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The Foundation for Science and Technology
10 Carlton House Terrace
London
SW1Y 5AH

Telephone
020 7321 2220

Fax
020 7321 2221

e-mail
fstjournal@foundation.org.uk

Editor
Sir John Maddox FRS

Sub-editors
Wendy Barnaby, Simon Napper, Charles Wenz

Production & Layout
James McQuat

www.foundation.org.uk

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'Weaknesses' in Research Council strategies

Research Council strategies for promoting knowledge transfer betray a number of weaknesses, according to a report issued on 15 June by the House of Commons Science and Technology Committee.

In its report, *Research Council Support for Knowledge Transfer*, the Committee said that the view of knowledge transfer taken by some Councils was too narrow, "with a focus on technology transfer and little attention paid to the wider issues, such as policy development". It added that "there is also a perception that the Research Councils are not closely attuned to research user requirements and that their attention is focused on informing stakeholders rather than consulting on stakeholder needs".

It said that it had found little evidence of coordination or sharing of best practice in knowledge transfer. And, despite their "clear remit to coordinate and harmonise", the Committee could not find any added value from Research Councils UK in this area.

The report welcomed the recent External Challenge of Research Councils knowledge transfer activities, but it claims that this review failed to evaluate individual Research Councils' knowledge transfer schemes due to lack of resources. "Since the Research Councils conduct little internal impact analysis of their knowledge transfer schemes, it is difficult to see how they can effectively allocate funding to different knowledge transfer activities," the Committee concluded. ❐

www.publications.parliament.uk/pa/cm200506/cmselect/cmsctech/995/995i.pdf

Europeans ambivalent about impact of biotechnology

In its latest soundings of consumer opinion, the EU's Eurobarometer survey found that just over half of those interviewed (52 per cent) thought that biotechnology would improve their lives. However, in specific areas they were more optimistic.

Europeans and biotechnology in 2005 shows that most Europeans are in favour of medical applications of biotechnology when there are clear benefits for human health. The same holds for industrial applications, but most remain sceptical about agricultural biotech, and will continue to be so unless new crops and products are seen to have consumer benefits. Confidence has increased in the EU's regulation of biotechnology but there is no evidence that this has influenced the public's reported purchasing intentions, especially for GM foods. Overall, optimism about biotechnology's contribution to improving society has grown significantly since 1999. There was also support for research using stem cells, provided this is tightly regulated. ❐

www.ec.europa.eu/research/press/2006/pr1906en.cfm

Post-Montreal ozone levels

Two major studies have come up with broadly positive news on the consequences of the flagship international agreement on environmental protection. The 1987 Montreal Protocol banned CFCs and other chlorine-containing pollutants from use in aerosols and as coolants: the question that can only now be answered is whether this will have the desired effect of reversing depletion of the atmosphere's ozone layer, thereby restoring the protection against ultraviolet radiation afforded by ozone.

A team at Japan's National Institute for Environmental Studies, led by Eiji Akiyosh, has published numerical simulations that suggest that although the Antarctic ozone hole is currently at its largest, we can expect it to begin to contract around 2020, and possibly disappear by around 2050.

The Japanese report is largely in agreement with a study by Betsy Weatherhead of the Cooperative Institute for Research in Environmental Sciences, a joint institute of CU-Boulder and the National Oceanic and Atmospheric Administration, and Signe Bech Andersen of the Danish Meteorological Institute. They conclude that the ozone layer is slowly being replenished, but the recovery is occurring in an ever-changing atmosphere and is unlikely to stabilise at pre-1980 levels. ❐

Ozone Hole (in Japanese). National Institute for Environmental Studies (NIES), May 19, 2006.

E C Weatherhead and S B Andersen. 'The search for signs of recovery of the ozone layer.' *Nature* **441,** 39-45, 4 May 2006.

Europe's ailing knowledge economy

In a speech to the French Académie des Technologies, and in an opinion piece in the science journal *Nature*, former European commissioner Chris Patten has sounded a warning to European nations that the continent's once dominant position in higher education and scientific research is seriously threatened by lack of new investment.

Patten is now the chancellor of both Oxford and Newcastle universities, but his criticisms are aimed at governments right across Europe. Much of Europe's higher education system is in severe difficulties; the research base is threatened; many of the best researchers are being lost and all this is happening at a time when global competition in the knowledge business is fiercer than ever.

In tertiary education, spending on research per student in 2005 was just over US$ 9,000 for France, about $11,000 for Germany and $12,000 for the UK. Austria, Belgium, Denmark, the Netherlands and Sweden do better, but the figure for the United States is $26,000. Europe also performs badly in terms of spending on tertiary research as a percentage of gross national product (GNP). This figure is 1.1 per cent for Europe as a whole and roughly the same for France, Germany and the United Kingdom nationally. It is 2.6 per cent for the United States (1.2 per cent from public funds and 1.4 per cent from private). This pattern is mirrored in lists of academic attainment.

In that context, Patten sees little chance of realising the 'Lisbon strategy' – the EU's aspiration to become the most competitive knowledge-based economy in the world by 2010. The market economy cannot supply the necessary investment in knowledge and learning, and without it Europe will lag behind the United States, China and other Asian countries in the competition for global markets, scientific prestige and political influence. ❐

Full text on: **www.admin.ox.ac.uk/po/news/2005-06/feb/Pattenspeech.pdf**

Patten C (2006) Europe pays the price for spending less. *Nature* **441,** 691-693

Radar and wind turbines

The skies over Clatter mountain near Newtown in Powys, mid-Wales, are the setting for unusual military manoeuvres as the Ministry of Defence tests new technology designed to overcome interference on civil and military air traffic control radar.

The MOD is working with the DTI and the British Wind Energy Association (BWEA) with support from National Air Traffic Services (NATS) and the Civil Aviation Authority (CAA), to test two technologies from BAE Systems and Selex SI to see if they resolve problems posed by wind turbines. An MOD mobile Watchman radar has been located in an area of multiple wind farms and both the RAF and an independently appointed safety team are conducting calibrated trial flights.

If the technology is deemed fit for purpose it will free a significant number of potential locations for wind farms across the UK. ❐

It's good to talk

In these days of email communication, it is often forgotten that the telephone can in fact be a quicker means of contact, as BT would be quick to point out. For this reason, it helps to include a contact telephone number below your signature. ❐

Partnerships bring a number of benefits to the participants. Is the UK maximising its opportunities in this area and, in particular, should there be more R&D collaboration with the US? The meeting of the Foundation on 12 July 2005 examined these issues.

Reducing barriers to collaboration

Gareth Roberts

Sir Gareth Roberts FRS FREng is president of Wolfson College, Oxford, president of the Science Council and president of the Engineering and Technology Board. He is a member of the Higher Education Funding Council for England. Before his move to Oxford, Sir Gareth was vice-chancellor of the University of Sheffield. He had previously held chairs in physics at the New University of Ulster and the University of Durham. He has also held two industrial posts, as a senior research scientist with the Xerox Corporation in the USA and as director of research and chief scientist at Thorn EMI.

In my view, the UK should be actively seeking to reduce barriers to research collaboration, not just with the USA but also with the rest of the world. Collaboration with American agencies and universities should be seen as just one part of a greater undertaking. That said, the USA is the preferred partner for international research partnerships and makes a significant contribution to the leading edge performance of collaborating nations. This is in large measure due to its massive investment in research and development, about one-third of the world's total. The total federal investment in research alone amounts to about $56 billion which dwarfs the approximately $6 billion distributed by UK Research and Higher Education Funding Councils.

It should be a strategic imperative therefore to optimise existing links and to invest further effort and resources to establish new research networks involving the USA. Further evidence to support this position comes from a bibliometric analysis of jointly authored publications commissioned from Evidence UK as part of my Gatsby Foundation sponsored study of UK-USA Research Partnerships[1].

These investigations revealed some important points:

- Over the past five years, collaboration between the USA and UK has increased more than those between the USA and other countries;
- Between 1994 and 2003, the proportion of all UK papers in arts, humanities, social sciences and engineering that were co-authored with Americans increased to 10.6 per cent. In the fields of biological and health sciences the percentage was approximately double that figure;
- Importantly, 30.5 per cent of the most highly cited papers published between 1997 and 2001 had an American co-author;
- These co-authored UK-US papers had a greater average impact factor (citations per paper) than those written solely by UK authors, by US authors, or by co-authors from other countries.

Further analysis revealed that there is no advanced nation that does not depend on US input to produce a high proportion of its world-class research.

In order to strengthen and expand our research partnerships with the USA, we need to address a number of issues. There should be no need to suggest expensive artificial incentives to collaborate, so long as some help is provided to overcome the natural obstacle (distance) and the artificial ones (lack of information, different funding systems, outdated perceptions etc). Unlike the supportive arrangements in place to encourage intra-European collaboration, my study has highlighted that research groups cannot be confident of obtaining support on a bilateral basis from UK and US Government funding agencies (this does not apply to partnerships funded by large charities, defence agencies and industry). This double jeopardy occurs when it is necessary to obtain a favourable funding decision from each of two different funders. A concerted effort in transatlantic diplomacy to address this issue could yield lasting benefits for both countries. Furthermore, a new office or small unit should be established in Washington DC as a primary liaison point with the federal funding agencies and to proactively disseminate information about funding opportunities in the USA to the UK research community.

A second barrier is the difficulty involved in providing supplementary research grants aimed at creating lasting links with US research groups – 'glue money'. There is limited support at present for this type of expenditure and it is not very well publicised. By contrast, the National Science Foundation in the USA has recently recognised the need to enable American institutions to develop long-term collaborative research with foreign partners and has established a special research funding round for that purpose (which has been heavily oversubscribed). Increasing transatlantic mobility, especially for young people, is a must; there are some excellent examples whereby students can qualify for a doctorate from universities in both the USA and in the UK.

Technology transfer is another very important area and, because of the dominant position of the USA in both R&D and in enterprise, the UK devotes considerable resources to managing, stimulating and coordinating innovation and technology links across the Atlantic. Approximately 200 staff are engaged in this important

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Building global networks. A number of speakers noted that the most successful research partnerships are those which avoid elaborate bureaucratic accounting. One notable example is the arrangement for ships used in oceanographic studies: researchers from any country can apply to join any ship in any area relevant to their research, no matter which country owns the ship. Several speakers made the point that informal networks between professors and researchers who have worked in various countries, or who have moved between industry, academia and Government, are the most effective catalysts of partnerships.

role, mostly under the aegis of the DTI's Global Watch Service, the Foreign and Commonwealth Office's Science and Innovation Network and UK Trade and Investment. Senior members in all these departments have acknowledged to me the need for better coordination and a reconsideration of priorities, focussing more on science and innovation.

In some research fields, cooperation is thriving at all levels, from *ad hoc* collaboration, to larger networks and inter-agency partnerships. However, in the arts and humanities as well as the social sciences, the links tend to be informal, not to say solitary and lacking any firm institutional structure. Collaboration is often hindered by the lack of research materials in digital form. There is a need to assemble a truly colossal and cross-searchable transatlantic database that would open up many exciting new avenues of collaborative and comparative research.

My study has prompted the first tangible research partnerships between the two national libraries and between the Arts & Humanities Research Council (AHRC) and the US National Endowment for the Humanities. An initiative is now well underway between these partners, plus the Economic and Social Research Council (ESRC) and the Higher Education Funding Council for England (HEFCE), to optimise the potential of physical and virtual access to research resources in printed, digital and other formats in the libraries, museums, archives and data centres of the two countries. Substantial, targeted funding has been allocated by UK partners to the project, including 20 scholarships annually for UK postdoctoral fellows to be based in newly furbished space at the Library of Congress in Washington. Moreover, following extensive discussion between the Director of the National Science Foundation, the Chief Executive of the ESRC, Ian Diamond, and myself, significant progress has been made in these areas to overcome the double-jeopardy problem.

There is, of course, considerable scope for the UK and USA, in partnership, to develop a comprehensive set of strategies for addressing major world problems such as the effective harnessing of science and technology to meet human needs in Africa.

In summary, the scale of the research base in the USA means that there is immense scope to add value through collaboration. UK-USA collaboration represents about one-third of the UK's strongest research – it should therefore be a fundamental strategic imperative to ensure that our links with the USA are maintained and strengthened although not, of course, at the expense of partnerships with other countries. Any model for a successful science base must entail significant engagement with the USA. ❐

1. Electronic copies of the final report can be accessed at the Wolfson College, Oxford, website **www.wolfson.ox.ac.uk/UK-US-Academic-Collaboration**

Partnership in multiple dimensions: a view from industry

Robin Saxby

Sir Robin Saxby is a founder and chairman of ARM, a company that designs microprocessors that are embedded in a wide range of consumer products, including practically all the world's mobile phones. He is also deputy president of the Institution of Engineering and Technology. He served as chairman of the Open Microprocessor Initiative Advisory Group, which advised on collaborative R&D activity within Europe. He is a visiting professor at the University of Liverpool.

When we started ARM it was clear that we needed to collaborate with people in the USA. The Americans are far better than the British at selling – they understand that unless a customer explicitly wants a product, the technology has no value. The largest technology market in the world is still the USA: without this market and our collaboration with colleagues there, our company would not have succeeded. Yet it was collaboration in Europe with Nokia that really helped us 'take off', while today China is very important to us. To survive in the technology business one can never stand still.

The semiconductor industry in which we operate is about 50 years old and looks set to continue for a further 50 years. New technology arrives in waves: today CMOS (complementary metal oxide semiconductor) is dominant; tomorrow it may be polymers. The industry is driven by the need to pack more and more transistors on a chip. This miniaturisation has reduced costs and enabled an increasing complexity in digital consumer products – and ARM has played a significant role in making this happen. In the mid to late 80s US companies were focused on increasing performance in terms of speed, whilst Acorn in Cambridge focused on getting the lowest chip size and therefore the lowest cost as well as an increase in speed. That put the ARM architecture in a different space from its competitors.

