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contents

Climate change is big business

Prime Minister Tony Blair lent his support to a new London-based consortium called the Climate Group, attending the launch event on 27 April. The consortium's central aim is to seek ways of reducing greenhouse gases beyond the targets of the Kyoto Protocol.

The consortium has received a cautious welcome from many environmentalist groups, the caution deriving from the presence of oil multinationals (BP and Shell) and big business (including Marks and Spencer and the HSBC Bank) among the founder members.

Membership of the Climate Group is open to all companies, non-governmental organisations and local, regional and national governments committed to a "leadership agenda on climate protection" and to reducing greenhouse gas emissions. The Climate Group says it will "actively seek out those organisations that fulfil these criteria", but that any organisation may enquire about joining.

In his speech at the launch, Mr Blair reiterated the Government's commitment to the Kyoto Protocol targets and repeated government science adviser David King's conclusion that, even if we were to implement the Kyoto Protocol, it falls significantly short of what we will need over the next half century if we are to tackle this problem seriously and properly. During Britain's hosting of the G8 Summit next year, said Mr Blair, climate change would be one of the two issues that the Government would be focusing on — the other being Africa.

The Climate Group's launch website is www.theclimategroup.org ❒

Contrasting awareness of nanotechnology

A Royal Society and Royal Academy of Engineering opinion poll published in March revealed that the vast majority of UK citizens — 71 per cent — had not even heard of nanotechnology. Only 19 per cent were able to give some sort of definition of nanotechnology, and only 68 per cent of these thought that it would improve things in future. The Royal Society and Royal Academy of Engineering were commissioned by the Government in June 2003 to carry out an independent study of the future of nanotechnology. The nanotechnology working group has been taking evidence from interested parties and the study is due to be completed this summer (see page 21 for more details).

In contrast, public awareness of nanotechnology in China appears to be high. So much so that Kiu Hung International Holdings, which makes toys and decorative gifts, has high hopes that its antibacterial plush toys will turn round the company's ailing fortunes. Interest in its nanotechnology-based plush toys has been strong since the SARS outbreak and the company expects to begin mass production towards the end of this year. The company's tests claim that the nano-processed fabric is able to drain away some 96 per cent of *Escherichia coli* and K*lebsiella pneumoniae*.

Elsewhere in Asia, Japan is investing US $6 billion in nanotechnology, while in Taiwan 800 graduate engineers a year are devoted to working in this and related fields.

At the Los Alamos National Laboratory (LANL), USA, an initiative to build a new Center for Integrated Nanotechnologies (CINT) has just been announced. The new Los Alamos facility, part of a partnership between the Los Alamos and Sandia National Laboratories, will become one of five nanotech user facilities in the country under the umbrella of the Department of Energy. Costing US $18.2 million, the facility is intended to enable private and government researchers, on both sides of the security fence, to participate in a broad range of nanotechnology research. Neal D. Shinn, outreach coordinator for CINT added a note of caution at the announcement ceremony: "Like any new science, we'll have to study the safety and health effects, while we're learning how to use them". The National Academy of Sciences has predicted that nanotechnology may become a trillion-dollar industry in the next decade. ❒

Prion research network launched

Last month in Paris, European Research Commissioner Philippe Busquin launched what has been termed the world's leading research network on prion diseases. With 52 laboratories in 20 countries, the network brings together 90 per cent of European research teams working on Bovine Spongiform Encephalopathy (BSE), variant Creutzfeldt Jakob Disease (vCJD, the human form of BSE), scrapie (a sheep prion disease) and other types of prion diseases. The European Union research budget will provide €14.4 million over five years to the network. A new prion research facility will also be launched at the Commissariat à l'Energie Atomique (CEA), a multidisciplinary research organisation in France and the institution that will be coordinating the neuroprion network.

BSE was first identified in 1986. Since then, 180,000 cases of BSE have been diagnosed in the United Kingdom. Only 4 out of the 25 EU Member States have not yet declared any cases. A number of countries outside Europe have also found cases, making this a global disease. ❒

Life sciences research

Two events in May showed that the UK government is actively trying to support the biological research and biotechnology industry that has received some recent setbacks — notably the withdrawal of plans for a primate research centre in Cambridge. The new ventures are the world's first bank for storing embryonic stem cells and a centre for the study of the "three Rs" of animal experimentation.

On 19 May, the health minister Lord Warner officially opened the UK Stem Cell Bank in South Mimms, Hertfordshire. The bank is funded by the Medical Research Council (MRC) and the Biotechnology and Biological Sciences Research Council (BBSRC). It is hosted by the National Institute for Biological Standards and Control (NIBSC) and is to be responsible for storing, characterising and supplying ethically approved, quality controlled stem-cell lines for research and ultimately for treatment.

The bank (www.ukstemcellbank.org.uk) currently has two human embryonic stem-cell lines on deposit, developed separately at King's College London and the Centre for Life in Newcastle.

On 21 May the UK government announced plans to set up a National Centre for Replacement, Refinement and Reduction of Animals in Research, which is to focus on what has become known as the three Rs of animal experimentation: replacing animal use; refining the procedures involved to minimise suffering; and reducing the number of animals used.

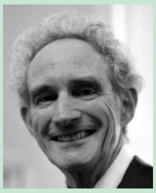
The director is to be Vicky Robinson, currently head of the Medical Research Council's Centre for Best Practice for Animals in Research (CBPAR), which will be the core of the new centre, with annual funding increased from £330,000 to £660,000.

Announcing the new centre, Science and Innovation minister Lord Sainsbury stressed the fact that the United Kingdom already has one of the most rigorous licensing systems for animal experimentation in the world and that some animals still need to be used in research. But he felt that "a major opportunity now exists to make progress in replacing, refining and reducing the use of animals and improving their welfare". ❒

On 25 February 2004, the Foundation continued its concern for the public funding of universities with a dinner discussion at the Royal Society centred largely on the redesign of the Research Assessment Exercise and the Royal Society's call for a fundamental review of university funding.

The pathologies of the RAE

Robert May



The Lord May of Oxford OM AC PRS FMedSci, president of the Royal Society, began his career as an applied mathematician and theoretical physicist. He is a professor (in zoology) jointly at the University of Oxford and Imperial College, London. Among his several international awards is the 1996 Crafoord Prize of the Royal Swedish Academy of Sciences. Between 1995 and 2000 he was chief scientific adviser to the UK Government and head of the Office of Science and Technology.

I shall mostly be talking about university research, but I have not forgotten that universities stand on three legs: teaching is every bit as important as research and both need to be inter-digitated with the larger community. I will return to that at the end.

An antipodean such as me is better able than a charmingly whinging Pom to say that the science base in Britain is extraordinarily strong. Universities are one of this country's treasures. A recent study by the Education Institute in Singapore, using a curious but not implausible set of measures, concludes that, of the top ten universities in the world — and in the Universe for all we know — two are British and the other eight are American. In the top 20, four are British, one is Japanese and fifteen are American. Given that the population of the United States is five times greater than that of the United Kingdom and its GDP is seven times bigger, we outperform them on this admittedly tendentious basis.

The same conclusion follows from a measure of the quality of research. Of the most cited one per cent of papers in science, medicine and engineering over the past two decades, the United States produced 32.5 per cent and Britain 8.8 per cent — proportionately more, allowing for population and GDP.

All of that has been done by sustaining basic research with two streams of funds. One stream, peer-reviewed competitively, comes from research councils and charities (and to some extent from business and industry) and supports specific proposals. The second stream, equally vital, meets indirect and infrastructure costs, including the launching of new projects and the winding down of old ones. It is essential that this second stream of funds should be held centrally by the academic administration and that it can be spent flexibly, not simply redistributed to the groups whose existence brought it in.

Fifty years ago, in a much smaller world with fewer universities and fewer people going to them, everyone was deemed to have access to a well-found laboratory; people then competed for the direct costs of their research projects. As we have quadrupled the number of universities — around 30 half a century ago, around 120 now — funds for the direct costs have more or less flexibly expanded so that good people in unlikely places are still funded, while money does not go to less good people, even if they happen to be at outstanding universities. The peer-review process sees to that.

Now, very sensibly, we have invented a research assessment exercise (RAE), a second, separate form of review to attribute the indirect infrastructure costs. Initially, the results were salutary. It was far better than just giving the money out uniformly or trying to provide everybody with access to a well-found laboratory. But despite the initial benefits, it is now my belief, and that of the Royal Society's council, that at its heart lies a structural pathology.

The RAE aims to evaluate the performance of departments. But departments are bureaucratic entities and, as such, do not do research. That falls to individuals and groups. And the United Kingdom is an unusually collaborative place, with more than half the publications in sciences, medicine and engineering involving collaborations between two or more different institutions, much less departments.

The rigidity of attempting to assess departments inhibits cooperation not only across disciplinary boundaries within institutions, but also among institutions.

In the last RAE, I personally was told that my two top-cited papers could not be submitted because I was in the zoology department and the papers were not zoology papers. This kind of idiocy is a pathology built into a well intentioned system. Not only does it inhibit the one thing that we are particularly good at — interdisciplinary work — but it also makes it harder to recognise and bind into the system really excellent people in unlikely places. Further, it creates inertia in the system, making it harder to wind down what was good and is now bad and to let new enterprises grow.

It is easy to say that the RAE is not much of a burden. Each exercise costs about £40 million, which is only about 1 per cent of the money given out for research. If that were the only burden, it would indeed be small. But the real burden is the distortion of the fundamental enterprise of research by a set of rules not closely related to what the game is really about.

Parenthetically, I must add that any well run university must have external reviews of individual departments and enterprises. At Princeton, such reviews were carried out by panels of international experts put together by the university's deans, themselves academically first among equals, not people who had left research to become deans. There was not much fuss and paper, but searching examination and thoughtful questioning, resulting in extreme cases in the closure of a department. When I contrast that bureaucratically-minimised, substance-maximised process at Princeton with the bullshit that increasingly afflicts what we do here, I could weep.

The RAE ship has a lot of inertia and will take a long time to turn around. The Royal Society's council recognised that. We shall have to have the next RAE and I should say that I personally believe the proposals that Graeme Davies is bringing to us, building on Gareth Roberts' earlier report, are in many ways extremely helpful and praiseworthy. They may not be a silk purse, but they are much better than the pig's ear we started with. In particular, I commend the notion that we should have longer intervals between RAEs. I am pleased to learn that the countervailing notion that, to keep bureaucrats busy, there should be a "light touch" assessment at mid-interval, will be consigned to the bin where it belongs.

But many of the structural pathologies remain. It is still to be clarified how you take 70 individual units and group them into 20 over-arching entities, or how you move away from what I regard as largely mindless babble about strategies to recognise what actually goes on in the creative process. These are problems still to be resolved. The major proposal in the Royal Society document, which I would reiterate here, is that we move forward to the RAE assessment in 2008 along the lines that Gareth and Graeme sketch for us below. We must also begin now looking at other countries and learning from them about what is better and what is worse, to ask whether there is a better way of doing it, a way that does not foster larger and larger bureaucracies, either within universities or centrally. We could even be testing some of the ideas as we move to 2008.

Not the least of the structural pathologies of the RAE is that it has become a major behavioural modifier in universities. It is a one-dimensional totem that afflicts the value that we should be putting on teaching.

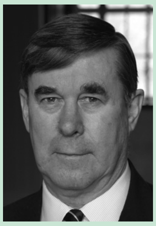
I end, as I promised, with a rhetorical flourish. In the Italian Dolomites you can find what they call *via ferrata*. You can climb a 200-metre cliff by ladders and attached to a cable. Anyone in the audience who can climb a ladder and does not suffer from vertigo could do it. I cannot imagine the skill of the person that climbed the clean rock in the first place, much less the effort that put in the ladders and cables. Even further beyond imagination is the original vision that recognised it could be done. But now the *via ferrata* are there, anyone can climb the cliff. I worry that the rigidities and burdens of successive RAEs are inimical to the "clean rock" culture, so that we run the risk of falling back to using the ladders and cables put up by others.

