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THE FOUNDATION FOR SCIENCE AND TECHNOLOGY

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Scientific advice to Government

A consultation on updating the Code of Practice for Scientific Advisory Committees (CoPSAC) has been announced by the Minister for Universities and Science David Willetts and the Government Chief Scientific Adviser Professor Sir John Beddington.

This follows the publication of the Government's revised *Guidelines on the use of scientific and engineering advice in policy making* and *Principles of Scientific Advice to Government*. These Principles are now reflected in the Ministerial Code.

Both documents highlight important steps that have been made recently in embedding good practice for the management and use of scientific advice. It is hoped that updating CoPSAC will, in parallel, underline developments in good practice for the operation of Scientific Advisory Committees.

Mr Willetts said: "Getting expert scientific advice is fundamental to ensuring that policy is credible and sustainable. This consultation on the Code of Practice for Scientific Advisory Committees demonstrates the Government's continued commitment to promoting scientific advice of the highest quality."

www.bis.gov.uk/Consultations/code-of-practice-for-scientific-advisory-committees-consultation-document?cat=open

Global threats to water security

The protection of the world's freshwater resources requires scientists and policymakers to diagnose threats over a broad range of scales, from global to local, argues a paper published in *Nature* (467: 555-561).

The paper presents a worldwide synthesis jointly considering human and biodiversity perspectives on the challenge of water security.

The study uses a spatial framework that quantifies multiple stressors and accounts for downstream impacts.

The study found that nearly 80 per cent of the world's population is exposed to high levels of threat in regard to water security.

Massive levels of investment in water technology enable the richer nations to offset high stressor levels without tackling their underlying causes. Less wealthy nations, meanwhile, remain vulnerable to water scarcity.

A similar lack of precautionary investment jeopardises biodiversity, concludes the paper. Its analysis suggests that the habitats associated with 65 per cent of continental discharge deserve to be classified as moderately to highly threatened.

www.nature.com

Science budget secure in CSR

Following the Comprehensive Spending Review (CSR), the Department for Business, Innovation and Science (BIS) is to reform Higher and Further Education funding. This will deliver broadly 65 per cent of BIS resource savings.

However, it will continue support for the highest value scientific research, maintaining the science budget in cash terms over the Spending Review period with resource spending of £4.6 billion a year by 2014-15. A ring fence will be maintained by the Department to ensure continuity of investment in Science and Research.

Key capital projects include £220 million in funding to ensure that the UK Centre for Medical Research Innovation goes ahead as planned. Funding will be provided for the Diamond Synchrotron worth £69 million.

In line with the Browne recommendations, the Government is changing the way that Higher Education is funded, moving away from the current model to one where those who benefit make a greater contribution to the cost.

However, the overall resource budget for Higher Education, excluding research funding, will reduce from £7.1 billion to £4.2 billion, a 40 per cent, or £2.9 billion, reduction by 2014-15. The Department will continue to fund teaching for Science, Technology, Engineering and Mathematics (STEM) subjects.

Over the course of the Spending Review period, the Department for Business, Innovation and Skills (BIS) will reduce its resource budget by 25 per cent. Taking into account anticipated receipts, the cut to capital spending by 2014-15 will be 44 per cent. The Department's Administration budget will be reduced by 40 per cent, including savings from abolition of the RDAs.

Some of the Government's spending on science falls under other Departments and details about this were still awaited as *FST Journal* went to press, as was information on Technology Strategy Board funding.

http://nds.coi.gov.uk/ImageLibrary/detail.aspx?MediaDetailsID=2489

Plants face extinction too

A global analysis of extinction risk for the world's plants, conducted by Kew together with the Natural History Museum, London, and the International Union for Conservation of Nature (IUCN), has revealed that the world's plants are as threatened as mammals, with one in five of the world's plant species threatened with extinction. The study is a major baseline for plant conservation, says Kew, and is the first time that the true extent of the threat to the world's estimated 380,000 plant species has been known.

Scientists carried out the Sampled Red List Index assessments, a representative sample of the world's plants, in response to the United Nations' International Year of Biodiversity and the 2010 Biodiversity Target.

The work relied heavily on the vast repository of botanical information held in Kew's Herbarium, Library, Art and Archives, which includes some eight million preserved plant and fungal specimens; on specimens held in the Natural History Museum's own extensive herbarium of six million specimens; on digital data from other sources; and on collaboration with Kew's network of partners worldwide.

www.kew.org/news/one-fifth-of-plants-under-threat-of-extinction.htm

New guides to climate change

The Royal Society, the UK's national academy of science, has launched a new short guide to the science of climate change. The guide has been written to summarise the evidence and to clarify the levels of confidence associated with the current scientific understanding of climate change. It makes clear what is well-known and established about the climate system, what is widely agreed but with some debate about details, and what is still not well understood.

The guide concludes that, as in many other areas, policy choices will have to be made in the absence of perfect knowledge, but that the scientific evidence is an essential part of public reasoning in this complex and challenging area.

A new website which explains the science behind the headlines on climate change has been launched by Government Chief Scientific Adviser Professor Sir John Beddington. The website presents an overview of some of the main areas of study in climate science, to help anyone wishing to get beyond the day-to-day headlines and gain a deeper understanding of the fundamental scientific issues involved.

http://royalsociety.org/climate-change-summary-of-science
www.bis.gov.uk/go-science/climatescience

Science, technology and the Millenium Development Goals

Professor Sir John Enderby CBE FRS is the Editor of FST Journal. He was Professor of Physics at Bristol University from 1976 to 1996. He was elected a Fellow of the Royal Society in 1985 for his pioneering studies into the structure and properties of liquids and amorphous materials. He served as Vice-President of the Royal Society from 1999-2004 and was responsible for publishing. Sir John was President of the Institute of Physics in 2004. He is Chief Scientist at Institute of Physics Publishing.

In 2004 the International Union of Pure and Applied Physics organised a major conference in Durban, South Africa. The conference brought together physicists from the developed and developing countries to address a specific topic: how can science and technology assist in economic development? Some of the issues discussed included: medical diagnostics, provision of clean water, better exploitation of local resources, interconnectedness and access to international scientific literature.

Following this meeting, the Institute of Physics (IOP) decided that it would, with help from the World Bank, the American Physical Society and others, instigate a series of workshops under the general heading "Entrepreneurship for Physicists and Engineers". Although there was some opposition from representatives of the developed countries to the idea of such workshops, the concept was enthusiastically endorsed by delegates from developing and emerging countries, especially those from India, Brazil and South Africa.

The International Centre for Theoretical Physics (ICTP), based at Trieste in Italy, offered to host the first workshop. ICTP has a long tradition in organising workshops, conferences and fellowships for scientists from developing countries and its foundation in 1964 was the inspiration of a Nobel Laureate, Abdus Salam. Since the first meeting in 2005, some six workshops have been held in locations alternating between the ITCP and a developing country. They are hugely oversubscribed (typically 300 applicants for the 40 places) and consistently receive highly positive feedback from the participants.

Remarkable science

In October 2009, I attended the workshop held in Cape Town where the participants were chiefly drawn from sub-Saharan Africa. The host institution, the iThemba laboratory, specialises in nuclear physics and supplies radioactive isotopes for medical diagnostics. There were surprises in store for those of us who were unaware of the situation in Africa. First, there were remarkable examples of high-level science been carried out under very difficult conditions. Secondly the idea of acquiring entrepreneurial skills was high on the agenda; in the exercises carried out by the participants working in small groups, some quite outstanding ideas for commercial enterprises emerged. Yet perhaps the most memorable impressions centred on the hope that the Millennium Development Goals would indeed be met and play a major role in lifting Africa out of its poverty-stricken situation. Delegate after delegate referred to the MDGs and pressed those of us from the West about our commitment to them.

It seems that after the initial enthusiasm generated by the Millennium Summit in 2000, the eight goals have dropped out of sight among many of us in the West (myself included). I suspect that the deterioration in the global economy and the huge problems faced by nearly all governments as they try to stabilise public finances has diverted our attention from the needs of Africa. For me and others from the West, it was

World summit

With only five years left until the 2015 deadline to achieve the Millennium Development Goals, UN Secretary-General Ban Ki-moon called on world leaders to accelerate progress towards the MDGs at a special summit in New York on 20-22 September 2010. The summit concluded with the adoption of a global action plan to achieve the eight anti-poverty goals by their 2015 target date and the announcement of new commitments for women's and children's health and other initiatives against poverty, hunger and disease.

a salutary experience to hear at first hand the importance of the MDGs from an African perspective.

Grim outlook

On the face of it, the situation looks grim. Of the 20 sub-goals identified by the UN, three have shown no progress or have actually deteriorated while the progress of the rest is insufficient to reach the 2015 target if prevailing trends persist. Against this background, the current administration in the UK is to be congratulated for promising to maintain DFID's funding at its present level, given all the calls on the public purse.

It is idle to pretend that science and technology alone can address the goals given the problems associated with governance, inter-racial strife and social values. Nevertheless, at least six goals do require intervention at the scientific and technological level. The Royal Astronomical Society, for example, aligned much of the 2009 Year of Astronomy to address Goal 1 (poverty and hunger), 2 (primary education), 3 (gender equality) and 8 (global partnership). IOP will continue its commitment to development through entrepreneurship and several other organisations and universities are playing their part.

The challenge facing the UK and other developed countries is how to ensure that the science and technology made available to all developing countries is geared to local needs and infrastructure. The Astronomers, The Royal Society, IOP and others are making significant efforts, albeit on a modest scale, but the fundamental question remains: can these piecemeal but highly laudable activities address major issues such as the fact that women in developing countries face a 1-in-26 lifetime risk of death during pregnancy? A further 900 million people currently rely on water from 'unimproved' sources.

In short, given the proposition that science and technology, broadly defined, will be an essential component in the race to achieve the MDGs, is there a better way to coordinate the various contributions made by the UK – or is there strength from diversity in emphasis and delivery? The UN Secretary-General, Ban Ki-Moon, recently declared: "We must not fail the billions who look to the international community to fulfil the promise of the Millennium Declaration for a better world."

I hope this topic might form the basis of a Foundation Discussion in the not too distant future, or at least before the deadline of 2015! □

THE MILLENNIUM DEVELOPMENT GOALS		
Goal 1	Eradicate extreme poverty and hunger	
Goal 2	Achieve universal primary education	
Goal 3	Promote gender equality and empower women	
Goal 4	Reduce child mortality	
Goal 5	Improve maternal health	
Goal 6	Combat HIV/AIDS, malaria and other diseases	
Goal 7	Ensure environmental sustainability	
Goal 8	Develop a Global Partnership for Development	

On 16 June 2010, the Foundation for Science and Technology held a joint meeting with The Royal Society, as the UK's premier academy of science celebrated its 350th anniversary.

Securing our future prosperity

Martin Rees

The Royal Society's report *The Scientific Century* was prepared by a broad group not limited to fellows of the Society. This included two Nobel Prize winners and it pre-figured coalition politics in that it included both William Waldegrave and David Sainsbury – former Science Ministers who earned bi-partisan respect.

The report documented the UK's strengths in academic science: with one per cent of the world's population we deliver 10-15 per cent of its scientific output. The report distilled two important messages to the Government: first, science and innovation must be at the heart of any long-term strategy for economic growth; and, second, that there is a fierce challenge from countries which are investing at a scale and speed which the UK may struggle to match.

President Obama pledged, and I quote "the largest commitment to scientific research and innovation in American history". The biggest 'tectonic shift' in the world of science, though, is stemming from burgeoning growth in the Far East – from China above all. Since 1999, China's R&D spend has risen by 20 per cent a year, up to a level which is second only to that of the USA.

UK strength

The UK's current strength in science is substantially due to our university system. We are fortunate to be the only country outside of the USA with several universities in the premier league. Harvard, Stanford and Berkeley are perceived as major national assets because they attract global talent; this is due to the collective expertise of their faculty and the consequent quality of their graduates. They are connected into all the world's research.

These big universities are able to seize on an idea from anywhere in the world and run with it. They are repositories of expertise and there is direct knowledge transfer from university labs to the spin-off companies around them, the most effective knowledge transfer being by the movement of people. That is true of the major US universities but it is true here too – the high-tech clusters around our universities have grown and Cambridge was said in an FT article to be a 'low risk place to do high risk things' because of its successful cluster.

The Lord Rees of Ludlow OM Kt PRS HonFREng is President of The Royal Society, Astronomer Royal and Master of Trinity College in Cambridge. He has undertaken research at Princeton, Caltech, Harvard, Sussex and in Cambridge where he was Plumian Professor of Astronomy and Experimental Philosophy. Lord Rees is a foreign associate of the National Academy of Sciences, the American Philosophical Society and the American Academy of Arts and Sciences.

Over the last 10 years British academia has become more productive and more attractive. Young people educated here – whether British or foreign – have felt that our universities offer challenging career opportunities. A substantial proportion of faculty posts have, in recent years, been filled by distinguished people attracted from abroad. Our universities will only stay in the top league if they can attract world-class faculty – to do that they will have to offer the conditions of their leading competitors, Harvard, Berkeley and Stanford.

In a world of mobile talents this perceived attractiveness of the UK compared to others is very sensitive to funding levels.

This attractiveness includes relative autonomy and reasonable prospects of resources to pursue the research we choose (choices which are anything but frivolous as most academic scientists stake much of their working lives and reputations on them).

It is fair to say our leading scientists have staked their careers on a particular line of research – and have chosen well. They were given the space and the freedom to take professional risks, but the paths they took were unpredictable and often the pay-off was long in coming. Our universities will not stay competitive unless they can attract and nurture such people.

Tertiary education

I want to draw attention to the provision of tertiary education to the great majority of young people for whom the traditional honours degree is not appropriate. The expansion in the last 25 years of full-time Higher and Further Education is to be applauded. We should now remember that universities now accept about 40 per cent of each age group, compared to less than 10 per cent some 50 years ago. Yet this very welcome expansion has not been accompanied by greater diversity of role – we should not be listing all universities on one league table, they should all be doing different things. And here we can learn from the USA, where there are several thousand institutes of higher education, regional colleges, top quality liberal arts colleges and world-class universities. Of those many thousands, less than 300 offer PhDs in any subject. I think we can learn from this diversity.

I would like to venture an heretical opinion – I think there is an undue

DISCUSSION

Translation

Have we devised adequate policies for translating research into business opportunities? The Royal Society report was right to identify long timescales and large investment as necessary to bring research through to commercialisation. The Hauser recommendation for Technology and Innovation Centres is also a sensible one. But these do not wholly meet the need to get small companies, big companies and academia to work together. Nor do they address the problem of a lack of capital, when venture capitalists refuse to support new companies directly. In such cases, big companies need to act as venture capitalists themselves to support smaller ones.

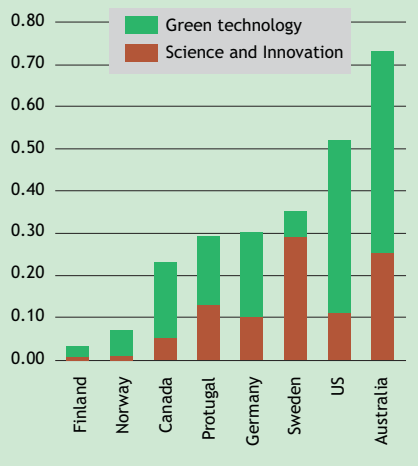


Figure 1. Expenditure on 'science and innovation' and 'green technology' in stimulus packages during the recent recession (% of GDP)

focus on traditional three-year degrees. Universities are too defensive and apologetic about drop-out rates. An American will say "I had two years at college" and will often rightly regard that experience as positive – it is surely good that universities are less selective, take risks on admission and give even unpromising students the chance. Some may leave after two years, but they should leave without being typecast as failures, and they should have the prospect of continuing later.

The research universities

The crucial point, though, is to ensure that we do not jeopardise areas where we are currently strong – and this means particularly the research universities. There have been two disquieting developments recently. Even the best postgraduate students and post-docs are now very worried whether there will be a future for them in British science. The signals for these people are discouraging and, if not reversed, the same signals could turn off the next generation.

Compared to two years ago, the perceived attractions of the UK have fallen relative to other countries. So now we are less able to attract talent and we even risk losing what we have. The sums involved in sustaining British research morale and competitiveness are trifling in budgetary terms, even compared to the cost of bankers bonuses they are trifling. Output is very sensitive to signals – it makes a big difference whether funding is level, going down a little, or rising – there is a multiplier effect in that talent attracts talent, high morale stimulates risk-taking while on the other hand pessimism erodes confidence and discourages people from going into science.

Right now, it is the job of the scientific and engineering community to help the Government to meet the immediate challenges and realise its long-term ambitions. We accept that not everything can be funded, but some cuts are more irreversible than others. Scientific knowledge is collective, public and international but its benefits can only be captured by those who are educated and that is why each country needs to maintain strong and broad expertise: this is especially true of the UK.

Short term decisions

So, short-term decisions should not undermine continuing improvements in the UK economy through national assets like our research universities. We must be allowed to punch above our weight in developing the technologies needed for our economy and to meet global challenges.