The design engineers from Acorn were spun out to found ARM with me and with seed money from Apple and VLSI Technology. From the start, we targeted our processors to have the lowest power consumption and cost, whilst also having high performance. This focus on cost and power consumption is one of the reasons why ARM is now used in 90 per cent of the world's mobile phones and it enabled ARM's partners to ship 1.7 billion chips in 2005.

Computing has evolved in parallel with the semiconductor market. We have moved from mainframes to minis to personal computers and PDAs. Today my Apple iPod has a bigger hard disk than my laptop, and the ARM processor is as much about computing as semiconductor technology.

In the early days of the microchip industry, individual companies undertook the entire process of designing, assembling and manufacturing transistors and silicon chips. Today, intellectual property licensing has become a subsegment of the semiconductor industry. Design, assembly and manufacture are often carried out by different companies in different countries and most top design teams are truly global. Semiconductor foundries which build wafers for everyone have emerged over the past 15 years: TSMC, headquartered in Taiwan, is the market leader and China is the fastest growth area. Because of the large capital sums needed to build wafer factories, economics drives decision making. High-volume manufacturing is carried out wherever it is most cost effective, causing a dynamic shift in favour of the East. Over the past 30 years, we have seen the Japanese challenge the Americans, the Koreans challenge the Japanese, and now the Chinese are challenging the Taiwanese.

Our model at ARM was very simple: to "license our technology to everyone and become the global standard in all digital products"; and to secure a royalty on every silicon chip produced. In order to do this, we had to find partners across the planet starting in the USA, then Europe, then Japan, then Korea, then Taiwan, then China, etc. Today we employ about 1500 people located in R&D centres in the UK, USA, France, Belgium, India and so on – but our global partners employ hundreds of thousands of engineers working on the ARM architecture in most of the industrialised countries on our planet.

At ARM we design digital engines, semiconductor building blocks or libraries, software and hardware design tools, and embedded software that we provide to our global partners. We have silicon partners like Texas Instruments and Intel who design and manufacture complete chips; software partners like Microsoft and Symbian who design operating systems and applications that run on our architecture; semiconductor design tools partners, such as Cadence, Mentor and Synopsis, and many others. We call this our 'connected community'. We also work with universities – mainly to source good people, but we also do collaborative R&D with Cambridge, Manchester, Liverpool, Stanford and Michigan, for example. It is important for us as industrialists to drive and influence this research so that it delivers to our timescales. We also have acquired several smaller companies over the years as a way of buying-in technology and shortening time-to-market.

Our biggest acquisition to date is Artisan. To best implement our designs, we need to build the architecture out of 'bricks'. Artisan builds and designs 'bricks' or 'libraries', which are then licensed to semiconductor companies. We bought Artisan because, with the advent of deep submicron technology, we have to care about the libraries as well in order to achieve the best power consumption and performance. We also believe the industry will adopt Artisan libraries as a standard as it has already done with the ARM architecture.

Industry, academia and governments have different timelines, different objectives and different performance measures. As a business, we have to meet quarterly targets, so we must deliver in the short term as well as developing the long term strategy for growth. In general, university research works to longer timescales. However, I believe that, in the West in particular, we could harness the brainpower in our universities better by aligning it with the needs of business; governments might stimulate this. The US space programme is one example of a successful collaboration between business, academia and government. All successful economies are now thinking about innovation and wealth creation in order to preserve and improve their standards of living. I believe the only acceptable answer to this challenge is to be the best at what you do and to collaborate with strong global partners. ❐

US/UK collaboration – a personal perspective

Charles Vest

Professor Charles Vest was president of the Massachusetts Institute of Technology from 1990 to 2004. He chaired the President's Advisory Committee on the Redesign of the Space Stations and serves as a member of the President's Committee of Advisers on Science and Technology, the Massachusetts Governor's Council on Economic Growth and Technology, and the National Research Council Board on Engineering Education. He is a member of the board of directors of IBM and EI du Pont de Nemours and Company.

For many years the UK has been the destination of choice for American academics on sabbatical leave. The UK offers an opportunity to work with first-rate colleagues, particularly in the disciplines of science and engineering. Americans love to come here and live for periods of time in the great British universities, which have a longer and, in many ways, deeper history than our own. We enjoy working with each other and that is an important point: successful collaborations work because the participants want them to. One would look in vain around any US university for a faculty member or a researcher who does not have a few close British colleagues and, indeed, if you were to glance down the hallway of any great American university you would hear some very familiar accents – our faculties are all blessed with folks who come to us from the UK.

There are some particular ties between my institution, the Massachusetts Institute of Technology (MIT) and England – notably the joint work carried out in the radiation lab at MIT during the Second World War. Many historians argue that the development and successful deployment of radar-based technology was at least as important as the Manhattan Project in winning that war. The experience of collaboration gained in that laboratory was seminal in creating MIT as we know it today.

Among more recent collaborations, the sequencing of the human genome stands out. Here I must mention the role of Cambridge, UK, without which the young American Jim Watson may never have stumbled across Francis Crick and formed the partnership that made our understanding of the human gene possible. The bulk of the recent gene sequencing work was done at the MIT Whitehead Genome Center, here at the Sanger Laboratory and at Washington University in St Louis, although many other laboratories and countries participated. A very high level of scientific leadership on both sides of the Atlantic was needed for this project and the work could only be done in institutions with the skills and capability to build the necessary infrastructure. It succeeded because those involved were committed to a shared vision, were able to work on a large scale and to surmount and/or cooperate with bureaucracies on both sides of the Atlantic in government, university and industry. It is an outstanding example of an international research partnership.

Partnerships tend to fall into two types – symmetrical, in which both partners have equal core strengths, and asymmetrical, in which the partners have different capabilities. Almost every US-UK partnership is symmetrical. Asymmetrical partnerships are seen more broadly internationally, often with the USA or UK using its capabilities to build capacities in other countries.

The Cambridge-MIT Institute (CMI) is primarily a symmetric partnership, but there are areas of asymmetry, where one side or the other has particular strengths. Obvious advantages to this partnership are a shared language and familiarity with each other's culture. I see CMI as a bold experiment and a strategic alliance of two great universities, with the very important long-term goal of enhancing the competitiveness, productivity and entrepreneurship of the UK. It is a major investment by the UK Government.

CMI sprang from the Chancellor of the Exchequer's deep concern about the productivity, entrepreneurship and competitiveness of industry in the UK. He came to believe that there was a relatively weak relationship between universities and industry in the UK. MIT had a long history of partnerships between universities and industry and the Chancellor looked to us for some ways in which we might form partnerships. Establishing CMI required much painstaking work on the part of both faculty and administrators at Cambridge and MIT and involved the Department of Trade and Industry and others in the UK Government.

discussion

Learning to think collaboratively. Participants agreed that the ultimate goal would be to develop sufficient numbers of relationships across countries, sectors, academia, government and industry to enable collaboration to occur naturally, because people want, and know how to, work with each other. There is much pent up demand for opportunities to work in other countries: the seven Fulbright awards in the US each attracted 300 applications. Seen in this light, the benefits of the Cambridge-MIT Institute, and the farsighted initiative of the UK Government in funding it, are clear. There is no doubt that the 140 students in the CMI project are beginning to affect the way science is viewed and taught.

There are three primary modes and models of the work of CMI:

- Knowledge integration in research;
- Education of students to be innovators;
- Engagement of industry with universities.

Knowledge integration is of vital importance. At CMI we have begun to form what we call 'knowledge integration communities' (KICs) in all of our research programmes. They bring together several stakeholders – academic researchers, representatives of large and small companies, government policy makers, communications agencies, regional development authorities here in the UK and educators from a variety of institutions. KICs work together from the inception to the implementation of projects and, most importantly, dissemination of their results.

We have KICs working on programmes in a number of areas: the development of silent aircraft to improve the environment for those living and working near airports; next-generation drug discovery; communications research networks; competitiveness in education; and quantum computing. Faculty acceptance of this approach has been very good. It can perhaps be best summed up in the words of Louis Pasteur: "Chance favours the prepared mind". What a KIC does, in essence, is prepare a collective mind.

We have also learned much about what it takes to encourage students to become innovators. When CMI began, we wanted to find out about the process of innovation. To that end we put together a group of students from the two universities. They had never met each other. We asked them to do some problem-solving exercises involving issues on their university campuses.

For the first couple of days, the students from MIT were very intimidated by the Cambridge students, who were so articulate, well-spoken and well-informed that the MIT students hardly dared say a word. However, the MIT contingent soon found its feet and amazed their Cambridge colleagues with their ability to roll up their sleeves, organise and develop a creative solution. At the end of the exercise we gave the students a questionnaire in which we asked them to tell us how they would go about implementing their solutions. The British students thought they would write a formal proposal to the administration of the university. Their American counterparts, however, said that they would just get on and do it. I think this little anecdote illustrates the ways in which we complement and can learn from each other.

However, it is essential that both partners have a profound conceptual knowledge of the fundamentals of science and technology. This is something we do well in different ways on both sides of the Atlantic. In addition, we must create opportunities for students to work together in teams, to think in an organisational context and refine their ideas with a view to product development. We need to instil in our students a sense of self-efficacy, that is, students need to learn that they can make a difference. They need to believe that they can make things happen rather than wait for things to happen to them. They need to understand that they do not need to fit into a preconceived mould, and that they should be prepared to take risks.

I believe that UK-US partnerships will remain strong as long as policy makers and funding agencies provide the will and the means for them to succeed. Both Governments need to invest strongly at home in order to support their best researchers, create core competencies and develop infrastructures that will allow such partnerships to flourish. ❐

discussion

Balancing commercial and scientific needs. It is clearly important for research students to think beyond their immediate research to the management and commercial development of their projects. However, some participants warned against taking this too far, at the expense of diluting the emphasis on fundamental scientific learning. It had to be recognised that not all researchers will be happy working in a commercial environment. MIT's success was built on doing good science and being open to business, but it was not its job to concentrate solely on the latter. A suggestion that a commercial company might underwrite the costs of a university department in exchange for specific research work aimed at producing patents, was received with mixed feelings.

Carbon abatement technologies offer the opportunity for continued use of fossil fuels but with greatly reduced carbon emissions. Their development was discussed at a meeting of the Foundation on 25 October 2005.

Mitigating our continuing dependence on fossil fuels

Malcolm Wicks

Malcolm Wicks is Minister of State for Energy at the Department of Trade & Industry (DTI). He has served in the Government since 1999 when Tony Blair appointed him a junior minister in the Department for Education & Employment. In July 2001 he moved to the Department for Work & Pensions where he was promoted in 2003 to Minister of State for Pensions. He was appointed Minister for Energy after the 2005 General Election.

Let me put the issue about carbon abatement technologies, or 'CATs', in some context. The climate change review is being led by DEFRA and Margaret Beckett[1]; there is also a review being undertaken by the Treasury into climate change and its interface with the fiscal system, which has an international as well as a domestic dimension. The Prime Minister has said that he wants to see new recommendations on energy policy and this is a new opportunity to debate a whole range of issues relating to energy policy. Clearly, whatever we say about CATs needs to be placed in that wider context. There are important issues at stake about the climate, about energy supply, about the future of nuclear, as well as these new technologies.

Encouraging the development and deployment of sustainable energy technologies, security of supply and competitive markets, have been the core of our policy. To date, we have concentrated on renewable technologies because they offer opportunities in the short term to meet our target of a 10 per cent reduction in CO_2 emissions by 2010. However, the Energy White Paper (published back in 2003) set the UK on a longer-term path for reducing our CO_2 emissions by some 60 per cent by the middle of the century, 2050. This is a challenging target and it is clear that, in the medium to longer term, we will need a portfolio of sustainable technologies, as well as a focus on energy efficiency.

CATs have a role to play in this, and an important role in achieving security of supply. What has become clear from the analysis used to develop the strategy, is that even in 2050 we shall still be very reliant on fossil fuels for power generation. I know that there are some who would wish it otherwise – there are some who see a cleaner, greener future through energy efficiency and renewables and microgeneration – but the reality is that the world, including ourselves, will be heavily reliant on carbon, on coal, on oil, on gas. In fact, by 2020 we expect some 75 per cent of our electricity to be generated from fossil fuels, a little more than at present (these forecasts also suggest that we will be more dependent on natural gas than we are now, with about 58 per cent of our power coming from this fuel). These are the current projections, of course; whether they are altered by the outcome of the Energy Review and the deliberations around it is another question. So, in the longer term, to achieve the lower emission levels we need by 2050, all new fossil fuel plants will need to employ CATs.

When do we think that we shall start to need them? The answer is clearly as soon as possible but, in the medium term, we are thinking about improved efficiency in boilers and turbines and co-firing with biomass. Some of you will have noted Sir Ben Gill's report on biomass[2]. Now we would expect biomass plant to emit 10-20 per cent less CO_2 and they could be deployed from 2010.

In the longer term, we expect carbon capture and storage (CCS) techniques to make significant reductions as they have the potential to reduce the emissions by around 85 per cent. There is still considerable R&D required to reduce the costs of these technologies and mitigate the negative impact they have on plant efficiency; we do expect, however, that they could be commercially viable by about 2020.

The Government is putting aside some £25 million for demonstration plant and £4 million of Government funding is being allocated to CATs in the next call for R&D proposals. In addition, we recognise that market incentives are needed. The Chancellor, in his Budget Statement, promised to look into these and they are included in the review of the climate change programme.

While capture is more to do with technology development, storage is an issue which is concerned with regulation and public acceptability. Geological storage of carbon under the North Sea is well understood, given the experience and knowledge of our oil companies from North Sea oil exploration. On the Norwegian side, Statoil have been doing this now for nine years in the Sleipner Field without any problems. We need a regulatory regime that will, in very simple terms, ensure that we can safely and reliably sequester or capture the carbon and enable us to know and demonstrate that it is staying down there.

discussion

More questions than answers?
Participants were keenly aware that carbon abatement technologies are not commercially proven and that the economic and regulatory frameworks needed to encourage uptake are far from clear. Were we in danger of spending large resources on carbon abatement, when other fuel sources – renewables and nuclear – might rapidly overtake fossil fuels? What were the comparative costs of biomass to fossil fuel? Were the various engineering and other professional bodies working closely enough together to meet the challenges and train staff? Had the Government got the right organisation for dealing with energy issues? Was there a case for reviving the Department of Energy?