One of our rare treasures in Britain is that it is a place that encourages our eccentricity and individuality in ways we do not understand. We may not understand what was special about Shakespeare's London or Pericles' Athens, but we do know that the past 50 years and more in Britain have been rather special. The good things I announced at the beginning are immanent in people trained in a past culture.

I am told that since 1997 the Civil Service has grown by 20 per cent, adding £7 billion to the tax bill. A proportionate share of that has gone into helping tell people in universities how to run themselves. The universities understandably react by colluding and by doing similar things at their own centres. That is not wicked; everyone involved has the best of intentions but the result is a culture that is inimical to something that we do well. We ought to do something about it. ❐

Beware unintended consequences

Graeme Davies



Sir Graeme Davies FRSE FREng is vice chancellor of the University of London and chairs the newly created Higher Education Research Forum, which will inform ministers of problems and opportunities in university research. He was educated at the University of Auckland, New Zealand. He was chief executive of the Higher Education Funding Council for England (1991-95) and principal and vice chancellor of the University of Glasgow from 1995 to 2003.

I agree with much of what Lord May has said. Certainly I am at one with him in the belief that we have a healthy, admirable and flexible system and that we must be careful not to damage it. But the landscape of higher education is even broader than that laid out in the Royal Society document.

Take the university funding structure, which is extraordinarily complicated. It is an interconnected system; adjustments in one area can, through the hypothetical law of unexpected consequences, have effects in other unexpected directions. The money comes from a huge diversity of sources. The cost of running the British university system is roughly £14.5 billion a year, of which the two streams of the dual-support system are a small part. This does not mean that the dual funding streams are unimportant; they are important, but warrant scrutiny.

Teaching is a major part of the core business of universities and has already been under scrutiny. The recent Funding Council consultation will extend that. We are also aware of what is happening with tuition fees and of the debate on the Bill wending its way through Parliament. Many of you will know of recent changes that have led us to re-position the sector on overseas students and on the growth of income that that can bring. It is piquant that many overseas countries have responded to recent restrictions on US visas by looking to the other providers of English-language based higher education, notably the United Kingdom.

I turn now to research income. It is important to recognise that there are major players other than the public agencies. The sources of research money in 2001–02 are shown in Figure 1, opposite. It is important to note that research funds provided by industry are a comparatively small part of the total.

Since last November, Britain has had an explicit policy for the public support of research. The three goals are a dynamic, world-class research sector, the maintenance of the dual-support system and the determination that the UK research base should remain financially sound and sustainable. To my mind, these are important policy issues that we need to stick with. As part of the effort, there is to be a stakeholder group called the Research Forum, which I have agreed to look after.

I agree with Lord May that there are deficiencies in the current dual-support system. I suspect that most of us would answer "No" to the questions whether the current system is properly in balance and whether the current allocations of dual-support funds are appropriate. But most of us could probably identify the problems with the current arrangements if we turned our minds to the task.

The timing of the next RAE in 2008 gives us a breathing space. We have the opportunity to stand back and review the bigger picture deliberately. But there are many traps that we could fall into. For example, from the high correlation between the outcomes of the RAE in income terms and the outcomes of peer-reviewed project evaluations by the research councils, the conclusion could easily be drawn that two independent systems of evaluation are unnecessary. "Let's just switch from one to the other." But the strong correlation is not surprising; those who are good at research are going to get the best money from wherever it comes. I believe the tension between the two systems is healthy.

Some of you may have seen a new report on the dual-support system by Adams and Bekhradnia[1] which, among other things, estimates the cost of distributing funds by the two routes. In round numbers, it costs £1.6 in preparing the basis for distributing each £100 of RAE money compared with just over £4.5 per £100 for money from the research councils. Compliance costs are also 1.6 per cent and 4.5 per cent, for the RAE and research councils, respectively. Those figures might lead some people to the peculiar view that the research councils should be abandoned, but I would not conceivably advocate that; I believe in the healthy tension.

I conclude with a few observations on Lord May's points. There may be forms of the RAE that are pathologically rigid, but that is largely the fault of those making the judgments, not that of the RAE as such. The rules enable the rigidities to be overcome; it is particularly important that the RAE should not be a device for inhibiting collaboration. The healthiness

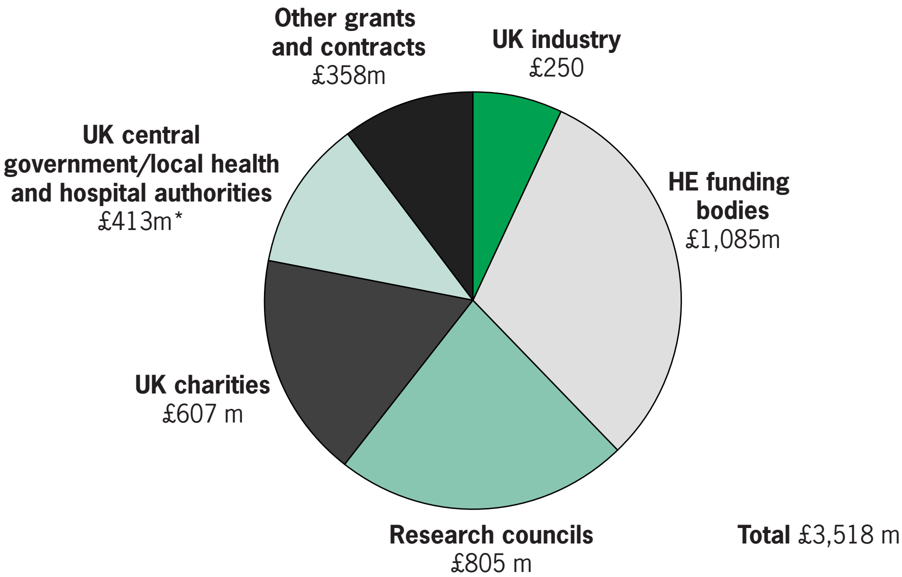


Figure 1. Sources of research income. Source: HESA 2001–02.
*Predominantly from EU Government and other overseas sources.

of intra- and extra-university collaboration is a rich part of British research.

There is also the issue of selectivity. In Scotland they have made a conscious decision that highly selective funding of institutions is wrong but that selectivity of disciplines is right. They are working on a concept called the Scottish Institutes of Advanced Studies. The first, just about in place, deals with physics and runs across three departments in Glasgow, Edinburgh and St Andrews, with second-order links to other institutions.

The scheme, admittedly favoured by geography, is interestingly clever in that the departments in this research string will be required to have a joint strategy on what they teach, where they do research, who they recruit and how they share their expertise. They will also be required to make a collaborative multi-institutional RAE submission.

On the RAE in general, I feel strongly that it has benefits other than merely guiding the distribution of funds. It has also brought about much better management of the research environment and of research as such. Again, I agree that management should not operate as a dead hand, but my now-long experience is that it is not possible to keep good researchers down. When they feel a dead hand upon them, the best researchers just bite it off.

1. www.hepi.ac.uk/articles/docs/dual_exec.doc

discussion

Wish lists galore. There was a certain air of unreality about the evening. It was easy to agree that the RAE was defective and demand a review. But, without a clear understanding of the limits of a review — what principles must be maintained; how stakeholders are to be brought in and conditioned to accept the conclusions; and whether, given the political climate, such a review would be welcomed and its conclusions implemented — discussion lacked focus. Wish lists and complaints predominated.

The Government would be unlikely to welcome a review unless it were confident that it would not: lead to a demand for large extra resources, bring into question the whole structure of university finance and be so conducted that it would command agreement from all parts of the sector. It seemed unlikely that these three conditions could be fulfilled. In that case, is there any point in having a review?

Archimedes

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

Redesigning the research department

Mark Walport

Dr Mark Walport FMedSci has been director of The Wellcome Trust since 2003. He was previously professor of medicine and head of the Division of Medicine at Imperial College. He won the Graham Bull Prize in Clinical Science (Royal College of Physicians) in 1996. He has served as registrar of the Academy of Medical Sciences and is a member of the Council for Science and Technology.

My starting point is the talk that Dr Chris Henshall gave here in July last year[1]. Over the past decade, total research grants and contracts at British universities have nearly doubled, but the QR (quality-related) component of university research funding related to RAE (research assessment exercise) performance has increased only by about a quarter. This is the sustainability gap. Dr Henshall's message was that the gap must be closed.

We all seem to agree that the RAE has produced a whole series of unintended consequences, many of which have been referred to already. Here are some more. The RAE has driven universities to increase the volume of their research at the expense of physical and human infrastructure. Because the interval between RAEs has been relatively short, there has also been pressure for short-term research results and a tendency to appoint lecturers rather than support key staff that underpin the infrastructure of research because universities are rewarded financially for the former rather than the latter. The work of teams has been devalued and, sadly, teaching has been devalued as well. The fact that these perverse consequences are unintended does not make them less serious.

On staffing, the changes induced by the RAE have been quite dramatic. In the Russell Group of universities, the numbers of full-time academic staff in the biomedical sciences increased by about 2,000, or roughly a third, between 1992 and 2001 (spanning two inter-RAE periods), technicians and postgraduate research assistants increased in number only modestly, while the numbers of postdoctoral scientists increased by an alarming 150 per cent; what careers will these post-docs have?

The universities have been accused of playing games in response to the RAE, but this is not a fair criticism; it is no game for a university to try to maximise its funding. One of the rules of the RAE is that departments or other "units of assessment" may choose to select which members of their staff have their research records assessed. It is interesting to compare biomedicine, engineering and the humanities in this respect. Figure 2 (opposite) shows that the humanities and engineering have become modestly more stringent in their submissions, but that biomedicine behaved differently and omitted a fifth of staff members in the 2001 submission.

One of the unintended consequences of not declaring all staff for the RAE is the creation of a group of disgruntled investigators and teachers who feel that they are not valued by their own institutions. Did the universities profit from these "games", as they have been called? Perhaps a little. Between 1996 and 2001, the lowest grade (labelled "1") was virtually eliminated in all disciplines and, while biomedicine perhaps did slightly better as judged by 5 and 5* grades, the differences are probably not statistically significant.

There is a problem. University behaviour has been driven by the RAE and in a perverse direction. It is true that a lot of effort is going on trying to fix this. I applaud some of the changes that are proposed for the forthcoming RAE. For example, it always seemed to me that there would be a problem in not having continuous grading scales; sure enough, there was. Another problem has been the inability to assess groups of scientists; the importance of team working has been devalued.

I appreciate that there is now intense discussion of the review of the dual-support system. It must be right that the full economic costs of research are recovered and that there should be greater transparency. It is also good news that there is to be a review of the funding councils' funding model and, from the Treasury, that there will be a 10-year plan for science in the Spending Review to be announced later this year.

But in reality, I think that we have got this all wrong and the tail has been wagging the dog for far too long. It is now time for the dog to wag the tail. We ought to step back and carry out a strategic review of universities, asking what departments in different fields of activity would be like if they were fit for first-class research and teaching. What kind of staff complement would there be? What would be the balance of technical staff? What infrastructure is needed? We should design a department and then devise a funding model that might promote it, rather than the other way round.

It would surprise you if I said nothing about what charities can contribute. They have been doing a very great deal for a very long time. The Wellcome Trust funds excellent research, all rigorously peer-reviewed, and the best scientists. We have a varied portfolio and have spent nearly £2 billion in the last five years on research, people, buildings and resources. Importantly, we have been successful because we have been funding in partnership with government.

We have been funding some very basic resources for the biomedical community.

