STANDING ON THE SHOULDERS OF GIANTS (*Sir Isaac Newton 1676*)

MEETING OF THE PARLIAMENTARY AND SCIENTIFIC COMMITTEE ON MONDAY 15TH NOVEMBER 2004

Gordon Brown's canny science investment helps the UK Ltd's innovative industries retain world class status and attract school leavers considering science and technology. The money is now in place but what do the the UK Scientific and Engineering Community intend to do about it? Our 65th birthday provides an opportunity to consider the drivers and future direction of UK Science and Engineering. We need to lay out our objectives and begin to allocate the new resources created by the Chancellor's investment if it is not to be squandered on increased bureaucracy.

The Parliamentary and Scientific Committee provides a successful and dynamic model for bringing science and politics together in a Parliamentary context. George Smith presents his view of the challenges facing the exciting, unpredictable and largely undiscovered potential of the materials world. David King considers Global Change is more important than Terrorism and provides insights into how this affects policy and scientific investment. Julia King lays out her strategy at Imperial College where she directs 10 world class Engineering Departments.

A Personal Perspective on UK Scientific Research

Professor George Smith
Head, Department of Materials, Oxford University, and Chairman, Polaron plc.

Summary

In the past Britain held a pre-eminent position in many areas of science. Present achievement is more pedestrian, especially in the Physical Sciences and Engineering. There are clouds hanging over the future, because of the inherently conservative nature of the current peer review process for research proposals, and the ever-increasing micro-management and regulation imposed by Government. Paradoxically, as the degree of control has increased, the output performance of scientists at the very highest level appears to have declined.

There is no doubt that British science and technology has a glorious past. Basic scientific discoveries include the laws of gravity, motion, electromagnetism; elementary particles such as the electron, proton and neutron; the atomic nucleus; vaccination, antibiotics, and the structure of DNA. In the area of invention, British ingenuity led to the steam engine, locomotives, railways, electric motors and generators, bulk steel production, the modern bicycle, television, radar, the jet engine, hovercraft, the pocket calculator, and a host of new materials including Portland cement, stainless steel, superalloys, polythene, polyester, carbon fibres, and liquid crystals. Britain was also responsible for the world's first electrical power station, the first civil nuclear reactor, the first jet passenger aircraft, the first supersonic passenger jet, useful devices such as traffic lights, cats' eyes, flush toilets – and even Viagra!

So what about the present state of our scientific achievements? It depends on what you measure, and how you measure it. At a routine level, things look pretty healthy. The proportion of the world's scientific papers written by British scientists is high in relation to our total number of scientists, our citation levels are ranked second only to the USA, and our scientific "value for money", in terms of the cost to the nation of each paper that is produced, is arguably the best in the world. But are these the right measures? What about the episodes of real genius, the inspired achievements that set the world alight? At this top end of the range, I believe we have more reason to be concerned. A German academic, Wolfgang Schoellhammer, carries out a regular survey of Nobel Prize awards, analysing them by the institution and country of the winners. His most recent (2003) data on the proportion of prizes awarded to British scientists is summarised here.

UK Nobel Prizes

Percentages of prizes awarded to UK scientists

	1901-2002	1978-2002	1988-2002
All categories %	15%	8%	7%
Chemistry	18%	10%	6%
Physics	13%	2%	0
Physiol/Medicine	15%	14%	15%

Source: Wolfgang Schoellhammer, Nobel Prize Survey 2003

In Physiology and Medicine, we are maintaining an excellent record, but in Chemistry the performance has slipped. In Physics, the decline has been steeper, redeemed slightly by the award of the 2004 Physics prize to expatriate Anthony Leggett, of the University of Illinois.

The figures in the table are expressed as percentages, but if absolute numbers of prizes are counted, a more disturbing picture emerges. Five of the seven prizes in Chemistry and Physiology/Medicine that were won by British researchers during the period 1988-2002 were attributable to a single institution, the MRC Laboratory of Molecular Biology, in Cambridge. If this remarkable institution is removed from the data, then the overall number of awards to the rest of the UK looks thin indeed.