Developing such a regulatory regime will involve a considerable amount of work over the next few years. It includes the development of monitoring and verification techniques to confirm the carbon is not leaking – and possibly enabling carbon credits to be earned under emissions trading. We also expect changes will be needed to the London and OSPAR conventions which govern dumping at sea so that geological storage is not in contravention.

In addition, there is a need to reach out to the public and NGOs to assure them that we are not creating an environmental problem for future generations. New technologies of this kind can engender not just optimism but also suspicion. What is encouraging in all of this is the high level of interest and, dare I say, undiminished enthusiasm which has been shown by UK companies in bringing on CAT technologies. Importantly, industry has recently established a carbon capture and storage association, which, I am sure, will be effective in promoting these technologies. The fact that the European Commission is starting to take carbon capture and storage as a serious future sustainable technology, with the announcement of a new technology platform for zero emission fossil fuel plant, can be attributed to the hard work that has been put in by industry and experts over the years.

Not only is the momentum building in Europe but, closer to home, the BP/Scottish & Southern Energy Project for hydrogen generation at the Peterhead Power Station, with surplus CO_2 being used to enhance oil recovery in the Miller oilfield, has the potential to make the UK a world leader in CCS technologies.

I think we need now, notwithstanding the precedents that I have mentioned, some major demonstration projects on carbon capture and storage; the BP project is the best that we have at the moment and very exciting indeed. BP have already taken an initiative on their own with the CO_2 Injection Project at the In Salah gas field in Algeria, and they are clearly developing a reputation as a company committed to clean energy systems.

I should add that when we had the first ever summit between OPEC and the EU some months ago, I was struck by how open OPEC was to the new carbon abatement and carbon capture technologies. I think that this all leaves a very encouraging picture for the future of CATs as well as providing a solid foundation for the future development of these technologies.

As we get into the serious scientific work of building the evidence base for the energy review, it is absolutely vital that the scientific community and the technology and engineering communities make a very, very full impact on that process. I will do my best, as a mere social scientist by background, to achieve that; it is an important thing to say in this rather august institution. ❐

1. The new programme was published on 28 March 2006. **www.defra.gov.uk/environment/climatechange/uk/ukccp/index.htm**
2. **www.defra.gov.uk/farm/acu/energy/biomass-taskforce/btf-finalreport.pdf**

Taking an international approach to carbon abatement

Nick Otter

Nick Otter OBE is Director, Technology and External Affairs, at ALSTOM Power. He is an energy adviser to the UK Government where his positions include chair of the UK Department of Trade and Industry Advisory Committee on Carbon Abatement Technologies for Fossil Fuels and UK representative on the Carbon Sequestration Leadership Forum. He was awarded the Order of the British Empire (OBE) for services to the UK energy industry in the Queen's New Years Honours 2003.

The transition to zero emission power generation is a key issue. If you look at the growth of CO_2 emissions in different parts of the world it becomes clear that China will be the biggest CO_2 emitter by 2015 – it will overtake the US. Engaging emerging market economies like China will be absolutely vital if we are truly to attack the issue of global climate change.

I think it is now increasingly accepted that the clean use of fossil fuels is a critical transitional issue in achieving a sustainable energy future and that many countries now have active programmes to address it. A twin-track integrated strategy approach to achieve zero emissions fossil-fuel power plants, as being developed in the UK, is being adopted by many[1].

Figure 1 shows a chart of carbon reduction over time. The lower line is the efficiency line: this is, if you like, the line of no-regrets with improvement in efficiency being achieved and investments being forthcoming. It involves the development of high efficiency plant. However, we would like ultimately to have zero emissions from fossil fuels. That means using carbon capture and storage (CCS). The pathway to achieving this 'zero emission' – in effect going from the lower line to the higher one – is likely to be a very complex process. Policy and regulation will play a significant part, as will the fiscal framework necessary to encourage investment. The value of CO_2, such as that coming from the Emissions Trading System, will be a critical element. There will also be a strong geographical impact with different countries taking different routes.

One issue is clear: high efficiency plant and components will be required to achieve zero emissions – if only to offset

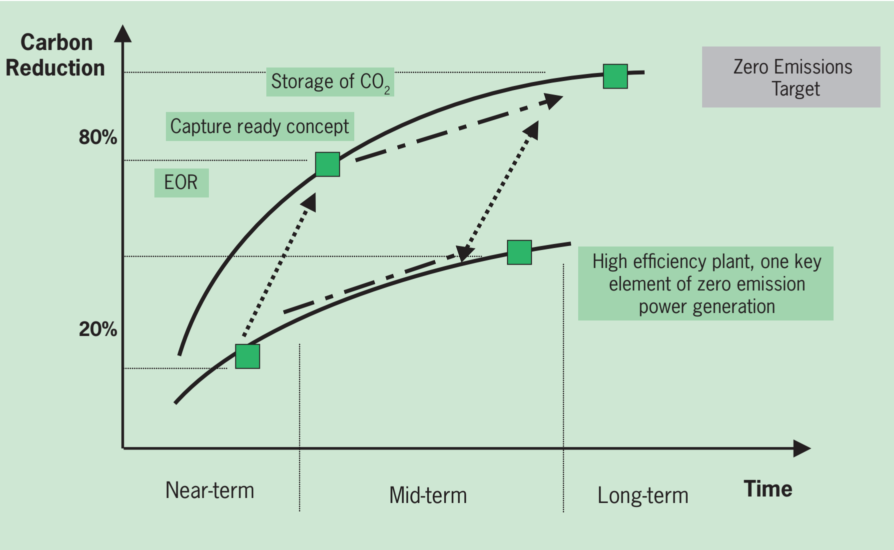

Figure 1. Pathway to zero emission power for fossil fuels.

the detrimental impact that capture has on the overall plant performance. However, it should be possible to proceed up both trajectories with the development of 'capture ready' plant, and using Enhanced Oil Recovery with CO_2, as stepping stones to full CO_2 storage systems.

What does 'capture ready' involve? Simply, it means that whatever new plant is put in now, it can be extended for capture in the future. Such an approach would be important for the likes of China, where a GW of power is being installed each week, mostly coal-fired plant. Otherwise, these could ultimately be stranded assets even though they are relatively high efficiency plant. You cannot achieve zero emissions unless you plan that from the start.

One uncertain element about market-based instruments is that there is no fiscal or regulatory environment encouraging the take up of these technologies. Carbon capture and storage is not yet part of the Emissions Trading Scheme although the topic is now being actively addressed; the European Commission has announced a review of the EU Climate Change Programme and will have a working group specifically looking at the mechanisms by which these types of technologies can be introduced into the trading scheme.

For geological CO_2 storage in the oceans, it is necessary to address the regulation issues arising from the London and OSPAR conventions, the monitoring verification issue, the long term ownership of CO_2, planning and authorisation, as well as standards: all these different things have to be addressed in parallel with the technical issues. The focus technically will probably be cost reduction. Reductions should be achievable, not just through technical development but also with deployment of such technologies at scale in the market place. As an example, just look at the reductions achieved in FGD technology (desulphurisation), where a factor of four was achieved over the period of a decade. This could be achieved for CO_2 capture as well.

These issues are being taken up in a European context. Energy, environment and climate change feature as major themes in the proposals for the next Framework Programme. On the energy side, all the expected topics are included but what has also been accepted, I think after a lot of discussion, is that zero emissions for fossil fuels are to be addressed. It is therefore a full 'portfolio' approach over seven years which, hopefully, will attract financing of the order of €2-3 billion. It has to go through the EU's conciliation process and there are all the budget issues, but I think there will be substantial action on these topics.

The European Commission is also seeking to have major critical 'mass actions' – it calls them Technology Platforms. The Zero Emission Fossil Fuel Power Generation Platform has been formed with good support from a wide range of industrial sectors; an Advisory Council of senior individuals was established in June 2005 with a formal launch in December 2005. The whole initiative is driven by industry (with good involvement from the UK) with the simple vision of having these technologies ready for 2020. In order to do that, two things have to be developed: a strategic research agenda (in effect, a route map); and a deployment plan. There is no point in developing all this technology unless you can get it into the market place. The working groups that are now being formed cover all the technical and non-technical issues and address all the issues raised within the UK and its CAT strategy. The UK has therefore provided a substantial input to European action.

It has to be recognised that this is a major initiative because it is setting the agenda for Europe up to 2030-50: it is essential to have such a timeframe as the decisions taken now on future power plant will be with us for the next 30-40 years. It is not, though, just about the European framework programmes; it includes all the Member States' programmes and all the other aspects of financing that will be brought together to achieve the critical mass programme.

All this needs to be positioned in an international context. We need to see how these technologies fit into an overall map on a world basis. The European initiative is analogous to the Carbon Sequestration Leadership Forum (CSLF) and its related action on hydrogen and fuel cells, the International Partnership for the Hydrogen Economy (IPHE). Each of these has about 20 countries as members, all of which are developing road maps for zero emission. There is therefore a very strong thrust internationally for a greater coordination worldwide. Also, the Intergovernmental Panel on Climate Change (IPCC) has issued a special report on CCS[2]. All this has happened in the last two years or so.

To me, there will be no single winning technology and so the portfolio approach will be essential. This must include the 'clean fossil' issue if we are to address global climate change. The critical issue will be the deployment of such technologies, so it will be essential to have some sort of stable,

discussion

Transferring knowledge to developing countries. The point was made that countries like China and India did not need lectures from us about emissions reductions; they needed help in developing technologies to enable them to obtain growth without damaging the environment. But knowledge transfer raised difficult questions about intellectual property; it would be naïve to suppose that companies would willingly communicate financially valuable technical information. Countries such as China, if they were serious about carbon abatement, should understood that they would have to pay for at least some of the help they might get.

regulatory, fiscal framework to encourage investment: it is not there at the present, there is no incentive for the generators to go down this route at all. We have got the Emissions Trading Scheme and a value for CO_2, but we really need better visibility of the value of CO_2 in the future.

In conclusion, there is urgent need for continuing action – if we are going to meet these emission reduction targets we have to do something now, and we have to maintain the impetus. A key issue is the need for greater clarity post-2012 so that investments can be made with some confidence. Remember, the life of a power plant is some 40 or 50 years and we are going to have to make decisions in the next few years, here in the UK and worldwide, that we are going to have to live with for that time. If we get it wrong, we will have to live with the resulting carbon emissions, so we really have to set the agenda now for the future. ❐

1. **www.dti.gov.uk/energy/coal/cfft/cct/pub/catreportlinked.pdf**
2. **http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/ccsspm.pdf**

Making carbon capture and storage a reality?

Kjell Bendiksen

Dr Kjell Bendiksen is president of the Institute for Energy Technology (IFE) Group, Norway. IFE is the largest energy research laboratory in Norway, performing contract research within oil and gas, nuclear safety, and other energy and environmental technologies. He chaired the Norwegian Gas Technology Commission, appointed by the Norwegian Government in 2001. He is a member of the Norwegian Academy of Technological Sciences.

Addressing our global energy and climate realities is a complex and sobering task. I am going to consider one aspect: how to cover the expected increase in energy demand, particularly in developing countries, without Greenhouse Gas (GHG) emissions running wild. What is the potential of Carbon Capture and Storage (CCS) technologies in this regard? Do they represent a sustainable solution – or may we see the sunset of fossil fuels?

Fossil fuels today encompass more than 85 per cent of global energy supply, and this share is *increasing*, nearing 90 per cent, as most of the growth must be met from fossil sources. Global energy-related CO_2 emissions are expected to soar by 50 per cent in just 20 years, according to the International Energy Agency (IEA), in sharp contrast to the aims and ambitions of the Kyoto Protocol for a swift decrease.

Predicting the future is a difficult business, so why could the IEA predictions not turn out wrong, too? Excepting global economic or other disasters, there are two main reasons why this will not be the case:

1. According to the IEA, more than 95 per cent of energy growth in the next 20 years will be in developing countries, not in the OECD area. China and India have more than one-third of the world's population, but a current share of global energy consumption of less than one-seventh. This situation is rapidly changing. Actual growth may be 50 per cent lower or 20 per cent higher than predicted; it does not really make much difference to the result.

2. Growth will be based on fossil fuels (in excess of 90 per cent) for several decades. New renewables will remain insignificant for a long time. Even in the most optimistic scenarios, with a large increase in nuclear power, renewables and energy efficiency measures, the predominant share of this energy supply will be based on coal, if nothing drastic is done.

The question is: what *can* be done? How do we meet this enormous short term growth in energy demand in developing countries? The only viable response, apart from reducing demand (which may be very difficult), is changing to new low emissions (LE) energy technologies.

Renewable energy sources represent a 'natural' sustainable energy solution. But they have long time horizons and are not expected to get a significant share of global energy supply for several decades.

In the short term, there seems to be a growing consensus that 'clean coal' is the key to large reductions in GHG

discussion

The international dimension. Several speakers pointed out that carbon reduction had to take place in an international context. First, carbon reduction by the UK and Norway, or even by the EU as a whole, was only 'nibbling at the edge' of the problem, given the much greater emissions from other countries. Second, individual countries would have to be mindful of their competitiveness; they could not allow their energy costs to become significantly greater than their rivals. Third, no real progress on energy efficiency or carbon reduction techniques could be made without a full exchange of knowledge and best practice.