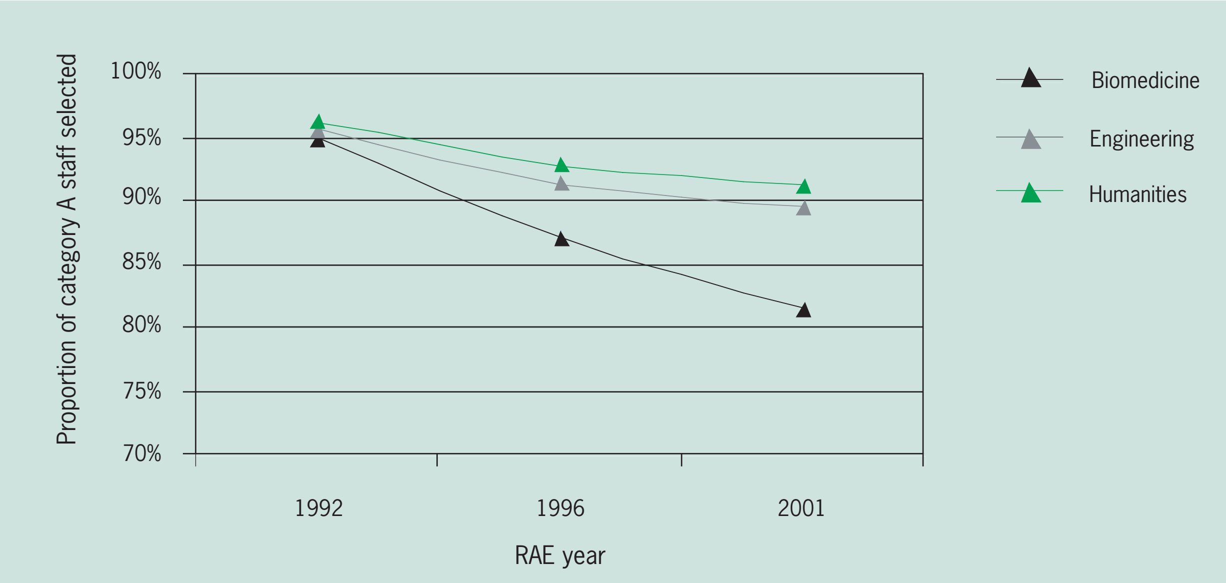


Figure 2. Staff selection patterns. Figures are for Russell Group staff. Biomedicine equates to: UoA 1-8, 13, 14, 17 (and 12 for 1992 and 1996), Engineering equates to UoA 18 to 32 expect 21 and Humanities equates to UoA 35, 36, 50-55, 57, 59, 62, 63.
Source: www.hero.ac.uk/rae/index.htm

One of the most important is biological databases, including the gene sequences of humans and many other species important to biomedical research. Another resource is the UK Biobank (in partnership with the Medical Research Council, Department of Health and the Scottish Executive) which is a study of genes, environment and health in half a million people.

The success of charitable funding is attributable to partnership both with government and universities. How could this change and even be improved? The concept of partnership funding has been gaining ground. The idea is that there would be a formulaic award to universities *pro rata* with their charitable income. The money would go directly to vice chancellors, as does QR.

In practice, an explicit volume of QR funds would be diverted to a partnership fund. In present circumstances, this will mean over £200 million from the QR allocation (and that means that the total QR needs to be increased). Such a system would directly reward success; universities that win charitable funds get more, those doing less research get less.

The peer review of such a system is more rigorous than the blunt instrument of the RAE. The *quid pro quo* for such an arrangement would be an agreement on the national capacity for charitable funding and on eligibility; if some charity proposed spending £200 million a year on research in transcendental meditation, it seems doubtful if that would be a sensible or proper use of the partnership fund. The new Funders' Forum could be a means of deciding questions such as that.

I conclude with a quotation from John D Rockefeller, a pioneer in the art of philanthropy, who wrote an article called *The difficult art of giving*[2]:

"We frequently make our gifts conditional on the giving of others, not because we wish to force people to do their duty but because we wish, in this way, to root the institution in the affections of as many people as possible, who, as contributors, become personally concerned and thereafter may be counted on to give to the institution their watchful interest and cooperation."

That is the key issue in partnership funding. The charities fund effectively in the universities but we fund with government and it is very important that we share our "watchful interest and cooperation", and that means money.

In summary, I think that we have to step back. We have to have universities that are fit for their purpose and that means devising a funding model that promotes excellence in teaching and research. We have to work in partnership to achieve that. ❐

1. Henshall, C. *FST Journal* Vol. 18, 1 pp 6-7 (2003).
2. John D Rockefeller, *Random Reminiscences of Men and Events*, Tarrytown, N.Y. : Sleepy Hollow Press and Rockefeller Archive Center, c1984.

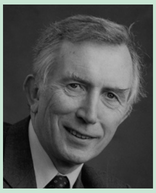
discussion

Lack of diversity. Participants in the discussion were concerned that, by concentrating on the problems of research, the overall function and purpose of universities was being overlooked. What were universities for? What was the right balance between research and teaching? We had developed a one-size-fits-all system, which might well not be appropriate for divergent demands in higher education. It had led to the requirement that any institution, no matter what its strengths, should seek to become a university with a demanding research role. When it failed to reach the highest research standards it was promptly labelled as dull, or failing. Inevitably, teaching was devalued and it was doubtful if the growing use of teaching fellows would make much difference.

Why had not the junior college system, widespread in the US, and which produced large numbers of graduate students, emerged here? A specific question — was teaching as good as Lord May claimed for research — received a mixed response. Some thought that, because of major investment in structures and the recognition of the importance of research-led teaching, it was; others disagreed, citing the heavy teaching loads, the lack of equipment and the desire of good researchers to escape teaching.

Model of research for industry

Nick Cumpsty



Professor Nick Cumpsty FREng has been chief technologist at Rolls-Royce since 2000. Previously, he was for 28 years a member of the teaching staff of the Engineering Department at the University of Cambridge and in 1989 was appointed professor of Engineering and director of the Whittle Laboratory in the university, which specialises in aerodynamic research relevant to jet engines.

I shall be very brief, and therefore shall talk mostly about Rolls-Royce and university research.

Why do we support research in universities? Not as philanthropy, but because universities are a vital means of acquiring technology. One beneficial consequence to the researcher is that the company really cares about the results. We would not be where we are now, with a strong position in our markets, without the support of universities, on which we rely heavily. It would be very difficult now to go back to doing the research in-house. Because it matters so much to us, we have to make sure — and we do make sure — that the universities are working effectively. We have a real interest in their success.

The activities we support are diverse, but I shall concentrate on what we call the University Technology Centres (UTCs), of which we have 20 in the United Kingdom. Each is in a different field of importance to the company. Success is assessed on useful technology delivered, not on publications. Secondary benefits to the company include the recruitment of good people whom we have had the opportunity to assess.

Research using our funds is primarily directed at the medium term. We do not look for short-term fixes, and for true long-term research, perhaps ten years in advance of application, we look mainly to research supported by the research councils. We encourage the university centres to get funding from elsewhere to supplement what we provide. Some of the factors that allow a university technology centre to succeed are the following:

- Usually we have as director of the centre a professor in the university with a substantial reputation and experience. It is also important that the company's relationship with the UTC is the responsibility of the business unit that wants the results, not administrators in research and technology departments;
- We make long-term agreements to provide support for UTCs. We require a critical mass of staff and students, which requires some concentration of our activities into a limited number of university centres;
- The establishment of mutual trust is probably the biggest single factor in the success of the UTCs; we give them access to sensitive company information, and this allows them to work on problems of real interest. My own experience as director of one of the centres is that there is real satisfaction in working on topics that are important and useful.

One of the other things about this trust is that, so far, we have avoided unnecessary wrangling about intellectual property rights.

There are frequent visits by engineers in both directions; an experienced Rolls-Royce engineer acts as coordinator to help make the relationship work. The involvement of the people is more important than the money.

Rolls-Royce has made a long-term commitment to the UTCs. We encourage the highest quality work and we encourage publication (though publications are not how we assess the usefulness of the centre). We occasionally fund posts to fill gaps in the teaching staff.

After 15 years, we are beginning to modify the original model; in particular, we are encouraging partnership between UTCs or with university departments elsewhere.

Our system of university involvement is commended as best practice in the Lambert Report and in the DTI document on innovation, but what gives us most satisfaction is that it has been emulated by our main US competitor. We must be doing something right.

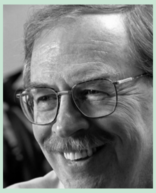
I turn to the thorny question of intellectual property. In my opinion, the arguments and concerns about intellectual property are undermining the responsiveness of UK universities to industrial proposals. A company will carry out research in a university only if the proposed royalties make it cost effective for the company to exploit its outcome. Otherwise, there is no point in doing the research in a university. In these discussions, universities tend to forget that, without relationships with industry, they have no route to market for their discoveries. And if companies have to pay fully-absorbed overhead rates, they will expect a very different level of service and, moreover, support for research students and long-term research is likely to be reduced.

Finally let me say that government support for research is clearly vital. Rolls-Royce has benefited greatly from it, and public support for underpinning fundamental research where we have our UTCs is critical to their success. The importance of government support probably could apply to all companies making extensive use of universities for their research. ❐

On 25 November 2003, in the wake of the Energy white paper, an FST discusssion meeting, Energy policy: the renewables target, was held at the Royal Society. With speakers from science, engineering and government, it was a lively event. The discussion was noted by Sir Geoffrey Chipperfield KCB.

Pressures for energy

Bernie Bulkin



Dr Bernie Bulkin was chief scientist at BP and is on the Board of Governors of Argonne National Laboratory, the Energy Board of SAIC and the board of the UK Centre for Environment and Economic Development. He is deputy chairman of the Low Carbon Vehicle Partnership and is the author of more than 100 papers and two books.

I want first to categorise renewables. The ones I want to look at are wind, wave and tidal and solar — photovoltaics. There is also thermal and biomass, in particular woody biomass. I am not going to say much about geothermal and hydro. Geothermal is a good idea if you are looking at energy in Yellowstone National Park where you have a volcano close to the surface or where there are hot rocks, as in Iceland. Hydro is a mature technology which, worldwide, expanded significantly during the 1990s.

Some of these renewable energies are niche applications. There are those who argue that all renewables are niche applications but I do not agree; some of them are much more widely available. Wind is widely available, solar is universally available and so these have much broader application. Biomass is not so much a niche question as a local question; you cannot transport biomass large distances so the slogan "all biomass is local" is a good one. I want to sort out this pot of renewables and discover which offer the best opportunities.

But before I do that, I want to look at the pressures on energy today and ask whether these pressures lead us down the track to renewables? The pressures on energy in the world today are fourfold:

- Politics, by which I mean issues of energy security, energy diversification, the gap between rich and poor countries and the idea of access to energy as a human right.
- Environment. No matter where you are — and this includes the US — environmental pressures are driving the future of energy. These include both local and global air quality, as well as issues of waste associated with many fuels.
- Culture. Our culture is slow to change, although we have gone through massive cultural changes in relatively short times. For example, attitudes towards smoking, a big shift in a short time; recycling, even 10 years ago, recycling was for people who associated themselves with environmental movements but now, every house has a bin outside for recycling collection. We can take on big changes and, in many places, we are moving to a cultural change that despises waste. If we make that sort of change, this will also change our use of energy. In the UK today, one large power plant, approximately 1 gigawatt of power, is required just to power appliances on standby. Could it become unacceptable for guests to walk into your house and to see all those little red lights glowing? This kind of cultural change is important and could influence energy use.
- Technology. There are many new energy technologies trying to come to market today. But, when you combine the other pressures with a new product, one sees that novel technology can give a country a change of position in terms of energy security or energy diversification. Instead of having all your road transport fuelled by oil, natural gas, hydrogen (from diverse sources), or other fuels could take on significant roles. When this kind of technological change comes about, then one has the potential to relieve the other pressures.

Do these pressures favour renewables? I think the answer is always "yes, but". The most important questions are those of cost and of scale. In the United Kingdom we are trying to make changes with government incentives and, sometimes, interventions, with policies and with targets. But, in our market-driven energy economy, we are in the tricky business of trying to do two things at once, keep the market economy and drive change through policy. This makes both cost and scale important.