I will quote what Melvin Bragg said when he gave the Wilkins lecture for The Royal Society in the Sheldonian in Oxford a few months ago. He said "We are supposed to be a clever country. We used to be a common-sense country, but not for much longer if the politicians continue to undervalue the potency of those Francis Bacon called 'the merchants of light', of new knowledge, especially scientific knowledge which is unarguably the only sure wealth of the future." □

http://royalsociety.org/the-scientific-century

Shaping a vision for UK research

Paul Nurse

I am speaking on behalf of the Council for Science and Technology (CST) and I want to emphasise three messages springing from our report, *A Vision for UK Research*. The first is that scientific research is of great value to the UK: science matters. The second is there should be a greater focus on people rather than projects, for the highest quality research. The third point is that we need to be better at translating research into social and economic value.

I want to start with the attributes of science that make it the most effective and powerful process for improving knowledge of the world and of ourselves. It is very difficult to talk about scientific method but easier to think of attributes which define science. By 'science' I should say that I include the social sciences. Both respect reliable and reproducible data and observation – that is central. They emphasise the need for a coherent and consistent general view of the world. They generate ideas and theories which are capable of being tested and refuted. They encourage a healthy scepticism – no scientific dogma is so sacred that it cannot be attacked: at the limits of research, knowledge is tentative and only becomes more certain as a consequence of constant challenge and testing. Knowledge gained in this way is reliable and gives us the power to change the world. Francis Bacon said in 1597: "For also knowledge itself is power, knowledge can be used to change the world."

Sir Paul Nurse FRS is a member of the Prime Minister's Council for Science and Technology and President of Rockefeller University. Sir Paul became Rockefeller University's ninth president in September, 2003. A Nobel Prize-winning biologist, his research focuses on the molecular machinery that drives cell division and controls cell shape.

By providing this knowledge and power, science is of great value for the creation of wealth, for the improvement of health, for enhancing the quality of life, for protecting the environment and, in league with our colleagues in humanities, for enriching our culture. Countries like the USA that have heavily invested in science have done very well economically.

Other countries like China and India have also recognised this and they too are strongly investing in science and technology. The UK must do the same. Yet to be effective, investment must be done well and the CST recommends a greater focus on the people to drive science and its applications forward, especially at the discovery

end of science. We need a culture that will find the best scientists, inspire them, educate them and train them to engage in the scientific endeavour.

A focus on people

The CST focussed on two proposals, looking first at graduate students and post-doctoral workers and then at more senior investigators and research professors. We suggest the PhD should be re-examined, perhaps looking more closely at the balance between a Masters and a PhD. We would wish to keep a broad base in skills so that people are still able to engage in a wide variety of subsequent career paths; with the best graduate students actually choosing research. This may lead to a smaller number of PhD students, but these would be of higher quality. We also propose that a prestigious national scholarship scheme be established to support the very best PhD students from the UK and around the world – a scheme equivalent to the Rhodes Scholars.

I personally feel that it is very, very important to create a new, highly prestigious research professorship scheme. I think that the UK could identify 100-150 researchers of the highest level, the programme could be based on the Royal Society Research Professorship Scheme, covering all subjects but also with direct grant support for their research. Such a scheme would send a signal to the world that the UK is serious about science.

One of the biggest challenges in directing research funding is that most talented scientists are driven by powerful curiosity and they are sceptical. They do not, therefore, respond well to top-down direction. However, society has its needs and it wants certain problems solved. I think we need much more creative thinking about how we can best couple these two, often conflicting, aims. We have to inspire our best scientists so that their curiosity is driven by problems and issues of relevance to society itself.

The best people also need excellent infrastructure and excellent support which is why the present challenge to university funding is so worrying. They need to be very open to inter-disciplinary working as it is often in the spaces 'between subjects' where innovation is found.

Achieving translation

We must also have better translation of research into value. We sometimes beat ourselves up a bit too much about this in the UK. I have spent the last seven years in the USA and they worry about it there, too. They do not think they are doing it very well and a National Academy report, *Rising Above the Gathering Storm*, made just that point. I believe that no-one knows how to do it really well: if we recognise that, we can think creatively how to do it better. Translation works better in the USA in part because there is more money in total, and in part because of the entrepreneurial nature of the business community which is prepared to take risks.

We also need to employ a different time frame: it takes time to innovate well. As Bacon said in 1625: "Time is the greatest innovator" – well, it is the same today. The stock market and investment community are often too short-term, driven by the imperative of the casino, which is not conducive to innovation. We need to emphasise the long-term if we are going to get true innovation with less attention to marketing or short-term profit.

Achieving better translation is a big challenge. I think we need to dramatically increase the 'permeability' between the academy and the applied sectors. There must be a better flow of people between these two, recognising as David Sainsbury has said that we need an 'ecosystem of innovation'; we need networks and we need permeability.

The UK Centre for Medical Research and Innovation will attempt to find solutions to this challenge; it will be people-focussed, recruiting the best, training them well and providing high levels of research support but it will also experiment with the innovation which we absolutely require.

Science is powerful. It has the power to do good, and of course it has the power to do bad. To keep the trust of society, scientists need to engage the public in dialogue about their research and its outcomes, listening and discussing. We have to earn our 'licence to operate'. □

A Vision for UK Research — www.bis.gov.uk/cst/cst-reports#vision

Rising Above the Gathering Storm — www.nap.edu/catalog.php?record_id=11463

Establishing a successful long-term strategy

Richard Friend

The first recommendation in the Royal Society's report is the establishment of a long-term framework. It is the one point about which the Royal Society Working Advisory Group, of which I was a member, was able to agree on unanimously. The secret of success, if we want to bring about breakthroughs in research, is to ensure some predictability of funding for projects which may take several years to complete.

Timescales

Taxpayers pay for research on quite a large scale, particularly for university research. A key reason is that the timescale from genuine discovery to large-scale industrialisation is worryingly long. It is said, but I am not sure it is still true, that in life sciences patents protect drugs and there is a long timescale for trials. This has somehow preserved the industry and allowed it to continue its long-range, long-term process of discovery through to profit.

In the physical sciences where I work, life is much harder. It is very difficult to sustain value over long periods outside vertically-integrated corporates. Yet we have done away with these in the West although they exist in Asia and are remarkably successful in bringing forward expensive technologies.

However, I think I am correct in saying that Vodafone (which is not a technology-heavy company now) succeeded because a company called Racal had a technology advantage which could be applied locally. This attracted investment, which attracted bright people. I think it can work for us that way round. Opportunities to grow our own industries will come if we get our technology right. We need to be confident that we can take forward some of the big challenges. There are big risks, but potentially big pay-offs.

People

The people are key. We are in danger of taking snapshots of universities and looking at random white-haired professors, but actually we should concentrate on the PhD students and post-docs passing through – and we should be measuring their 'velocity', not their position.

Most of what goes on in the univer-

sities involves people moving through. There is an interesting chart in The Royal Society's report which indicates that just 3.5 per cent of PhDs end up as academic staff in the university system, which means that the vast majority pass through on their way to something else.

The report recognises that their careers matter too, because these are the people who innovate. There is no correlation between the intellectual ability and the drive of my own PhD students and the likelihood that they stay either in academia or go to industry – it is just a different career choice.

I am convinced that basic science is at the core of keeping our universities great and we really have to be the best, not just competitive. We do succeed in producing universities which lead internationally. So we must make sure that excellence is preserved as a gold standard. With it we are able to measure ourselves directly and quantitatively against the competition.

Is there just a single model where the university sits at the top of the pyramid and the companies around it are there because of the university? I am not sure. I suspect that there are other opportunities that we do not pay enough attention to. There are many challenges that you do not find by going to academic conferences – of the type where someone from industry says 'we have a lot of data and we don't really understand it'.

Sir Richard Friend FRS is the Cavendish Professor at the Cavendish Laboratory, the department of physics at the University of Cambridge. He is perhaps best known for his pivotal role in developing plastic electronics, a technology that is about to reach the market.

The Hauser report

Let me turn, finally, to the Hauser Report*. It highlights an issue which I have also become aware of, largely through my own involvement with small, high-tech companies. This is the problem of technology handover. I think we are very successful at training top quality, international scientists and engineers. Many of them move into small companies in science parks, but they do not go into corporate labs in the UK because these have gone – GEC, Marconi, BT Labs, CEGB, British Gas and, of course, many of the MOD labs.

Where are our PhDs going to acquire the skills that these labs used to offer? We no longer seem to have the skill base and the engineering competencies to take projects through to the level of system engineering where it is possible to obtain funding through the market. As the Hauser report shows, where structures exist that allow a career path for practical, integrated system engineering to be acquired – such as the Fraunhofer institutes or the Holst Centre in the Netherlands – these are very effective in making a difference. The Hauser Report does suggest a way forward.

While the university sector remains in good shape, we have to pay some attention to ensuring that the right career options are available for the brightest students that we are attracting. □

* see pages 10-13 of this issue.

The impact of scientific research

Adrian Smith

Let me start with a clarification. The Science and Research Budget is both the budget that currently goes through the Research Councils – that is UK-wide – and it is the budget that currently goes into the English universities on the back of the Research Assessment Exercise (RAE), (Figure 1). About £4 billion of the £6 billion total administered by the Department for Business, Innovation & Skills (BIS) ends up in the universities; the facilities and international subscriptions that make up the rest are, in large part, serving the community who work in the universities. So the starting point here is that the universities and the university system are utterly fundamental to our work at BIS and we cannot, therefore, ignore the wider debate that is taking place about the size and the shape of the higher education sector, with the Browne Review on fees and the potential for some really radical thinking about the sector.

Over the last 10 years we have had sustained, increased investment – yet so have many competitive countries. Some of this increase represents 'volume', while some represents a financial change, in the introduction of full economic costing which was introduced in order to avoid over-trading and give sustainability in the system.

Professor Adrian Smith FRS is Director General Science and Research at the Department for Business, Innovation and Skills (BIS). Previously he was Principal of Queen Mary, University of London. At Imperial College, London, he was Professor of Statistics, Head of Department of Mathematics, Member of the Management and Planning Group and Company Director of ICON (Imperial Consultancy).

The number of researchers who submitted to the Research Assessment RAE in 2008 represented an increase of 12 per cent over 2001. I do not believe there was ever a policy or strategy discussion about the right growth of the number of researchers; it happened because we expanded student places in the university system. Universities consequently had to hire more staff. Research-intensive, ambitious and competitive institutions, meanwhile, sought more and more researchers who were integral to the RAE. I think there is an interesting question – what should be the right strategy on volume?

Long-term stability

Whatever the funding outcomes of the spending review are, whatever the strategy is, a long-term vision and long-term funding stability are fundamental to the whole enterprise. Furthermore, if we lose sight of the quest for excellence we are done for, although there may be a more nuanced debate as to what excellence actually means. There might be different forms of excellence – there might be different political views of what excellence

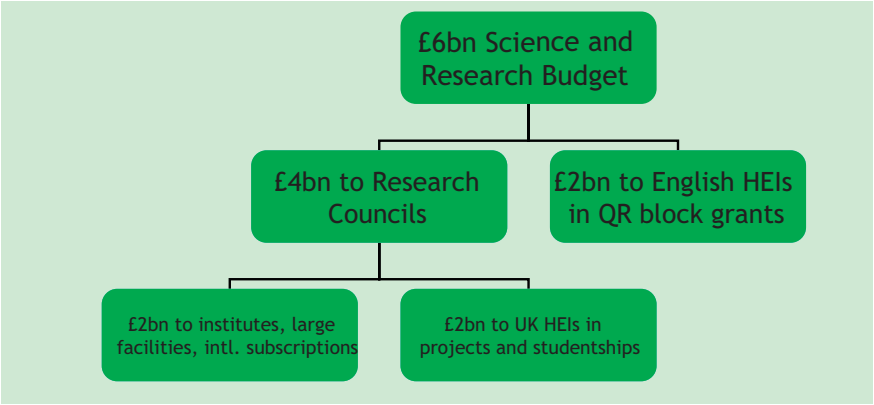


Figure 1. BIS research spend (simplified).

might be and we need to examine that.

There are more than 140 degree-awarding institutions in the UK but 90 per cent of public higher education research funding goes to just 40 institutions – and that number is getting rapidly smaller. Now, if we find ourselves with resources that are not increasing, the degree of concentration and the focussing of that resource on excellence and critical mass is something we need to consider. That could cause a perturbation in the funding pattern of higher education, as well as consequences in other policy spaces to do with access and geographic distribution. There is an interesting debate to be had here!

The starting point, though, which everybody recognises is that in terms of productivity and value for money, this has been a profoundly successful system. We out-perform our competitors.

There was talk, before the election, of higher education being moved into an education department: that is no longer being considered. As I and the Government's Chief Scientific Adviser Sir John Beddington constantly remind anyone who will listen, we have to regard BIS as the custodian of the research base on behalf of the whole Government. What comes out of the research base is fundamentally important to health, to energy, to the environment, to defence, to security, and so on. So there is a multi-faceted range of benefits from research which are not narrowly economic.

However, if BIS is to be the economics department that will drive the growth which will be the central feature of Government strategy, it is in all our interests to demonstrate the fundamental economic impact of the research base. A huge proportion of the output from that research base feeds into public policy, public services, debate, culture and the delivery of highly-skilled people to the labour market through every aspect of UK life. In more narrowly economic terms, it helps improve the performance of existing businesses and the creation of new businesses. The quality of the research base acts as a magnet for globally mobile R&D investment.

Universities and businesses

Over the years we have given universities the capacity to build commercial knowledge and technology transfer expertise. The number of spin-offs and the number that survive are, again, success stories. More broadly, the interface between universities and business, in terms of money generated, has been a great success as recorded by numerous studies.

We have now developed cross-cutting research programmes, in combination with Government departments and businesses, to respond to major challenges – living with environmental change, global uncertainty, aging, digital economy, etc. If the taxpayer is spending £6 billion, then we have to demonstrate that this is being used to solve the big problems of the age – yet, on the other hand most of us would accept that creativity comes from not telling other people what to do. At the moment about 15 per cent of the total Research Council budget goes into these programmes, so we need to ask if this is the right figure and if these are the right challenges.

We have a dual support system. The money that goes directly into the institutions enables autonomous universities to build great departments, to recruit and retain great people and develop their own plans. The money channelled through the Research Councils can be directed more strategically or it can be 'blue sky', and it supports PhD students. There are also substantial amounts of money going to The Royal Society, the Royal Academy of Engineering and the British Academy. Do we have the balance right?

Broader working

Politically, we need to encourage a culture where it is natural for people to work across the academic and business interface.

Looking at careers, we have to make it easier for people to move around the system in different ways – and this will involve the nitty-gritty of promotion criteria within universities and the signals that are sent through things like research assessment exercises. If only published work is important, how can you take five years away from academia to do something else?

The RAE did establish a competitive dynamic which significantly changed the quality and focus of research. In a time of straitened circumstances, do we need to reverse this somewhat to look for structures or incentives or edicts that encourage much more collaboration?

And the climate in which we are going to make these arguments is fundamentally affected by the public attitude to science – ultimately the taxpayer has to be prepared to spend money on science.

So we have to address the major challenges of the age, whilst at the same time recognising that creativity comes from letting the brightest and the best do what they want to do. We have to negotiate the settlement in a highly political context against a very difficult situation. □

DISCUSSION

Individual and community needs

Scientists are often highly individualistic, driven by passion for their subject, and so unlikely to respond to direction. Yet the Government has to address national priorities. The way forward is for the Government to devise a broad-brush approach incorporating social values, while leaving it to institutions and individuals to focus on specific projects. Individual scientists will respond to the need to work on areas such as climate change or world hunger from idealistic motives, if they know that such work will lead, if not to great financial reward, to meeting global needs.

If science and innovation is vital for the UK's future economic success, how can it be made more effective? A meeting of the Foundation for Science and Technology on 18 May 2010 considered the conclusions of a Government-commissioned review.

Bridging the gap between ideas and applications

Hermann Hauser

The UK leads in research, but lags in commercialisation. We can improve that by creating Government-supported technology and innovation centres (TICs), which I call 'Clerk Maxwell Centres'. Like the Fraunhofer Gesellschaft in Germany, they are intermediate institutions that cover the transition of a technology from a demonstration to a product prototype stage (technology readiness levels 3-8, see Figure 1).

These translational or intermediate institutes round the world perform a very valuable function in society, facilitating the path from research to successful products or licences. If it had not been for the Industrial Technology Research Institute (ITRI), Taiwan would not have its phenomenal LCD capabilities. If it were not for its equivalent, the Electronics and Telecommunications Research Institute (ETRI), Korea would not have its semiconductor industry today.

I am one of the few people still around who sat on the Alvey Committee – Margaret Thatcher's committee on high technology – when we sadly abandoned our own semi-conductor industry. At the time, with Ferranti and Plessey, it was as good, at least on the technology front, as any other semi-conductor technology in the world, perhaps with the exception of IBM. The reason why we gave up was quite interesting. Reports came in that Korea was going to spend $500 million on semi-conductors. Everyone thought this was ridiculous. Who would spend these very large amounts of money in a country that did not even have a semi-conductor industry? The rest is history.

Research to production

The classic way an idea makes it from research through to technology development, and on to production or service, is for development to be carried out in the central research laboratory of a large company. Maxwell Centres in many ways fill the void left by the demise of many of these central research laboratories, like Bell Labs, IBM, Philips – and in this country, Martlesham, GEC, Marconi Labs and EMI.