Why did the MRC laboratory perform so well, while the rest of the country has trailed? Obviously, the ability to attract world-class minds has been crucial. But I believe that part of the answer also lies in the organisation and funding of the institution. Recent accounts of the life and work of the legendary director of the laboratory, Max Perutz (1914-2002) have shed new light on this. By a mixture of luck and judgement, all efforts to integrate the laboratory fully into the departmental structure of Cambridge University failed. It was therefore largely immune from the vagaries of the Research Assessment Exercise (RAE), the need to write endless short-term, responsive mode research proposals for approval by Research Council Committees, and all the other multifarous (and nefarious!) reviews and audits to which the UK academic community is now subjected with increasing frequency and intensity. The MRC laboratory had bold, long-term objectives. Highly creative individuals were given the freedom to develop their most adventurous and speculative ideas, sometimes over decades, and they handsomely repaid the confidence that had been placed in them. They changed the world, and laid the foundations of molecular biology and medicine.

My concerns about the loss of adventure in British scientific research are shared by others, for example Don Braben, former director of BP Venture Research:

"Until the 1970s a scientist with a radically new idea could scrape together enough funds to explore its potential. That's not possible today. Researchers must now convince a committee before they can do anything. *Scientists are losing the freedom to be impartial*. Originality and adventurous research are discouraged because committees can't be imaginative. We have more scientists today than ever before, but they must concentrate on refining existing knowledge. It's easier to assess performance that way."

(Don Braben, Materials Today, October 2004.)

The moves towards increased regulation and control of British science began in earnest in the 1980's with the introduction of the concept of Research Selectivity, which tended to hit particularly hard those universities which worked most closely with industry. There followed a torrent of rules and regulations, onerous inspections of so-called "teaching quality" (which really only checked that all the forms were filled in correctly), and the full-blown Research Assessment Exercises that have taken up so much of our time and effort in recent years. Now Full Economic Costing (FEC) is due to be rolled out from October 2005. The provisional guidance and instruction documents for FEC already extend to more than 800 pages, and threaten to overwhelm an already overburdened University system.

"Career civil servants, who know very little of the world they are looking at, have produced a set of rules which are little short of lunatic in their notion that that which in the States is recognised as a time-consuming, difficult attribution of costs at the level of institution, should here be done at the level of each grant. Kafka couldn't have dreamed this up!"

(Lord May, President of the Royal Society, interviewed by The Guardian, 20 July 2004)

In parallel with the introduction of FEC for universities, we are witnessing the development of a set of Public Service Agreement (PSA) target metrics for the UK research base. These will particularly affect the Research Councils. So far, the reaction from the academic world has been remarkably subdued, but here are a few of the more outspoken comments, which highlight the threat posed to adventure in research:

"There are some worrying aspects. For example, the section on managing the research base calls for an 'integrated and efficient performance management system'. This may sound rather exciting to whoever wrote it, but it will make the room suddenly feel very cold to those creative researchers who thought the research councils were supposed to be dedicated to funding exciting scientific proposals."

(Peter Cotgreave, Director, Save British Science, quoted in THES, 16 July 2004)

"It is impossible to see how the research councils will want to support anything but safe, well-tried areas of work with guaranteed outcomes."

(Ian Haines, chair of the UK Deans of Science Committee THES, November 12 2004)

"What is the problem that this is supposed to be solving?"

(Paul Cottrell, assistant general secretary of the AUT, THES, November 12 2004)

Britain now has the most over-regulated, controlled and micro-managed scientific community anywhere in the developed world. Ironically, the increase in control has been matched by a progressive decrease in Britain's scientific success at the very highest levels. These two things are surely connected. Let the final word on risk and creativity in research go to Bill Gates, businessman and wealth-creator par excellence:

"If all your projects succeed, you have failed."

(Bill Gates, briefing the first Director of the Microsoft Laboratory in Cambridge, UK)

So let us try to restore the spirit of risk and adventure to British research before it is too late.

Note: The opinions expressed in this article are, unless otherwise stated, purely those of the author, and do not represent the official views of any organisation to which he is affiliated.

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Impacts of a Changing Climate on Government Policy

Professor Sir David King, Chief Scientific Adviser

I see climate change as the greatest challenge facing Britain and the World in the 21st century. In a speech given by the Prime Minister on 14 September 2004[1], he called climate change the world's greatest environmental challenge.

The weight of evidence for climate change, and the causal link with greenhouse gas emissions, most notably carbon dioxide, is in my view now unarguable. The evidence comes on many fronts: melting icesheets, receding glaciers, and increased and more frequent flooding to cite just a few. Over the past century the global climate has warmed by an average of 0.6C, with much of this seen over the past 30 years. The science is clear that this rise in temperatures will continue and will accelerate, leading to a rise in the range of 1.4C to almost 6C by 2100. At the same time, global average sea levels are also predicted to rise, by between 9 to 88 cm by 2100.