Cost is often confusing: some renewable technologies compete at the retail level on cost and some have to compete at the wholesale level and these are two different levels of costs. For this reason, stacking them all up on one graph and showing different costs is a mistake. If one has a very decentralised technology, that energy does not need to be as cheap at wholesale to be able to compete at a retail level.

And then there is the question of scale. Many countries have more access to renewables than they have to oil, gas or even coal, but can they get enough to make a difference? Think about this in the following way: power from nuclear power plants comes in gigawatt chunks, while from wind turbines it comes in megawatt chunks —1 or 2 megawatt chunks per wind turbine. From solar it comes in kilowatt chunks. These factors of 1,000 give you an idea of the scale a renewables project needs if it is to make a difference. What is required is sufficient scale to make a difference in terms of energy diversification or energy security as well as in terms of environmental impact.

It is worth mentioning the gap between rich and poor nations. Solar energy has proved itself in the developing world to be quite a powerful, accessible technology. In Africa, people are now using solar-powered refrigerators. The implications for this are huge: you can refrigerate vaccines, making a big difference to health in places without electricity. Remember that a third of the world's population does not have access to electricity today. BP has completed the electrification of 250 villages in the Philippines and 1,800 schools in Brazil using photovoltaics. Political and social issues — education, the ability of villages to start new businesses — are very much impacted by some of the renewable technologies. Large-scale solar could, of course, make a huge difference in terms of environment, but its impact is wider than that.

Cultural attitudes may be the strongest driving force because they can be marshalled regionally. There are some good activities happening in the United Kingdom: in East Anglia, with the Community Carbon Reduction Project (CRed), people feel that they are making a difference and they can see what the difference is. We should be looking at how we can do things on a regional basis. By that I mean looking at an area that people can identify with and asking "how do we make cultural change in our own region?"

Lastly, I want to talk about technology. Today, not one of the renewables, with the possible exception of wind at big scale, is really cost competitive. We have to decide which ones are most likely to have a breakthrough in the technology that will bring them down the cost curve. Alternatively, will just mass manufacturing bring them down the cost curve enough? For example, wind power has benefited a lot from mass manufacturing.

The action in science today is in biotechnology, information technology and materials science, including nanotechnology. Looking at renewables in that context, biomass has a bright future. Biotechnology today is making improvements on how we use waste biomass, rather than valuable food, for energy. That has the potential to make improvements of many orders of magnitude — factors of 10,000. There are currently some large companies working on this in addition to all the activity in the small to medium enterprise sector.

Solar power is about materials science. BP is flooded with ideas, good ideas, on new solar technologies and next generation solar technologies and we are supporting some of these. There are also huge breakthroughs coming out of nanotechnology, such as quantum dots. And there are other organic technologies developing with big potential for breakthroughs; these need to be supported and encouraged.

With some of the other renewables, take wind for example, the technology is almost optimised in terms of materials. Some benefit may be gained from information technology and computer control to gain higher utilisation of wind turbines. I do not see how wave or tidal power will benefit from advances in any of the science areas; this is a low-tech power source requiring a lot of concrete and propellers under the water. You could improve some of the engineering (I won't talk about the environmental issues around tidal barrages and so on) but there is no mass manufacturing benefit and I don't see that there is going to be any benefit coming from new science.

Where does that leave us? Renewables have a very big chance and they are fast growing businesses. Many people would love to invest in our solar business that grows at 25 per cent a year, year on year. There is a lot of promise in this business, as costs have to come down and mass manufacturing can still bring more benefit.

The potentials for breakthroughs are science based. Any country that wants to have a good position in renewables, both for using them and for making this industry important, needs to back the science behind it, because that is where the real energy is going to come from. ❐

The practical reality

Malcolm Kennedy

Dr Malcolm Kennedy CBE FREng FRSE is chairman of the Royal Academy of Engineering Working Group on Energy. His early career was spent in the consulting firm Merz and McLellan specialising in electricity supply system design, construction and performance. In 1999 Dr Kennedy became chairman of PB Power. He has served on many government advisory bodies.

Over the last two or three years, in terms of renewables, we have dreamt up a target. As an engineer I am going to be as pragmatic as possible and give you an idea of the scale of effort that is going to be required to meet the 10 per cent renewables target by 2010 that the Government has set out in its Energy white paper.

I could see the confidence in the DTI when I spoke to a colleague recently and I asked "in which part of 2010 do you expect to meet the target?" and he replied "31 December, of course". I thought that that gave the game away. I hope that nobody will think that I am a pessimist or that it cannot be done, because I believe that anything can be done, provided there is the will to do it, that there are not too many distractions and that there is enough money.

The Energy white paper objectives are, in alphabetical order: affordability, competitive market, the environment and security. I leave you to judge which of those four objectives, clearly set out in the white paper, is the most important and whether any combination of two or more can be achieved at the same time.

How are we to meet the Government's targets? The only technology available today that is going to make a significant contribution to that 10 per cent figure is wind and we must sub-divide that wind generation into onshore and offshore. Sadly, I believe that, in the case of the onshore wind generation, we have already picked the low-hanging fruits and much of the additional capacity will have to be built offshore.

Using machines of an average size of about two megawatts, irrespective of technology, we are going to need to build between now and 2010 some 5,000 machines. These machines will have to be designed, we have to devise projects to build them, we will have to bid for them, to manage and maintain them. That is what we have got to do to meet the target.

In addition to that is the Government's combined heat and power (CHP) objective, for which we have to generate 5,000 megawatts of CHP from somewhere in an industry that is moribund right now. We have also to commission between 1 and 3 million domestic CHP units; that is another four machines every day. This is a complete change of paradigm in the way that we heat our homes and provide electricity for them.

This needs imaginative engineering solutions. Are there barriers to innovation? I believe that there are still some barriers to innovation and I will touch on these.

The cost of creating the 8,000 megawatts of renewables or 10,000 machines is £15 billion and that doesn't include the £3 or £4 billion required to re-wire Britain. The re-wiring of Britain is a kind of poor relation; it has not got the romance of some of the new technologies yet it will have to be implemented some time in the future.

The Government has listed the renewable technologies that are available in the UK and whether or not they are able to attract the renewable obligation certificates (ROCs) that underpin the whole financial performance and the costs and the revenue of those particular technologies. Landfill gas and sewage are genuinely niche markets; in this country, there is not a great deal of opportunity to develop any new hydro; onshore and offshore wind are going to be the most important, possibly 80 to 90 per cent of the total. As for coal-firing of biomass — putting wood into the boilers of big power stations in order to win the ROCs makes money for the owners — as an engineer, I shudder to think what this does to boilers designed for pulverised fuel.

Which brings us back to wind. Onshore wind is approaching the limits in England and most of Wales. Most of the remaining onshore wind will come from Northern Scotland but the difficulty of getting it to where the demand is should not be underestimated.

We talk about technology as if you can switch it on and develop something overnight. It takes time to get from a bright idea to something that can be sold, something that can be maintained, where competitive bidding can be procured and all the necessary market conditions applied. It took the ballpoint pen 58 years and continuous steel casting 25 years. The pressures to bring these technologies on-stream will perhaps be greater now but, for those who have not yet woken from their dream, I should just draw attention to the fact that Rome wasn't built in a day.

Some other difficulties have to be overcome before we can move ahead. Planning, of course, in this tiny island harbouring 60 million people is always going to be a problem; the Ministry of Defence, for example, seems to be more concerned about stopping offshore wind than ever before. Then there is the shortage of technologists. In 2000, only 70 power engineers graduated from all our universities; that doesn't even scratch the surface of the number needed to replace retirements. If we also need technical people to design the thousands of machines, put them in place and make them work, we are going to have to do something rapidly. Are the manufacture and building rates required to meet the target feasible?

Are the companies that are currently making wind turbines solvent? I read, with some alarm, that the third biggest turbine company in the world had financial difficulties already and many of the start-up companies that nestle round the big ones will have the growing pains that we all know about with small start-up companies.

There are also some serious grid-system limitations. The UK Grid was never built with this kind of generation pattern in mind; it was built to interconnect big generating stations and, of course, the high-voltage system is not configured at the present time to reach those places where most of the renewable generation will be sited. Furthermore, the distribution system that operates at 132,000 volts

discussion

Compatibility. A theme in the discussion was the compatibility of the various objectives in the white paper and the context in which the Government was placing them. Was, for example, the commitment to competitive markets compatible with the renewables target? Germany and Spain had been cited as examples of how quickly renewable capacity could be built, but their industries did not operate in a competitive market, but one dominated by monopolies. The competitive market mantra had so far resulted in UK generating and distribution capacity falling into the hands of continental and US companies; they would be unlikely to show enthusiasm for developing competition. Reducing fuel poverty was a social aim and should not be part of an energy policy. Serious consideration needed to be given also to reassuring investors about future pricing and policies which would affect prices, such as extension or withdrawal of ROCs and exemptions from the climate change levy. The Government must have made an assessment of the amount and the return on capital necessary to meet the renewable targets and it should be considering its market objectives in the light of these.

discussion

Incentive to invest. Wind power had found investment and was showing a return, but the greater risks of going offshore had yet to be subject to market reaction. It had also the benefit of ROCs, but again the question arose about long-term security. But only historic cost was available for the additional wind power. It seemed that onshore wind power was now competitive with oil and gas generation. The Government and Ofgem were searching for innovative economic and financial structures which would create incentives to invest in distributed generation, but they had yet to be seen to be viable. Had the investment community taken on board the fact that the cost of carbon will continue to rise and affect fuel competition? Had the effect of cultural change, suggested by Dr Bulkin as a powerful agent, been realised? There were reasons why the City might become more interested in investment in distribution and renewable generation, but the timescale, if the targets were to be met, was short. To enable investment to take place, which would produce the same scale of CHP in the UK as in Denmark, you would need prescriptive legislation which would require hot-water mains to be laid in every town.

and below has never significantly changed in technology or use for the past 80 years. If we are going to move quickly to meet our targets, we have only got one distribution price review before 2010; something has got to give there.

Until the North Hoyle scheme came on-line, our offshore track record was just two generators offshore, near Blyth. The bet that we are placing is that, over the next seven years, this technology is going to deliver the vast proportion of our renewables target. Yet there are many offshore unknowns: how much maintenance will be needed, whether special boats and helicopter pads will be required, what problems there will be with corrosion and the cable systems that are going to connect them.

Electricity is the City's bête noire. Since the Enron fiasco, the City has turned its back on investment in electricity almost totally and if it is investment in new technology out at sea the City remains unconvinced. With all renewables the City is asking the question "how do you make uneconomic solutions pay?"

In the distribution system as it works today, power comes from the top down, filtering down into our homes and our factories. We are going to change this to a situation where some of the power — most, in our lifetime — will come from the transmission network but the rest will come from within the system itself. The system will be interactive which is a complete change of approach as compared with today. An active network needs to account for customers generating as well as consuming electricity, not quite as easy as it sounds.

I have spent most of my career building bigger, more efficient generating stations at falling real cost per megawatt and connecting them to higher voltages. In this decade we are going back to 1-2 - megawatt generators with a connection voltage of perhaps 11kV. This is a complete U turn in technological terms.

There are many barriers to distributed generation that have to be overcome. Although distributed generation can bring benefits, investors remain wary. We are still using security standards on our system that were invented in the 1960s and will no longer be appropriate. Worst of all, there is no incentive for the distribution network operators of today to connect any generators to their system; unless we get that put right in the price review in 2005, it will remain that way.

There are technical barriers, such as fault levels and power flows and voltage and so on. There are difficulties with the negotiations as there is no common basis on which to negotiate with a distribution company. The City has doubts. Innovation has not yet been mobilised. We have a human resource limitation; we are going to need thousands more people to help fulfil these objectives.