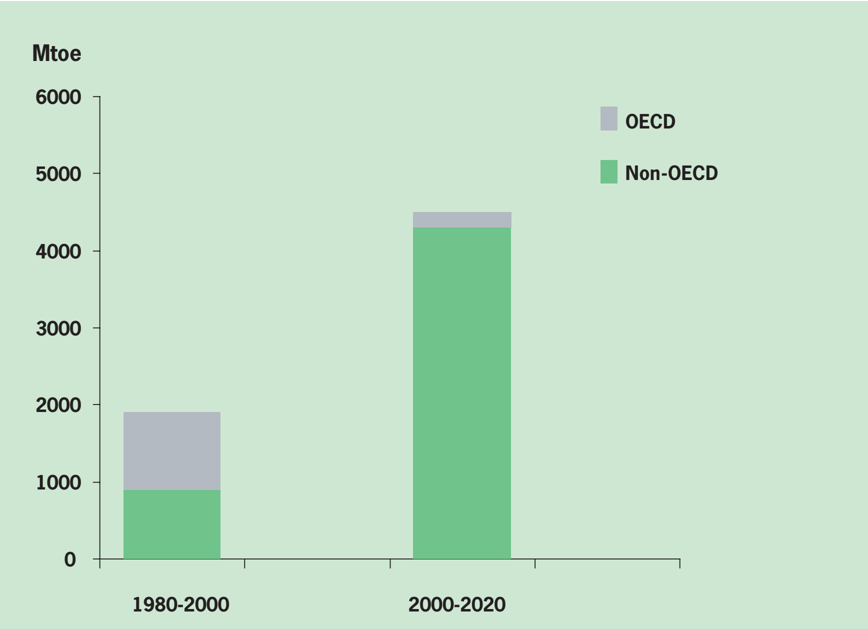

Figure 1. Global energy demand growth. (Source: IEA WEO 2002).

emissions. The new Norwegian government has made a very ambitious commitment to implement full scale CCS solutions at all new natural gas power plants based on enhanced oil recovery (EOR) via CO_2 injection, if at all feasible. The Kårstø plant, under construction, will be conditioned for retrofitting with CO_2 separation systems.

In general, CCS solutions are far from proven or commercially accepted technologies. There are still no full scale or large demonstration plants anywhere in the world. This is to me the most important short-term issue: to develop and *build* large demonstration plants of, say, 100 MW, with the necessary CO_2 infrastructure. This was a main recommendation of the Norwegian Gas Technology Commission. But, almost four years later, we still have no sizable pilot or demonstration plants in operation, or even committed.

Technological innovation is crucial to reduce the CCS cost gap and to minimise energy losses. As an example of new CCS concepts, the Institute for Energy Technology (IFE), in cooperation with CMR and Prototech AS, is developing a Zero Emission Gas Energy Station. It will produce electricity from natural gas in a High Temperature Fuel Cell, simultaneously producing hydrogen in an adjacent reactor, using the fuel cell's waste heat. Our objective is to achieve very high electricity efficiencies (70-80 per cent), simplified and energy efficient hydrogen production, and to get pure CO_2 separated out as part of the process at no additional expense.

This is, however, a research project, so far largely funded by the Norwegian Research Council, with many uncertainties and a time horizon of some 5-10 years. Similar systems may also be developed based on gasified coal, and there are, in fact, such initiatives in the US.

How can we get rid of the CO_2, once it has been captured? The obvious, 'standard' solution is to deposit it in deep geological formations. The most discussed option in Norway is to use CO_2 from gas power plants for increased oil recovery from fields in the North Sea. However, recent studies by the Norwegian Oil Directorate, Statoil, NVE, NGOs and others on the use of CO_2 for enhanced oil recovery have reached very different conclusions with respect to costs, process efficiency, capacities, safety, reservoir properties over field life, and so on. It is still not straightforward.

Other innovative solutions are based on binding CO_2 in stable carbonates of silicate minerals, such as olivine, which would also provide valuable commercial by-products. The most promising from a Norwegian perspective is to use olivine minerals, with a potential capacity of some 10-20 Mt CO_2 annually over a very long period, just in Norway.

Recent initiatives in the North Sea region aim at large-scale disposal of CO_2 in deep subsea saline aquifers, or focus on enhanced oil recovery based on CO_2. At the Sleipner natural gas field, Statoil operates a platform-based CO_2 removal plant and injection system. Since 1996, about 1 million tonnes of CO_2 have been injected annually into the nearby Utsira aquifer, some 1,000 metres below the seabed. The movement of CO_2 in the aquifer has been carefully monitored, and the results are promising, with no release of CO_2.

Statoil has since decided to implement a similar solution on another offshore gas field, Snøhvit, in the Barents Sea region; this is expected to come onstream next year.

Carbon sequestration can never become cost free. Carbon dioxide must be separated out, pressurised, transported, injected and safely disposed of for thousands of years. CCS requires additional processes and equipment, costing money, but more important also *energy*, reducing plant efficiencies by 10-20 per cent. Separation technologies are not perfect either, resulting in leakage of CO_2 in the order of 10 percent or more.

Looking ahead, will these technologies provide a long term solution to the problem of greenhouse gases? According to an IEA study from late 2004, the answer is a qualified 'yes'. CCS technologies may in theory enable stabilisation of CO_2 emissions in 50 years' time, at a slightly higher level than today. The crucial assumption is that there must be a cost attached to emitting straight to the atmosphere – quite a high one, in fact. If not, forget it. According to the IEA, a universal 'carbon penalty' of as much as $50 per tonne of CO_2 is required; this would be introduced gradually over the next 10 years (but delayed for 15 years in the case of developing countries).

To make a significant impact on the global climate situation, however, there would need to be thousands of CCS (coal) power plants over the next decades. An estimated 18 billion tonnes of CO_2 must be separated, transported and deposited annually by 2050!

Is this realistic? May CCS technologies provide a sustainable solution, or will they just be a necessary transitional fix, an historical parenthesis? It is not only a question of safe disposal sites and capacities, but will we be able to establish and operate a global infrastructure for, say, 200 billion tonnes of waste CO_2 every decade?

The gap between reality and the politically desirable widens. If the anthropogenic climate issue really becomes serious, and we have to stabilise atmospheric CO_2 levels and thus reduce emissions drastically, we face a serious challenge indeed; to develop and deploy competitive low emission technologies on a very large scale, in just a few decades.

Judged from our current technological basis, CCS technologies alone will not provide the answer. There are *no* simple solutions: a sustainable energy system will require new technologies that we hardly can imagine today. The only sensible approach at this point is to keep all options open. ❐

A special conference was held on 26 October 2005, in the presence of HM King Harald V and HRH The Duke of Edinburgh, to discuss the future of British and Norwegian cooperation in the energy sector.

British and Norwegian cooperation in North Sea oil

John Browne

The Lord Browne of Madingley FREng FRS is Group Chief Executive of BP plc. Born in 1948, he joined BP as a university apprentice in 1966. He holds a degree in Physics from Cambridge and an MS in Business from Stanford. He is a non-executive director of Intel and Goldman Sachs. He was knighted in the Queen's Birthday Honours in 1998 and made a life peer in 2001.

The United Kingdom and Norway have a long history of cooperation in the science and technology underpinning the development of the North Sea. In the 40 years since the first fields in the North Sea were discovered, its history has mirrored that of the history of the industry as a whole. Through the 1970s and 1980s, the end of significant production was predicted, but technological developments kept the fields producing. The Forties field, for example, was expected to be decommissioned by the mid-1990s, having produced perhaps 45 per cent of the oil in place. Its recovery rate has reached over 60 per cent and the field is still producing.

This continued success is due to the application of constantly advancing science, the use of IT techniques such as visualisation, and the management of pipeline and processing technology. These advances have extended the life of the North Sea beyond the most optimistic predictions of the 1960s and 1970s.

Although some believe the industry has entered its final days, they ignore the fundamental characteristic of industry and of human life generally: the capacity to adapt. But being optimistic is not to deny the scale of the four major challenges the industry faces.

First, demand is rising with the growth in world population. There are around 200 million new customers for commercial energy every year, worldwide. Although alternative energy sources are being developed, the timescale involved in commercialising them means that energy demand will focus on hydrocarbons, chiefly oil and gas, for the foreseeable future. By 2015, demand for oil will be between 15 and 20 per cent higher than it is today – over 90 million barrels a day. The demand for gas could increase by 40 per cent.

Second, the requirement for trade is growing. World trade in oil has grown by 18 per cent in the past five years. Available resources are concentrated in a limited number of places — Africa, the Middle East and Russia — some of which remain beyond the reach of current international investment.

Third, investment is needed to ensure resources are developed to meet rising demand. The annual requirement for investment in all forms of energy is now around $560 billion a year; more than a third of that is for oilfield development and the infrastructure necessary to bring it to market. This represents a 20 per cent increase over the level of investment made during the 1990s.

Finally, there is the longer-term challenge of the environment. Carbon emissions into the atmosphere are now probably 16 per cent higher than they were in 1997.

HM King Harald V of Norway being welcomed by The Rt Hon the Lord Jenkin of Roding, President of the Foundation for Science and Technology.

They could be 33 per cent higher by 2010.

These are serious challenges, but adaptation is taking place. The increase in prices from 2000 onwards has increased available funds. Over the past five years, annual upstream investment by the five largest companies in the industry rose by over 50 per cent to around $50 billion a year. Investment is effective as we learn how to spread knowledge and share information, increasing the efficiency of every dollar spent.

The most significant organisational change in the industry recently has been the development of the 'supermajors', giant global companies that can quickly apply knowledge across the world. Two years ago we invested in Russia, creating a company called TNK-BP. It has increased production by 35 per cent and increased reserves year by year. Applying technology developed in the North Sea and the United States has increased recovery rates, improved the management of reservoirs and identified new structures. This is partly due to technological breakthroughs, but mostly to the application of knowledge on an international scale.

We cannot ignore the evidence on environmental change, nor can we wait for global political agreement: we must act now. The example of BP is replicable in other businesses. Starting by reducing the emissions from our own operations, we planned to reduce emissions by 10 per cent below the 1990 base line. We established an internal trading system to apply resources effectively, rather than asking every business unit to achieve the same percentage reduction. We met the target and found that the process added over $600 million of value because most reductions were achieved by efficiency improvements, new business practices and eliminating routine flaring.

Another step is now needed. Carbon pricing will be widespread globally within the next decade. The European emissions trading system is an excellent initial step, as are the initiatives being taken by different states in the United States. As carbon is priced, there will be a market for technologies that reduce emissions and displace energy production that would otherwise generate emissions.

The carbon capture and sequestration process allows us to separate carbon from the other elements in different forms of hydrocarbon, capturing and storing carbon and using the remaining hydrogen to produce carbon-free electricity. One project uses gas from the North Sea, sending the hydrogen to the onshore power station at Peterhead. As we learn from the North Sea project we hope to develop a series of others in Europe, the United States, India and China. Similar initiatives are being taken in Norway.

Sequestration and the production of

Lord Browne addressing the conference.

decarbonised fuels will help change the fuel mix in the power sector (which is responsible for a greater proportion of emissions than any other), demonstrating the action which the industry can take to meet the challenge of climate change and avoid that challenge becoming a crisis.

Technology has transformed the potential of the North Sea and the industry worldwide. Today there are new, serious challenges. By continuing to develop science and technology, and the mechanisms to apply that knowledge globally, we can meet those challenges, proving that those who are writing off this industry have once again got their timing wrong. ❐

Energising the future: opportunities and challenges

Helge Lund

Helge Lund became chief executive of Statoil in August 2004. He graduated as a business economist from the Norwegian School of Economics and Business Administration (NHH) in Bergen, and has an MBA from the Insead business school in France. In 1997 and 1998 he served as deputy managing director for Nycomed Pharma AS. He joined Aker RGI Holding ASA in 1999 as deputy chief executive and chief operating officer, before becoming chief executive of Aker Kværner in 2002.

(Photo: Øyvind Hagen, Statoil)

The British and Norwegian oil and gas assets discovered in the 1970s provided an opportunity for extensive cooperation. The UK-Norway framework agreement signed by the UK and Norwegian energy ministers in April 2005 has the potential to fast-track the development of significant reserves.

The International Energy Agency expects the world's primary energy demand to grow by almost 60 per cent in the next 25 years. This creates business opportunities while presenting environmental challenges, particularly concerning greenhouse gas emissions and climate change.

Fuel prices are high, even in historic terms. Energy demand and import dependency rise, while emissions of carbon dioxide increase. Growing import dependency and resource competition make security of supply a growing concern in large energy markets. Fossil fuels will account for 85 per cent of the increase in demand by 2030, making reliable energy suppliers ever more important. The growing energy demand creates opportunities for Statoil. To capture them we must deal with four sets of challenges.

First, we have political challenges. Oil and gas resources lie in parts of the world that often leave much to be desired in terms of governance, transparency and the rule of law. Second, huge efforts are required to develop the technology and competence needed when moving into deeper waters, harsher climates and unconventional oils, many of which are far from existing infrastructure and markets. Third, significant investment is necessary to meet future energy demand. Finally, energy-related CO_2 emissions could be more than 60 per cent higher in 25 years' time.

A key feature of the growing demand for energy is the increased importance of natural gas, the fastest-growing fuel in the world. In key gas markets like the US and Europe, demand grows while domestic production is stagnating or in decline. Statoil exports some 25 billion cubic metres per year to the European market and our ambition is to double our gas production by 2015. UK gas imports are increasing. Britain may have to import 50 per cent of its gas by 2010.

Through the Statfjord Late Life project, Statoil is converting the giant Statfjord field from oil to gas production. The new Tampen Link pipeline will transport rich gas from Norway to the UK. The start of Ormen Lange deliveries through the Langeled pipeline from 2007 could enable Statoil to service 10 to 15 per cent of UK demand. We are further developing the Troll field, with possible new transportation systems to the markets of north-west Europe.

The growth of liquefied natural gas (LNG) will have a profound impact on the global gas business. With LNG technology available, the Arctic Barents Sea will be an important source of global gas supply. Within just over a decade, the Norwegian and Russian parts of the Barents Sea could be connected to existing gas transportation systems for direct supply to European markets.

However, access is not enough. Business must be conducted in a sustainable manner. Statoil's operational principles are: zero harm, clean sea and co-existence.

How can we meet growing energy demand while reducing global emissions of greenhouse gases? Statoil is working from the assumption that fossil fuel consumption, CO_2 emissions and global warming are linked. The world's energy-related CO_2 emissions will increase, largely from developing countries dependent upon energy for their social and economic development. In our effort to minimise the climate impact from our operations, we have intensified development of clean energy carriers. The Kyoto mechanisms are key tools for short-term, cost-effective reduction of global emissions.