Dr Hermann Hauser CBE FREng is a member of The Prime Minister's Council for Science and Technology and co-founder of Amadeus Capital Partners. He was invited by the previous Government to conduct a review of the UK's science and innovation structures. He was also a member of the previous Government's Council for Science and Technology. In 2009 he took over the Chair of the East of England Stem Cell Network.

A good example of how this can work would be Cisco, which bought a company called Kalpana. Kalpana was a company which had revenues of $10 million. Cisco paid $100 million for it, and we all thought they had gone completely crazy. Why would they buy a company with $10 million revenue for $100 million? The answer was that it invented switched Ethernet. Within two years the revenue that they had gained from that acquisition was $2 billion.

We need these centres now, but not just because of the demise of the central research laboratories. Britain is placed second only to the United States when it comes to the quality of research papers that we produce, but we lag in commercialisation. Maxwell Centres will avoid sub-critical initiatives, help with the national strategy and encourage the skills base. The centres' main objective is to make research investment-ready.

A particular sector warrants a Maxwell Centre if it is big enough to justify Government's and tax payers' money being spent on it. There has to be billions of pounds of market opportunity for the establishment of such a centre to be worthwhile. In addition, the UK must have a research or technology lead in that sector. There must be a platform technology that has the opportunity of creating dozens of companies and licensing technology to a number of large companies. The sector also needs to have the ability to retain a valuable part of the supply chain. Last, but not least, of course it needs to attract global lead companies in the sector.

As to which sectors might be of interest to the government or the TSB, a few (which are by no means exhaustive) are: regenerative medicine; renewable energy; future internet technologies; plastic electronics; and advanced manufacturing.

The funding levels will be substantial, some £50-100 million over a 10-year

DISCUSSION

Funding worries

There are real issues to be resolved about: the practicalities of funding; the ability to focus Technology Innovation Centres (TICs) on selected sectors; the relationship of TICs with the existing academia/business relationships, where universities are already spending much effort on technological development and commercialisation; and the number and regional spread of TICs. While industrial partners will need to provide much of the funding for TICs, there will inevitably be a need for Government funding. Yet it may be unrealistic to expect new money from Government. This, in effect, means looking at existing structures and removing or modifying them. Institutional resistance will be strong, and Ministers will need to demonstrate political will if progress is to be made.

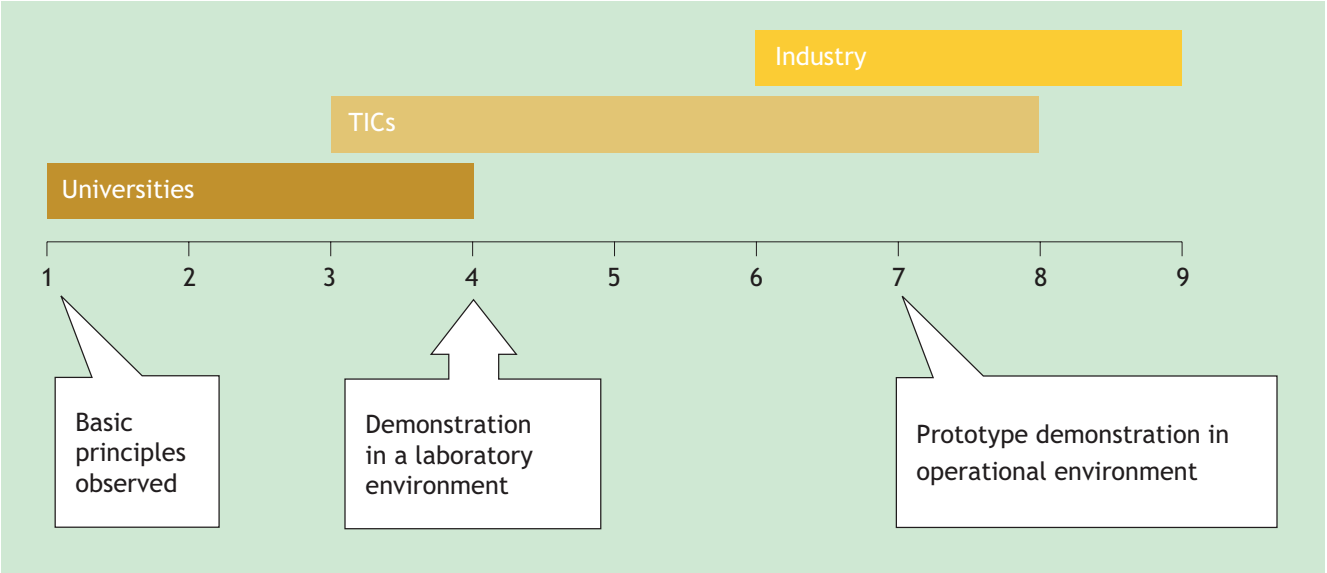


Figure 1. Technology readiness levels. Source: BIS

period per sector, so that means £5-10 million a year per centre. The idea is that about a third should come from Government, a third from industry and a third from Government or European Union projects.

Recommendations

The recommendation of the report I wrote for the previous Government was that it should establish a number of these elite, business-focussed Clerk Maxwell Centres. The Technology Strategy Board (TSB), the Research Councils and industry should work on this national strategy with a 10-year vision. They should select sectors which meet the criteria I have outlined, and work with existing TICs and Research and Technology Organisations. When choosing the location for a new Maxwell Centre they should remember that it needs to be close to where the research is, but also close to where the research can be absorbed – either through large companies or through an environment that supports start-ups.

Government procurement, in my opinion, could make a bigger change to the entire high-tech sector in the UK than anything else we do. The reason is very simple. If I had to choose between having a start-up company receive some more equity money or some money from a customer, there is absolutely no doubt why the latter is preferable. It is not just that the money does not need to be paid back, because it is money that a customer pays for a good product. Importantly, an informed customer helps the supplier to define the product so that it is precisely what the customer wants. So it is not just the money involved, but it is also the relationship that a good procurement office establishes with a young company that is important, teaching them what is essential in their products.

There should be a permeable membrane between the centres of academia and the centres in industry. This would help match technologies to the market. We should have an active secondment scheme between academia into the centres, and between the centres and industry. This is something that we do not do as well as we should.

The TSB is the obvious organisation to lead the definition and the funding of the centres. With UK Trade and Investment, it should promote them internationally, develop links, attract inward investment and make research investment-ready. □

The Current and Future Role of Technology and Innovation Centres in the UK; a report by Dr Hermann Hauser for Lord Mandelson, Secretary of State, Department of Business, Innovation and Skills, 2010. www.bis.gov.uk/assets/biscore/innovation/docs/10-843-role-of-technology-innovation-centres-hauser-review.pdf

On 25 October 2010, the Government made a £200 million investment in TICs.

The view from the Research Councils

David Delpy

The partnership between the Research Councils and the Technology Strategy Board (TSB) has been a real exemplar of success in this current spending round. Both bodies provide support for research and technical development in areas beneficial to the national economy, including creative and financial industries as well as more traditional areas. Despite what some academics may think, the Research Councils and the TSB do actually work together and they see each other as partners.

In considering the Hauser Review, we have to decide where precisely in this innovation landscape Technology and Innovation Centres (TICs) will sit. At RCUK we see them probably falling within the TSB 'space', rather than directly into the Research Council area.

We have a complex and well-populated research and innovation landscape. Research Councils are already involved with a variety of different forms of institutions and centres which are looking long-term. Despite rumours to the contrary, we do get involved in long-term funding of research: all the Councils do.

The one agency that I think is near-

est to what Dr Hauser has described as a 'Clerk Maxwell Centre' is probably the Innovation and Knowledge Centres (IKCs) that we have been funding jointly with the TSB and now other Research Councils. These centres are an attempt to meld the academic base with industry and long-term user involvement. There are four centres, and currently a call has been issued for more. They are very successful and are recognised as such by the academic base. We have had 32 applications for the two new centres that we are proposing to fund.

So there is a great deal of activity – and long-term activity – at that interface between the researchers and the users, but it is not perhaps at a large scale, which is what I think the Government was looking for.

A response to the report

We must identify areas on which to focus investment. The mantra "we can't pick winners" in the UK sometimes seems an excuse for not selecting or deciding anything. We cannot continue on that path: we have to make decisions. Dr Hauser has been brave enough to state his conclusions. His recommendations do link very strongly into the Research Councils' impact strategy. If we select the right areas, then these centres can build upon some real gems of work we currently support.

So, as long as there is a guarantee of sustained funding, we strongly support the conclusions of this review. It has to be implemented at the sort of level that Dr Hauser has proposed, but most important, the programme has to be guaranteed – it has to be sustained. People have to know that it is worth them investing in the long term.

Let me give a personal view – not, in this instance, that of RCUK. These ideas have been around for a while; more than 10 years in one guise or another. If this is worth doing then I would argue that further delay just compounds an error that we have already made. It puts the UK even further behind its competitors, so if it is worth doing we should just get on with it.

Professor David Delpy FRS FREng FMedSci is Chief Executive of the Engineering and Physical Sciences Research Council (EPSRC) and spoke on behalf of Research Councils UK (RCUK) at the meeting. His research interest is the development of techniques for the physiological monitoring of patients and especially the imaging of neonatal brain function. He has worked closely with many companies who have marketed the devices developed by him and his team.

Conversely, if we decide it is not worth doing, or if we cannot afford to do it, then let us make that decision quickly because there are a lot of other things we should concentrate on and we do not need the diversion.

So my interpretation of the rather cautious response of the TSB is that they ought to just jump one way or the other – and rather more quickly than they might prefer. That, as I said, is a personal view, though.

Contribution of the Research Councils

If these new centres are going to succeed, in the long term they have to be linked to the very best research groups. The one thing the Research Councils can bring to this agenda is that we know where these groups are. The reality is that research excellence is not uniformly distributed around the country. Yet we know, at a detailed level, where that excellence is – we know where it is within individual institutions. I can actually tell you who is good, and if you are going to put the best partnerships together I would argue that the Research Councils have that information.

More importantly than just straight success figures, we have really good information on individual academics and their ability or desire to work with users. The Research Councils bring an intimate knowledge of the research base to the determination of which centres to set up and who they will work with.

The funding for this initiative should clearly not come from the Research Councils' budget. It does not fall into their space, and I would argue that it has to be done with new money, or money raised from somewhere other than TSB or the Research Councils. If the funding is taken for this initiative from the Research Councils then the academics will see the TICs as competitors for funding and not as collaborators. Why would they work with an agency which is taking funding away from their research base?

Part of the success of the current collaboration with TSB has been that we have not been competitors. In fact, we have been collaborators who bring funding together from different sources and I think that has enabled us to work very well together.

TICs need to be intimately linked with skills training as well as postgraduate training. I would really like to see one of my centres for doctoral training working in collaboration with an agency which is also training apprentices and people with practical, technical skills. Bringing those two trainee groups together would bring enormous practical benefit.

To conclude: overall, both the Research Councils and the TSB are very supportive of the establishment of the sort of centres the Hauser Review advocates. However, they are only worth pursuing if the money is not raided from the existing Research Council or TSB activities – or unless some existing TSB activity can metamorphose sensibly into Clerk Maxwell Centres. We would also need a guarantee of funding for 10 years. □

Reflections from personal experience

Alec Broers

In the spirit that these occasions are sometimes referred to as 'debates', I am going to disagree with Professor Delpy. I approach this issue from a slightly different direction as I do not think that universities are the most important participants in these Clerk Maxwell Centres: I think industry is. I believe that the fundamental reasons for our lack of success in developing world-leading products lie more with industry than with the universities.

It is not the best of times to be launching new initiatives, but I would argue that the creation of the centres should be, in large part, a rearrangement of what we are presently doing. This would not necessarily require new resources.

Additional capital will be required to establish the centres initially, but it is my feeling that the ongoing expense need not be greater than we are spending at the moment in a distributed manner.

Of course, resources will have to be re-allocated in order to gather the long-term funding that the Review refers to and this is going to be painful for some, perhaps many. That will, however, be an inherent consequence of the change that, in my mind, we have to bring about. We must learn a lesson from the past. It has been our inability to face such difficult decisions that has led us to fail in many areas of technology, despite being strong in research – as Dr Hauser points out.

It is dangerous to draw general conclusions about the translation of science into commercial products because of the huge range of products that have to be considered. I am going to focus on the development of fundamental technologies, rather than on the design of products that use established technologies or that rely solely on software. I recognise that the design of such products can be complex and important and might well benefit from the establishment of Technology Innovation Centres (TICs), but I have little experience in those areas.

Instead I am going to draw upon my experiences with, and knowledge of, several international centres that are referred to in the report, as well as my experiences in the R&D laboratories of IBM, which actually continued for over 30 years. My observations reinforce many of the conclusions that underlie the report's recommendations.

Lessons to learn

I want to highlight the need to gather together multiple disciplines in order to bring technologies to the marketplace. I saw this especially when I was working in the R&D laboratories of IBM where, in effect, there were numerous TICs. In the teams I was a member of, there were electrical engineers, chemical engineers, pure and applied mathematicians, chemists and chemical engineers, experts in polymer and organic chemistry, materials scientists and computer scientists.

We must learn that the development and evolution of fundamental technologies – whether they be plastic electronics, genomic medicine, drug design, microelectronics, some aspects of renewable energy, communications, and so on – require collaboration with scientists and engineers with broad skills. These are not blue-sky science projects, although new science often emerges en route to the successful product; and I would say that in my experience more new products emerge through an evolutionary process in industry than they do from totally new science in universities.

The Lord Broers FRS HonFMedSci FREng is Chairman of the Diamond Light Source as well as Bio Nano, a joint venture between Imperial College and UCL. He is a former Vice-Chancellor of the University of Cambridge and a former Chairman of the House of Lords Select Committee on Science and Technology, of which he remains a member. He is also a former President of the Royal Academy of Engineering.

The members of the team in these centres must have common goals if commercial competitiveness is to be realised. I am not here talking about the setting up of manufacturing facilities but the stage of demonstrating commercially viable technologies.

Another lesson we should learn is that the resources required to establish international competitiveness are, in most cases, very large. We will have to restrict ourselves to a handful of TICs if we are to have a hope of succeeding. This may mean that some people have to change their subjects, or at least the particular direction in which they are focussing their expertise. I do not think it will be possible to modify our existing approaches in some comfortable way and still manage to establish these TICs and create real competitiveness.

It is important for adequate resources to be concentrated in a single facility, rather than allow ourselves to be bullied into setting up various facilities. It is also important to provide easy access for external users. I was closely associated with the establishment of the Cornell Nanoscience and Technology Facility in 1977. Although the main aim of that facility was not to produce product-worthy technologies, the facility is used a great deal by industry in developing and understanding nanotechnologies.

Collaboration with industry

It is essential that industrial partners ensure that the R&D pursued in the centre where they are participants, is what they really need to support their operations – rather than just more general research that might (or might not) be of interest to the company at some time in the future.

To make sure this is the case, the industrial partner should assign to the project or centre – preferably full time – some of its key engineers and scientists, not just employees that happen to be 'doing nothing' and looking for something to do.

The most effective way to transfer technology is via people. The presence of industrialists with a full understanding of their companies is essential if the centre is to yield commercially viable technology.

There are other centres I have been (and still am) involved with, such as the Diamond Light Source, where many of the desirable characteristics I have been referring to have been met, especially the concentration of expertise, the attention to users and the desire to work effectively with industry. The main aim is not to develop viable commercial products, but the advances that are being made are none the less important in the development of competitive products whether they are new drugs or more reliable turbine blades.

Conclusions

So let me finish by gathering together the conclusions that I have drawn from my experiences over the years. I am assuming that we are going ahead with these centres and that we are not going to dither about whether to proceed or not.

First, we need to draw together experts from a very broad range of science and technology. Many of these will work together within the centres, but outside participation should be possible and should be encouraged. Everyone, however, should share the same goals and, when working within a centre, be under the centre's management.

Second, the industrial partners must consider the work of the centre to be as important as their own internal work, and as a consequence assign key people to it.

Third, and perhaps most important, we have to concentrate our resources very much more tightly than in the past. At the same time, we have to get people to work in a focussed way on bringing scientific advances to the marketplace.

I can hear the objections and screams of the scientists, but to me – and I have spent a lot of time on what can be regarded as pure science – there is no satisfaction greater than seeing one's research being used to bring benefit to others. ☐

The UK needs skilled people in order to compete globally. The role of the education system in developing young people was the subject of a meeting of the Foundation on 28 April 2010.

Science and society in the 21st century

Mark Walport

The UK is not rich in natural resources, but has a wealth of human capital. All political parties have recognised the crucial importance of science, mathematics, engineering and technology for the future economic and social wellbeing of the UK. That future depends first and foremost on the value placed on education by society and on the resulting quality of our education system.

It was a privilege to chair one of five independent advisory Expert Groups set up by the previous Government in April 2009 to develop the UK's *Science and Society* Strategy. The group focussed on the 14-19 age group, investigating ways to 'stretch' more able pupils who have the potential to study natural science, mathematics or engineering at university. We consulted extensively, including written consultation, one-to-one and group meetings with stakeholders, and visits to schools and colleges. Finally, we held several workshops to 'road-test' our recommendations.

