that for other electronic products.

However, there are opportunities for cost reduction in other elements of PV systems and a globally coordinated programme, focussing on these components, could be very productive.

Solar thermal technology is mentioned in the report. It is a viable technology and can already be deployed at scale as demonstrated in California. Yet it is expensive, and basically low-tech, using mirrors to generate steam. There is no obvious route to a step-change in cost.

Wind

Onshore wind is cheap and has taken its place with nuclear as a major source of power. Even in the UK, there are months where 15% of electricity comes from wind, primarily onshore. In Spain, onshore wind is usually the biggest single source of electricity over a year. The report says that investment should be stepped up in order to realise more cost reduction, but I disagree.

Cost reduction came in the past from increasing the size of the turbines. However, these are as big as they can be now, because it is just not possible to move bigger blades along roads. The market has reached a plateau on the cost curve and the future opportunity is small. We do need to understand why it took 20 years to drive down costs, though: that is too slow.

Offshore wind is completely different – a concerted effort will easily eliminate one-third of the cost, while industrialisation can do even more. The challenge for offshore wind is to accomplish in five years what took 20 for onshore.

In my view, offshore wind is the best candidate to achieve a breakthrough from a global programme. There is a lot to do and parallel processing with coordination is the way to get it done. It is interesting to contrast the opportunity for wind with that for nuclear – thousands and thousands of wind turbines can to be built, compared with some tens of nuclear plants (although possibly up to 300).

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Marine

Marine technologies make a tempting target for a global programme, because the resource is big and costs are high. However, the costs are so high, the conditions so difficult (especially for ocean energy) that I think the mountain may be just too big to climb. Major industrial players have tried and given up.

Biomass

This can have such a big impact at scale, across different geographies – and it does not need storage. Biomass electricity is very amenable to an Apollo effort, especially because of opportunities for biotechnology-enabled intensification of production, links to advances in food production and increases in farmers' income, as well as decisions about global land use.

Renewable heat

Renewable heat requires a great deal of clever engineering. The difficulty is that, even in the developed world, this is tackled in so many different ways. The hundred or more possible existing solutions need to be screened and the successful choices validated for scale-up. This, too, is very suited to an Apollo effort and especially applicable in colder climes. In addition, renewable cooling might hold some quick wins.

Electronics and storage

In the absence of cheap storage, there have been great advances in electronics for easy switching between generation inputs. This is very useful and important, because it allows, for example, solar and diesel to work together in places in Africa where these are the two best options. These switching systems must be cheap, invisible to the customer, and able to work both quickly (in the event of cloud cover, or an abrupt drop in wind speed or change of direction). They also need to be applied at a range of scales, from several kilowatts to many megawatts. While much has been done, we should view this as a key component for the Apollo effort.

Everyone agrees that storage is absolutely crucial, one of those areas of investment where

A concerted effort will easily eliminate one-third of the cost of offshore wind, while industrialisation can do even more.

Whatever other technological progress occurs, we will gain from advances in electricity storage. It is an area of investment where there are no regrets.

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The biggest opportunity at present is the lithium-ion battery. Costs have halved and halved again, and one more halving would achieve the $100/kWh target. It could be cheaper than lead acid within five years.

As a chemist I am pessimistic about completely new battery technologies, because batteries are basically limited by the characteristics of the periodic table. However, new materials, such as graphene, and new manufacturing ideas, such as semi-liquid Li-ion, and much better engineering, hold a great deal of promise.

Untruths

In the past six months, there have been comments – primarily from the oil and gas industry – that militate against progress here.

- "Renewables will not be big enough to take place of coal, let alone gas and oil." This message on renewables, heard over and over again, is most concerning.
- "Develop CCS for coal in developing world and for gas in OECD." I am pessimistic about CCS; it does not solve the sustainable development problems of coal, which go far beyond CO_2, and adds a tremendous burden to the cost of energy.
- "Establish a carbon price globally." This is particularly advantageous for gas suppliers, wanting to take some of coal's market share.
- "Oil will continue to be the dominant fuel for transport for the foreseeable future." This fails to recognise our ability to progress biofuels for aviation, decarbonise electricity and charge electric vehicles, at scale, during off-peak hours.