Carbon capture and storage (CCS) technology has great potential for long-term reductions of global CO_2. Statoil pioneered CCS technology on the Sleipner Field in 1996, separating one million tonnes of CO_2 annually from the gas stream for permanent storage. With BP and Sonatrach, we introduced the world's first onshore CCS project in the In Salah field in Algeria.

By making the development of environmental technologies and realisation of climate initiatives a natural part of our business, the process will gain momentum. Transforming CO_2 into a commercial product, we can build a value chain from CO_2 capture, through injection into reservoirs, where it can help us recover larger proportions of the oil in place. This is an area with potential for future UK-Norway cross-border cooperation.

Tony Blair recently said that "Science and technology cannot alone provide the answer. But they certainly provide the means to ensure that we can reduce greenhouse gas emissions without damaging our economy. Indeed, over time they provide the prospect of significant business and economic opportunities". Statoil shares this perspective, because it puts environmental performance at the heart of good business. ❐

A Norwegian view

Odd Roger Enoksen

Odd Roger Enoksen is the Norwegian Minister for Petroleum and Energy. He was formerly a minister for regional government. He is the Member of Parliament for Nordland County. Mr Enoksen has been a member of Storting (Parliamentary) committees on business and industry, foreign affairs and defence.

The crude oil price has been on a rising trend in recent years. \$60 a barrel is a level few could have imagined only a year ago.

High crude oil prices signal a need to expand upstream capacity. Today's price level is the result of under-investment in energy infrastructure over a number of years. Oil demand is expected to grow relatively rapidly, particularly in countries like China and India. Demand will also be strong in the transportation sector where there are no realistic alternatives to oil in the foreseeable future. OPEC must provide most of the new capacity needed to meet growth in oil demand. Yet it is important that non-OPEC countries also expand production. Gas is becoming increasingly important in both the short and long term energy mix. The fact that the Norwegian Continental Shelf is located close to the market puts us in a very fortunate position compared with other suppliers. In the EU, increasing demand and declining production create a growing need for new gas supplies. Norwegian gas makes up 14 per cent of total European gas consumption. Both remaining resources and our infrastructure will enhance Norway's role as a stable gas supplier. We expect gas exports to increase to a level of 120 billion cubic metres by 2011. Norway will pursue opportunities in the LNG market as demonstrated by the Snøhvit project. Gas-to-liquids and LNG are markets that are evolving rapidly, making natural gas a global commodity.

We also consider the climate challenge. The negative environmental effects of continuing fossil fuel use must be dealt with. Carbon capture and storage could play an essential role in the development of a more sustainable energy system over time. The problem is global: solutions can only be found through combined efforts at the international level. Norway has an ambitious policy to reduce emissions of greenhouse gases. The United Kingdom's efforts to address the issues of climate change through the presidency of the G8 and the EU have been commendable.

Considerable efforts in research, development and deployment of new technologies must all be part of our energy policies. Carbon capture and storage must be developed as a viable option. To achieve this, technological development is needed to reduce the costs of capturing CO_2. In an effort to speed up this development, Norway has established a new state entity called Gassnova. Its aim is to support pilot projects to facilitate faster development and deployment of CO_2 capture and storage technologies in connection with gas power production. Gassnova has a NOK 2 billion fund at its disposal.

However, Norway cannot solve the issue of carbon capture alone. We must join forces with international industry, research institutions and other governments.

Norwegian research institutions participate extensively in EU co-funded research projects in the area, and the Norwegian Government participates in the Carbon Sequestration Leadership Forum. The Ministry of Petroleum and Energy participates in an informal governmental forum on CO_2 for enhanced oil recovery, which includes Denmark, the UK and the European Commission. The Netherlands and Germany have also been invited to participate.

Technology development is vital to ensure increased supplies of oil and gas. In 2001 the government established a strategy initiative called Oil & Gas for the Twenty-First Century (OG21). Major stakeholders, from universities to oil companies, are involved in OG21. The task is to create a concerted R&D strategy for Norwegian petroleum. To extract maximum benefit from OG21, we must put research and technology development in a global context. This is why we also involve international players and try to develop solutions that are applicable worldwide.

Relations between Norway and the UK are close, increasingly so in the energy sector. This is evident from the new framework agreement on cross-border petroleum cooperation. The agreement paves the way for increased activity in our common North Sea corridor for years to come. ❐

The UK perspective

Malcolm Wicks

Malcolm Wicks is Minister of State for Energy at the Department of Trade & Industry (DTI). He has served in the Government since 1999 when Tony Blair appointed him a junior minister in the Department for Education & Employment. In July 2001 he moved to the Department for Work & Pensions where he was promoted in 2003 to Minister of State for Pensions.

The United Kingdom is becoming a net energy importer, and our partnership with Norway is a mutually beneficial component of this. The treaty signed earlier in 2005 means that the first part of the new Langeled pipeline will feed Norwegian gas into the UK network for the winter of 2006–2007. A new interconnector pipeline from the Netherlands and an upgrade to the existing interconnector with Belgium should increase our import capacity by the winter of 2006. Two major new liquefied natural gas terminals in Pembrokeshire will bring in supplies from further afield, and new gas storage facilities over the coming years will help the industry manage supply and demand. This is in addition to improvements already onstream: a liquefied natural gas terminal in the Thames estuary, improvements and changes to storage capacity at Rough and Humbly Grove, and an initial upgrade to the interconnector with Belgium.

A Framework Agreement now covers a range of cross-border projects, so that we do not have to conclude a new treaty for each project, with five median line field and pipeline projects approved last year. There are valuable supply chain initiatives designed to build on the best our industry can offer. But there is still a great deal more that can be done in this wider cooperation process – we continue to challenge industry to bring forward more cross-border projects.

The world faces many social and economic challenges. Catastrophes caused by Hurricanes Katrina and Rita demonstrated the potential knock-on effects to energy supply. The United Kingdom, along with other members of the International Energy Agency (IEA), initiated a coordinated response to release extra supplies to help the market deal more effectively with the disruption. We must ensure secure, affordable and diverse future energy supplies.

Climate change is at the heart of our energy policy. The way we produce and consume energy has a profound impact on climate change, contributing significantly to increases in greenhouse gas emissions: therefore we made climate change one of our energy policy goals. The future development of the energy supply sector will be critical to the United Kingdom's ability to meet our short, medium and long term climate change goals.

Carbon capture and storage is an important option for future sustainable power generation, given its potential to reduce CO_2 emissions by up to 85 or 90 per cent. In the Norwegian sector, since 1996, Statoil has been storing over one million tonnes of CO_2 a year at Sleipner. The UK is also starting to take initiatives in this area. BP, with its partner Statoil, has established a CO_2 storage project in the In Salah gas field which is also storing about one million tonnes of a year.

BP, Shell and Scottish and Southern Energy are working to demonstrate the full range of CCS technologies. The captured CO_2 will be used to enhance the recovery of oil from the Miller field, not only extending its life but also permanently storing it away from the atmosphere. This will allow the hydrogen created as a result of the capture process to be used for near-to-zero emissions power generation at the Peterhead power station.

We have some way to go before these technologies become a commercial reality, not least because present costs are high, but also because we must demonstrate them as complete systems. We must show that we can safely and reliably store CO_2 in the geological strata beneath the North Sea over long periods of time. We cannot leave an environmental problem for future generations. It is important that our two countries work closely together to establish a set of guidelines by which we manage the storage of carbon beneath the North Sea. ❐

The scientific evidence for climate change and possible ways of tackling rising greenhouse gas emissions were examined, from the viewpoints of the USA and the UK, at a meeting of the Foundation on 22 November 2005

Reading the signs of the times

David King

Sir David King KB ScD FRS was appointed Chief Scientific Adviser (CSA) to HM Government and Head of the Office of Science and Innovation on 1 October 2000. Prior to this appointment, he was head of the Department of Chemistry and Master of Downing College, University of Cambridge. He continues as Director of Research at Cambridge University and Fellow of Queens' College, Cambridge, where he continues to actively supervise graduate students.

I begin with a cautionary tale – that of the tsunami on 26 December 2004, which killed an estimated 220,000 people in Thailand, Indonesia, Sri Lanka and India. Those who study the movement of the oceanic plates on the seafloor can tell where stress is building when adjoining plates are jammed against each other. On that basis, people were persuaded by the summer of 2004 that there was an imminent risk of a major earthquake on the floor of the Indian Ocean. Scientists from California and Britain tried to warn the Governments in the region of the danger.

The estimated cost of an early-warning system is $30 million. We cannot be sure, but more than 100,000 lives might have been saved had there been an early-warning system in place. The message I take from this tale is that Governments ignore scientific advice only at the peril of their citizens.

I now turn to the major problem facing us this century – that of climate change. People have been working on this for years. The science is now gelling very rapidly before our eyes. I start with a simple plot of carbon dioxide levels taken from ice cores drilled from the Antarctic, and covering the past 60,000 years (see Figure 1). Carbon dioxide levels were about 200 parts per million (ppm) in the last Ice Age, rising to more than 265ppm as we entered the current warm period – the Holocene – about 12,000 years ago.

The most arresting feature of the plot is the past few hundred years. The compression of the timescale makes this feature inconspicuous on the graph, but carbon dioxide levels have increased to 381ppm. And they continue to increase by 2ppm each year. There is no argument about the correctness of the data. What we must discuss are their implications for the future.

One immediate impact is that the temperature is rising. Since the Meteorological Office was founded in 1864, it has collected temperature records from 300 weather stations around the world. What the records show is that the change was fairly gradual and small until about 50 years ago, since when there has been a significant rise, amounting to 0.7 degrees Centigrade.

This behaviour is well represented by the modelling done by the Hadley Centre. It is crucial that the modelling also works backwards in time, reproducing historic temperatures so far as they are known. I must emphasise that the modelling includes all the physical processes that armchair critics claim have not been included – sun-spot activity, volcanic activity and so on. It is striking that when the models are run without the inclusion of carbon dioxide changes, the recent increase of temperature disappears.

To what is the increase of carbon dioxide

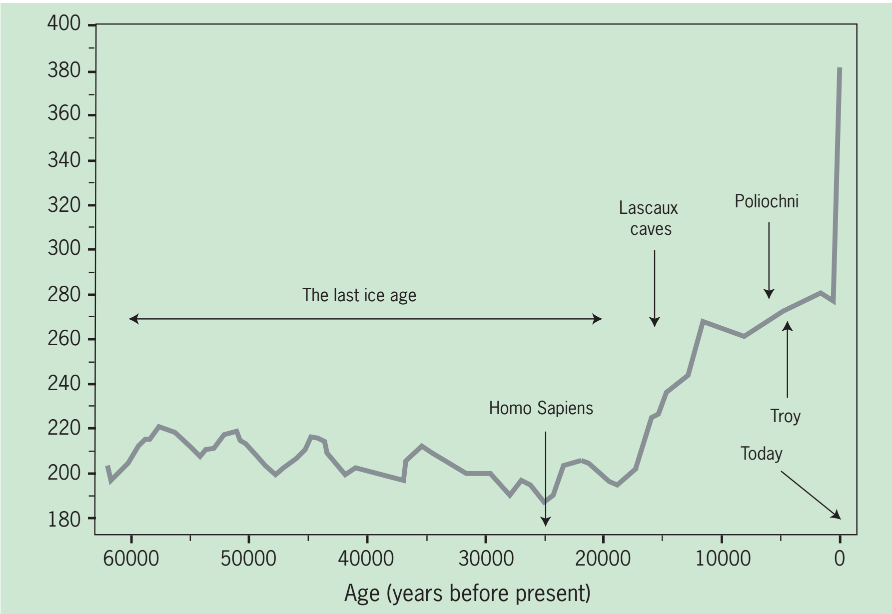

Figure 1. Carbon dioxide levels (ppm) over the last 60,000 years. Source: University of Berne and NOAA.

attributable? Changes of land use, especially deforestation, are one source: our population is now 6.3 billion and still increasing. Another is increased use of fossil fuel energy. Four fifths of the post-glacial increase of carbon dioxide is due to our use of fossil fuel.

There have of course been many critics of this analysis of the process of climate change, including some scientists. Science operates by challenge, requiring people to go back and look carefully at experiments. But what we see, week after week in the journals, is evidence that the modelling has been pretty well spot on.

I now turn to another prediction of the modellers – sea-level rise. The change in the average sea-level of the planet was measured by a satellite, designed to yield an average value, over the period 1992-2002. The design avoids the difficulty in deriving information from measurements carried out at fixed places on the Earth's surface, where slow-moving ocean swells can be a complication. Average sea-level has increased by about 35 millimetres in the decade. That rate agrees with what the modellers predict.

Here I will focus on what is already happening, not the long term impacts. Take, for example, flood events. Since 1950, there has been a striking increase in the frequency of floods. On most of the world's continents, the number of floods per decade has increased ten-fold in half a century. The exception is Australia, where some substantial areas are turning to desert. For most of the world, flood events have become a major problem. The underlying problem is water - both excesses and shortages. These are signs of a change in the planetary climate system.

What about the impact on the temperature? In Central Europe, the summer of 2003 was the hottest on record (see Figure 2). Based on tree-ring data, it was the hottest summer for several thousand years. With an estimated 32,000 fatalities, it was also the biggest natural disaster in the region. In some areas, the local temperature was a good 10°C above the average.

There are three plots in Figure 2, of which the smoothest is a running average of the annual average temperatures in Central Europe over the past 100 years. The plot culminating in the 'Summer 2003' record shows the annual average temperature. The third plot is the outcome of a modelling run in which all but natural influences on the climate have been omitted: it is a graphic representation of the degree to which temperatures have already increased.