Recent experience in the UK and the rest of Europe shows that extreme events can have significant human and economic costs. In the UK, the hottest day ever recorded in Britain occurred 10 August 2003, when the temperature reached 38.1 deg C (over 100°F) in Gravesend. The heat-wave also affected much of Europe and caused some 30,000 premature deaths. And had an estimated direct economic cost of $13.5bn[2], making it the worst natural disaster in Europe for 50 years. The heat wave was particularly severe in France leading to some 15,000 premature deaths. A recent study published in the journal Nature, by the Hadley Centre[3] demonstrates that it is very likely that increased concentrations of greenhouse gases in the atmosphere, due to human activity, have more than doubled the risk of occurrence of a hot European summer like that of 2003, and statistical analyses from the study show, with 90% certainty, that roughly half of the severity of this extremely hot summer can be attributed to global warming.

More extreme rainfalls are also expected to be a feature of climate change. The impacts of these could be significant. In 2002, the severe floods in Europe caused 37 deaths and had an estimated direct cost of $16bn. A recent report from the Association of British Insurers noted that in 2000 the UK experienced its wettest autumn for almost 300 years, with heavy rainfall leading to damage to 10,000 properties and nearly £1 billion in insurance claims.

Claims for storms and flood damages in the UK have doubled to over £6 billion over the period 1998-2003, compared to the previous five years, with a prospect of a further tripling by 2050. It is too early to link such events unequivocally to climate change but they are an early warning for what we might expect.

The Third Assessment Report from the Intergovernmental Panel on Climate Change (IPCC)[4] concluded that "most of the warming observed over the last 50 years is likely to have been due to increasing concentrations of man made greenhouse gases".

Carbon dioxide levels are approaching 380 parts per million (ppm), a concentration in the atmosphere not seen for at least 740,000 years and quite possibly for about 55 million years[5]. The current level is already well beyond that seen in the atmosphere during Earth's "warm periods" between ice ages, and is consistent with the Earth's "hot periods", such as around 60 million years ago when all ice on the planet melted and when mammals would have found Antarctica one of the most comfortable places to live.

According to a NASA study, the Greenland ice sheet was retreating at a rate of around one metre a year in 2001. The latest study indicates its moving back at about ten metres per annum. If the Greenland ice sheet were to melt, the sea level would rise by between six and seven metres. That would create a major problem for cities like London, New York and all other cities located by the coast. This issue was explored at length in my recent Foresight report into flood and coastal defence management for the UK.

More intense rainfall events are expected to be a feature of climate change. If we do not prepare for these, the impacts could be significant. We already know the power and devastation that can be unleashed on our communities through extreme weather events, such as the flooding in Boscastle in Cornwall, Londonderry in Northern Ireland, and most recently Carlisle.

Although some climate change can always be attributed to natural cycles in the earth's climate system it would be impossible to explain the general trend over the last century without increasing human induced effects, due largely to fossil fuel usage and deforestation.

The international community must now make a concerted effort to limit the extent of global warming on the one hand, and adapt to those changes in the climate which are now unavoidable. Effective action demands international agreement on processes, which engages the world community in tackling what is a truly global problem.

So where do we start? In 2002 I commissioned my Foresight team in the Office of Science and Technology, together with over 90 experts, to look at the threat of increased flooding and coastline vulnerabilities that we are likely to face from climate change. The group concluded that, in the highest emission scenario, by 2080, flood levels that are expected to occur once in 100 years could well be occurring every 3 years. This is an example of adaptation activity.

To mitigate against the long term climate change, various global levels of action are required. First of all, the Kyoto Protocol, which was ratified by Russia in December, will come into force on February 16. Although I am pleased to see it come into force it is just the start of a process and will need to be ratcheted up so that we can really bring emissions under control. It is important that in the extension of the process the USA, Australia, India, China and Brazil are brought on board.

Ratification of the Kyoto protocol presents a raft of business opportunities in sustainable growth and an unprecedented opportunity to accelerate the move to a low carbon economy. It will also provide a platform for the UK and EU to lead by example.

In 2003 the UK Government published an Energy White Paper. Four goals for our energy policy are laid out to put ourselves on a path to cut the UK's carbon dioxide emissions – the main contributor to global warming – by some 60% by about 2050, with real progress by 2020; to maintain the reliability of energy supplies; to promote competitive markets in the UK and beyond, helping to raise the rate of sustainable economic growth and to improve our productivity; and to ensure that every home is adequately and affordably heated.