We made a series of observations and recommendations in our report, *Science and Mathematics Secondary Education for the 21st Century*. There is good news – participation and achievement in most science and mathematics subjects is increasing in the UK. Similarly, the numbers of students applying to study science and engineering in Further Education institutions are rising, though less in some subjects than in others. However, the bad news is that many young people arriving at university to read physics, engineering or chemistry do not have the depth of knowledge needed for Higher Education, especially the necessary mathematical skills. There is also an important shortage of specialist teachers: for example, 25 per cent of schools are without a specialist physics teacher.

How do we compare internationally? The UK's performance in science and mathematics education is broadly similar to that of other highly developed countries but this provides no grounds for complacency. Many educators and politicians in the USA are equally concerned with the quality of science education in their high school system. We must raise our game.

Sir Mark Walport FMedSci is Director of The Wellcome Trust and a member of the Prime Minister's Council for Science and Technology. Before joining the Trust, he was Professor of Medicine and Head of the Division of Medicine at Imperial College London where he led a research team that focussed on the immunology and genetics of rheumatic diseases.

Educational quality

There are six domains of activity that underpin a first class education. The first three are obvious and inextricably interlinked: teaching, curriculum and assessment. If any one of these is weak, then the education system fails. The fourth domain is the educational environment – the ethos and value systems of schools and colleges are of overwhelming importance. As one respondent put it, "You know the ethos of a good school when you walk through the door". Ethos is about leadership, community and governance. The fifth is the home environment, which, although extremely important, was beyond the scope of our work. The sixth is 'market pull', which is crucial for student perceptions and subject choices. It is not sufficient to state that science or mathematics is a 'good thing' – students have to be shown how these subjects can add value and provide opportunities for a better life. We made observations and recommendations for five of these six domains.

With respect to the triangle of teaching, curriculum and assessment, our consultation showed sadly that a dominant driving force is assessment. Examinations were reported to be 'the tail that wags the dog', with students increasingly taught to pass tests – and poor tests drive poor education.

Many of us recall the lifelong influence of a small number of charismatic teachers. There is no substitute for a good teacher and these have a deep love for their subject coupled with an ability to communicate this. Specialist teachers and technicians are essential if teaching is to improve. These must then be retained within the education system. Up to 40 per cent of science and mathematics teachers who qualified in 1999 were not in teaching five years later. The profession has to be made more attractive to improve retention. This can be achieved by improving prospects for career development and providing high quality continuous professional development (CPD). A key element of this is subject-specific CPD. Universal participation in CPD requires a cultural change in the behaviour of the teaching profession. One way of ensuring this would be to require that the school's executive must account for the uptake of CPD by their staff. Teachers' career progression should be linked to professional development and pay structures used to reward and retain specialists.

We found with respect to curriculum and assessment that Higher Education institutions, professional bodies and teachers have become progressively disengaged from the process of devising curricula and assessing academic performance. It is extremely important that these bodies re-engage and are held accountable for making certain that the curricula and examinations work well. Standing expert groups should be established in each subject area to advise on the development of curricula and on the criteria for the examinations. There was a universal chorus of complaint about insufficient mathematics content in the science curriculum. Mathematics content must be boosted substantially in the physics, chemistry and biology curricula for 14-19 year-olds.

In-depth learning

A good curriculum must balance breadth and depth of learning. It should provide a core of knowledge and beyond that should provide flexible scope for in-depth learning in areas suited to the interest and aptitude of both teacher and student. Young people should have the opportunity to

undertake an extended project in which they study a subject area in depth; ideally this should include hypothesis generation and practical work. Such projects might form one component of a portfolio which the young person would use in support of their application to Higher Education, in much the same way as art students already submit a portfolio.

To improve assessment we recommended that the overall burden of exams – in particular the modular system in which exams can be taken at different times and can also be repeated – should be reduced. Modular exams should be restricted to a single period in the summer term.

The examinations themselves need to be better constructed. More work is needed to strengthen the quality of the examination questions and to ensure that they test in-depth problem-solving and a deeper understanding of the subject. Examinations should also take into account whether the answers are clearly and grammatically written. It is important that scientists are able to communicate clearly.

In England, there are three examination bodies and there is concern, acknowledged by the examination bodies themselves, that competition between them could lower standards, schools and students choosing those that are perceived to provide the easiest tests or highest grades. There needs to be tough regulation to ensure that examination bodies work to raise standards rather than to reduce them. If this fails, the less palatable alternative is that the number of examination bodies should be reduced. In addition, the practice of examination bodies endorsing textbooks based on their own examinations drives the primacy of the test rather than the education and we recommended that this should be stopped.

'Market pull' is key to influencing subject choice and key subject choices are made early in education, often before the age of 14. School students need high quality, consistent information about the value and opportunities provided by different subjects, ideally delivered in the classroom by specialist teachers. This would enable them to see clearly the relevance of different subjects and how study of these might open doors and provide opportunities in the world outside the classroom.

Ethos

School and college ethos initially seemed to be a somewhat 'soft' area for recommendations. However, it ultimately became the subject of one of the key recommendations: that the equivalent of the 'corporate combined code' applied to businesses, or the 'statement of recommended practice' applied to charities, should be developed for schools and colleges. This would set out the key performance criteria for a school or college, emphasising the quality of education as the prime parameter. This code would be used by the executive team and governing body as a framework against which the executive would perform and the governing body provide support and challenge. Schools and colleges would report annually against this code in the same way that businesses and charities report against their respective codes of practice.

As an example, such a code would cover career development for teachers, including retention, promotion, and continuous professional development. For each of the activities necessary to develop an outstanding school or college, the code would set out the relevant parameters. At the end of the day, the best schools and colleges have outstanding leadership coupled with first class governance.

Ultimately it is the quality of teachers that matter. We must empower well-qualified teachers to use their skills and professional judgement to deliver the best education in a flexible fashion. They should be enabled to teach their subjects in depth and in ways that are interesting. They should have opportunities to link with the wider science, engineering and mathematics community in academia and business. This must be done in the context of secure subject content and standards. All of this depends on strong governance and accountability in every domain of education, from schools and colleges to the bodies that set curriculum and examinations. We owe this to the teaching profession and to future generations of children. □

Science and Mathematics Secondary Education for the 21st Century. **Available at: http://interactive.bis.gov.uk/scienceandsociety/site/learning/2010/02/25/new-science-and-learning-expert-group-report**

Improving science teaching

John Holman

The quality of an education system ultimately depends on the quality of its teachers. One can have excellent laboratories, well designed curricula and good examinations, but if good teachers are lacking then the system will not be successful. The mission of the National Science Learning Centre is to improve the professional development of teachers. Project ENTHUSE is a partnership project that provides bursaries for teachers from all over the UK to come to the National Science Learning Centre for professional development. The project is a three-way partnership between The Wellcome Trust, the Government and seven major science-based industries.

Sir John Holman was Director of the National Science Learning Centre in York until September. He has served as National STEM Director since 2006. After studying Natural Sciences at Cambridge, Sir John taught in a range of secondary schools. In 2000 he became Salters Professor of Chemical Education and Director of the Science Curriculum Centre at the University of York.

Science is a broad area that needs to be considered alongside technology, engineering and mathematics. A 2009 CBI survey of employers found that, of those who expressed a preference, two thirds said they prefer people with degrees in STEM (science, technology, engineering and mathematics) subjects – see Table 1. STEM looks rather different, depending on whether you are standing inside a school looking out, or outside a school looking in. In a school there is a large amount of science and mathematics in the curriculum, with a lesser amount of technology and engineering. Outside the schools, by and large, people employed in STEM fields are mostly working in technology and engineering, using knowledge gained by studying science and mathematics.

Table 1. Employers' preferences for degree subjects (%).	
No specific preference	42
Science, technology, engineering, maths	40
Business	13
Social sciences	3
Humanities	1
Source: CBI Education and Skills Survey 2009.	

The language of science

Mathematics is the language of science and underpins much of what modern employers want. It needs to be an intrinsic part of science teaching and included in science examinations. If you are an aficionado of science examinations, you will know that you have to hunt quite hard to find mathematics in GCSE and even in A-level science papers, and I do not think that is right.

It is encouraging that between 2005 and 2009 the number of students taking mathematics at A-level rose by 40 per cent – a higher increase than in any other A-level subject. Although this reflects the low number of students choosing mathematics prior to 2005, it also demonstrates that young people are increasingly realising that rigorous, quantitative subjects such as mathematics will make them more employable. There are a number of factors behind this, the two most evident being the current economy and the introduction of tuition fees. However, more positive reasons include Government initiatives such as the National Centre for Excellence in the Teaching of Mathematics (NCETM) and a brilliant programme called the 'Further Maths Support Programme'.

Returning to the CBI survey, 42 per cent of employers said they had no preference regarding degree subject. When the CBI asked what the most important factors were, a set of criteria that might be called 'employability skills' came at the top. These criteria included generic skills such as team working and problem solving. Clearly young people need a broad curriculum that includes a wide range of activities such as team sports and drama, but they also need science and mathematics to be taught in a way that will enable them to learn these generic skills.

Influences in primary school are crucial factors in the choices young people later make. There is abundant evidence that young people make up their mind about what they want to be and whether they want to have a scientific career very young. When the Royal Society asked over 1,000 scientists and engineers when they decided that they wanted to be a scientist, nearly two thirds of them said it was before the age of 14.

Primary science

One of the very successful parts of the National Curriculum in England was the introduction of primary science and the stimulation that this gave to the teaching of science in primary schools. However, there have been a number of studies suggesting that children's interest in science is declining, particularly as they get towards the end of primary schools, into Year 6. There are probably a number of reasons for this, including the introduction of tests in primary science and the fact that in some schools quite a lot of preparation for tests goes on, particularly in the last year of primary school. That has now changed and there are no longer tests for science in primary school – but will we be able to capitalise on this?

In primary science there are three very important points to bear in mind. The first is that in primary schools, unlike secondary schools, most teachers are not subject specialists. Therefore subject knowledge and, even more importantly, the confidence to use subject knowledge and engage in science is very important for primary school teachers. Professional development, including training of the kind that the Science Learning Centres provide, is essential if primary school science is to continue to grow in strength and inspire young people to go into science.

The second point is that science is a core subject in the primary curriculum, alongside mathematics and English, and until recently it was tested. Science tests have now been removed from the primary curriculum. On the one hand this is beneficial because studies have suggested that children's interest in science declines as they near the end of primary school, and this may be a result of the focus on preparing for tests. On the other hand, removing the tests has reduced the importance of science in the eyes of some head teachers. So it is even more important to keep the profile of science high in primary schools. An example of this is the introduction, with the support of the Science Learning Centres, of the Primary Science Quality Mark. We need to make sure that primary science remains strong and valued.

The third point is possibly the most important of all. Graduates alone are not enough.

Technical skills

Historically, we have not valued those whose skills are on the technical and practical side. Cogent, the sector skills body for process industries, forecast that by 2022 the demand for 'core workers' (technicians and operators) will be greater than that for 'higher-level workers' (managers and professional). They predict a shortfall of 40,000 core workers and an oversupply of 13,000 higher-level workers. We ignore the people who are going to be the technicians of the future at our peril.

This is also signalled very strongly in the recent report from the UK Commission for Employment and Skills, which highlighted the growing importance of technicians, especially in specialist STEM areas such as advanced manufacturing and new technologies. The European Centre for Development of Vocational Training echoes this forecast.

The sector that does most to train people to be the technicians of the future is the Further Education sector. It educates three million people every year and is an extraordinarily important part of our educational system. According to the Royal Academy of Engineering, 350,000 learners began an engineering qualification in further education, compared with 26,000 who began engineering in higher education. The 350,000 learners signed up for one of 605 engineering qualifications.

A further 601 qualifications exist but have no learners! Choice is a good thing, but complexity can bring problems. Work is being done within the qualifications accreditation framework to simplify this area of qualifications for technicians. It needs to be understood by parents and by pupils and employers with the same sort of clarity that A-levels are understood.

I will finish by quoting from Nobel Prize-winning Sir John Sulston about whether we will ever know the truth: "We continue from era to era of growing understanding, always with uncertainty at the leading edge." That is why we need really good science education. ☐

Increasing scientific understanding in the general population

Lisa Jardine

As an historian of science I will remind you that the motto of the Royal Society, the venue for this meeting, reads *nullius in verba*, meaning 'Take no man's word for it'. It was probably coined by John Evelyn in the 1660s to capture the concept that science is never to be taken on trust. Science is to be grasped, understood and absorbed by every individual – a sort of great Utopian ambition. Everybody in the English-speaking nations would internalise their understanding of the new science and they would then become functioning, scientific members of the nation, the community in which they lived. Acceptance comes through understanding – 'take no man's word for it'.

The heart of the problem under discussion is simply this: 80 per cent of the British public have to take science on trust because they lack the competence to scrutinise and assess it for themselves.

A scientific world

We inhabit a scientific world. If we did not have electricity we would have to live with candles and without phones. The experience of every moment of every day that we live is underpinned by science. The fact that ordinary members of the public are incapable of grasping not just the foundations of science but the scientific method of argument that would allow them to assess the evidence, is shocking.

When I was on the governing bodies of primary schools I became infamous on appointments committees. Miss X would come in and show us her dexterity on the recorder and how she could do leaf prints, Mr Y would come in and show us how he strummed on his guitar and tell us how he would take the children for nature walks. I would always ask them if they could teach the children how a lavatory flushed ... and they would just sort of fumble. Yet although it seems funny (and it always made everybody on the committee laugh) it is a really serious matter. Teachers in primary schools are not specialists and most of them lack confidence precisely in the area where 5-11 year-olds need to be given the confidence – in assessing the information they are presented with.

Professor Lisa Jardine CBE is a writer and broadcaster who holds the Centenary Chair of Renaissance Studies and is Director of the Centre for Editing Lives and Letters at Queen Mary, University of London. She is also Chair of the Human Fertilisation & Embryology Authority. Professor Jardine is a Trustee of the V&A Museum, and Patron of the Archives and Records Association.

I once made a radio broadcast about uncertainty in science, using the example of climate change. I showed how factual information can never be presented in its entirety and made the point that we all need to be able to process information when looking at these kind of issues. I received a deluge of email criticising me for treating the view that climate change is man-made – all of it highly emotional and devoid of rational scientific argument. The fact is that the British public is swayed to and fro like a straw in the wind by bigots and pressure groups of various kinds and is unable to focus on the problems facing practising scientists.

Assessing scientific advice

C P Snow wrote a set of essays entitled *Science and Government* which describes how close we came to tragedy in the Second World War because nobody in Government was equipped to assess the advice given to Churchill by scientific experts. In 1944, when all scientific resources were brought to bear on trying to bring Germany to its knees by aerial bombardment, the advice given by the statisticians closest to the Government was disregarded and replaced instead with the advice of the Chief Scientific Adviser. His advice was that the strategic bombing initiative would bomb Germany into submission. However, the statistics underlying that advice turned out to be ill-founded. Huge numbers of our airmen died and we did not bring Germany to its knees.

What Snow was saying in his essays was that the Cabinet had no way of judging which of the scientific proposals was the right one to adopt; so the day was carried by the politician who was personally closest to Churchill.

To a very large extent this is still the situation today. The number of parliamentarians with an understanding of science is pitifully small, and diminishing. The prospect of an advanced Western nation with a Government that is permanently hostage to committees of scientists, whose opinions cannot be properly assessed by parliamentarians because they do not have the wherewithal to do so, is a frightening one.

At Queen Mary there are many times more applicants for English than for Physics. Yes, let us produce great scientists, but let us also produce *more* scientists. □

DISCUSSION

Governance and collaboration

School governing bodies must play an effective role in ensuring good governance and proper accountability. Unfortunately, the effect of recent legislative changes to increase the proportion of parent governors has reduced the number of governors with special skills. These changes need to be reversed if some of the recommendations in the report are to be implemented. Employers, as well as further and higher education institutes, should engage with schools in order to improve the quality and take-up of learning in STEM subjects. While there may be resource implications for companies, greater efforts in this regard may lead to significant benefits both for schools and for employers. Science education is not just for a career; it is for life and all players (schools, higher and further education institutes, and employers) have parts to play in bringing about the required improvements.

Among the major infrastructure projects proposed for the UK is a new high speed rail network. A meeting of the Foundation for Science and Technology on 17 March 2010 considered the issues involved.

The future strategy for high speed rail in the UK

Andrew Adonis

The Government's proposals for the High Speed 2 (HS2) rail link, outlined in the recent White Paper, arise in no small part from the remarkable success of high speed rail in France over the past 30 years and that of the High Speed 1 (HS1) route from the Channel Tunnel through the Kent and Essex countryside to the gloriously restored London St Pancras station.

One of the biggest challenges we face in Britain, where the planning system is so complex, is to persuade people that it really is possible to plan and to build a high speed line. The history of the planning and building of HS1 was indeed a nightmare at times, but we can now look back on a project successfully completed and now well received. If we can build a high speed line through the 'Garden of England' and into London, then there is no reason why we cannot build a high speed line going north from London, connecting the great cities of this country – and ultimately continue to Scotland.

We have shown that it can be done. This Command Paper demonstrates why and how it should be done. Let me deal with the 'why' first. High speed rail will deliver significant journey-time savings between Britain's major metropolitan centres – London, Birmingham, Liverpool, Manchester, Glasgow, Leeds, Newcastle and Edinburgh. Central Birmingham will be 49 minutes from London Euston. Manchester, Leeds and Sheffield will all be 75 to 80 minutes from London.