The data in Figure 2 also point to another feature of the changing climate. In the 20th century, the hottest summer on record was that of 1947. It stands out from the second plot, but that peak is more or less level with the right-hand side of the plot that shows the running average of the temperature. In other words, the hottest summer of the 20th century is now the average summer temperature in Central Europe. The models suggest that it will take about 40-45 years for the summer of 2003 to be the average summer temperature. There will, of course, be other extreme events (like 2003) before then.

I must now draw your attention to a further complication. The Earth's climate system has a massive heat capacity, meaning that climatic impacts may be much delayed. If we were to halt carbon dioxide levels at 381ppm, where we are now, temperatures would continue to increase for the next 20 or 30 years. Nothing much that we do now could affect the course of climate change in that interval. Beyond 2030, however, we could make an enormous change if we could reduce carbon dioxide emissions now.

Other features of our climate will be affected by the changes now under way. Areas in which drought is endemic will expand, for one thing. From 2050, the models show, drought will be a serious problem.

Hurricane Katrina and its successors that hit the Southern states of the USA last year have raised the question of a connection with global warming. We know from observations that if ocean temperatures in the mid-Atlantic are less than 26°C, hurricanes do not form. That would imply that, as ocean temperatures increase, we shall need to worry more about the intensity of hurricanes. A recent paper strongly correlates, both in the North Atlantic and the North Pacific, the intensity or destructiveness of hurricanes and cyclones with surface ocean temperature. There remains a possibility that the recent changes may reflect a cyclical process, but the evidence is highly suggestive that they are a consequence of increased temperature.

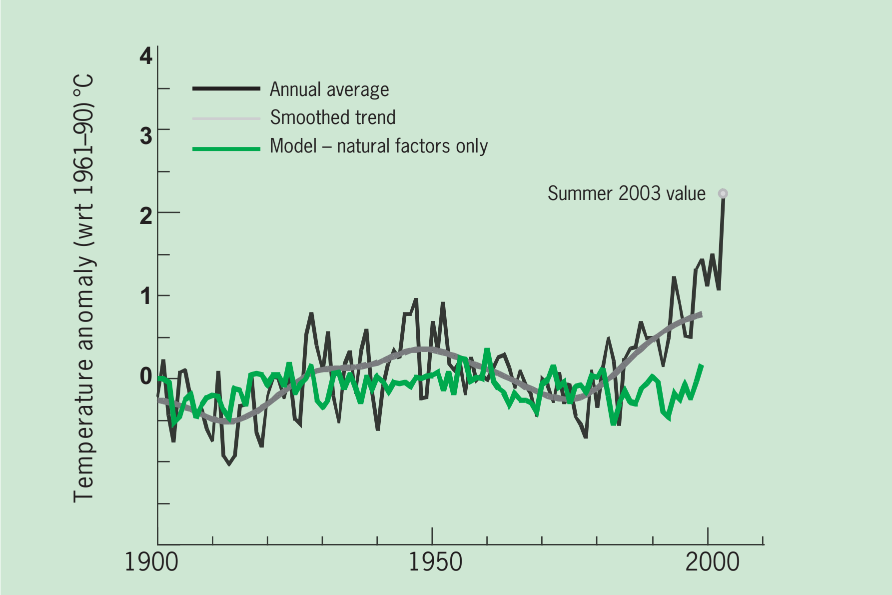

Figure 2. Annual European summer temperatures. Source: Hadley Centre

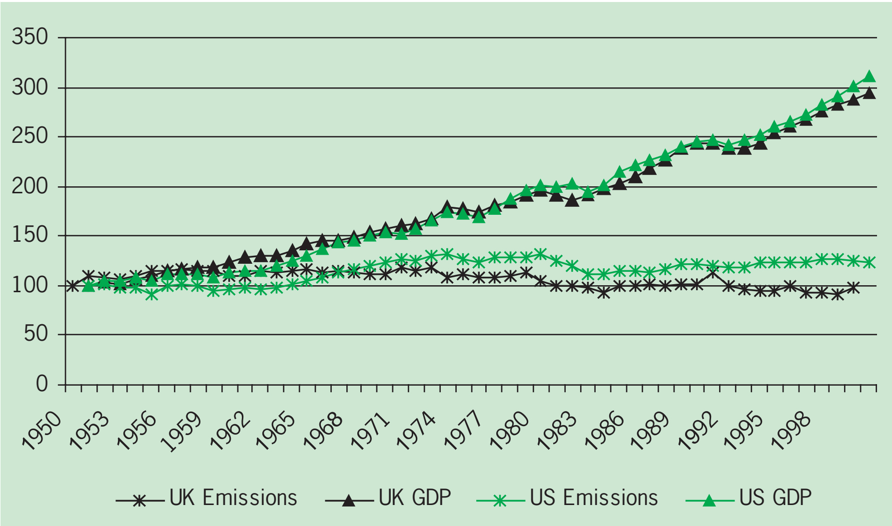

Figure 3. Per capita GDP and emissions. Source: Penn World Tables and ORNL.

Then there is the matter of what is happening to the ice on Greenland and in the Antarctic. If all the ice on Greenland were to melt, sea level would rise by 6.5 metres. The melting of the Antarctic ice would add a further 100 metres. Sadly, the satellite images obtained over the period 1992-2002 indicate that the annual extent of the ice-melt in Greenland is greater than that predicted by the Hadley Centre's modelling. What rightly concerns us is that carbon dioxide levels may be reached at which the melting would be irreversible. It is very difficult to imagine how we would halt that process.

At what level of carbon dioxide in the atmosphere would irreversible melting be avoided? There will be continuing debate on that point. People in the field talk of a range of 400 and 700 ppm; at the present rate of increase the latter would be reached in about a century. My own opinion is that, with global agreement on this issue, it may be possible to plateau out at below 550ppm. I am not advocating this as an ideal: I would be happier if we were still at 270ppm.

There are other issues. We have recently heard a fair bit about the collapse of the North Atlantic circulation, perhaps triggering an ice age in northern Europe. There is also concern that rising temperatures may destabilise the materials called methane hydrates, which are solid molecular compounds of water and methane that exist only at high pressure, in the deep oceans for example, or at low temperatures, as in the permafrost. That is potentially important because, molecule for molecule, methane is 15 times more effective than carbon dioxide at trapping heat in the lower atmosphere. One gloomy possibility is that the unexpectedly rapid melting of the Arctic ice is explained by a positive feedback effect not yet fully included in the models: ice melts, reflectivity is reduced, the local seawater picks up more solar energy and so ice melts even more quickly.

One of the issues we now face is how quickly these changes will happen and how quickly we can adapt to them. I cannot stress too strongly that we need to do two things: we need to adapt because of the challenges already in the pipeline and we need to mitigate for the longer term because most of us are concerned about our grandchildren. Both should be immediate goals.

Let me just quickly say – if you normalise the growth of the UK and US, as GDP per capita over the period 1950 to the present, you may be surprised to see that the growth in our two economies is pretty well parallel - a three-fold growth over that time. But, carbon emissions growth has been very small over the same period, so when we talk about emissions intensity, then we know that we have already achieved a reduction without any regulatory system in place. What we now need is an absolute reduction in emissions, not in emissions intensity.

As we move forward in time, I believe that what is essential - and this is the British Government position - is that we have a fiscal process to bring the private sector on board in reducing our emissions.

Well, we have good examples in the private sector and I will finish in just a moment. Let me just emphasise, for example, that BP introduced internal emissions trading about four years ago, it cost them $30 million to set it up in companies around the world and their audited accounts show that, over the first three years of operation, they have saved $650 million. This is what I would call 'attention deficit', in other words the company had not previously really worried about its own energy usage but, by introducing carbon dioxide emissions trading, the various parts of the company actually became quite competitive about reducing their energy usage and the net result is a substantial saving to the company. The American company, Wal-Mart, is aiming to move entirely to renewable energy, changing their fleet and investing a significant sum in reducing emissions.

Emissions cap and trading is the fiscal process that we believe is going to bring forward the reduction, through bringing on the private sector. What I would emphasise is that emissions trading is not alone, we of course have introduced a Renewables Obligation in this country which is already having an impact but, just to stress the point of emissions trading, it was introduced from Britain (we began it here) into the EU, in January 2005, at €8 per tonne. I would like to see it up at about €30–40 per tonne at which point the utilities will really need to move away from coal-fired power stations that do not have carbon capture and storage. ❐

Taking practical, cost-effective action

James Connaughton

The Hon James L Connaughton is Chairman of the Council on Environmental Quality (CEQ) in Washington DC. In this capacity, he serves as the senior environmental and natural resources adviser to the President as well as Director of the White House Office of Environmental Policy, which oversees the development of environmental policy, coordinates interagency implementation of environmental programmes, and mediates key policy disagreements among Federal agencies, state, tribal and local governments and private citizens.

Sir David outlined the science and the magnitude of the issue that we are grappling with. I am giving the policy maker's perspective so this is a very good hand-off – the science side of the equation to the policy maker's, and how we integrate that thinking into what we are doing.

The policy maker's perspective is well-established in the literature: the transition follows the Kuznets curve from the economist's perspective (Figure 1). The

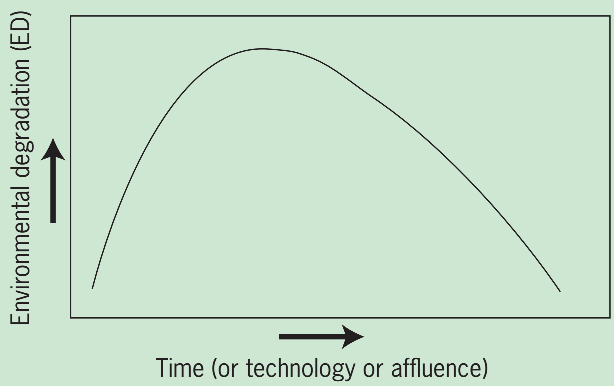

Figure 1. Kuznets curve showing growth and reduction of environmental pollution with time.

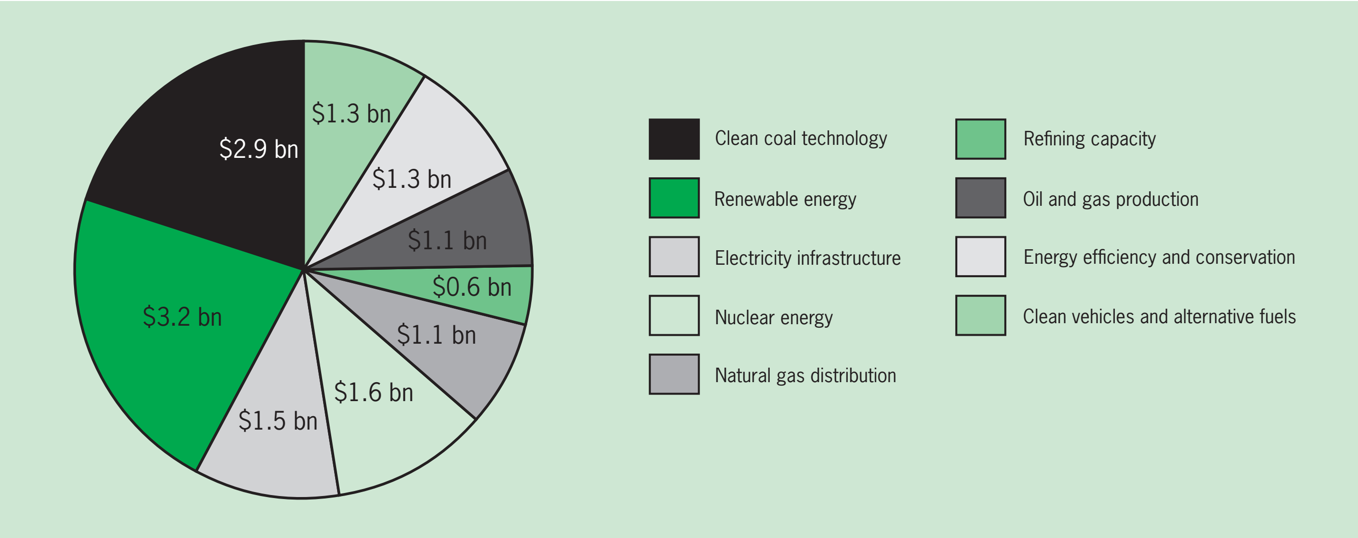

Figure 2. Energy Bill tax incentives.

initial introduction of high value economic opportunity comes with a fairly significant environmental footprint. With time and technology and affluence, we see the capacity both to appreciate environmental degradation (which is Step One) and then to take the actions which slow the rise in degradation, level it off and reduce it again. If you took the UK's experience with air pollution, you would probably actually invert that curve – it was a long time in rising and then a very rapid decline: the same is true in the US. Since 1970, we have seen our economy nearly triple, our population and energy use approach a 50 per cent increase and yet we have managed to cut air pollution by more than 50 per cent. Importantly, 10 per cent of that 50 per cent occurred just in the last four years, so we have an accelerating rate of progress. Yet in those past four years we added the combined population of Norway and Ireland, 8½ million people, and added the equivalent of the entire economy of China to the USA GDP, and still we managed to tug our greenhouse gases down by nearly 1 per cent. The UK enjoys a similar record of stable greenhouse emissions with rates of economic growth and affluence similar to the USA; in our levelling-off, the two countries stand alone.

Now let me broaden the conversation to focus on domestic actions. In 2001, I was handed three issues in the same week: I was given the chairmanship of our Cabinet Council on climate change policy; I was made the head of the Cabinet Coordinating Process on our clean air strategy; and I was asked to chair the process of streamlining energy projects. This is because you cannot work on one of these issues without thinking about the other two.

Our initial effort was to try to figure out how we obtain the maximum level of air pollution reduction, while doing it in a way that takes account of our future aims on climate change and in a way that keeps a future for coal in America. The continued use of coal is not just important to our economy, as our most affordable and domestically secure energy source, but the more the US uses its own natural resources for energy, the less it competes on the world stage for those resources and so driving up prices and hampering economic growth worldwide. We are implementing a market-based cap and trade system with a mandatory pollution reduction of 70 per cent; it will apply to all 1300 of our large and mid-sized coal-fired power plants in two phases; it is structured to promote technology innovation and cost reduction; it is going to provide regulatory certainty for capital planning; and the investment will be the single largest investment in pollution control in the history of the world - $52 billion.