Although a 60% reduction in CO_2 emissions seems an ambitious target, we have already put in place measures that should help us achieve it; the first one is simply by improving energy efficiency – a win-win situation.

The Government is also investing in developing new energy technologies that can replace fossil fuels. The limits of providing energy from low carbon sources are endless but we should not second guess which new technologies to chase. Rather we must set up the right economic framework and let the marketplace choose the right mix.

At the start of this year the Government took over the presidency of the G8 and the Prime Minister has declared that climate change is one of just two priorities. The aim is to build on the already growing consensus amongst governments around the world and promote more vigorous action. Quite simply climate change is real and needs global action. Action is, and will be, affordable. Inaction won't.

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2 UNEP/DEWA~Europe, 2004, "Impacts of summer 2003 heat wave in Europe", Early Warning on Emerging Environmental Threats 2, http://www.grid.unep.ch/product/publication/earlywarning.php
3 Human contribution to the European heatwave of 2003, Peter A. Stott, D. A. Stone & M. R. Allen, Nature 432, 610–614 (2004);
4 Intergovernmental Panel on Climate Change: http://www.ipcc.ch
5 J F McManus, Nature 429 (2004), 611

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Engineering the Future

Dr Julia King
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Introduction: engineering is changing

In September 2004 I returned to academia after10 years spent mainly in industry. What struck me most are the changes since I left Cambridge University in 1994. Engineering is now responding to the needs of industry and business, of healthcare, and of the environment and encompasses a dynamic set of disciplines that can do more, and more quickly, to save millions from dying of water-borne diseases than the best new drug development programme. Engineers will deliver the solutions to global warming. Engineers will design the reactors and the processes to grow stem cells into replacement organs and play a major role in almost everything that is important. And yet we are failing to get these positive messages across to young people and the public. The numbers of UK students studying physics and maths at school, proceeding to read engineering at university and taking up jobs in engineering continues to fall. As engineering changes, the way we teach engineering and the ways we recognise and reward excellence need to change as well.

People and systems: people in systems

Engineering is about people – we are its end users and its creators, a key part of how it works – customers, users, maintainers, practitioners, researchers… But as technology advances and the products get more complex, the effect is to make many people feel alienated from the engineering that should serve them. In a country where over half the population is female, less than 13% of graduate engineers are women and a much smaller proportion is involved in designing and making the products we buy and use.

A human-centred approach to engineering is needed to ensure that "how will a person use this" is a key part of any product specification. It is also needed as systems get larger and increasingly complex. Most organisations are struggling with the challenge of networking "key" systems, often communication and information systems. Many approaches to this assume that it can all be done, cost effectively, with technology, but have failed spectacularly. It is essential to recognise that people will remain at critical nodes and interfaces in large networks for the foreseeable future. Therefore designing these systems with an understanding of human behaviour in the operational environment is critical. Yet how many of our engineering degree courses have traditionally covered these issues?

But things are changing.

Shortly after I joined Rolls-Royce in 1994, I was sent to spend a month with American Airlines, Rolls-Royce's largest customer. The biggest impact of my visit – spent holding flashlights for maintenance crews changing engines at Chicago airport at night or inspecting the new arrivals each morning at the overhaul base in Dallas – was my early morning talks with a friendly technician who took me on the morning round of the engines and told me about the problems. He was keen to know where the "best" engineers in Rolls-Royce worked, so I told him about all the latest technology developments in the Trent 800 – the 3-D aerodynamics in the compressor, the new materials, the dynamic impact modelling for the fan case… He quietly pointed out that they very rarely saw these parts of the engine at the base. Most of their time, and much of the cost, was involved in unravelling the spaghetti of pipes and wires that form the engine dressings around the outside of the fan case, to correct an oil leak or a minor electrical fault. Access amongst the mass of tubes was difficult and replacing them under the cowling was almost impossible. The customer's view of the engine was very different from mine: an area of major impact to the customer was a Cinderella area to me.

But Cinderella does get to the ball. A comparison of the RB211 with the dressings on a current Trent 500 engine demonstrates how this issue has been addressed. I spoke to Keith Thomas, the head of the team responsible for Externals Engineering at Rolls-Royce plc, who commented "After a period of seeing Externals Engineering as a low technology – because parts like pipes and brackets are simple to make – and therefore something we don't need to develop core capability for within Rolls-Royce, we have now gone full circle. Over the last few years we have worked very hard on developing our tools and people in externals design. On the Trent 900, designed for the Airbus A380 super jumbo, we have achieved a further big step forwards in externals design quality – leading to improved maintainability/aesthetics as well as far fewer snags and changes in the development programme – compared with the Trent 500."