As far as practical, the plan is to operate the system much as they do in France, where high speed trains can run on both the high speed line and the 'classic' lines. HS2 will join the West Coast Mainline at Preston and the East Coast Mainline just south of York. It will be possible to run services through to Newcastle, saving about half an hour on the current journey time and through to Glasgow and Edinburgh in an estimated three and a half hours. That is a critical target because at three and a half hours a significant shift is achieved in passenger numbers away from the plane.

The Rt Hon the Lord Adonis was Secretary of State, Department for Transport, from June 2009 until the May 2010 General Election. He had previously been a minister in the Department for Children, Schools and Families (DCSF). Before joining the Government, he was a Fellow at Nuffield College, Oxford, and a journalist on the Financial Times and the Observer. He is now Director of the Institute for Government.

Additional capacity

Yet journey time savings are only one of the reasons why it is in the public interest to take forward a high speed rail project: two other factors are equally significant. First, there is the need for additional capacity. Our estimates are that very significant additional inter-city capacity will be required in the 2020s, 2030s and beyond. There are only a few ways that it can be provided. We could build entirely new motorways, but our judgement is that this is not a sustainable step forward; motorways do not reduce journey times and do not go into city centres. Increasing domestic aviation is the other alternative, particularly in respect of Glasgow and Edinburgh to London, but it is not a practical alternative.

That leaves rail which, in terms of carbon emissions, is sustainable. Estimates in the Command Paper show no net increase in carbon emissions as a result of the high speed rail project, despite the huge additional capacity that it creates. Indeed, there is the potential for a major reduction in carbon emissions if there is a big shift from the plane to the train for journeys between Scotland and London.

In terms of capacity, therefore, the high speed line offers significant advantages over the other modes of travel, but also over other rail options. Atkins (the consultants) estimated that to increase capacity by 100 per cent through upgrading existing conventional lines, you would need to invest more in cash terms than in building the high speed line (from London to the West Midlands). This is due to the cost of disruption during the upgrade works. We concluded that the same will be true for increasing capacity further north.

There are marginal connectivity benefits from upgrading existing lines, while there are transformational connectivity benefits with the high speed line, and the cost/benefit ratio is far more favourable for a high speed line than it is for upgrading conventional lines. That is an important piece of analysis, because there are many who worry that the high speed line will take investment away from the classic railway. The experience in France and elsewhere is that once you embark on a high speed rail project, it tends to attract more traffic on to the railways overall.

Connectivity

High speed rail is not just about increased speed though, there are transformational

DISCUSSION

Rail freight

Freight would not be allowed on HS2 (HS1 was a special case). Network Rail would probably want to maintain its preference for passenger traffic, because it does less damage to the track; and the passenger operating companies would want to expand services rather than be constrained by freight movements. So if there is to be an increase in rail freight it can only use the existing network. How realistic is this?

capacity benefits and a set of connectivity benefits that come from not only running trains faster, but from fundamentally changing the Victorian railway map of Britain. The Victorians built their railways with private companies, all seeking to connect their own lines to their own individual terminus in London, hub and spoke – for this reason there is very poor connectivity between them.

For example, the distance between Birmingham and Manchester (the second and the third largest cities in this country) is just 82 miles, with a standard journey time today of an hour and a half. Leeds to Birmingham (the fourth largest economic centre in the country, connected to the second) has very poor connectivity: 116 track miles between those cities, standard journey time of two hours. Both of those journey times would be halved by the high speed line because it will be a single integrated line going from London to the West Midlands and then forking either side of the Pennines. Leeds to London via the West Midlands is precisely 20 miles further than Leeds to London via the existing East Coast Mainline which branches off at Doncaster. However, the trains run at 200 miles an hour rather than an average of barely 100. Then, if the TransPennine link is upgraded (as projected in the Northern Hub Proposal), the effect continues across to Manchester.

These connectivity benefits, which will fundamentally change and improve the relationship between our cities and economic centres, are further intensified by the connection of Old Oak Common with Crossrail at the Crossrail Interchange. This has two very important connectivity benefits. First, it is a 10 minute journey from Heathrow by Heathrow Express, so passengers will come straight into Crossrail Interchange, cross the bridge onto the Heathrow Express and be at Heathrow terminals in 10 minutes. We are looking to see whether that connection can be further improved, and there is a debate as to whether there should be a station at Heathrow itself.

Yet much more important is the connection onto Crossrail from Crossrail Interchange station (which is just 31 minutes from the West Midlands), where you will cross the bridge and go straight into the highest capacity, fastest underground line in London. From the Crossrail Interchange it is 10 minutes to the West End, 15 minutes to the City and 20 minutes to Canary Wharf.

If the political consensus holds and if we have the drive and the determination over the coming years that High Speed 2 has shown in taking this project forward over the past year, then I believe it is just possible that in 2026, we will all be at London Euston when the ribbon is cut and the first HS2 train leaves for the North. And the relationships between our major cities will have been transformed, for the better. □

http://webarchive.nationalarchives.gov.uk/+/http://www.dft.gov.uk/pgr/rail/pi/highspeedrail/commandpaper/pdf/cmdpaper.pdf

DISCUSSION

Future proofing

The whole project rests on assumptions about population and employment growth, people's travel habits and land-use planning policies. All of these could fundamentally change over the project timescale. Even now working from home, internet usage and technical developments in road transport and highway management are affecting future predications. How flexible are the plans? Can they adapt to such changes?

An opportunity to expand rail travel

Iain Coucher

At Network Rail, we welcome the proposals for High Speed Rail. Five or six years ago the Government was more interested in making the current system work properly than in expansion. Why the change? Today we run a record number of trains carrying record numbers of people, making record numbers of journeys at record levels of punctuality. Our safety record has been re-established and demand is growing. Some of the growth comes simply from population growth and some as a result of changing employment patterns and long-distance commuting. We have stimulated growth by offering better services at more relevant times, opening at weekends and through various marketing strategies.

Then there is growth on the railways that is driven by external factors. Congestion on the roads makes rail a better product. Road pricing, congestion charging and carbon interventions in the future will continue the trend of making rail travel more attractive.

Iain Coucher, Chief Executive of Network Rail, was previously Chief Executive of TubeLines, a preferred bidder for the London Underground public private partnership. He has extensive experience in the transportation sector, particularly with London Underground. He led the development of the Underground's smartcard ticketing system when on secondment to the TranSys consortium.

But there is still scope for more growth. Each day we carry between three and four million people on the major railways. In any year probably 10 million of the people who live in this country will use the railways — which leaves perhaps 50 million more out there who choose road or air rather than the railways.

A vast untapped market

That is a vast untapped market. Rail's market share, as the preferred way of travelling, is 12 per cent for journeys between 50 and 100 miles, 14 per cent for 100 to 200 miles travel and 16 per cent for 250 to 350 miles. That shows us the travellers that we must target in future, and the time savings made possible by High Speed Rail 2 can be an important factor in making rail more attractive than road and air.

There is almost universal support for investment in rail; we talk to all of the major political parties and they all see benefits in investment in rail. They recognise the good that rail can bring to the community, driving economic regeneration, employment and development. And

of course it is good for the environment as well. In terms of carbon emissions, the more people we can get onto trains the better. There is plenty of capacity available: at most a three-lane motorway can deliver about 12,000 people per hour into a city centre. We can deliver as many as 30,000 people an hour into inner city locations. With rail you can move so many more people — and much more freight — than on the roads.

That is why I believe rail must be at the heart of our transport and infrastructure planning. The infrastructure we put on the ground today could last up to 100 years and we need to plan for that sort of time horizon. Demand will double and probably treble inside the timescales that we have planned for our infrastructure and the high-speed rail development is a huge contribution to that vision.

A nationwide inter-linked system

To sum up, we welcome the current enthusiasm for high-speed rail being shown by all political parties. But there are a number of principles which we think need to be applied to the building of this new railway. The railway is a nationwide interlinked system and it needs to be planned and operated as such. High-speed rail should take as much time as possible off people's journey times, yet be fully integrated with the classic railways, both to allow efficient interchange and as a back-up system.

So it is important that the investment necessary to build a high-speed rail network does not come from the budget for existing rail networks. Passengers should not have to put up with years of disruption while it is being built. For instance, if there are major works at Euston Station (one of our busiest stations), the process needs to be sensitive to those who use the railway station today. And we need to stress the benefits of rail development for society as a whole and for the communities they serve — an important factor in ensuring that we obtain planning permissions for the new routes. □

Running high speed rail networks

Guillaume Pepy

Much of the impetus for the renewed interest in high speed rail in the UK has come from the success of the HS1 link between the Channel Tunnel and London, as well as from continental Europe, where the French TGV — the *Train à Grande Vitesse* — has been running successfully for almost 30 years. So I want to outline the French experience with high speed rail, and to explain our plans for the future.

In France we currently operate 1,850km of high speed lines at speeds up to 320km per hour. However, TGV trains actually run on a rail network four times longer than the total length of the high speed lines.

Since the very start of the high speed services, the traffic growth has been steady at around 5 per cent per year. In 2009, we carried 113 million passengers on domestic routes; and the TGV accounts for more than more than 50 per cent of the high speed passenger market in Europe.

The major concern when it comes to investing in high speed rail is the issue of market share: will shorter travel times significantly increase the attractiveness of rail compared to short-haul air travel and long-distance motorway journeys? Our experience suggests that, in the critical 400-1,000km journey range, upgrading to high speed rail diverts business from road and air. And of course this 'modal switch' significantly reduces greenhouse gas emissions.

Guillaume Pepy, President of the French national railway SNCF and Chairman of Eurostar, has been the driving force behind the success of the company's star product, the TGV. SNCF strengthened its European presence by recently winning a major inter-urban transport service development contract in London.

The future

What about the future high speed network in Europe? In France four new infrastructure routes are currently under construction, on top of the existing 1,850km of high speed network. The new routes extend to Spain, Geneva, Strasbourg and the Rhin-Rhone region. Several projects are planned – to Brittany and Bordeaux, and between Nimes and Montpellier. The National High Speed Master Plan encompasses 6,500km of lines. In Spain the ambition is to extend the high speed network from 1,600km today, to nearer 10,000km by 2025.

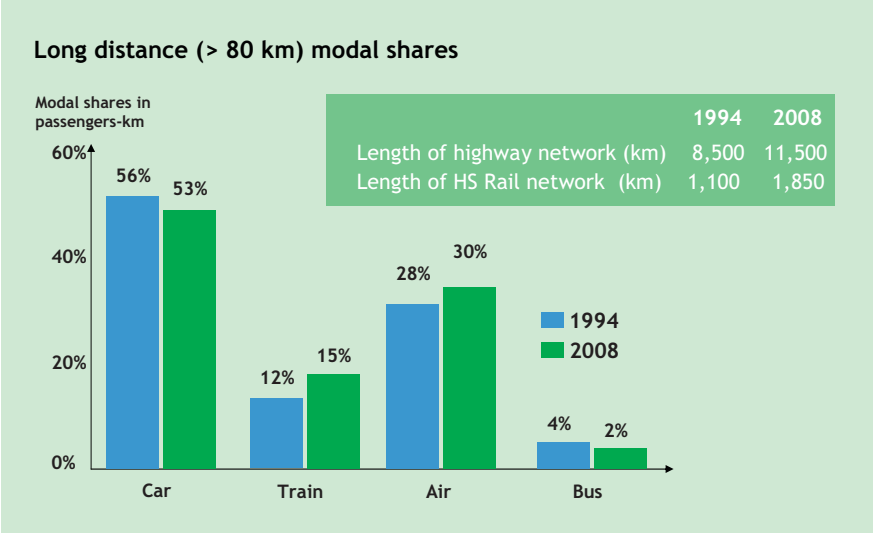
So a high speed rail line can succeed, but only if it is the right type of line, built in the right place. Upon what criteria should those decisions be made? Distance and travel time are important of course: high speed rail is at its most competitive for journeys taking between one and four hours. This is good news for the UK: the whole country could be linked effectively by high speed routes bringing all major cities to within three hours of London. Your country is the ideal size and shape for high speed rail!

Choosing the speed at which a line is to be operated is a crucial factor. Speed is not just a way of attracting customers, it is also a way to reduce both operating costs and rolling stock capital costs. The optimum speed will vary from route to route, depending on the characteristics

DISCUSSION

Congestion in city centres

HS2 trains will deliver large numbers of passengers into city centres already heavily congested and with overloaded local public transport systems. Even if Crossrail is built as planned and takes passengers quickly to Heathrow or Canary Wharf, there will still be large numbers wanting to use London underground and buses. Similar, although less extreme, problems will arise in Manchester, Leeds and Edinburgh. Are there adequate plans to cope with these problems? It is not enough just to plan new stations (which need to take into account the needs of an aging population who find long walks on stations and interchanges difficult) but much more effort must be given to the whole journey from start to final destination.



Changes in preferred mode of transport for journeys of more than 80km in France, 1994-2008.

of the corridor. For example, the first phase of the high speed line from Paris to Strasbourg successfully captured much of the air traffic. The second phase, now under construction, will not attract more customers from air on this route, so it can be designed to run at less than 320km per hour: and our choice may be around 250kph for financial reasons.

By contrast, the line between Tours and Bordeaux will compete with air routes between Paris and the south-west of France, where there are still five to six million air passengers per year. On this corridor, travel time is of the essence and speeds of up to 360km per hour would help capture the share of traffic we need. Environmental concerns will also be considered by taking appropriate operating measures such as, for example, a reduction of speed at night on the Paris to Marseilles route.

Most in need

That raises the next important factor; which routes are most in need of a high speed rail link? Potential transfer from air traffic is a good guide: for example the bulk of the remaining air traffic in France is located in the south of the country. There are still 13 million air passengers per year travelling between Paris and the south-east; by extending the Mediterranean TGV we should catch the bulk of this.

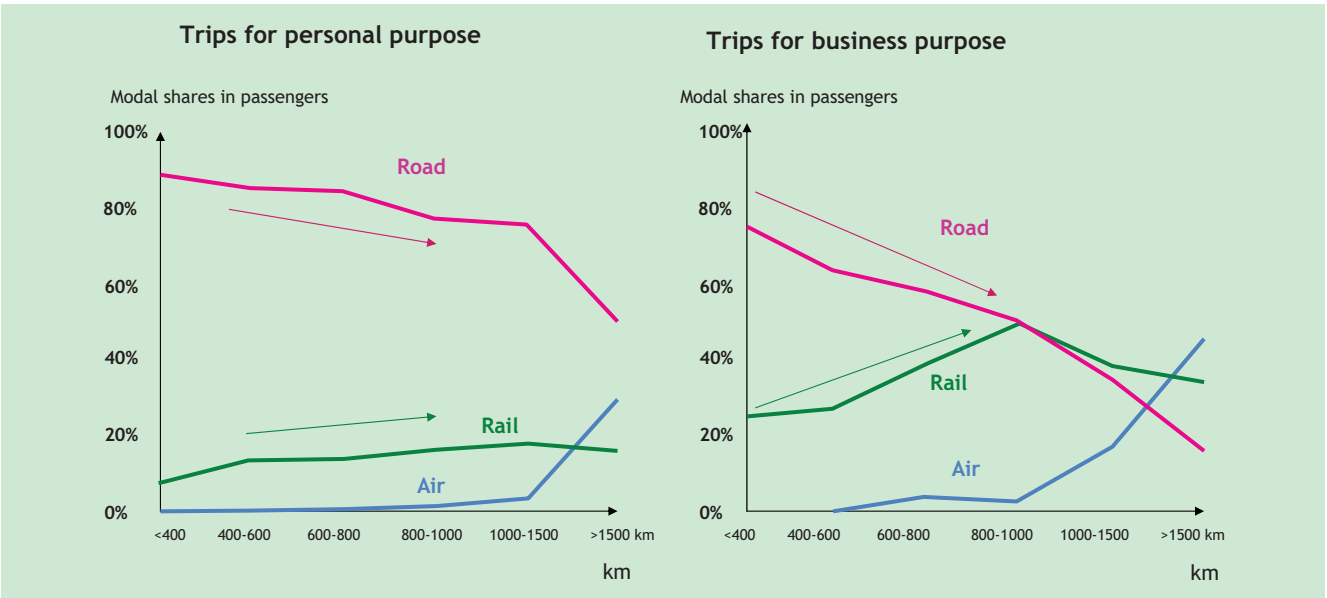
Of course there may be considerations that go beyond a straightforward cost-benefit analysis, such as political decisions to provide high speed rail to new regions on account of the socio-economic benefits that it can bring. In France, the Auvergne and some Massif Central regions come into this category.

And whatever the shape of the high speed network, it is important that it has good links to the conventional network. This is vital politically, to avoid criticisms of a two-speed network. It also feeds customers into the high speed services and allows those services to reach more destinations, and a broader market.

So now to conclude. In Britain you have a fine railway heritage, with a rail network spread across the length and breadth of the country. You have in St Pancras probably the most beautiful station in Europe, where high speed rail links to the conventional network. With Eurostar you have already gained some extremely valuable experience in high speed rail. That is a strong foundation for the future.