Remember, to meet the Government's target for renewables by 2010 (31 December), we must commission a renewable generator every eight hours — I have not yet heard of any today. I am an optimist, I believe that it can be achieved but there is a lot to be done. ❐

Planning: 2010 and beyond

Claire Durkin

Claire Durkin is head of Energy Innovation and Businesses at the DTI. Ms Durkin has spent her career in the civil service in the Department for Education and Skills and the Department Trade and Industry in competition and consumer policy, labour market policies and the skills agenda. In her current post she is responsible for primary energy sources, their safety and security.

I am in agreement with much that the previous two speakers have said. However, I am going to present a different emphasis.

Science is partly the key, and we are not talking niche markets. We can achieve the very challenging Government targets, although I cannot say for sure at this stage whether we shall succeed or not. To make progress, we have to: (1) be serious; (2) listen carefully to those who have worries about our progress; and (3) always put the work on renewables in the broader context of Government energy strategy.

Huge changes face us in the next 10 years on security of supply. We remain committed to meeting these challenges through the workings of effective markets, which means our policy is not irrespective of cost. The only intelligent approach to building a new energy sector is to do so within the context of changing sources and effective markets.

Our record in developing a renewables sector in the United Kingdom is nothing short of abysmal. Many other countries are doing so much better. Only 1.7 per cent of our electricity comes from renewable sources; 3 per cent altogether, if you include large-scale hydro. This is a hopelessly low position in comparison with Germany or Spain.

Up to 7 or 8 per cent of our renewable electricity up to 2010 is likely to be provided by wind, while 1 to 3 per cent will be from biomass or hydro. To achieve this by 2010 we have to get 1 gigawatt per year on line. This is daunting but not impossible. For example, Germany has brought 2 gigawatts per year on line over the past four years from onshore wind.

We need to assess the challenges seriously. We estimate that we can achieve 3 megawatts per turbine; even so, this is a lot of machines. It took some time to develop North Hoyle, our first major offshore development. On the other hand, in the most recent development in Denmark, they achieved a building rate of a turbine a day. Our challenge is greater. We have to build 400 wind turbines each year; more than a turbine a day.

There are three issues that government must address to tackle the challenge: finance, planning and the Grid. Finance is clearly important; there are lots of complexities if following a market solution and we have to work hard to ensure that we have confidence in the market. The Renewables Obligation is our most significant financial tool and to date it has proved very successful in creating a climate where investors are serious. We have also introduced exemptions

discussion

Other technologies. One speaker felt that the possibility of tidal stream (not tidal barrage) technology had been underestimated. It was proven and had little environmental impact; it could make a substantial contribution earlier than expected. Enabling technologies, such as DC transmission, superconductivity (which could also have a significant impact on carbon reduction by allowing electricity to be transported from gas fields, with the carbon from the gas being sequestrated in the reservoir) and storage technology (compressed air) would help, but the scale, cost and timing of their contribution was uncertain. More funds for well directed R&D were important, given the paucity of funding in the past, compared with the funding in Germany and the US.

to the climate change levy. And we have substantial direct government support for research and development, demonstration and capital grants. However, when you consider the costs of new build in energy, the Government's direct support of a £350 million budget becomes a very modest amount. Ultimately it is for the private investors to develop this market.

On planning, we are making progress. The Energy Group is working very closely with other government departments on both policy and attitude. We are developing communication strategies to win minds and hearts, and we are helping support technologies that can make planning more acceptable for such problems as radar and aviation.

The reform of the Grid is a major challenge. I have, as part of my domain, the Engineering Inspectorate which has statutory responsibility for monitoring the robustness of the Grid: they inspect the lines and the wires and they regularly tell me how much more difficult their job is going to be when we re-wire the country and move to a more complex structure of transmission and distribution. So I am well aware of the challenges. On the other hand this is also an opportunity. We would need at some stage to update the current system and the introduction of the renewable sector creates a fine opportunity to ensure that we have a modern, intelligent and a robust grid system. This is a huge amount of work for which, fortunately, we have a lot of dedicated expertise.

For renewables to be delivered effectively we have to get the infrastructure right, the financial controls and the confidence of the City, and we have to get the message out consistently and steadily that the Government is determined that a significant renewables sector should be developed. Government has to ensure all the structures are in place to enable a critical mass to build up; people have to be confident that it will work in the United Kingdom and that it is worth getting involved. But we have always to bear in mind that it is the private sector that is going to deliver the renewables sector.

If I were to spend all my time on renewables, concentrating only on what needs to be achieved to meet the 2010 target, we would have no prospect of meeting our aspirations for 2020 and people and institutions will not invest just for the relatively limited 2010 target.

For the United Kingdom to have 20 per cent of its electricity from renewable sources by 2020 we need a wide range of renewable technologies. And it is at this point I come to a personal disappointment in what I heard in the previous two presentations: both considered that there was very little prospect of renewable energy from wave and tidal sources. I cannot accept this. The opportunities are so great for the United Kingdom: we have more tidal flow that anywhere else in Europe and tide is predictable. I hope that there is a future for wave and tidal energy, even if the scientists and engineers have not yet cracked it.

In government we have not made the progress we would have liked in joining up policies to promote biomass. There are obvious limitations to the use of biomass: ours is a small country and we have to be clear about how extensive this technology can be in practice. We need more policy development and more work in engaging the many different communities involved to focus our activity.

You have heard about photovoltaics and, in terms of cost, about retail versus wholesale debate. Photovoltaics may seem expensive but they offer significant benefits in better building policies.

Longer term we need to look at very new technologies. The US is investing heavily in fuel cells and hydrogen. We will work with them, as we are working with global partners on cleaner coal technologies. Wind is not the sole aspiration for renewable and cleaner energy technologies.

On research and development we are working with the research councils on the establishment of a UK Energy Research Centre to bring a degree of coherence to research — something that may have been lacking in the recent past. I want us to work much more closely with the research councils and other organisations such as the Carbon Trust to develop a strong, coherent approach.

Skills is a challenge. We ought to be waking people up to energy and environmental issues in a way that they are not at the moment. Rather than say to your bright 17-year old "come in and do science, come and be an engineer" (there has been a poor response to such exhortations in the past), we should help people to combine subjects and courses in a more imaginative way. We have significant skills shortages across the board in engineering. As an extreme example of work needed in seemingly declining industries, the de-commissioning of Dounreay site is set to continue for up to 50 years. And the industries just emerging offer challenges to excite and attract young people.

Our vision is not about hitting a target on 31 December 2010; it is about a significant renewables development in the first decade of this century that will lead to other renewable technologies alongside wind in the second decade. This is a dramatic change and a significant challenge. We need a coherent approach, with government taking action where that is helpful and the private sector leading in the commercial development. I am confident that, for our security of supply, there is room for all of our energy industries. ❐

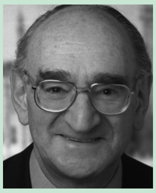
discussion

The big picture must include nuclear. Without it, there was a looming energy gap in Europe and security of supply could not be guaranteed. But had nuclear a future? There is a danger that politicians use the promise of renewables to avoid having to tackle the question of nuclear, leading to long-term additional costs and problems of base supply. There were inevitable arguments about its costs and, in particular, whether the development and decommissioning costs were fully included. But the main obstacle to further nuclear development in the UK was the shortage of nuclear engineers.

On 11 November 2003 the Foundation held a workshop on the future of manufacturing in the UK. The discussion meeting that followed at the Royal Society is summarised here.

Fostering innovation

Simon Haskel



The Lord Haskel of Higher Broughton was a member of the House of Lords Select Committee on Science and Technology. During his career in textile manufacturing, he rose from technician to become chief executive of the Perrotts Group, and was its chairman from 1973–97. He was created a life peer in 1993 and was a Labour front bench spokesman on trade and industry in opposition and government.

Does manufacturing have a future in Britain? I believe it does. Manufacturing continues to play an important part in modern, developed economies. In the United Kingdom, between three and four million people are employed in manufacturing industries and a further 2.5 million work in services directly related to manufacturing. The sector provides 60 per cent of all UK exports.

In addition to creating jobs and balancing trade, manufacturing is important as a driver of technological progress. As production and industries migrate from developed economies to less developed countries, new production processes and industries of greater technological sophistication arrive to take their place.

The decline in British manufacturing has been mirrored in all developed countries and can be seen across sectors; indeed, the British textile industry declined for all of the 30 years that I worked in it. In the United Kingdom, our initial response was to protect manufacturing by controlling imports. This had the effect of delaying our move into products and services needing greater management and technological sophistication. To our continuing cost, it also delayed the need for and introduction of higher skills.

Some firms realised that they needed to compete on quality, style, design and service, and many prospered. Others moved into sectors requiring new and sophisticated technology. Others chose to lower costs by outsourcing production to cheaper areas of the world such as Africa and Asia. However, it requires a very sophisticated and determined management team to outsource and still maintain the value of their products against global competition.

A variation on this is intelligently to combine manufacturing and service, as in the aircraft industry, where jet engines are sold at a low price so that the manufacturers can retain the service, maintenance and replacement contracts that require many sophisticated skills. The separation of manufacturing and service is now an artificial one and most successful manufacturing companies combine the two.

Outsourcing has become a fashion — but fashion is a poor business guide. During the 1990s the production of clothing and textiles in Britain declined by 40 per cent; similar declines were seen in France and Germany. In Italy, however, this trend was reversed: production increased and Italy is now the second largest exporter of textiles and clothing after China. The sector represents 12 per cent of Italy's manufacturing output. How did they do it? A commission set up to find out reported that the Italians "appeared more innovative in all aspects of the business — yarns, fabrics and machines. British and Italian factories are equipped with broadly similar machines…such differences as were observed were either a matter of preference or they flowed from the differences in manufacturing philosophy. Italian suit producers, for instance, add value not so much by machines but through imaginative ideas and a deep understanding of materials and how garments are best constructed, and the skills of employees". By contrast, British manufacturers had opted for simpler production methods that were intended to cut costs, but resulted in production being moved offshore much more easily.

At the heart of the thriving Italian textile industry lie the country's secondary schools, which in one district alone produce more school leavers with A-level equivalent qualifications relevant to the industry each year than the total number of NVQs and Level 3s awarded in textiles and clothing in the whole of the United Kingdom.

Manufacturing is not easy and many firms see themselves as being at the mercy of impersonal forces such as inflexible wages, exchange rates, industrialisation of developing economies, new technology, poor access to capital and overbearing regulation. Yet successful firms somehow overcome these obstacles by investing in quality, productivity, skills and innovation. They use the proven techniques of continuous improvement, eliminating waste, identifying unused capacity and talent and rewarding ingenuity, creativity, resourcefulness and initiative. These items appear on no balance sheet but without them there would be no innovation, no new products and no new services. Although many consider this approach to be "soft" management and less effective than the "hard" management of mergers and acquisitions, downsizing and re-engineering, there is substantial evidence to show that it leads to increased productivity, profits and stock market value. It is a mystery why more firms do not follow this successful formula.

The British technical textiles industry incorporates many of the elements I have been discussing. It combines textile technology with other technologies and sciences to produce innovative products for specific markets. Examples include clothing that keeps you warm and dry yet breathes, fabrics that incorporate medical or hygienic properties, fibres and fabrics that can be moulded into engineering components, geo-textiles that are used in construction, fabrics that are used once and discarded and those that are made to last for many years. One product that I think has a great future is the netting that screens out mobile telephone calls. These added-value markets are vigorous and growing.

It was said recently that if we don't imagine the future and prepare for it, we become yesterday's people. I can imagine numerous uses in the future for textile technical products, a sector in which both small and large companies have the opportunity to flourish. One way or another, there will be a future for manufacturing in this country. ❒

The role of Government

Simon Edmonds

Simon Edmonds is director of the Materials and Engineering Sector Unit at the Department of Trade and Industry and a non-executive director of DKL Marketing. His background is in marketing and strategic management and he has been involved in a leadership role in the development of small and medium enterprises. He has also worked in a directorial capacity in a range of industries.