A big, well-funded global programme, if properly focussed, can make a difference. While science breakthroughs do not usually happen from such programmes, advances in engineering and industrialisation do, which is where the big opportunities lie.

An essential element in making such a programme a success, though, is to robustly counter untruths about 'renewables vs. fossil fuels' that are still being repeated over and over again. □

New technologies for a low-carbon future

Ed Heartney

President Obama has stated clearly that "Climate change is a fact. And when our children's children look us in the eye and ask if we did all we could to leave them a safer, more stable world, with new sources of energy, I want us to be able to say, we did."

The USA now has a Climate Action Plan and has pledged to reduce carbon emissions by between 26% and 28% by 2025. The plan emphasises energy efficiency and low carbon energy such as solar, wind and nuclear, and stringent environmental standards for power plants.

We are also leading on the international stage, as shown by our joint announcement with China on carbon emission reductions last November. The USA accelerated its commitment to reduce carbon emissions and China agreed for the first time to peak carbon emissions and a path for

SUMMARY

- Better and cheaper energy technologies are needed if the world is to succeed in its climate-change goals.
- The US is fully committed to tackling climate change and is working hard to make the forthcoming Paris talks a success.
- The Federal government is not the only supporter of these technologies. Much is happening in individual states.
- The US government supports a range of energy technologies but ultimately it will be the market which decides the ones that are adopted.
- Energy storage and smart grids help to ensure the efficiency of energy supply.

their reduction. At the Paris talks later this year, we will be seeking an ambitious, durable and effective agreement. The agreement must include everyone. Unless countries such as China and India are included, emission reduction plans just will not work. There will be tough negotiations, but with commitments from the EU, USA and China – covering over half of global emissions – good progress is being made toward a global climate deal.

Countries are submitting their intended national determined contributions (INDCs) in advance. We want legal standards so that everyone can compare what countries are pledging.

I would also point out that the Conference of the Parties (COP 21) in Paris is not the end of the process. Analysis of the INDCs suggests that a limit of 2°C global temperature rise may not be achieved. The United States wants the UNFCCC process to raise its ambition every five years, as technology gets cheaper and there is more public pressure for action. Moreover, one of the most important functions of the COP 21 talks is to give the private sector a strong signal to keep innovating – and investing – in low-carbon technologies.

It is not only the federal government that is taking action on climate change, but many individual US states, too. Thirty states require renewable energy to supply a percentage of their power: California, for example, requires 20%. States have cap-and-trade emissions plans, including nine northeastern states and California. A number are also pushing ahead on smart grids to reduce energy demand. While there may be no federal climate change law, there are many different initiatives bubbling up from the state level.

Solar energy

The United States is a huge country with strong sunlight and solar costs have fallen dramatically. The Sun Shot Initiative seeks a further cost reduction of 75%, in order to reach grid parity, where it can compete without subsidies.

The Initiative supports research and innovation with businesses and academics. It will last for 10 years, but has already reached 60% of its goal within four. It is helping to create a strong solar energy industry, with 140,000 jobs.

Wind

The Department of Energy is also pressing ahead on wind energy, both offshore and onshore. It is a lot like the Sun Shot Initiative and the proposed Apollo programme, trying to drive the costs down to grid parity. Once again, the government works in partnership with business and researchers to solve a wide variety of issues, from turbines through systems to manufacturing and placement. Costs have fallen dramatically. Deployment has increased sharply, too. Wind production has tripled, there are wind farms in 39 states and the USA is now exporting wind technology.

A great deal of effort has focussed on onshore wind, but now attention is shifting to offshore generation as well. The United States, just like the UK, has tremendous off shore wind potential and is investing in order to keep offshore wind costs down.

Carbon capture and storage

It will be very hard to meet our emissions reduction goals without carbon capture and storage (CCS). The International Energy Agency expects fossil fuels, including coal, to be in use for decades. However, it estimates that CCS could contribute 14% of cumulative CO_2 emissions reductions by 2050 and beyond.