The future remains largely unknown but we can shape it. Today in China, as well as in France, high speed trains run daily commercial services at a speed that would have been a world speed record only 30 years ago. A high speed rail network created today is not just for a decade or two, but for a whole century.

Do not underestimate the leaps high speed rail can achieve in terms of technology, commercial success and changes in society: "Think big — and be ambitious."□



Growth of rail at the expense of road travel.

Delivering high speed rail infrastructure

Terry Hill

I am going to outline the lessons learnt at Arup working on the HS1 link between the Channel Tunnel and central London. And the first is the importance of consultation. There had been some pretty stiff opposition when the early plans were announced. The proposed route would have delivered high speed, international services directly into the centre of London, but with little benefit to those communities that it went through on the way. We started our involvement by listening. It was a lengthy process, sitting down with parish councils, community groups and amenity groups in all the boroughs and districts affected, trying to find out what it was that people wanted out of this.

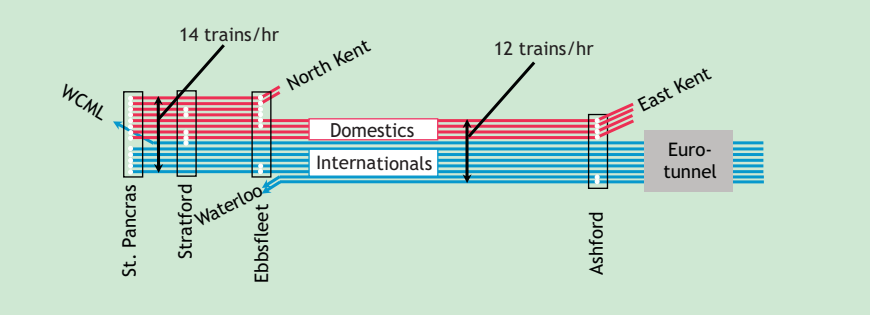
We had one important calculation in our favour: two tracks through the Channel Tunnel, half of the capacity being taken by the Shuttle, and then two tracks from there to the centre of London. QED, we have half of the capacity left over. How could we use that to bring benefit to communities along the route through Kent and East London? We could do it by providing stations and services and totally transforming their local rail services as well as the international service.

A hunger

In the early1990s there were high levels of unemployment, and some of the most deprived parts of the country were in North Kent and East London, so there was a hunger to try and get the railways built through their boroughs. Whether at Ashford, Ebbsfleet, Stratford or St Pancras, we could bring local benefits, with the railway as the catalyst.

We were also able to reassure local groups that we would be able to take account of the environmental concerns that are inevitable when such a major infrastructure project is undertaken. Enthusiasm for the project was such that when the planning application for Ebbsfleet was made, it was not 'called in' by the minister, a notable achievement for such a large-scale project.

As a result of the work that we did on HS1, we were appointed to work on some of the problems that were being encountered in France, on the LGV Méditerranée which connects the regions of Provence-Alpes-Côte d'Azur and Languedoc-Roussillon to the LGV Rhône-Alpes on the TGV network. It was one of the first times that there was opposition to a route south of Lyons, and we went there with the approach I have just talked about – listening to people, talking to people and finding the route that eventually emerged. The line began operations in June 2001 and has competed successfully with the airlines.



Train services to London on the HS1 link up to 2018.

Terry Hill FREng is Chairman, Transport Markets, at Arup, a global design and business consultancy. His role is to ensure the delivery of the transport projects in the aviation, maritime, rail and highways sectors throughout the world. He has a background in civil engineering and economics.

Investment in the future

Further afield Arup has worked on stations at each end of the Beijing–Tianjin Intercity railway. Longer and faster than HS1, part of the route was operational in time for the Beijing Olympics. China is planning eight new lines by 2020. That expansion is clearly a product of China's economic boom but also an investment in future growth — an approach echoed in the USA where President Obama certainly sees rail as a component in his fiscal stimulus package. There is an initial $8 billion investment in the California High Speed Rail, where Arup is also involved.

So, back to HS2. Our experience in the UK and elsewhere suggests that HS2 could be welcomed by those affected if they could see the benefits. There is cross-party support for the idea of HS2 — though there will of course be disagreements, discussions and debates about how some of the specifics of the project are handled. But that support from the political parties is vital: these projects need several administrations to deliver.

The message I would like to leave you with is: is it possible to find high-speed rail routes that will get buy-in acceptance with local residents saying "please put it through my borough"? It can be done by following existing transport corridors, using good design, finding areas both in need of remediation and regeneration – and of course by establishing a strategy for stations that serves the best interests of the travelling public and the areas around the stations. Infrastructure is the greatest gift that engineers can give to society. It changes people's lives. ☐

DISCUSSION

Public support

Maintaining HS2 as a national priority depends on the public being convinced of the wider benefits to all, not just to the rail travelling public. The taxpayer must understand that rail investment is in his interest, even if he or she does not use rail. This demands not only a prolonged and effective PR campaign but also a firm and enthusiastic political lead. The rail authorities cannot take such a leadership role. Essentially, therefore, the success of the project would depend on the leadership of successive Secretaries of State for Transport, strongly supported by the Prime Minister and Chancellor.

The international negotiations on combating climate change are continuing, so a meeting of the Foundation on 2 June 2010 considered the options for future progress following last winter's Copenhagen summit.

What next after Copenhagen?

John Beddington

I think the Copenhagen Summit enjoyed a degree of success. For the first time, developed and developing countries agreed upon a 2°C target and that was no mean achievement. More importantly, more than 70 countries – accounting for more than 80 per cent of global emissions – committed to reducing those emissions.

If those 70 states achieved the maximum reductions indicated in their pledges, emissions may peak by about 2020. The science suggests that even this will not achieve limit global warming to a 2°C average. Even if the target is reached, a warmer world is not particularly comfortable. A 2°C average is just that – an average across all oceans and land masses. In the Arctic, that it likely to mean somewhere between 2-6°C. There are fundamentally different models with different initial conditions and different assumptions – so there is an underlying level of uncertainty with these predictions.

There are other concerns about the means we use. Professor Bob Watson taught me that I should not ignore the albedo effect – if we clean up coal production so that sulphur dioxide emissions are substantially reduced we will reduce the albedo, with a potential for a further increase in temperature.

But 2°C warmer is profoundly better than 4°C. In such a situation the Arctic would warm by between 8-16°C. I would remind you again of the uncertainties involved.

Post-Copenhagen

What is going to happen post-Copenhagen? In the UK, the Committee on Climate Change recommended that we reduce greenhouse emissions by at least 80 per cent by 2050 and that we should reduce emissions by 34 per cent by 2020. This is a formidable task and we need to ponder both their feasibility and cost: irrespective of either, though, the scale of the challenge is daunting.

Figure 1 indicates our emissions in 2006. I have deliberately left the 2050 objectives completely blank, not indicating how sectors will be affected, because I do not think we know. There are formally an infinite number of solutions that would satisfy this reduction. I know David MacKay, the Chief Scientific Adviser at the Department of Energy and Climate Change (DECC) and his colleagues are examining how we actually achieve these cuts in the different sectors. The preliminary analysis announced by the previous government spoke of fundamental shifts in the way energy is produced and consumed.

Professor Sir John Beddington CMG FRS is Government Chief Scientific Adviser at the Government Office for Science. His main research interests are the application of biological and economic analysis to problems of natural resource management. He has been at Imperial College since 1984, where he headed the main departments dealing with environmental science and technology. He has been an adviser to a number of Government departments.

First, there needs to be a dramatic reduction in energy demand. Then, a substantial level of electrification for heating and surface transport must be accomplished. Any analysis of the situation leads to the conclusion that electricity supply needs to be largely decarbonised by 2030.

Sustainable bio-energy is important but is actually quite limited in its impact. As we move towards 2050, emissions from agricultural waste, industrial processes and international transport will need to be tackled.

The engineering community will play a considerable part in achieving these goals. If we look at the low carbon innovation process as currently set up in the UK, the basic research is carried out by the Research Councils. On the application side, we have the Energy Technology Institute – bringing together BP, Shell, E.ON, EDF, Rolls-Royce and Caterpillar. This is funded equally by Government and industry. The Technology Strategy Board is also involved at this stage and is working closely with a number of organisations and bringing in funding. Finally, there is the Carbon Trust, involved in demonstration and deployment.

We know we need to achieve a significant degree of decarbonisation in electricity generation by 2030. This includes increased energy efficiency – and we can start doing that already. We currently have third generation nuclear power being commercially deployed, and development work is taking place on the fourth generation – but it is likely to be the 2020s before we move to demonstration schemes. These are only very early days for demonstrations of carbon capture and storage (CCS). We are beginning to see demonstration projects for deep offshore wind which may see some commercial deployment from the middle of this decade. We do not yet have the capability for tidal power: deploying this will probably take us into the middle of the next decade. We have the technical knowhow to build barrages, but whether we want to build a Severn Barrage given the enormous investment and the relatively low return is debatable.

While the speed at which we can develop each technology cannot be predicted with certainty, we can look at the sensitivities facing the different sectors and the cost of actually producing each type of energy. What combination and trajectories are needed to deliver an 80 per cent reduction in emissions? This is the question that Government is posing to the engineering community.

Offshore wind and marine power (wave and tidal) will be key technologies for our future energy supplies. The next generation of biofuels (which will be based on plant residues) has been the subject of much discussion as has the use of algae to produce energy. While these have potential, we need to consider whether, as a small country, we would use home-grown biofuels or should we import them from countries like Brazil which can produce first- and second-

generation fuels more quickly?

We have well-tried technologies for third generation nuclear and then there is fusion. The Culham Laboratory has achieved great results on fusion already.

Mitigation and adaptation

So far, I have focussed on mitigation, but one of the lessons of Copenhagen is that we cannot forget adaptation. In one sense, in the community of Chief Scientific Advisors, David MacKay and DECC are concerned with mitigation while Bob Watson and Defra are focussed on adaptation. The Climate Change Act requires that a national climate change risk assessment be produced every five years, the first due by January 2012. There are obligations on a number of organisations, including local authorities, to consider carefully what actions they can take to adapt to climate change and all Government departments have already lodged their own plans (in March 2010). The adaptation sub-committee of the Committee on Climate Change, chaired by Lord Krebs, is providing general oversight on this matter.

So much for work in progress, how is it going to be carried out in practice? Now we do not have an extensive evidence-base, but recent work by the Met Office for Defra looked at what we might expect in the future. Among the conclusions was a high probability of much more rain in the winter and hotter, dry periods in the summer, particularly in the south of England. We need to decide how we adapt to that.

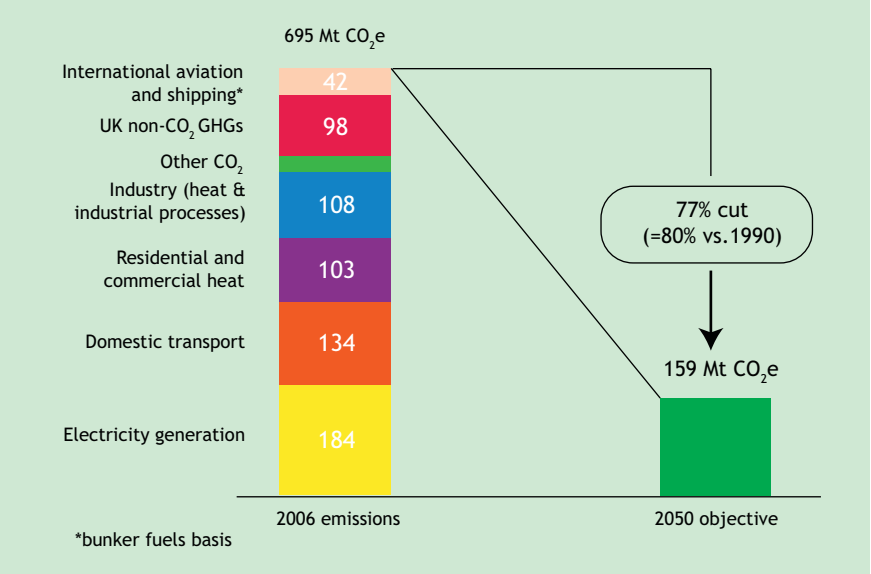


Figure 1. The challenge for the UK to reduce emissions by 80%

Let me sum up with three key messages:

- All the countries committed to reducing climate change must fulfil their 2020 pledges – and then go much further. That way we might be able to hit the 2°C target, although there remain large uncertainties about this, both in terms of the practicalities and the underlying science.
- The UK faces huge challenges, both financially and in engineering terms, in meeting our commitments to reduce greenhouse gas emissions by 34 per cent by 2020 and 80 per cent by 2050.
- Finally, we must plan carefully to adapt to climate change.

Even if we can achieve our targets and even if we can bring the international community with us, the greenhouse gases already in the atmosphere will determine our weather to 2030 – and some of that weather could be quite extreme. □

Achieving an international consensus on climate change

Michael Jay

I was involved in climate change for the first time in 2005, when I was working for Tony Blair as his 'sherpa' or personal representative for the G8 summit at Gleneagles. When I told my G8 colleagues that he wanted to focus on climate change, there was silence around the table. Then somebody plucked up the courage to say: "Why does the Prime Minister want to focus on a third-order issue like that?" It took a great deal of persuasion over the next few months to convince them that this was an important issue for the future. I do not think anyone today would ask that same question.

Despite the recent controversies, I am struck by the consensus (although not a complete consensus) about climate change and its implications. Across the political spectrum, through much of industry and civil society, climate change is recognised as a real challenge and indeed, for many, an opportunity.

As well as being a member of the House of Lords, I am also on the boards of three French and two British companies. For business, it is inconceivable not to conclude that the chances of man-made climate change are real, that people will be worried about it and will want to respond to it. That is almost irrespective of the details of the scientific debate – it is a judgement that you make as business men around a table about likely demand and about where the world is going to go.

Business wants and needs a clear international framework, accepted by all, in which to operate. NGOs want it, the Government wants it: the question is whether the British Government can exert real influence to bring it about? Now it seems to me they should be able to. At a recent breakfast meeting for new MPs organised by GLOBE, the international group of parliamentarians, I was struck by the fact that politicians with very different backgrounds were all trying to solve the same issue: 'how to react to a world which is going to get warmer, with the very difficult consequences that entails?' Britain has a chance, with a coalition government and with the Labour Party's position on green issues, to make a real impact on the climate change debate over the next few years.

A doubt

Yet there is a nagging doubt in my mind. The final meetings at Copenhagen – between the Americans, and the new group of BASIC countries (Brazil, South Africa, India, China) did not include the UK or the EU. Will we in future find that the USA and China work together while the rest of us – the EU as well as the poorest countries – find ourselves being brought into an agreement reached elsewhere without playing a full role? That would be a big mistake because I do not believe the USA and China will develop the kind of international framework we would want to be a part of – nor one that would be good for our business or welcomed by our NGOs.

Can we remain in the centre of the debate over the next few years? I think there is an opportunity for Britain to do that and I hope we will seize it. This Government has started well; it is committed to generating 15 per cent of our energy from renewables by 2020, there is an energy security and green economy bill on the horizon, and there is an openness to nuclear energy for the future.

On the international stage, too, this Government has started well. Pushing for EU leadership, including an increase in the EU emissions reduction target to 30 per cent, is very important. As Lord Stern pointed out in his report, it is cumulative emissions that count, and the later the reductions take place the harder and more painful they will be. The short-term costs of a 30 per cent reduction now, given the recession, are similar to a 20 per cent reduction a few years ago – we ought to be pushing for this.

The poorest countries

We should also focus on the needs of the poorest countries. If the major negotiations take place between China and the USA, then the countries that are really going to suffer from climate change (countries in Africa, as well as low-lying countries such as Bangladesh and the Maldives) will not be given a full and proper say in the negotiations. The UK is in a position to argue for their full participation.

The Lord Jay of Ewelme GCMG is a member of the Global Legislators Organisation for a Balanced Environment (GLOBE) and the House of Lords. He served on the Parliamentary Committee on the Climate Change Bill and on Select Committees on the European Union and on International Institutions. He is a non-executive director of two British and three French companies, and is Chair of the medical aid charity Merlin.

I hope that real progress on the less controversial issues is made in Mexico in December, even if this is a staging post towards a comprehensive agreement in South Africa a year later. Mexico holds a hugely important position, being outside the main groupings. It is a member of the OECD yet still considered a 'developing country'. It has also played a very positive role on climate change over the last few years as one of the so-called '+5' major emerging economies, developing progressive ideas such as the 'Green Fund' proposal to help break the deadlock on climate finance, as well as hosting a ministerial meeting of the Gleneagles Dialogue, one of the outcomes of the UK's 2005 G8 Presidency. As such it has credibility as an honest broker in some very difficult negotiations – something sorely needed after the breakdown in trust between developed and developing countries at Copenhagen. Yet, with much work still to do, it does seem to me a comprehensive international agreement is more likely in South Africa in 2011 than in Mexico in 2010.

Even that will not be easy to achieve and the new Executive Secretary of the United Nations Framework Convention on Climate Change (UNFCCC) will need to show real leadership as well as flexibility. There is a risk that if UNFCCC approach does not deliver, then the USA and China will take over to develop a 'G2' type approach – something that would not necessarily be in the interests of Europe or the poorest developing countries.