Jacqui Smith, Minister of State for Industry and Regions is unable to be here this evening, so I have taken on the mantle of elucidating the Government's role. Some commentators have suggested that the Government's role in manufacturing will be limited to managing its decline. We think this is only part of the picture and that there are very real opportunities for modern manufacturing in the global marketplace.

It is true that a key long-term trend in advanced economies is de-industrialisation — a decline in the share of manufacturing in the economy and a rise in the share of services. This can be seen in the USA, where the proportion of employees in manufacturing has fallen from 34.5 per cent to 14 per cent over the past 50 years. However, manufacturing continues to be a strong performer in the United Kingdom, representing one-sixth of our economy and bringing in around two-thirds of the £270 billion we earned from international trade in 2002. It is also responsible for 80 per cent of the R&D carried out by businesses.

Computers, robotics and advanced modelling and design processes are all being harnessed to achieve greater productivity and efficiency. Falling transport costs, reductions in tariffs and the development of high-speed communications have resulted in manufacturing increasingly being organised on a global basis. For example, last July the Prime Minister opened a new factory at Airbus's UK facility in Broughton, north Wales. The factory will manufacture wings for the Airbus A380, which will be transported by specially built ferry, barge and road to the final assembly line in Toulouse, France.

So what are the opportunities for manufacturing in the United Kingdom? We have the latest knowledge and technologies in the modern sectors of biotechnology, pharmaceuticals and mobile communications as well as in traditional sectors such as automotive, metals and technical textiles. One of the regular winners of manufacturing awards is Brintons, based in the West Midlands. They are the world's leading manufacturer of Axminster carpets, exporting to more than 70 countries. They have managed to stay ahead by investing heavily in dyeing, yarn and carpet manufacturing, with computer-controlled gripper Axminster looms designed and built in-house by the company's engineers.

Another strong sector is pharmaceuticals, with industry exports in 2002 totalling £10.03 billion, creating a trade surplus of £2.6 billion. The industry employs around 70,000 people and generates another 250,000 jobs in related industries. Many more examples from other sectors could be cited, including British Aerospace, Rolls-Royce, Smiths Industries, ICI, BIC, Bookham, ARM, Oxford Instruments, IMI, Bombardier and Westinghouse. One-quarter of all of Ford's engines worldwide are made in the United Kingdom.

Clearly, we need more companies to move to this level. That is why, when taking over as secretary of state, Patricia Hewitt brought together all of the key stakeholders for a manufacturing summit, and out of that summit came the Government's Manufacturing Strategy.

It has become clear that there are longstanding weaknesses in UK manufacturing in terms of skills, investment and innovation. We cannot compete on the basis of low-cost, low-skill, low-margin goods. We are vulnerable to competition from lower-cost economies such as China, where merchandise trade increased by more than 20 per cent last year. Our response must be innovation to achieve higher value-added products and more rapid and better production processes.

The Government is investing strongly in science and technology as an important driver. The UK science budget is increasing by 7 per cent per annum in real terms and, as a result of the spending review in 2002, it will increase by 10 per cent per annum between 2003 and 2006 so that by 2005–6, the science budget will be almost £3 billion, compared to £1.3 billion in 1997-98. We are already seeing results: the number of spin-off businesses from UK universities has risen by 22 per cent and the number of patents filed by higher education institutions has increased by 26 per cent. In addition, the R&D tax credit has been extended to all companies.

We are also providing a further £180 million to develop the new generation of modern apprenticeships and investing in the development of foundation degrees. At the same time, funding to Regional Development Agencies (RDAs) will increase from the current £1.7 billion to £2.04 billion in 2005–6. RDAs have a crucial role in encouraging innovation and stimulating workforce development among local industries.

Finally, I want to mention two important initiatives close to my own heart. The Manufacturing Advisory Service provides free advice and support to manufacturing companies all over the regions, including Scotland and Wales. Since its launch in April 2002, it has handled over 17,000 enquiries from manufacturing companies and has carried out over 3,000 diagnostic visits; the total value-added benefit to firms so far has been over £18 million.

In addition, we currently support 15 industry forums that target sector approaches to supply-chain initiatives, value-stream mapping and networking as a means of delivering world-class best practice in sectors such as marine, aerospace, metals and process industries. A pilot project in the construction equipment sector shows that we have already identified savings averaging over £180,000 per small/medium enterprise engaged in that sector.

The Government is committed to helping manufacturing move forward by raising its investment, applying innovation, implementing best practice and upgrading skills. That is what will ensure, we hope, the future of manufacturing in the United Kingdom. ❐

A historical perspective

Tim Woodbridge

Tim Woodbridge is chief executive of Web Dynamics, a textile firm specialising in design, development and production of high-performance, intelligent fabrics for specific applications. He worked in the textile industry in Australia before returning to the UK to take up an appointment as director of a manufacturer of high-tech apparel. He set up Web Dynamics with his business partner Derek Gray in 1997.

When my business partner and I went into textile manufacturing, we soon realised that the industry was full of enterprising, engaging and energetic individuals, all of whom had found that the Government had given up hope on them. There seemed to be a complete lack of confidence in the manufacturing sector. How has this come about? To put things in context, I would like to go back and look at the origins and history of textile manufacturing in the United Kingdom.

In the 18th Century a weaver named Hargraves realised that the vertical wheels used to drive carts could be turned on their sides to create spinning wheels that could make multiple yarns. That development encouraged another entrepreneur, Richard Arkwright, to link the yarns and harness the power of the water wheel to create the first factory system. Both of these men were working at a time when there was great enthusiasm for science and innovation, and a sense of empowerment.

Jump forward 100 years and Britain had become an industrial nation. By 1850, half of UK exports were in textiles and this sector became critical to the future of the economy. Infrastructures were set up to support it and markets created in the USA and Europe.

The invention of synthetic materials at the end of the 19th Century represented another quantum leap and coincided with a decline in the cotton industry. Courtaulds set up a plant in the USA in 1910 to produce viscose, followed by Du Pont in the 1920s with the patent for rayon. These were the first technical textiles.

Du Pont's head of R&D, Wallace Carruthers, showed that molecules could be joined in long chains — polymer chains — to create material, leading to the invention of nylon. On the day of its launch, 5 million pairs of nylon stockings were sold.

On the other side of the Atlantic, the British cotton industry was attempting to preserve its longevity by protecting itself rather than innovating in the face of competition from the new American synthetics. However, one man, JR Winfield, who worked at Calico Fibres in Accrington, thought differently. Winfield studied the work of Carruthers and discovered that the latter had created a mixture in powder form but subsequently abandoned it. Winfield and his colleague Dixon added ethylene glycol to that mixture and in 1946 registered the patents for polyester.

Polyester, then, is a British invention. However, at the time, cotton was still seen as the future in British textiles and the energies of Britain's politicians and business people were going into the preservation of the cotton industry. By the end of the Second World War, Du Pont with nylon, ICI with polythene and Courtaulds with viscose dominated the global textile industry. Winfield and Dixon's polyester patents were sold by Calico Fibres to Du Pont for the US market and to ICI for the rest of the world. Du Pont then blended polyester with cotton, creating Dacron (polycotton), which became, like nylon before it, one of the great successes of its time.

Britain watched helplessly as its cotton industry declined further during the 1960s, culminating in its final collapse in 1970. Meanwhile, in the USA, Du Pont invested $100 million in R&D, leading to the invention of Lycra and Teflon in 1969, along with less familiar names such as Kevlar, which is used in brake linings for cars and sails for boats. Since then, the creative technologies available in textiles have grown enormously. By 2000, the European business for these new textiles was worth around €22 billion, of which the United Kingdom has around €1–2 billion.

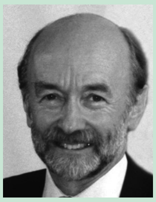
This scenario is being repeated in other sectors. Making wings for Airbus, for example, is really supplying wings to a French manufacturer for use in the French aviation industry: we lost that opportunity when we allowed them to build an industry around Concorde. A large number of companies trading in the United Kingdom today are multinationals that have their own countries' interests at heart. In other words, the United Kingdom has become an offshore manufacturer. We need a stronger message from the DTI in support of manufacturing. This does not mean making everything in the United Kingdom; rather, it means putting UK interests first. Despite the previous speaker's words, I do not think the Government has been successful in conveying its message to industry.

Our company, Web Dynamics, grew out of a conviction that the multinationals dominating textile manufacturing in the mid-1990s were inflexible. We designed a system and a factory that could challenge the multinationals, with rolling innovation on the line built in. As a colleague put it, it is a system whereby we could steal the crumbs from the giant's table. A key element was the creation of a manufacturing culture that encouraged innovation and fresh thinking. We gave 25 per cent of profits to the employees, who were not called employees, but members. The result was an extraordinary success. We doubled our first-year turnover of £1 million every year for five years, with capital of only £20,000.

However, as innovators, we were creating enemies — those from whom we were taking business — and we turned to the Government for help. What we found was very worrying. If you are a local manufacturer in the United Kingdom today, the Government will help you out with bits and pieces, but the unspoken implication is that the Du Ponts of the world are where the opportunities really lie. It is this attitude that needs to be addressed to secure the future of manufacturing in the United Kingdom. ❐

Modern manufacturing: myth versus reality

Mike Gregory



Professor Mike Gregory CBE is head of the Manufacturing and Management Division of the Department of Engineering and director of the Institute for Manufacturing at the University of Cambridge. His early career was in industry and in 1985 he initiated research into broad-based manufacturing strategy. Professor Gregory has served on a range of institutional and government committees, including the DTI Basic Technologies Advisory Group, EPSRC Review Panels and EU advisory groups. He chaired the General Engineering Panel of the Research Assessment Exercise 2001.

I would like to begin by dispelling some popular myths.

"There is no serious manufacturing left in the UK." This belief is especially prevalent among young people. However, we made more cars last year than we have ever made before. We are also versatile: any type of product you wish can be made in the United Kingdom.

"We are no good at manufacturing." In fact, we make airplanes, optical equipment and medical instruments of the highest quality.

"Manufacturing is low value-added." So all we do is dig material out of the ground and from it make complex metals, glass, optical instruments and more. Would you say that is low value-added?

"The future is in service industries." When I worked in a factory we employed a barber. We also had accountants, lorry drivers and others who we did not realise were working in service industries; we thought they were part of manufacturing. These types of jobs are now provided from outside the manufacturing sector, so rather than a decline in manufacturing, what we have seen is a restructuring of industrial activity.

"Labour costs are too high in Britain." In fact, wages are much higher in the US, Germany, France and Japan, all of which nevertheless seem to have healthy manufacturing industries.

Why do these myths persist and how can we grapple with them? First, those of us who believe in the importance of manufacturing have not been sufficiently articulate in its support. Traditionally seen as a production process, in reality modern manufacturing encompasses the full cycle of marketing, design, production, distribution and service. Thus, it is perfectly possible to be in manufacturing without owning a factory! For example, ARM, the designers of the chips that are used in 75 per cent of mobile telephones, have no production plants: they sell their designs directly to the final user and factories then make the chips to their specifications.

In automotive components, GKN uses its production capability to deliver high-quality R&D material science and engineering and now commands 40 per cent of the world market for constant velocity joints. GKN has attained a leading position in this field by linking its production capability to its R&D, maintaining close alliances with its customers and having production facilities around the world.

In the clothing sector, the Spanish company Zara owns all of its production capability, enabling it to move products from the design stage to being in the shops in a fortnight. This gives Zara an enormous advantage over its competitors who outsource production to areas such as the Far East, where a lead time of two, three or even six months is common. Zara can respond rapidly to customer demand, tailoring production accordingly and leaving their competitors trailing behind.