I currently chair the Defence Scientific Advisory Board for the Ministry of Defence. It is an opportunity to see engineering in practice in an environment where we rely so heavily on the people. A soldier in action could be carrying over 50lbs of kit. He may well be tired, anxious… Will performance be enhanced by concentrating our engineering resources on giving him more technical capability or less to carry? If the soldier were a woman, how would this change the assessment? Similar considerations need to underpin much more of our engineering activity.

Engineering the Future

The emphasis over the past 10 years has moved towards sustainability, environment, healthcare and well-being in undergraduate engineering courses, as well as in research and industry.

We can now grow tissue on a silicon microchip – showing the compatibility between engineering and life. It is not difficult to envisage the possibility of tissue growing to form contacts in a circuit, delivering some life-supporting function – replacing a damaged optic nerve to restore sight – or monitoring a person's condition. This area of "engineering life" for the rich world could mean proactive healthcare – continuous monitoring via your mobile phone from implanted sensors so that your GP or clinician can call you in before any real concern arises. Or the vision of intelligent stem cells: control of stem cell growth, initially in a reactor vessel and subsequently after implantation into the body, to develop the right types of cells for specific "human repairs" – early successes could be insulin producing cells to cure diabetes or bone marrow to cure leukaemia – through real-time monitoring and control of the cells themselves and the growth environment.

For much of the rest of the world, the concept of engineering life is more basic – sanitation. Over 1.2 billion people lack access to clean water. The Asian tsunami disaster has served to remind us of the importance to human health and life of a clean water supply. 5% of all deaths each year are from TB, the spread of which is closely associated with the lack of clean water, and the figure is growing. To provide for those who still do not have clean water and meet the future needs of urban populations in the developing world, we will need to build sanitation systems for 350,000 people every working day – equivalent to a city the size of Belfast. The impact of appropriate engineering could be immense.

Engineering and health is just one of the key areas for engineers.

Between 1900 and 1999 per capita resource consumption and waste generation increased four times, accompanied by a four times increase in population – multiplying by sixteen our impact on the planet. In the first 50 years of the 21st Century it is estimated that resource consumption will double again, with a further population increase factor of 1.5. So our impact on the earth from 1900 to 2050 will have increased fifty fold[1]. It is not surprising therefore that the effects of our activities are increasingly apparent.

Other essential areas for engineering include solutions for sustainable energy and reduction in our impact on the environment, combined with wealth creation. Engineering will be successful where product design focuses on the user.

Future Engineers

Moving from product-centred to people-centred engineering enables us to recruit bright students who have not been strongly engaged hitherto. On engineering courses only about 13% of undergraduates are women. On the new bioengineering degree course at Imperial College, which started in 2001, women now make up 50% of the students. A packed syllabus includes plenty of engineering: imaging – for biomedical applications; mechanics – of the body and skeletal repair; electronics – for prosthetic repair of the nervous system; sensors – for biological agents and systems; combined with cardiovascular, connective tissue and respiratory medicine.

The training of engineers will continue to change. Engineers increasingly need to be able to think through systems, include human behaviour and performance at the centre of their approach and consider the ethical and environmental implications of their work, whether that relates to controlling the growth of stem cells or emissions from a new form of personal transport.

The Challenge

Communicating the changing nature of engineering and getting more of our best and brightest young people to study it is a major challenge. The example of bioengineering is encouraging. To quote a Nature editorial "Getting bright young scientists and engineers interested in the world's water problems is vital…There are prominent role models to show that scientific excellence and the application of appropriate technologies can go hand in hand."[2]

We must not let outdated perceptions of "excellence" stop the changes that are happening. The way we assess and value engineering must recognise excellence in customer focus and appropriate delivery for people.

References

1 T. Homer-Dixon "The Ingenuity Gap" Vintage Canada, 2001

2 Nature **422**, 243 (20th March 2003)Canada, 2001

In discussion the following points were made:

Investment in innovative science and engineering penalises research institutes that undertake routine environmental monitoring required by the Hadley Centre to predict global warming impacts. Investment should be divided between academia, industry and the research institutes. Cost benefit analyses are needed before additional levels of regulation are imposed on researchers. There is no comparable research assessment exercise in the USA. The London market is too short term, and this has negative impacts on science compared with government-led tax incentives, as in Singapore and innovative business clusters in the USA, requiring a culture change in the UK. Action on global warming is needed immediately if London is to survive for 1000 years!