Parliaments and parliamentarians

There is also a role for parliamentarians over the next few years: any agreement reached among governments will have to be ratified by parliaments. And it will be legislators who develop and pass the domestic legislation that will be needed to underpin any international agreement. The more that parliaments can be involved at an early stage, the greater the chance of a positive response to governments. I note that governments are using international parliamentary groups like Globe to explore the sorts of ideas that are too difficult or too sensitive to test in the formal negotiations – this is another important role for parliamentarians. I also believe there could be an important role for Globe and parliamentarians in monitoring and evaluating performance after an agreement has been reached. After all, it is legislators who oversee governments' performance against domestic and international commitments. □

The continuing debate on climate change

Ron Oxburgh

Although a majority of scientific opinion supports the view that human activity is having a damaging effect on the Earth's climate, there has been much recent discussion of a different view. I want to begin by examining the contrarian view on climate change.

There are some legitimate questions such as: "We have just had the coldest winter for years, how can there be global warming?" "Hasn't the Earth had warm periods before? What is different now?"

There have also been a number of efforts to popularise the science of climate change and make it more accessible to those without technical backgrounds and to politicians. The argument has been made that it has been over-simplified and uncertainties glossed over. This is a matter of judgement.

Then there are a number of more specific criticisms. A few, and only a few, among many hundreds of studies presented by the International Panel on Climate Change, have been shown to be spurious. Yet the argument is: if there was some spurious evidence, how much more is there?

Probably the most serious criticism, however, concerns feedbacks in the natural system that are not adequately captured by computer models. A feedback occurs where a relatively small change in temperature produces a much larger consequence (because it acts within a

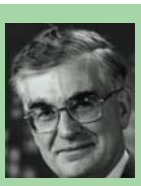
broader system). This consequence can be negative (in the sense that it cools the system) or positive in the sense that it enhances heating. One of the best examples of a positive feedback is the melting of glaciers. As temperature rises the glaciers melt. A smaller fraction of the Earth's surface is then covered with ice and so less radiation is reflected back into space, with greater residual heating. In terms of negative feedback, clouds are potentially important; I think most modellers agree that they cannot handle clouds adequately

Then finally, there are arguments about the manipulation of data. It was alleged that the University of East Anglia Climatic Research Unit had manipulated data to achieve a certain outcome. However, an investigation at the University that I chaired found no evidence of this. This conclusion did not mean that we endorsed their results, but we felt that they were honest.

Dealing with the data

Observations on climate change are not easy to interpret. We have to distinguish short term trends from long term ones – we are looking at a very, very noisy climate signal and looking out of the window at what the weather has been doing for the last 10 years is not very informative. A set of observations made by the British Antarctic Survey on the Antarctic Peninsula between 1948 and 2005 shows around 30 glaciers that are advancing: on the basis of these alone, one might say: "Global warming? Nonsense." Yet these are interspersed with nearly 300 that are retreating. The noisiness occurs both in space and time.

Consider the measurements made from instruments over the last 150 years. We expect instruments to give us fewer problems, but instruments and the way that people have used them to measure average temperatures have changed over time. It makes a great difference whether you take four measurements a day at six-hour intervals and average those, or whether you take a maximum and a minimum temperature, take the difference between them and call that 'average temperature'. Older records are often incomplete and imperfect. Observatories change over time as do their surroundings – an observatory which began in the open country may, over time, find a town built around it and of course the town will raise the ambient temperature. So if longer term trends are to be recognised, corrections need to be applied and some would criticise those corrections.



The Lord Oxburgh KBE FRS HonFREng was Chair of the UEA Climate Science Assessment Panel. He trained as a geologist/geophysicist. He worked as Chief Scientific Adviser at the Ministry of Defence, Rector of Imperial College London and as Chairman of Shell Transport & Trading plc. He is now a crossbench peer and has chaired the House of Lords Science and Technology Select Committee.

Interpreting these observations calls for experience and judgement and it is probably fair to say that while they are consistent with anthropogenic climate change they do not prove it.

The greenhouse effect

Geology shows that in the past we have had extreme climates and these changes have taken place without human influence – there is a whole range of causes, including solar variability and orbital changes. So what is different today?

It was John Tyndall, a nineteenth century Director of the Royal Institution, who established experimentally that water, with the atmospheric trace elements carbon dioxide, and methane, have a large effect on terrestrial temperature – they create the greenhouse effect. His work led to a coherent theory of the temperatures of the four terrestrial planets.

To a first approximation, planetary temperatures are expected to be determined by their distance from the Sun – the nearer the warmer. This holds true for both Mercury and Mars, but not for Venus or Earth: both of these are warmer than expected. They are also the only two with significant atmospheres. Venus is several hundred degrees warmer than expected and has a thick CO_2-rich atmosphere, while Earth with its relatively low concentration of greenhouse gases is only around 30 degrees warmer than expected.

About 150 years ago, at the start of the Industrial Revolution, we began to see the onset of what is now a 30 per cent increase in atmospheric carbon dioxide; its chemical fingerprint shows that it is carbon dioxide from fossil fuels. It would be significantly larger were it not for the action of oceans and vegetation. There is no known geological parallel – 50 or 60 million years levels may have been as high, but there was not such a steep increase.

Now, as Tyndall showed, carbon dioxide and temperature are linked by observation and simple physics. The question therefore is whether it is sensible, in the light of what we know about the factors that determine the temperature on terrestrial planets, to increase the concentration of CO_2 in our atmosphere. All the computational models suggest a consequent rise in global average temperatures, which will also warm the oceans. This is like 'turning up the gas' under the atmosphere and we see shifts in weather patterns, more intense storms and rainfall, more extreme weather events, a rise in sea level and ocean acidification.

No one has come up with a credible alternative interpretation of planetary temperatures and that is what they would have to do if they are to deny the existence of the greenhouse effect on Earth. Alternatively, they have to postulate very special conditions under which increasing the concentration of greenhouse gases in the atmosphere does not translate into an increase in terrestrial temperature.

The sceptics

So who are the self-styled 'sceptics'? A minority are experienced engineers and scientists, mostly from other disciplines. The perceptive ones base their concerns on the still incomplete nature of the modelling. There are some diligent and well-informed amateurs – the people who pick over the IPCC data and find things that are wrong or inconsistent (which is actually useful, as well as embarrassing!). There are also some rather poorly-informed amateurs who make wild statements which do not make much sense.

The scientific community has not fully recognised that taking climate change seriously threatens very influential commercial interests worldwide, particularly in the coal industry. Looking back at the experience of the USA with tobacco, I think we are seeing a similar situation with climate change – professional lobbyists trying, by fair means or foul, to discredit the underlying science.

There will never be complete certainty about a malign human influence on climate but I do not think the risk of being wrong is worth taking.

International political action remains urgent. The real worry is that elected governments will not be able to take appropriate measures if the electorate does not believe those measures to be necessary. ☐

While clean water is a renewable resource, the world is approaching a situation where demand exceeds supply. A meeting of the Foundation on 14 July 2010 examined what can be done to ensure sustainable supplies in developing countries.

The task of restoring ecosystem function

John Liu

In 1995, I was assigned by the World Bank to film the initial stages of the Loess Plateau Watershed Rehabilitation Project in Northwest China. This first trip piqued my curiosity and has led to a long-term continuing inquiry. I have led 10 filming trips to the region with support from various development agencies. To date, we have collected more than 100 hours of broadcast videotape of the region, its people and the rehabilitation efforts. The dramatic changes on the plateau show that it is possible to rehabilitate large-scale damaged ecosystems. These findings have extremely positive and profound implications for the future of humanity and the Earth.

This is a complex story. The Loess Plateau is approximately the size of France, encompassing 640,000km^2 in the upper and middle reaches of the Yellow River. The Plateau gets its name from the powdery soil that is its primary feature. The mineral-rich windborne sedimentary loess deposits are hundreds of metres thick in places and have accumulated over geological time. The Loess Plateau stretches over parts of seven Chinese provinces: Qinghai, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi and Henan. Fossil remains prove that humans and their ancestors have lived here for more than 1.5 million years. This is generally accepted to be the second place on Earth where settled agriculture began and is recognised as the cradle of Chinese civilisation where the Han, Qin, Tang and other dynasties flourished.

When I first visited the Loess Plateau I found a landscape almost completely denuded of vegetation. Yet this land must have once been especially fertile as it gave rise to the most populous ethnic group on the planet. I learned that a nurturing ecosystem was over time fundamentally altered by human impact, leading to almost total ecological collapse over a vast area. Cutting the forests and preparing the earth to plant crops did several things. First, it exposed the fragile loess soil to the wind and rain, causing erosion which led to the many gullies that are now so evident in the plateau. This exacerbated the tendency of flooding during the rainy season, with drought and famine the rest of the year.

John Dennis Liu is an American who has lived in China for more than 25 years. Since the mid-1990s he has concentrated on ecological filmmaking. He is Senior Research Fellow, International Union for Conservation of Nature (IUCN) and Rothamsted International Fellow for the Communication of Science.

Removing the vegetation cover also devastated the microbiology in the decaying plant litter on the surface. This destroyed the cycle of natural fertility by breaking the cycle of regeneration – in which plants and animals gives their bodies to fertilise the next generation. This also reduced the ability of the soil to absorb the rainfall, disrupting the hydrological cycle. Gradually wild plants and animals disappeared. People planted crops on steeper and steeper sides of the gullies and took their sheep and goats further to eat grasses and bushes hoping to eke out a living. With their own activities further degrading the natural systems, the people became mired in poverty. This was the condition of life on the plateau for millennia.

It takes extremely ambitious vision to believe that what has been destroyed over 10,000 years can be restored; yet a little over a decade ago the Chinese government decided to do just that. Chinese planners from the Ministry of Water Resources and international planners from the World Bank worked together to design a workable project plan. Experts in hydrology, soil dynamics, forestry, agriculture and economics, as well as local officials and farmers, were consulted to determine what was possible. This research and planning phase took over three years.

The Chinese authorities then banned tree cutting, slope farming and free ranging of goats and sheep. They used participatory methods to engage the local people in more sustainable behaviour. They differentiated and designated ecological and economic land, ensuring that there would be a large amount of land set aside for ecological functions.

The Chinese and foreign advisors began physical steps to restore ecosystem function over an active project area of 35,000km^2. Geographic Information Systems (GIS) analysis was introduced, giving every watershed a specific address. Small dams were built to retain rainfall, terraces were built on the agricultural land and trees planted on the ecologically- designated land. Enterprise software was used to track all investments and interventions. The entire community was engaged in vocational training and benefited in several ways: they were paid for their labour, learned sustainable agricultural methods and owned the output of the newly-created fields.

Over the past decade, an astounding transformation has taken place. While we have been filming, once denuded hillsides have come alive with grasses, bushes and trees. Birds and insects are returning to the area. The humidity has changed as the soil absorbed moisture and the plants exchanged gases in respiration. The entire dynamic of the plateau has been reversed.

The success of the Loess Plateau Rehabilitation Project has resulted in profound changes for the local people; their economy, incomes and quality of life have improved tremendously. The seemingly hopeless cycle of poverty and ecological destruction has been broken. Millions of people have been lifted out of poverty. This has profound implications for the local people, the Yellow River basin, China and global ecology.

The Chinese have recognised that ecosystem function is more valuable than productivity and have allowed this to determine their actions. The 'Economics of Ecosystems and Biodiversity' in practice began 15 years before the efforts now being spearheaded by the United Nations. The results show that instead of consistent ecological and economic decline, it is possible to achieve positive social, economic and ecological trends in areas that have been historically degraded.

If this understanding were applied on a global scale it would lead to sustainability. ☐

The quest for water security

Michael Norton

In over 30 years as a water engineer, I have never seen so much interest in this subject as is evident today. Water is not the only urgent problem facing humanity; there is a dramatic rise in concern over the loss of ecosystems and biodiversity, for example, but some of these losses are linked to water scarcity. The fundamental problem that we face is a scramble for natural resources – two billion people in developing nations want a similar lifestyle to that enjoyed by those in the developed nations. This is exacerbated by the growth in the global population, set to increase by 2 billion in the next 20 years.

Consider some recent studies in this field. The United Nations World Water Development report is published every two years and the third edition *Water in a Changing World* was published in March 2009. This is a significant work, a status report on water on the planet and for water professionals it is essential reading. One of its recommendations is that water professionals should 'get out of their box' and engage with politicians and influencers. I believe we have a duty to do just that.

A second report comes from the World Economic Forum's Water Initiative, which began in 2007. Phase I sought, among other things, to catalyse a number of innovative partnerships, bringing industry, governments and communities together to look for ways in which they could solve local water scarcity or water security issues. This work concentrated on South Africa and India. The challenge for the second phase is to scale these initiatives up. Having already achieved some successes it might seem that to scale up is easy, but there are many financial, institutional and cultural barriers still to overcome.

A third study developed from the WEF Water Initiative. A group of companies within the organisation formed the 2030 Water Resources Group. The group was led by the IFC, the private lending arm of the World Bank, and by McKinsey & Company, the management consultants. It looked at the global picture of water scarcity and, looking forward to 2030, it concluded that current measures to increase supply and decrease demand will not close the very substantial gap between the two (Figure 1). The study then looked in more detail at five countries (including India and China) and proposed a series of prioritised actions that could be taken to close the gap.

Michael Norton MBE is Managing Director of the Halcrow Group Water and Power Business Group. He is an expert in the planning, design and supervision of the construction of water supply and wastewater projects in cool and tropical climates, and water sector restructuring studies including long range investment forecasting. He was a co-author of a recent Royal Academy of Engineering report on global water security.

The proportion of accessible fresh water within the 14 trillion cubic kilometres of total water on this planet is tiny. Humanity is already withdrawing and consuming a large part of this amount, to the extent that in many places there is no longer sufficient remaining water to sustain the wider environment. Of the fresh water abstracted, 70 per cent is taken for agricultural use (only 8 per cent of withdrawals are for drinking water) and the challenge is to keep 6.5 billion people from hunger.

The water cycle

Out of every 100 drops of water that fall as rain, 36 (on average) reach the ocean. Most of the remaining 64 sustain the planet's flora, ecosystems and rain-fed agriculture. This is called 'green water' – it falls on the soil and, with nutrients, it is converted by sunlight into biomass.

'Blue water', on the other hand, remains in free water bodies, in rivers, lakes and underground aquifers. This may be withdrawn for irrigation, for industrial production and, of course, for human consumption. Some of that water is contaminated during processing and is returned to the blue water as 'grey water'.

This leads us to another interesting concept – that of 'virtual water'. Virtual water is that which has been used in the growing or manufacturing of food and goods, and can be considered as being 'embedded' in those goods. It is a controversial idea but nevertheless a useful one. The way virtual water flows around the major regions of the Earth has been mapped, with some countries being net importers of virtual water and others net exporters. The results are sometimes surprising: Oceania, for example, is a net exporter. This happens because countries such as Australia have a huge export market for goods which use a great deal of water in their production, even though it is itself a water-scarce country.

Related to virtual water is the 'water footprint'. Figure 2 shows the water footprint per head of population of six countries – Australia, China, Israel, Ethiopia, UK and the USA. The amounts are given in cubic metres per year, per person. One surprising finding is that the water footprint for a person in the UK equates to 4.5m^3 per day. Typically, though, an individual will only buy about 150 litres per day from their water company; one thirtieth of the total water footprint. Some two-thirds of the total water footprint in the UK is virtual water associated with imported goods. China and Ethiopia have much lower water footprints per head and very little of it comes from other countries. The USA has a huge water footprint but again with very little from other countries.

Water cannot be considered in isolation because it is linked to energy and food in many different ways. Any proposed solution in one area is almost certain to impact

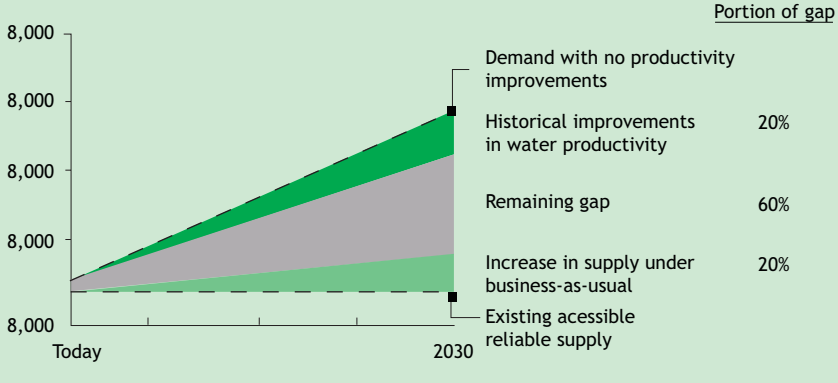


Figure 1. The gap between water supply and demand. Source: McKinsey

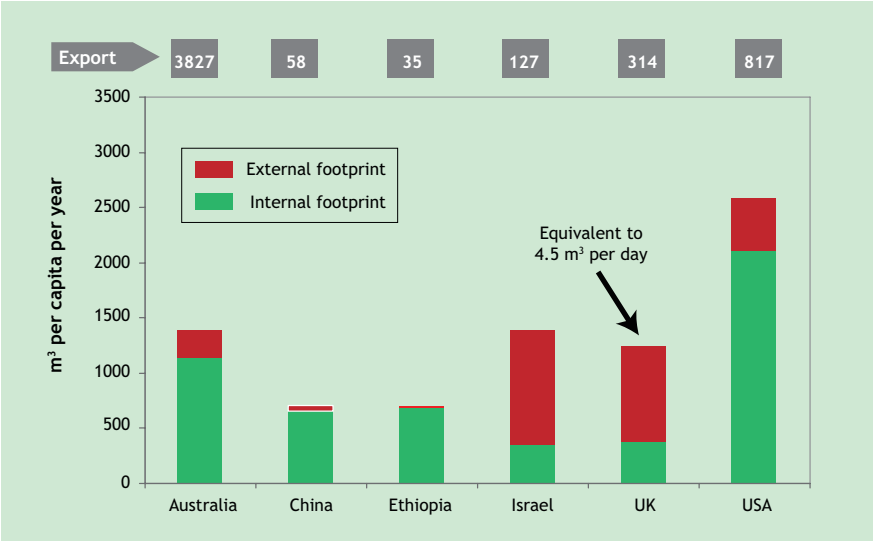


Figure 2. Water footprint per head of population (Hoekstra and Chapagain, 2008)

on another. These in turn are all overlaid by much bigger global issues, such as finance, trade and climate change.