The important first steps in meeting this new requirement will be significant investments in efficiency as the early, cost-effective way of reducing pollution. This will then give us a co-benefit in terms of greenhouse gas reduction from coal. This is an approach that we can sell politically because its enormous magnitude is justified by health savings and work-day improvements; the neat thing about it is that you get 100 per cent compliance with only a few dozen Government employees to achieve it.

We had to sell it politically, which means the lowest price impact on the consumer and manufacturer that we could make – it keeps us in coal and it gives us a foundation for coal technology.

We need to do the same thing in diesel. Our biggest opportunity in air pollution is diesel. We have a programme in place in which we are going to remove all sulphur from diesel fuel. This is important for climate change because we now have the technologies to meet health-based air quality standards, so we can introduce a massive infusion of clean diesels into the US marketplace, which will automatically bring a 20-30 per cent improvement in fuel economy. Clean diesels have particular applicability in the light truck fleets, which is where we have seen the growth in greenhouse gas related emissions. Importantly for our public, we are going to make that black puff of smoke from diesel vehicles a thing of the past and we mean *all* diesel vehicles - marine engines, locomotives, off-road construction equipment and farm equipment. This is a major effort.

We have now had some domestic energy policy changes too. We had a major cut in marginal tax rates for individuals in 2001, which led to a familiar effect – if you have more money in your pocket, you will buy the new refrigerator rather than pay for the repair of the old, inefficient one. So we have seen a major turnover in household goods, from less efficient to more efficient. We also had tax law changes in 2002 on capital expenditure and dividends: these changes are creating a flood of new capital investment and every new piece of equipment bought tends to be much more sophisticated in its efficiency and its productivity, reducing air pollution and greenhouse gas emissions.

We have some important regulatory reforms that go to the heart of enabling the deployment of renewables and nuclear, as well as ensuring the greater reliability of electricity markets. Every percentage improvement in efficiency we can get into our grid means a net reduction of air pollution and greenhouse gases; and these structural changes require both regulatory

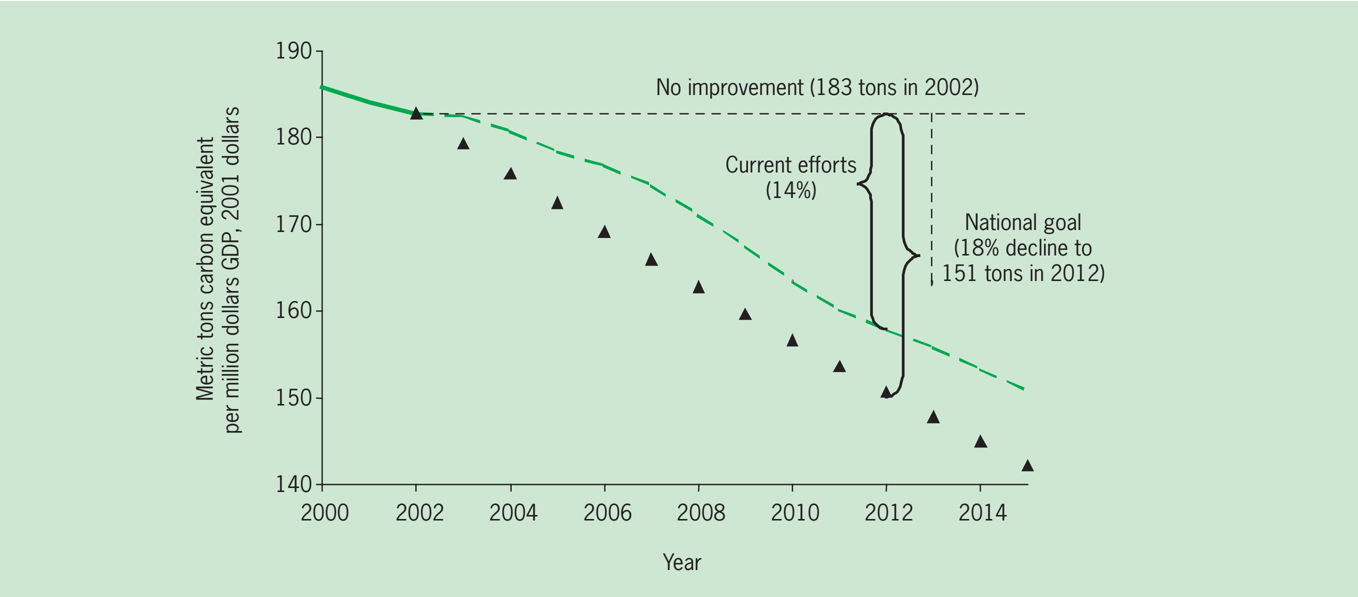

Figure 3. US Greenhouse gas reduction target to 2012

and market-based drivers. We also have, contrary to popular mythology, new rules that require a 15 per cent increase in fuel economy for large trucks, large light trucks and sports-utility vehicles (SUVs), including the Hummer.

Now, climate change: we could not do Kyoto — our targets were impossible to meet. We have a tough time, like the UK, when we make international obligations because we dedicate ourselves to meeting them. That, however, did not diminish our enthusiasm or diminish our understanding of the importance of this issue – the President did articulate a national goal of reducing our greenhouse gas intensity by 18 per cent.

Let me give you a few tangible examples of where progress can be made because our approach is focused on developing very practical business plans for the most profitable opportunities to reduce greenhouse gases. Why create the political angst of cost when there are many initiatives we can undertake that give profitable reductions?

We have more than 60 programmes, aimed at reducing emissions by about 500 million metric tonnes by 2012. To put that in perspective, that is about the amount of greenhouse gases that will be offset by the Kyoto parties, collectively, if they meet their targets. So what we are able to do in our economy is about equal to all of the rest of the Kyoto countries in terms of actual offsets of greenhouse gases emissions.

I want to highlight energy saving performance contracts. A new law a couple of years ago permits a technology vendor to spend its own money installing energy efficient equipment in federal facilities and to share the savings with the taxpayer: the taxpayer saves money, the technology vendor gets a steady stream of very reliable payments and therefore puts the money up-front. As a result, at Federal facilities alone, we have a plan to achieve energy savings that will cut CO_2 by about 47 million tonnes by 2015 – and that is about a tenth of the total package.

Another programme that I want to highlight is the Smartway transportation partnership. We have thousands of diesel vehicles, heavy duty trucks, going all across our country. At night they pull into a truck stop and use their huge diesel engines to run tiny air conditioners or heating systems and maybe plug-in TVs. We are working with all of our truckstop providers across the country to change that, by letting trucks 'plug into' a truckstop and get really good air conditioning, get internet access, get cable TV. It is an added-value proposition that will fundamentally restructure this wasteful practice of running diesels at night – and achieve huge gains. That is one example from dozens.

Not only do we have to take serious mitigation measures now, as Sir David suggested, but we need pathways for the mid-term. The one that I want to highlight is carbon and I want to give you the US example. To go from uncontrolled coal to zero emissions coal, you need the clean coal intermediate pathway. Until recently, the investment in carbon capture and storage (CCS) was largely a Government-led enterprise because there was no likelihood of a market. However, construction is now going ahead for pollution control reasons.

The alternative to coal in America, the cheaper alternative, is natural gas. This switch would be tragic for the world economy given its dependency on natural gas, especially for countries that do not have a resource endowment of fossil fuels like the US. We believe natural gas is not best used for electricity generation in America; however, unless we structure our programmes appropriately, any business manager is going to choose lower cost, natural gas plants. A natural gas 750MW plant costs a couple of hundred million dollars whereas an advanced clean coal plant is in the $900 million range and an integrated gasification plant is in the $1.1 billion range for the same output. If you are a capital investor, where do you prefer to put your money? If policies are not designed right, the money goes out of coal.

As it happens, nuclear power plants are cheaper than these advanced coal plants, so we have to find a way to ensure a balanced portfolio. We have at least four of our major utilities putting forward multi-billion dollar plans for advanced gasified-coal plants and also experimenting with some of the other technologies that might provide low-cost carbon capture.

Any serious conversation about cutting the harmful effects of air pollution and addressing this long term issue of seriously mitigating greenhouse gases has to include nuclear, at least in the next half century. At the very least, we have to replace what we have because the alternatives right now are fossil. We also think that we should add a further percentage that is founded on nuclear.

In conclusion, we must now focus on implementation. I think that we have had the lion's share of negotiation but we need to move our effort into the finance ministries, into the development ministries, into the technology side of the science ministries, into the energy ministries and the transport ministries, which have largely been on the sidelines of this diplomatic discussion until now. This is how we move forward. ❐

An insider's view of the mixed success in Britain of winning economic benefits from research

A half century of research reorganisation

Alcon Copisarow

"Men are today walking on the moon, radiotelescopes receiving signals sent in our direction a billion years ago, doctors are transplanting hearts, chemists wresting the secrets of heredity from nucleic acid – and even proving that beauty is a scientific phenomenon." Those were my opening remarks at a conference in Paris 40 years ago. I spoke of these achievements not simply because they were dramatic but because they stemmed from a huge increase in the public funding of research and development. But in themselves, they did not spell economic prosperity. They certainly did not alleviate the condition of a billion of the world's population whose constant companions were poverty, hunger, fear and disease.

The question now, as then, is how we can harness our scientific and technological achievements to benefit our economies and to bring prosperity? What can we learn from our past?

During and after the Second World War, science was recognised to be both an intrinsic part of our culture and a component of technology. At the time there was modest financial support for civil research from the Department of Scientific and Industrial Research (DSIR), responsible to the Privy Council, while the ministries of Supply and Aviation were responsible for military research. Then, in 1959, Lord Hailsham, Lord President of the Council in the Conservative Government, was redesignated Minister of Science. He was more an intellectual than a politician, believing that science is a cultural activity whose results cannot be commanded. It was for scientists through their research council to advise government on the best deployment of resources.

The Leader of the Opposition, Hugh Gaitskell, and his deputy, Harold Wilson, had meanwhile gathered around them a distinguished group. This included J D Bernal, who had very strong left-wing views, and Patrick Blackett, who wanted a dramatic shift in government support for research and development towards civil industry. Bernal insisted that scientific progress had to be planned and, if necessary, applied forcefully. Blackett contented himself with a review of the problems as he saw them – too few scientists, too little money and poor company management: he advocated contract research on a grand scale.

Wilson, in a speech at Scarborough, called for a far-reaching change in attitudes. "We must mobilise all the resources of science available to us in the new scientific revolution; harness socialism to science and science to socialism." That was a foretaste of his famous 1963 speech about "a Britain that is going to be forged in the white heat of the technological revolution".

And then, in January 1963, Gaitskell suddenly died. Wilson succeeded him and put Richard Crossman MP in charge of policy on science and higher education. He created a Science and Industry Committee with Blackett as his principal adviser. Blackett proceeded to bring everyone together for policy discussions, not least the Royal Society and the Fabian Society. Blackett had discussed his plans with me a year earlier. He was favourably impressed by the French planning system and by French estimates of the contribution that science and technology would make to their economy. He was also intrigued, on a visit to the Forest Products Research Laboratory (where I was director), that the industrialists we invited to our open days were awarding us research contracts to undertake work on their behalf.

In February 1962, Blackett proposed that a new Ministry of Production be set up, incorporating the National Economic Development Council (NEDC, known as Neddy) and an interventionist Ministry of Industry and Technology. They would deal with major companies in the civil sector as the Government did in defence. That very week I had been seconded to Neddy, so he asked my views. I said the machinery was confusing, its effect could be disturbing, and we had far too few civil servants with appropriate experience and business understanding for the roles envisaged. In defence, where the Government was the customer, the situation was different.

Neddy had been formed by the Macmillan government, at the behest of the Federation of British Industries (now CBI) as a forum to bring business and trade union leaders together with ministers, the Chancellor of the Exchequer presiding. Its aim was to identify the obstacles that prevented us from doing as well as our continental competitors. We were asked to say how we could achieve a 4 per cent growth rate in the economy and balance our payments while keeping unemployment below 300,000. I asked the Chancellor, Reginald Maudling, "If we cannot get all of these, what are our priorities?" He answered: "We just have to do the best we can."

The companies we consulted gave many reasons for their lack of innovation. Replacing equipment was unprofitable, skilled craftsmen were unobtainable, scientists and engineers were largely committed to defence projects (and those in the civil sector were unaware of customers' needs) trades union practices were highly restrictive, risk capital was hard to come by and the returns from innovation were too long-delayed and risky – the list was endless. In our own review we added specific shortcomings in management and a prevailing *laissez-faire* attitude, especially in industries such as textiles – then highly protected against competitive imports.

R&D expenditure in any event is not a true measure of technological performance. R&D can be too widely defined, while international comparisons of the R&D/GDP ratio can be misleading because of differences in costs, exchange rates and the efficiency of the R&D programmes themselves. In 1960s Britain, there was a wide variation between industrial sectors. Aircraft mopped up 38 per cent of our R&D spending, but accounted for only 5 per cent of our output and 4 per cent of our exports. Little attention had been paid to large but less sophisticated industries, but the benefits of research could often be quite disproportionate to its cost.

For example, in 1962 Britain was obliged to import nine-tenths of its timber at a cost comparable with our entire balance of payments. How could we extract the maximum economic value from this material? At the Forest Products Research Laboratory, we made a techno-economic assessment and took what was regarded as an unorthodox approach by starting at the far end of the industry's supply chain. To import timber, to season and to hold it for treatment and manufacture took up to five years. This delay incurred much of the cost – the interest paid on stocks – so we set out to reduce the seasoning time. By studying the physical characteristics of each species, carefully changing their kiln-drying schedules without harming them, the time was reduced to one-fifth. And so in time were our national stocks of timber. Within three years, it was calculated, tens of millions of pounds were saved in interest, representing more than a thousand times the entire cost of our R&D programme and perhaps a hundred times the cost to the industry implementing the change.