Canada has developed the world's first commercial scale CCS plant in Boundary Dam in Alberta. This will capture one million tons of carbon dioxide each year – the equivalent of taking 250,000 cars off the road. Canada has several other large-scale CCS projects in the pipeline.

The US is supporting eight different CCS power and industrial projects. The Department of Energy has invested $3 billion, and with our private sector partners there is over $17 billion of total investment.

The Kemper Mississippi CCS project is operated by Southern Power, with assistance from the Department of Energy. The plant will produce 582MW of power, and use the captured CO_2 for enhanced oil recovery. Technical operations are expected to begin by the end of this year, and commercial operations by mid-2016.

Smart grids

I am surprised by how 'un-smart' most of our power grids are. They are still using technology developed in the 1890s, and in the US there is a patchwork system that has struggled to keep up with demand. More and more consumer electronic devices need to be regularly charged and so peak demand for electricity has been exceeding transmission growth every year.

Smart grids use technologies that have been developed in other sectors to greatly increase the efficiency of the grid. The US Department of Energy has allocated $4.5 billion to modernise

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FURTHER INFORMATION

A global Apollo programme to combat climate change. Centre for Economic Performance, London School of Economics and Politics
http://cep.lse.ac.uk/pubs/download/special/Global_Apollo_Programme_Report.pdf
Carbon Trust www.carbontrust.com
Committee on Climate Change www.theccc.org.uk
Department of Energy and Climate Change
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Oxford Energy, University of Oxford www.energy.ox.ac.uk/solar

the network, from research and development, to demonstration and deployment, as well as looking at interoperability and interconnection. In short, the aim is to bring the energy grid into the 21st century.

Energy storage

Energy storage works with smart grids to complete the picture. With a great deal of variable power coming online, energy storage has to move power from when it is generated to when it will be used. Storage can smooth out the peaks and valleys and eliminate the need for new power plants. The Department of Energy has a programme to encourage research and development on a wide variety of energy storage technologies. It is also working with the state of California, which requires utilities to provide a gigawatt of storage by 2022.

Industry is developing its own strategies too. One American energy company plans to develop 40–80MW of energy storage from banks of lithium-ion batteries. AES already has such plants in the US and Chile, and believes that, with the right enabling environment, it can provide energy storage without a subsidy.

The only way to achieve an international agreement on climate change is by developing cost-parity low-carbon technologies. There are many different technologies, some of which will work and some will not – ultimately the market will decide. ❐

The debate

Following the formal presentations, a number of issues were raised in the debate.

Opening the debate, Sir Colin Humphreys noted that the assessment of long-term levelised costs of renewable options was critical to the development of future energy policy. Further, to balance the electrical supply, innovative storage and smart grid systems are essential.

The debate focussed on the challenges of scaling up renewable options, storage and smart grids. Political will is needed to address these challenges, the greatest of which is to develop energy storage technologies at scale at an acceptable cost.

Political commitment

As is recognised by the Global Apollo programme to combat climate change report, political commitment has to be agreed for a coordinated programme with sufficient resources in support. Germany already has a competitive edge after making substantial investments in electricity generation from renewables. Even geothermal energy is looking viable in some situations.

Already, the development programmes for these technologies are advancing in countries like the United States and China. We have to look again on what should be subsidised in the UK and for how long. Cooperation, even collaboration, should be encouraged as well as competition between the technologies and all involved.

There are also practical issues to consider such as the choice of materials for offshore wind, in order to extend the life of structures, gearboxes and blades in the harsh corrosive offshore environment. Carbon capture and storage projects (CCS) are underway but the cost penalty for such systems make it unlikely that schemes will be widely adopted.

Gas-fired electricity generation produces the lowest carbon dioxide emissions per MWh of generation and could provide an alternative to coal-fired generation while renewable technology is being developed. Currently solar energy requires 4-6 acres per MW of generation capacity. Research on novel materials such as perovskites has shown significant efficiency gains in the conversion of solar radiation to power.

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