Rolls-Royce has responded to customer demand by selling its car by the hour ("power by the hour"), a remarkable strategy that is responsible for 40 per cent

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In June 2003 the Government commissioned an independent study of development of nanotechnology and its potential risks. At a Foundation discussion meeting on 18 November 2003, four speakers were invited to give their views on the opportunities and threats from nanotechnology. Jeff Gill summarised the discussion that followed.

Opportunities and threats

Lord Sainsbury

The Lord Sainsbury of Turville is Parliamentary Under-Secretary of State for Science and Innovation at the Department of Trade and Industry. He read history and psychology at King's College, Cambridge, and studied also at the Columbia Graduate School of Business in New York. His early career was spent in the family company, J Sainsbury, where he became chairman and a director of Giant Food Inc until July 1998. He was elevated to the House of Lords in 1997 and became a minister in July 1998.

The United Kingdom has a strong academic background in nanoscience and nanotechnology and has been active in the field for two decades. The National Initiative on Nanotechnology in 1986 was the forerunner of a number of international initiatives and a LINK nanotechnology programme followed in 1988 to 1996.

Applications of nanotechnology are already emerging. Products are already available: hard disks based on giant magnetoresistance in nanostructured magnetic multilayers; sunblock creams based on UV-absorbing nanoparticles; and lasers, modulators and amplifiers for telecommunications. Applications close to the marketplace include electronic displays, glasses with scratch-resistant coating, "lab-on-a-chip" and quantum structure electronic devices.

Enormous commercial opportunities are predicted from nanotechnology over the next 10 years. For example, the US Government forecast in 2001 that the estimated global market would be £700 billion in 2010. The interdisciplinary nature of nanotechnology and the wide range of sciences it covers, mean its influence could pervade all aspects of society and most industrial sectors.

Nanotechnology research in the United Kingdom covers most aspects of the field and much of it can claim to be world class. This research should provide the foundations on which to develop nanotechnology for the benefit of UK companies and for wider society. Yet there have been concerns that UK companies are not commercially exploiting nanotechnology as quickly as our major industrial competitors.

With these concerns in mind Dr John Taylor, Director General of the Research Councils was asked to chair a UK Advisory Group on Nanotechnology Applications. The advisory group reported in June 2002 and found that there was a strong foundation on which to develop nanotechnology in this country but that we were not moving as fast as we should on commercialisation. Other governments and international companies were investing large sums in new facilities but here we lacked a coherent and coordinated strategy for accelerating the application of nanotechnology.

The advisory group's report highlighted a number of actions that should be taken:

- the creation of a stable, visible and coordinated strategy for public support;
- a reduction in the mismatch between our research and industrial capabilities;
- improvements in access to international research and development; and
- improvements in access to fabrication facilities to enable industry to trial its ideas.

The advisory group chose six specific, major application areas to act as benchmarks of progress and produced success

discussion

Ethics. The evening's debate had identified issues over health and safety but not questions of ethics. It was observed that if the hyped claims for achieving immortality through nanotechnology came true there would be big issues, but the main current questions were practical. The technology might make possible some worrying applications, for instance a greater capability for remote sensing. It was suggested that nanotechnology did not raise any ethical points which had not come up already in the context of other areas of innovation.

Something could be learned from contrasting public attitudes to stem cells and GM food. Research on stem cells had been accepted because a legal framework had been put in place at an early stage and the scientists were seen to be under control.

scenarios for each area just five years from now. The six areas chosen were electronics and communications, drug delivery, instrumentations, tooling and metrology, novel materials, sensors and actuators, and tissue engineering.

The achievable outcomes identified in tissue engineering were:

- 5 to 10 start-up businesses every year,
- 10 additional multidisciplinary groups every year;
- 2 per cent of a $50 billion market, worth $1 billion to the UK;
- 85 to 90 per cent of UK tissue engineering companies run by UK managers;
- new employment of 1,500 jobs;
- eight new products commercialised.

With a view to achieving these outcomes, I announced in July 2003 the DTI's latest investment in nanotechnology, £90 million over the next six years. This is to be spent on collaborative research and a new network of microtechnology and nanotechnology facilities. Of this, £50 million is to be available for collaborative research and development between industry and our science base. Strengthening these collaborative links is vital if we are to gain maximum advantage from the EU Sixth Framework programme, particularly the third priority area of Nanotechnology, Materials and Processes, worth some £900 million.

The UK Development Agencies have responded very positively to the creation of a UK MicroNanoTechnology Network. This network will receive £40 million of the fund to provide industry with access to cutting-edge nanotechnology research and resources in academic and industrial facilities throughout the United Kingdom. Existing and anticipated micro- and nanotechnology projects supported by the UK Development Agencies are expected to exceed £200 million over the next few years.

This substantial investment will help UK companies take advantage of the exciting commercial opportunities offered by scientific advances in nanotechnology and compares favourably with the level of investment in our major competitor nations.

Nanotechnology promises great things, but questions have been asked about safety. Sensationalist scenarios have been reported in the media, involving plagues of self-replicating "nanobots" turning the world into "grey goo". That's the stuff of science fiction and is far from the reality of what nanotechnology is about and what it can do. But there are some other genuine concerns. Concerns about releases into the environment, concerns about possible threats to health and concerns about the unknown properties of materials at the nanoscale.

discussion

Education. Nanoscience had been around for 100 years, but as yet there was very little production using nanotechnology apart from paints, pigments and catalysts. There was probably a five to ten year gap in which problems could be addressed before manufacturing really took off. Educational needs should be looked at for the next 20 to 50 years. People needed to understand the language.

Other participants stressed the importance of building interdisciplinary teams of multilingual scientists. There was an exciting opportunity for young people thinking of becoming scientists to decide to work together, to cluster with other scientists.

In the UK it was said that the most popular doctoral programme at Oxford University was for physical scientists moving into biology. Enthusiasm started early; pupils at one Cambridge school had their own nanotechnology web page. Attitudes needed to change. A lot of schoolchildren opted to study double science rather than physics and biology, and it was argued that the established scientific community ought to support this rather than complaining about weaknesses in basic sciences. Similarly in the universities the traditional disciplines were still dominant. One speaker saw a need to introduce interdisciplinary studies throughout the secondary and university systems and urged that they should be "given a good shake".

In their report *Scientific Research: Innovation with Controls*, published in January 2003, the Better Regulation Task Force identified nanotechnology as an area of great potential but where concerns are likely to be raised about the risks of the technology.

The report states that government needs to be ready to deal with these concerns and demonstrate that it has clear policies in place to ensure the safety of individuals, animals and the environment, whilst permitting the research to continue. We agree with the task force. The ground-breaking work in the early days of the science and technology of human fertilisation and embryology provides us with a useful precedent for action.

UK law on embryo research has evolved over 20 years of public and parliamentary debate, beginning with the Committee of Inquiry chaired by Mary Warnock in 1982. We now have one of the most comprehensive schemes of regulation in the world and the careful and thoughtful approach which was taken over this lengthy period enabled us to introduce the necessary regulatory change to enable stem-cell research to go ahead.

It was with these lessons in mind that we commissioned the Royal Society and the Royal Academy of Engineering to look at whether nanotechnology raised any ethical, health or environmental issues which are not covered by current regulations. Once the Royal Society and the Royal Academy of Engineering have publicly reported and some kind of scientific consensus has been reached, then I would see a wider public debate taking place.

What we should not be trying to do is to say whether, overall, nanotechnology is a beneficial technology and should be encouraged or a harmful technology and, therefore, should be stopped. No one has the foresight or wisdom to make such decisions.

To conclude, in the new global economy, the United Kingdom will not be able to compete on the basis of low costs with countries such as China which has 5 per cent of our wage costs. We will only be able to compete on the basis of our knowledge, skills and creativity.

Revolutionary technologies such as nanotechnology give us the opportunity to move into new high value-added areas both by creating new industries and by radically changing traditional ones. This is an opportunity we must seize and the Government will put in place the public goods such as a world-class science and technology base, incentives for knowledge transfer and high educational standards, to enable companies to put innovation at the centre of their strategies.

At the same time we need scientists and technologists to give careful thought to any ethical, health and environmental issues raised by nanotechnology, to say whether any new regulatory controls are required and to enter into an open dialogue with the public. Only in this way will we be able to maintain the confidence of the public and reap the full benefits of this exciting new technology. ❐

The science and business of nanotechnology

Samuel Stupp

Professor Samuel Stupp is director of the Institute for Bioengineering and Nanoscience in Advanced Medicine, and Board of Trustees professor of Materials Science, Chemistry and Medicine, Northwestern University, USA. He has served as a member of the Department of Energy's Basic Energy Sciences Advisory Committee since 1999 and is a member of the Nanotechnology Technical Advisory Group of the President's Council of Advisors on Science and Technology.

Nanotechnology will influence science, the economy, even the quality of life. It is a revolution across all the sciences that will impact broadly on all areas of technology. To imagine what "nanoscale" really means, think in terms of dividing the width of a human hair 100,000 times. And don't get the idea that we have been here before just because a hundred years ago somebody made some very small structures. The fresh vision of nanotechnology is the idea of being able to design, make, manipulate and probe the particles individually to learn about the properties of matter at the nanoscale.

Best known of the many nanostructures now being worked on are carbon nanotubes and quantum dots, which are tiny particles of semiconducting material. The development of nanostructures of differing kinds, particularly organic, presents the possibility that we could mimic the methods by which biology harvests photons in photosynthesis, and this would be an extremely important objective in making solar energy a more practical proposition than it has been so far.

In the new era of genomics, nanotechnology has the potential to reduce a DNA chip that on the microscale would be the size of a tennis court to something the size of a small coin. New materials, electronics and communications devices will soon become reality.

With all this great science in prospect, not long after taking office the Bush administration decided to evaluate the national nanotechnology initiative that was begun towards the end of the Clinton administration. The White House Economic Council was particularly interested in finding out whether or not we were making the correct investments in the field. I was asked to chair this study, which took a year, and the report, *Small Wonders, Endless Frontiers: A Review of the National Nanotechnology Initiative*, is available from the National Research Council website (www.nap.edu/books/0309084547/html/).

That report shows, among many other things, the areas of the world where major nanotechnology efforts have been started. One figure in the report was particularly important, the one that showed the extensive investment being made in Japan. This made quite an impact in Congress. Not long after, it doubled and then trebled the US investment in the initiative.

What of the business side of nanotechnology? New materials are beginning to be marketed and other contributors to this discussion have talked about sunscreen lotions and other early products of the nanotechnology industry. On a more high-tech level new forms of instrumentation are certainly going to be big business because nanotechnologists need to develop instruments to probe, manipulate and construct new devices.

Large companies, like IBM, Intel and Hewlett Packard, are already making substantial investments in nanotechnology and in the United States there may soon be public companies based on nanotechnology. Private start-up companies are emerging all the time and some of them are becoming well established.

Mention start-up companies and some people immediately think of the dotcom boom and bust. But I want to stress that nanotechnology is different. The dotcom bubble did a lot of collateral damage to legitimate science and technology. In contrast to many dotcom companies, often based on just a new computer program or a speculative new way of trading, nanotechnology involves actual innovation in the form of both new science and new technology.

For the medium-term future, we anticipate remarkable developments in medical diagnostics, hand-in-hand with the latest advances in genomics. This is

discussion

Consultation. There was a question how best to consult the public at a stage when the technology had great promise but little immediate application. Asking people whether they had heard of it and whether they approved, would invite the answers "no" and "no", but a more intelligent approach than that ought to be possible.

where nanotechnology will affect our quality of life. Novel therapies and novel ways of delivering drugs will revolutionise health care.

Nanotechnology will make it possible to make artificial systems of the same size, shape and basic structure as components of living cells. We will be able to interact with living tissue directly, perhaps to regenerate body parts by combining nanotechnology with the stem cells capable of forming any type of tissue or even body parts. What nanotechnology will do is design the environment around those cells to get them to become nerves of the central nervous system or heart or bones or, perhaps, liver and pancreas. Regenerative medicine is likely to be the next frontier of medicine.