Blackett continued to revise his plans by consultation with Labour sympathisers. I happened to come into the Athenaeum Club one day to see Crossman and Blackett together on the drawing-room sofa. They called me over. They were sketching out a new organisation. Crossman said: "How can we best marry a permanent civil service with outside expertise?" I said it was a pertinent question; but that, as with biological organisms, the civil service tended either to assimilate creatures it could live with or to eject them if they were indigestible. In due course, the idea of a free-standing Ministry of Technology prevailed shortly before the 1964 election.

When I was asked to join MinTech, there were just a dozen of us. Maurice Dean, Permanent Secretary and a Treasury mandarin, found himself reporting to Frank Cousins, a minister who knew nothing about government, and a brilliant scientific adviser, Blackett, whom he saw as a maverick. On my first day Dean told me that a good civil servant was one who could stop or convert a minister's half-baked schemes into a practical proposition.

By 1969, it was widely recognised that our economic problems were more deep-rooted than previously thought. Tony Benn himself agreed that some expensive MinTech projects, including the supersonic aircraft *Concorde*, made no commercial sense and should be stopped. Worst of all, across the spectrum of manufacturing industry, collaboration between Government and business, essential for successful innovation, was absent.

The new Conservative Government of 1970 under Edward Heath initiated further reorganisation. Heath regarded MinTech as a gimmick, and merged it with the Board of Trade to form the Department of Trade and Industry (DTI), which promptly suffered three changes of leadership in three years. Education and Science became the responsibility of Margaret Thatcher, who maintained that we should concentrate our science funding on universities and research institutes. "Science is less amenable to political direction than politicians like to think", she said. "The transistor was not discovered by the entertainment industry seeking ways of marketing pop music, but by people working on wave mechanics and solid-state physics. Development should be carried out by companies themselves," she added, "companies with less tax to pay."

A committee under Lord Trend, a former Cabinet Secretary, then recommended that the research councils were given responsibility for choosing what should be financed, in effect deciding where the national interest lay. Lord (Victor) Rothschild, appointed by Edward Heath to head the Central Policy Review Staffs CPRS (the Government think-tank) disagreed. Research councils could not take political decisions. Requirements boards were necessary to decide priorities, and research funds should be handed back to departments so that their chief scientists could commission work from the appropriate research councils. Whatever the logic, the scheme was strongly opposed by both the Science and Medical Research Councils and a compromise had to be found.

But there were other problems. The boundaries between the Department of Education and Science (DES) and the Department of Trade and Industry (DTI), and between DTI and the Ministry of Defence (MOD), were unclear. Furthermore, when research had been completed, the research councils could not provide support for subsequent development, but had to refer to the DTI. This, in turn, could go only to industry or to the NRDC (BTG), both of which looked for clear-cut patent prospects. There was no official route either to build a prototype or to establish whether there was a market.

The MOD, for its part, was keen on spin-off, but had not the resources, while companies themselves were slow on the uptake. The Trades Union Congress (TUC) complained in 1985 that the government was discouraging investment. What was needed was a body along the lines of the US Office of Technology Assessment. Neil Kinnock, then the leader of the Labour Party, the principal opposition party, said that Western Europe needed such an institution.

The mixed performance of British industry since the 1960s illustrates that we have progressed only where we have been both innovative and entrepreneurial. I recall the interesting remark made by Bruce Archer of the Royal College of Art. In industry, as in biological life, it takes two parties to bring a viable new system into the world – the innovative or seminal role, and the entrepreneurial or ovular role. Just as it generally requires millions of sperm to ensure a reasonable probability of fertilising an egg, an industrial product or process usually requires a multitude of bright ideas to bring off a viable innovation. To achieve a higher success rate, he said, we must improve the ovular entrepreneurial function.

To compete successfully we must dramatically raise our productivity. When Labour took office, US productivity was 40 per cent higher, and France and Germany's 20 per cent higher, than ours. The reasons given by the Economic and Social Research Council (ESRC) for our lagging behind are almost exactly the same as those given in the Neddy Report 40 years ago. Higher productivity is the only source of new wealth which, channelled into pay, savings, public services and leisure activities can bring a better way of life.

The key to its realisation is innovation. This calls for the effective interaction and coupling of ideas, resources and working relationships. Research may be the goose that lays the golden egg, but shut away it is just a broody hen.

Lord May, as President of the Royal Society, acknowledged that half of our productivity growth comes from new knowledge generated globally, and he has emphasised the critical role of scientists in diffusing knowledge widely and explaining its value. Academic scientists perpetuate our cultural heritage. Motivated by intelligent curiosity, they can be at their best when setting their own agendas, but they must not forget that those who financially support the culture of innovation are driven by economic arguments. The transfer of knowledge – or as I would prefer to call it, the translation of knowledge – is therefore crucial. The recent reviews of universities' efforts in this field (Lambert) and creativity in business (Cox), the Royal Society's Industry Fellowships and the highlighting of the competitiveness issue in the Government's 10 year framework are all to be welcomed. But much more is still needed.

The low level of investment in R&D by businesses in many sectors reflects a reluctance to invest further in new productive capacity. Confidence is needed. Upheavals in Government machinery, together with frequent policy, regulatory and tax changes, add to the uncertainty of likely returns.

Furthermore, timely and concerted action is needed by Government, business and universities together, for maximum effect, whether addressing the broader issues – globalisation, climate change, energy, longevity or civil contingencies – or selecting particular priority projects with market potential. And we should not forget that, over the past 40 years, many projects with relatively low research intensity made a disproportionately large contribution to our prosperity. ❐

This is an extract from Sir Alcon Copisarow's 2005 Churchill Archives Lecture, delivered as By-Fellow, Churchill College, Cambridge.

After research in colloid science, wartime naval radar, service as Scientific Counsellor, Paris, and the Departments cited, for 20 years, Sir Alcon was appointed a Senior Partner of McKinsey, to the Board of BNOC and British Leyland, and Chairman of APAX and of the Eden Project. He was a founder Chairman of the Prince's Youth Business Trust.

Meeting the challenge

Ian Diamond

In July 2005 the Treasury published five public policy challenges for the UK as part of its preparation for the 2007 Comprehensive Spending Review. Being comprehensive means that the Treasury has started with a blank piece of paper. The message for any Government Department is, you must demonstrate how you will be tackling the problems of an ageing population, the global challenge from emerging economies, the increased rate of technological diffusion, the threat from global insecurity and the increased demand for natural resources and energy (see box).

The way the Councils respond to these challenges neatly illustrates their relationship with Government. All eight Councils are set up by Royal Charter as independent public bodies and this reflects the Haldane Principle, that research funding should be made free from political pressures. How then can the Research Councils respond to the challenges without compromising their independence? What role is there for curiosity-driven research when Research Councils feel the need to address high-level Government priorities?

In essence, do we risk the politicisation of research? As Councils we are clear that this concern is unjustified. In allaying these fears, let us take the example of Challenge 4 – global insecurity and terrorism. This has clear relevance to almost all the Councils' work and is a useful case study. Our response, published on our website (*www.rcuk.ac.uk*), sets out the questions that research can answer, how past investments can address the challenge now, and how current and planned research will provide answers in the future. It shows that not only is the UK's research base excellent but also that it is doing excellent relevant research. We can point to research outputs that can have a profound effect on the way in which the Government chooses to tackle this problem, yet most of these outputs have come as a result of unsolicited research applications, many of which were submitted several years ago.

First, path-breaking research at the MRC Toxicology Unit has helped us understand how hazardous materials of possible use to terrorists act on the human body and how best to counteract them. In 2004-05, over £4.5 million was invested in this key MRC unit. Second, the involvement of Logica CMG in ESA's Huygens mission to Titan, joint funded by PPARC, led them to develop Cortex – an industry best practice system for complex management projects. Project managers involved have gone on to lead a £80 million Ministry of Defence communications contract for supporting British forces in Afghanistan.

Third, ESRC research into the psychology of face recognition has made a significant contribution to the way in which images are utilised by the police. As a result of research into how language shapes visual imagery, the police are now better able to help witnesses describe faces more effectively and enhance the possibilities for suspect identification.

There is a key role for managed research programmes too. An exciting development is EPSRC's Crime and Security programme which invests around £1 million each year in projects tackling the threat of terrorism. Through this initiative, research at Cranfield University is helping us understand how a blast wave propagates. This is essential for working out evacuation strategies and ways to build more robust structures. A collaboration between Kingston University and University College London has tested a prototype system at Liverpool Street Station to detect unusual behaviour within crowds, without the need for individual identification. In addition, AHRC, in collaboration with ESRC and the Funding Councils of England and Scotland, has invested £22 million in Language Based Area Studies Centres. The overarching aim is to create a world class cadre of researchers who have the language skills to undertake contextually informed research that will ultimately enhance the UK's understanding of a number of areas, embracing the Arabic-speaking world and Eastern Europe (including areas of the former Soviet Union).

The lesson from this, and indeed the other challenges, is that the processes employed by the Research Councils can and will result in research outputs that provide solutions to the Government's problems. We would be doing a disservice to Governments in the future if we were overly directive in our funding now. Through a balance of responsive and managed funding programmes, Councils can maintain or build capacity where necessary while ensuring that the best ideas, which come from active researchers, not civil servants or administrators, get funded. The Research Councils' role is to draw together research outputs and provide channels of communication between the research community and Whitehall. NERC's Science into Policy initiative and ESRC's Whitehall policy seminars are just two ways in which Councils achieve this.

What we are seeking to achieve therefore is the exact opposite of the politicisation of research: we are seeking to infuse Government thinking and policy-making with the research ethos. Our challenge for the next spending review in 2009 is to encourage the Treasury to have early discussions with us before they set out their priorities, to ask the research community what it thinks are the key issues facing the UK. ❐

Professor Ian Diamond has been chief executive of the Economic and Social Research Council since January 2003. He chairs the Research Councils UK Executive Group, a committee comprising the eight Research Council chief executives.

The Treasury's five challenges facing Britain

- A rapid increase in the old age dependency ratio as the 'baby boom' generation reaches retirement age;
- The intensification of cross-border economic competition as the balance of international economic activity shifts toward rapidly growing emerging markets such as China and India;
- An acceleration in the pace of innovation and technological diffusion and a continued increase in the knowledge intensity of goods and services;
- Continued global uncertainty with ongoing threats of international terrorism and global conflict; and
- Increasing pressures on our natural resources and global climate from rapid economic and population growth in the developing world and sustained demand for fossil fuels in advanced economies.

New President and Chairman

The Rt Hon the Lord Jenkin of Roding was elected President of the Foundation for Science and Technology at its Annual General Meeting on 9 May 2006. At the same meeting, The Earl of Selborne was elected Chairman.

Lord Selborne thanks Lord Jenkin for his nine years of service as Chairman of the Foundation.

The Earl of Selborne KBE FRS

The new Chairman has been a vice-president of the Foundation since 1994. The Earl of Selborne has served on a number of key committees and organisations in Parliament and outside. He is chair of the Royal Society's Science in Society Committee, chair of the Board of Trustees of the Royal Botanic Gardens at Kew and Chancellor of Southampton University. He has recently been a sub-committee chair of the House of Lords Committee on Science and Technology, having previously served as the Committee's chairman.

The Earl is currently chairman of a thousand hectare farming company specialising in fruit and dairy products. He has been closely concerned with agriculture for many years, being a former chairman of the Agricultural and Food Research Council and of the Joint Nature Conservation Committee. For five years he was a member of the Royal Commission on Environmental Pollution and he is a former president of the Royal Geographical Society.

As well as his parliamentary and scientific commitments, the Earl of Selborne has been an active supporter of a number of charities and also of local organisations in Hampshire.

He is a Fellow of the Royal Society, of the Royal Society of Arts, the Institute of Biology and the Linnean Society of London. He was made a Fellow of the Royal Society in 1991 and a KBE in 1987.

The Rt Hon the Lord Jenkin of Roding

Lord Jenkin of Roding, who has been chairman of the Foundation for Science and Technology for the past nine years, has now become President of the Foundation. A former industry and environment minister, he became chairman in 1997, the same year as he became a member of the House of Lords Select Committee on Science and Technology. ❐

comment

The dragons of expectation

Archimedes

Archimedes is an experienced observer of the evolution of public policy who contributes occasional comments on the character of the discussion at the Foundation's dinner discussions.

Robert Conquest wrote recently on the dangers of being so blinded by the belief that a certain policy or philosophy must lead to happiness, riches or peace, that evidence of other possible outcomes was ignored. He entitled his book *Dragons of Expectation* — an image taken from an Icelandic poem, in which people expect the sky dragons to deliver benefits, but instead they deliver only destruction.

Conquest's prime dragon was, of course, communism. But presentations and discussions at the FST reveal other dragons. There is, for example, the expectation that unhampered research must benefit humanity, as it will increase knowledge. The tenuous link between knowledge and understanding, and the evidence that knowledge can be malign as well as beneficent, are ignored.

Another expectation is that the more students in a society who undergo a scientific or technical education, the happier and richer that society will be. But such an education, however well taught and however a good remuneration it may lead to, may fail to meet the desires and interests of many, who will remain in life discontented and unsatisfied - a disruptive rather than constructive element.
A third dragon is the expectation that widening access to higher education by ensuring that there are no barriers of class or money, and by providing equality of opportunity through high quality schooling, will benefit society by providing more able and qualified workers. Yet such an expectation ignores the substantial increase in public expenditure (and taxpayers' resentment), the intrusive regulation of admissions and choice of courses, the unlikelihood of ensuring all teachers are above average, and the damage to the concept of excellence.

Of course, many are already warning about these dragons, as they did about the dragon of communism. But, as Conquest warns, for 60 years that dragon dominated the thoughts of intellectuals and politicians, with disastrous results. Let us hope these other dragons will be viewed more skeptically. ❑

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The Foundation for Science and Technology
10 Carlton House Terrace
London
SW1Y 5AH

Telephone: 020 7321 2220
Fax: 020 7321 2221
e-mail: fstjournal@foundation.org.uk

www.foundation.org.uk

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