Water security

By 2030 (just two decades away) there may be 8.5 billion people on this planet. Most will live in developing countries and will seek the same standard of living as their fellow human beings in developed nations. In such circumstances, the demand for food, water and energy consumption could each increase by around 50 per cent.

What would a water-secure world look like in 2030? These are five goals which are generally agreed:

- Affordable drinking water supplies for everybody. Though this area receives much attention the financial barriers to achieving this are not great;
- Sustainable sources of water for industry. This is a crucial issue because unless industry has sustainable sources of water, economic growth cannot be maintained;
- Integrated water resources management. Managing water in all its forms in a holistic and integrated manner from 'cloud to coast';
- Policy reforms which would lead to sustainable water development. Raising water management up governmental policy agendas to reflect its importance to physical and economic health;
- The mobilisation of substantial volumes of public and private funding to deal with the water gap. This will require the development of transparent and fair regulatory regimes to value and manage all kinds of water use, in order to give investors sufficient confidence to commit funds.

What needs to be done to make these things happen – and specifically, what can water professionals contribute? There are four areas where actions are needed:

- The debate about the inter-relationships between water, energy and food need to be intensified. There needs to be a much better understanding of the way these inter-connected systems work at local, national and global levels;
- The UK should pay more attention to initiatives around the world where water scarcity is being tackled rather sooner than here – Australia and Chile are two examples;
- Harmonising the aspirations of government, private sector and communities is being carried forward in the work of the World Economic Forum Water Initiative. This is vitally important because sustained success can only come when all three stakeholder components work in a coherent programme;
- Water professionals have to stand up and be counted. We have the knowledge and the tools. When government, private sector and the communities have their aspirations aligned, we can make things happen.

UN World Water Development Report: www.unesco.org/water/wwap/wwdr/wwdr3

World Economic Forum Water Initiative: www.weforum.org/en/initiatives/water/index.htm

Royal Academy of Engineering: www.raeng.org.uk/news/publications/list/reports/Global_Water_Security_report.pdf

Resilience in a changing world

Mark Fletcher and Jennifer Schooling

Let us start with a few definitions: the idea of 'peak water' was developed from the notion of peak oil. There is a difference though – oil is a finite resource; once pumped out of the ground there is no more. Water is a renewable resource, to some extent at least.

'Peak water' refers to the point at which global demand exceeds the natural global supply of water. That may currently be true in particular areas, but it is not true globally so we talk about 'water stress' and 'water scarcity' instead. 'Water stress' occurs where demand exceeds available supply, while 'water scarcity' happens in locations where natural climatic factors restrict the available amount of water. Both of these can be induced by human activity – economic or political.

By 2015, just five years from now, almost two billion people will be living in countries or regions with absolute scarcity and two-thirds of the world's population could face conditions of water stress. Tackling this challenge will drive us much faster down the road of sustainable water management.

Water usage varies a great deal around the world so solutions need to be local and specific. In addition to providing an adequate supply of drinking water, we must ensure enough food for the world's population, maintain industrial production lines, and so on. That requires a systems approach.

Ho Chi Minh City

Ho Chi Minh City is at the confluence of two major rivers – the Saigon and the Dong-nai rivers – so there are two basins draining into the city. During the flood season, dealing with excess surface water becomes an issue. However, during the dry season there is insufficient water to meet demand.

A workshop was held in the city, looking at the resilience of its water supplies.

This was part of Arup's work with the C40 Climate Initiative (a group of large cities committed to tackling climate change) and the Clinton Climate Initiative. It looked at the existing water resources, as well as the impact of demographic and climate change. The workshop examined the provision of greater resilience through water management so that the local population had access to the water they needed.

Supplies in the dry season can be maintained by managing the water flow with reservoirs. Interestingly, the problem of excess surface water in the wet season can also be substantially reduced in the same way – only in October are there any remaining concerns with flooding.

The projections for climate change now suggest that the dry season will extend through to June. In fact, the projections for water storage are that the city would still meet, in the short to medium term, its supply requirements. Over the longer term, there may come a time to embark upon sustainable management of consumption as well as supply.

In the Ho Chi Minh catchment area and the wider Dong-nai basin, a proportion of the water supply is used for irrigation, essentially for foods. Water is also used for salinity control: important for managing overall quality. Then there is domestic use as well as water for industry, hydropower and so forth.

With better demand and consumption management, however, local people can start to look at better methods of irrigation and industry can examine ways of conserving brown water. High quality water will be needed for a large population. More effective salinity control will become necessary to free more water for key uses.

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Expected climate change impacts include sea level rise, longer dry seasons and more extreme summer rainfall (which is the city's wet season). With sea level rising and more frequent extreme rainfall, more attention will have to be paid to the threat of urban flooding. Sea level rise also threatens to make water sources saline, which is of critical concern. With the longer dry seasons brown water, too, may become depleted. However, there are a number of things that can be foreseen and addressed.

With increased reservoir capacity, the city can tackle the threat of urban flooding and the availability of water. Demand management and improved basin management can address the threat of increased salinity. Such initiatives make sound sense, not just in terms of expected climate change: they secure more supplies for an expanding population and sustain increasing industrialisation.

The wider perspective

Water management, to be truly effective, has to take the whole system into account, the whole catchment area and all the different uses of water. Crucially, although the focus will inevitably be upon human needs, any sustainable strategy must ensure sufficient water is available for the ecological services that provide us with the basic resources for everything that we do.

Then there is the issue of water quality: matching the quality of the water to the application. Is drinking water really necessary for flushing toilets, for example? Can we supply lower grade water for different activities?

Infrastructure must be correctly scaled to ensure sufficient capacity (and to account for expected changes in water resources due to climate change) but without damaging the local ecology. Sustainable water management can go a long way to tackling water stress and water scarcity. Water scarcity is not inevitable. And let us not forget the consumer: the public needs to understand and affirm decisions about water management if these are to stick.

Water is not oil, it is renewable: if we are careful with it, we can live within our means. However, the water cycle is much affected by climate change, so this has to be a feature of any resilience planning for the future. ☐

Water, health and development

Chris Whitty

Water is the point where many areas of international development come together. Some of those intersections can lead to significant tensions. In agriculture, the largest consumer, water is clearly vital but whether it is seen predominantly as concerning food security or poverty reduction may lead policy in different directions. Water is obviously important to industrial development as well; after agriculture, industry is often the largest user, and as countries develop this is likely to rise. It figures strongly in health matters. Water is a key area of concern in climate change, and in the effects of urbanisation. Those are just a few of the interconnecting areas where water is central in development.

Whatever one feels about 'peak water' as a concept, and parallels with peak oil can be over-extended, we are undoubtedly getting to a stage in many countries where consumption will exceed sustainable supply if the situation is not addressed.

Available interventions to use water better can have unforeseen effects, often because no attempt was made to predict them, especially where they are distant in time or space from the intervention. Interventions now can have an impact later in time, for example by depleting aquifers. An intervention up-river can have an effect down-stream; altering the vegetation in one place can lead to a changed rainfall pattern somewhere else. So, thinking through the possible effects across time and space is essential before embarking on grand schemes – otherwise they may disadvantage people who are not the focus of the scheme in question.

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We can illustrate the complexity of the issues around water by looking at disease, but it would be possible to do this with examples for many other sectors. All involve trade-offs.

Communicable diseases

People in areas where water supplies are depleted or limited tend to suffer from malnutrition or are at least unable to obtain balanced diets. This is because the local water environments do not allow production of a full range of foods, or do not allow the generation of sufficient income from farming to buy them in. In some locations, water quality may be impaired due to chemical problems – arsenic in Bangladesh is a classic example. Yet the biggest water-related impacts on health are usually in the realm of communicable diseases. The classical way, still broadly valid, to classify these diseases and their interaction with water is under four headings: water-borne; water-washed; water-based; and water-associated in so far as they are not covered by the others.

Water-borne diseases include cholera, leptospirosis, typhoid and many of the diarrhoeal diseases; if you drink contaminated water you will, sooner or later, get a diarrhoeal disease. Some of these are debilitating and some of them kill, particularly the very young and the very old. Water-borne problems are due to a lack of *clean* drinking water.

The water-washed diseases overlap with the water-borne. In many diarrhoeal diseases, people contract them because their hands have not been properly washed, after defecation but before touching food which they subsequently eat. The problem is not that people have no drinking water – rather they do not have the additional water needed to wash their hands before cooking, eating or feeding children. Water-washed diseases also include trachoma and scabies – the less water available, the more prevalent these diseases, all other things being equal.

So in the first set, the issue is a lack of safe, drinkable water. The second set is associated with not having enough water of whatever quality. Sometimes there is a trade-off between these goals of quantity and quality.

In major water management projects, the issues that cause most problems are water-based diseases, like schistomosiasis, and again trade-offs may have to occur. This can be illustrated by two major schemes of important developmental importance. China is trying to eliminate *Schistosoma japonicum* which was one of the major parasitic diseases in that part of the world. Yet the construction of the Three Gorges Dam, which has clear development benefits, will not help this process. The dam provides an attractive habitat for the snails which carry the disease.

The two Aswan dams in Egypt did not lead to an increase in schistosomiasis (bilharzia) but instead replaced one species – haematobium which causes problems in the bladder – with another, more severe form that causes problems in the liver and the gut. While the Aswan dams have helped many in Egypt in terms of controlled irrigation and other benefits, the people of the immediate Aswan area have paid a price. So these large-scale water projects often lead to situations where society as a whole may benefit, but a proportion of the population may be disadvantaged.

The biggest water-related health impacts are often in 'water-associated' diseases and particularly the vector-borne diseases; most vectors can only live or breed in particular water environments. Of these, the most important in terms of global mortality is malaria. Changing the water environment for development may change the pattern of disease. Take one example from malaria. Rice farming is very important for development. Yet introducing it in different areas can have quite different consequences on malaria incidence. In West Africa, studies demonstrate that the introduction of rice farming has led to an increase in malaria. The vectors definitely benefit from this breeding environment. Yet in East Africa, it has probably led to a decrease because the local vectors are less favoured.

In urban areas, the common diseases are primarily water-washed and water-borne (particularly as sewage/faeces disposal is difficult to maintain in fast-growing urban areas). On the rural side, while water-borne and water-washed diseases have a major impact, the water-associated and water-based diseases become more important. Any changes to the environment, particularly in agriculture, can lead to significant changes in these particular diseases. Increasingly, though, as the urban population rises, issues of urban supply will come to outweigh those connected with rural supply.

Trade-offs

Tackling water-related issues in less wealthy countries almost always involves some complex trade-offs, especially when supplies are limited. Even where supplies of water are relatively plentiful, changes to consumption patterns (especially in agriculture and land-use) can have major consequences. Sometimes these trade-offs are geographical, occasionally they are inter-generational, but very frequently they occur between different sectors in society. While a society as a whole may benefit, certain sectors may be very adversely affected.

If a conflict of interest arises between a richer and a poorer group, it is seldom the poorer who win. Since much of the excess water will be used for industrial-scale agriculture and industry more widely, an improvement in the overall GDP of a country may lead to a significant reduction in access to water for the poorest in society. Sometimes, in the broader discussions about water and development, the potential disadvantage to the poorest gets forgotten. A classical, utilitarian approach, of the 'greatest happiness for the greatest number' is not always the right approach to water policy. □

DISCUSSION

Efficient use of water

Water trading can work to ameliorate shortages in limited areas, but is unlikely to be effective on an international scale. It has to be managed on a catchment-wide basis, and can have perverse effects on the economies of both parties to the trade: it may indeed exacerbate inequalities. A more promising way of improving water usage might be through the use of tariffs, which can be structured to make consumption more costly for large users while, through subsidy, diminishing the costs for those in poverty. Such schemes, though, have to run the gamut of political opposition from rich agriculturists, who would oppose them.

In March 2010, following several controversies over the accuracy of climate science, the InterAcademy Council, representing the leading science academies around the world including the Royal Society, was requested to review the workings of the Intergovernmental Panel on Climate Change. It published its findings on 30 August.

IPCC needs 'fundamental reform'

The process used by the Intergovernmental Panel on Climate Change to produce its periodic assessment reports has been successful overall, but "the IPCC needs to fundamentally reform its management structure and strengthen its procedures to handle ever larger and increasingly complex climate assessments as well as the more intense public scrutiny coming from a world grappling with how best to respond to climate change", according to the InterAcademy Council (IAC). The 18-member InterAcademy Council Board is composed of the presidents of 15 academies of science and equivalent organisations from across the world, including The Royal Society.

The IAC report makes several recommendations to strengthen the IPCC's management structure, including the establishment of an executive committee to act on the Panel's behalf and ensure that an ongoing decision-making capability is maintained. To enhance its credibility and independence, the executive committee should include individuals from outside the IPCC or even outside the climate science community, says the IAC.

Also, the IPCC should appoint an executive director — with the status of a senior scientist equal to that of the Working Group co-chairs — to lead the Secretariat, handle day-to-day operations, and speak on behalf of the organisation.

The part-time nature and fixed term of the IPCC chair's position has many advantages, the committee said, but the current limit of two six-year terms is too long. The IPCC chair and the proposed executive director, as well as the Working Group co-chairs, should be limited to the term of one assessment in order to maintain a variety of perspectives and fresh approach to each assessment. Formal qualifications for the chair and all other Bureau members need to be developed, and a rigorous conflict-of-interest policy should be applied to senior IPCC leadership and all authors, review editors, and staff responsible for report content.

The review process

Given that the IAC report was prompted in part by the revelation of errors in the last assessment, the committee examined the IPCC's review process as well. It concluded that the process is thorough, but stronger enforcement of existing IPCC review procedures could minimise the number of errors. To that end, the IPCC should encourage review editors to fully exercise their authority to ensure that all review comments are adequately considered. Review editors should also ensure that genuine controversies are reflected in the report and be satisfied that due consideration was given to properly documented alternative views. Lead authors should explicitly document that the full range of thoughtful scientific views has been considered.

The use of so-called 'grey literature' from unpublished or non-peer-reviewed sources has been controversial, although often such sources of information and data are relevant and appropriate for inclusion in the assessment reports. Problems occur, says the IAC, because authors do not follow IPCC's guidelines for evaluating such sources and because the guidelines themselves are too vague. It recommended that these guidelines be made more specific — including adding guidelines on what types of literature are unacceptable — and strictly enforced to ensure that unpublished and non-peer-reviewed literature is appropriately flagged.

Uncertainty

More consistency is needed in the way the Working Groups characterise uncertainty. In the last assessment, each Working Group used a different variation of IPCC's uncertainty guidelines, and the committee found that the guidance was not always followed. The Working Group II report, for example, contained some statements that were assigned high confidence but for which there is little evidence, said the review committee.

In future assessments, all Working Groups should qualify their understanding of a topic by describing the amount of evidence available and the degree of agreement among experts; this is known as the 'level of understanding scale'. And all Working Groups should use a probability scale to quantify the likelihood of a particular event occurring, but only when there is sufficient evidence to do so.

IPCC's slow and inadequate response to revelations of errors in the last assessment, as well as complaints that its leaders have gone beyond IPCC's mandate to be "policy relevant, not policy prescriptive" in their public comments, have made communications a critical issue.

The IAC report recommends that IPCC now complete and implement a communications strategy currently in development. The strategy should emphasise transparency and include a plan for rapid but thoughtful response to crises. The relevance of the assessments to stakeholders also needs to be considered, which may require more derivative products that are carefully crafted to ensure consistency with the underlying assessments. Guidelines are also needed on who can speak on behalf of IPCC and how to do so while remaining within the bounds of IPCC reports and mandates. □

www.interacademycouncil.net

In a letter published by *Nature* on 4 October, IPCC Working Group II responded to the IAC's report. The Group said it "welcome[s] its recommendations to improve the way in which the IPCC conducts its assessments". However, the Group disputed some of the IAC's conclusions, including the suggestion that its authors had failed to respond openly and willingly to external enquiries. The letter also said that "WGII does not ascribe higher confidence levels than appropriate, according to the definitions used by WGII". The IAC Review Committee has confirmed that it stands by its findings and recommendations.

http://blogs.nature.com/news/thegreatbeyond/2010/10/ipccs_second_working_group_res.html

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