Humane cancer chemotherapy and very early detection of cancer are areas ripe for innovation. Other possibilities, such as reversing blindness or paralysis, are exciting in terms of how they could improve our lives and also the nations' ecomomies.

After having a heart attack, why not be able to go back to the same state that you were in before you had the heart attack or after you had the stroke? Mend bone fractures? Would you like to have new cartilage?

Then, wouldn't you like to die with your own teeth? Most of us die with a mouthful of plastic and metal. Enamel regeneration is very much a nanotechnological problem, and this is the way that it is being looked at by groups of scientists who study biomineralisation.

These aspirations for medical treatments and personalised medicine would have been little more than science fiction a few years ago. But nanotechnology is on the verge of making these things happen, certainly a goal worth pursuing. ❐

The health effects of nanoparticles

Stephen Holgate

Professor Stephen Holgate is MRC clinical professor of Immunopharmacology, School of Medicine, University of Southampton. He has served on a number of government committees including as chairman of the UK Department of Health Committee on the Medical Effects of Air Pollutions and has been appointed as chairman of the DEFRA Expert Panel on Air Quality Standards.

Particles of various types have been producing adverse health effects for many years, but it wasn't until the 1950s that we really started to gain some insight into the health effects of particles. The recognition that particles issuing from the burning of fossil fuels, particularly coal, caused deaths from pneumonia and cardiovascular illnesses led to the introduction of the Clean Air Acts in 1956 and the early 1960s. At the time it was thought that the adverse health effects were largely driven by sulphur dioxide and sulphuric acid. But with the benefit of hindsight we can now see that the adverse health effects probably largely lie with these particles — small nanoparticles of carbon aggregated into much larger particles.

The Clean Air Acts did clean up the air of our major cities but air pollution did not disappear. Pollution caused by coal burning was replaced by pollution from road vehicles. In the past two decades vehicle pollution has proliferated in westernised cultures and in developing cities around the world. The pollution measurements that we use now measure not only gaseous pollutants but also the particles, as now the impacts of particles on human health is beginning to be understood.

What is the source and size range of the particles that we encounter in our day-to-day lives? Particles are produced by a large number of sources, the most obvious being physical friction and the evaporation of sea salt sprays. But most of the particles that we are exposed to in our cities come from the combustion of liquid fuels and these lead to the nucleation and formation of primary particles that fall into the nanoparticle range.

Secondary particles arise through the interaction of gaseous elements in the atmosphere catalysed, often, by photochemical reactions that lead to acids and other particles such as ammonium sulphate accumulating and contributing to the overall particle load. These are the nanoparticles that we are exposed to in the everyday environment and are encountered particularly during air pollution episodes.

Traffic is the most urgent concern in terms of air pollution today and it is the particles issuing from emissions that are causing most of the adverse health effects.

How does the human body cope with nanoparticles? Obviously lungs are in the front line; airborne particles find their way through the airways ending up in the alveoli, where gaseous exchange takes place. The body rids itself of small particles naturally by phagocytosis — particles are ingested by macrophages and eliminated from the body. Unfortunately, the macrophages in the lining of the lung become easily saturated by particles and then they can enter into the tissues, circulation and lymphatics.

So what adverse health effects are linked to particulate air pollution? There have been more than 100 epidemiological studies across the world on this topic. It is clear that the major adverse health effects lie in the respiratory and cardiovascular systems, with increases of between 1 and 3 per cent in mortality from stroke, heart attacks, pneumonia and various forms of bronchitis. In young people and children, air pollution with particles has been associated with an increase of about 3 per cent in symptoms of asthma and lower respiratory tract infection. Those percentage increases may not sound high, but potentially they are all preventable.

Have there been any interventions that link adverse health effects of particles to health in the opposite direction? There are the Clean Air Acts I have mentioned. Another more recent example is a study involving a steel mill in the Utah Valley in the United States which emitted particles containing a high concentration of transition metals; this was linked to increased hospital admissions for asthma and chronic obstructive pulmonary disease. When a strike of the work force put the mill out of action for just over 18 months, hospital admission rates fell dramatically but, as soon as the mill started up again, up went the hospital admissions for young people with respiratory illnesses.

What size particle fractions are most strongly linked to the adverse health effects? There have not been many studies in humans but there have been in animal models. Rats have been given latex particles of different sizes to inhale and, as the size range gets smaller and smaller, even though the mass stays constant, the number of inflammatory cells in the lungs progressively increases. Each particle is seen by the lung as a potential invading microorganism requiring elimination by macrophages. When the macrophages are overrun, a systemic reaction develops: the more particles above background there are, the greater the local and systemic response and the more the adverse health effects are seen. The health effects are driven more by the surface area than by the mass of the particle. That is why nanoparticles that comprise the ultrafine fraction (<0.1 μm mass median diameter) are so important in this respect.

These tiny particles interact with the lining cells not only in the lungs but also in the skin, the eyes, the nose and the gastrointestinal tract, generating reactive oxygen intermediates that drive an inflammatory reaction. This is accompanied by an acute phase response and adverse cardiac and respiratory health effects. When particles move into the circulation or into tissue, they activate the autonomic nervous system, exacerbating asthma and, importantly, in people with angina and coronary insufficiency increase cardiac arrhythmia. On reaching the liver, the bone marrow and the heart, particles can activate white cells that together contribute adversely to cardiovascular and respiratory health.

Broadly speaking, we can divide the health effects into two. First, there is the lung inflammation which is a local effect mediated largely through transition metals and various organic chemicals adsorbed onto the surface of the particle. Second, particles absorbed into the bloodstream activate the blood clotting pathways, stimulate the growth of atheromatous plaques and change the heart rate variability, leading to serious cardiovascular problems, even death.

There is no doubt that small particles derived from vehicle pollution have adverse health effects, particularly when they enter through the lungs and into the systemic circulation. The question that needs to be answered is whether nanoparticles that are manufactured in an industrial setting will also have these adverse health effects and, if so, how we can carefully monitor them? ❐

Benefits and risks

Ann Dowling

Professor Ann Dowling CBE FRS FREng is chairman of the Royal Society and Royal Academy of Engineering Study of Nanotechnology and professor of Mechanical Engineering at the University of Cambridge. Her research is aimed in particular at clean combustion and noise reduction in vehicles.

In June 2003 the UK Government commissioned the Royal Society and the Royal Academy of Engineering to carry out an independent study of likely developments in nanotechnology and whether nanotechnology raises or is likely to raise new ethical, health, safety, environmental or societal issues which are not covered by current regulation. As chair of the study, I have been asked to talk about the process and what we hope to achieve.

We are taking evidence through to April 2004. Reports of workshops and oral evidence sessions are posted on the website for comment as they become available (www.nanotec.org.uk). We are due to report in Summer 2004.

We felt it important to distinguish between nanoscience and nanotechnology. Nanoscience is both a study of and the manipulation of materials at small scales, in the range probably of 0.1 to 100 nanometres, the distinguishing aspect being that they are length scales where properties differ significantly from those at larger size. There is a lot of nanoscience going on right now in research laboratories. Nanotechnology is using this science commercially to produce new structures, devices and systems by controlling shape and size. We wanted to distinguish between the research studies and their practical application. Some people say that nanotechnology does not yet exist, but we have been hearing about some of the possibilities tonight.

The other speakers have listed many examples of devices that take advantage of nanoscience. It is out there in the marketplace already, in the form of sunscreen, where the reflective properties of nanoparticles are used, in self-cleaning windows, in fuel additives — it is claimed that nanoparticles added to fuel can increase efficiency by 10 per cent and reduce pollutants — and in computer hard disks.

In the near future, we will be seeing displays using field emission elements, fuel cells, low-cost solar cells and we have heard about drug delivery systems, bioremediation and so on. In the longer term, logic systems based on just a few molecules will be the interface between the human nerves and semiconductor devices. One of the benefits and challenges of nanotechnology is that, at this scale, science becomes unified, so nanotechnology is about the integration of medicine, biology, chemistry, physics and engineering.

From the early stages of the study there was the suggestion that there might be health and safety issues. For instance nanotubes can be similar in shape to asbestos — they are long and thin — so could there be health problems if they are inhaled? The working group has not yet reached any conclusions and there are still questions such as “how do they interact with the lungs?” But, if the body reacts in a similar way as to asbestos, then there may be implications for work that is going on in laboratories right now, where

discussion

Safety. The impact of small particles on health was both chemical and physical, and there was a synergy between the two effects. Particles could contain active substances, but even chemically inert particles could be highly active biologically due to their large surface area. It could not be assumed that nanoparticles made from a material which was safe in bulk would themselves be safe.

A manufacturer of nanotubes who already took sensible precautions wondered whether any lessons could be learned from blue asbestos. In reply it was said that the toxicology of that substance was still a mystery. The damage that it did seemed to relate not only to the needle-like shape of the particles but also to their surface chemistry. The surface chemistry of nanotubes needed to be investigated.

There was much reliance on small animal studies to model the effects of nanoparticles on human health, but rats and mice were adapted to living in drains and breathing toxic particles. Human airway epithelia were much more sensitive than the corresponding animal cells and studies using human cell cultures were needed.

It was argued that such research would be premature as it was not yet clear what the most important nanomaterials would be. Other speakers thought it important to address safety at an early stage. If the first thing people heard about a new development was bad this would stick, and it would be a mistake to wait until nanotechnology impacted on people through products. The public would expect scientists to be looking at possible health effects.

people are not always taking care in the way they handle nanotubes. There would certainly be issues when it comes to manufacturing. Additionally, if nanotubes become as ubiquitous as the enthusiasts think, they will be in a wide variety of products and, should they give rise to health problems, there will also be issues in terms of disposal and re-cycling.

We have heard tonight about inhalation problems that small particles may present. One reason for using nanoparticles is for their increased surface area; the reactions are different with such small particles which is why they may be useful in many applications. But the increased surface area may well create an enhanced or different toxicology. One of the concerns raised throughout the working group's consultations is that the toxicology of nanoparticles needs to be investigated. It is not enough simply to transfer toxicology results from larger scale particles down to the small scale. Also, of course, the small particles can be absorbed differently through the skin and through other organs.

Other points that have been raised so far are "be wary of fiction". Fiction comes from different sources, one being the over-hyped claims that some scientists are making; they make those claims to encourage funding but the danger is that they scare the public. So, while there are strong claims being made, our town meeting of experts thought that some of these were not helpful, were not feasible and they were raising alarm unnecessarily.

Another area of fiction, perhaps, is that, of the people that we have talked to, no-one can see how to make, in any foreseeable timescale, physically-constructed "nanobots" that can self-replicate, and the people we consulted included the greatest proponent of the nanobots, Eric Drexler. What he said was that this could only happen in a really long timescale and that there are more immediate health issues. Other people are saying that the "long" timescale is never and that they cannot see how self-replicating nanobots are even theoretically possible. However, there are already biological self-replicating nanosized devices, such as viruses. We adapt to viruses but we also know how devastating they can be, particularly if they undergo abrupt change into a form that we are not prepared for. There is a warning here that, if nanotechnology builds on biological systems, one has got to take care. ❐

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Continued from page 17

of the company's current revenue and has led to a rapid growth in its market share. This innovation in marketing has had profound implications for design and production and Rolls-Royce is in a position to capitalise on it.

Finally, the electronics company Selectron is one of several that have chosen to concentrate on production, acquiring overseas production facilities to achieve economies of scale, global production capability and the flexibility to respond to changes in demand. Consequently, its net sales increased from $6 billion in 1998 to $19 billion in 2001. This is a company that has made a business out of production.

All of these examples illustrate, in different ways, the close link between R&D, design, responsiveness, service and cost.

So what changes are we seeing in manufacturing and what is the future likely to bring? In all sectors manufacturing is moving from local to global production and from factories to networks, from providing commodities to providing innovations, from high volume to high flexibility, from hierarchical organisation to team working, and from craft-based to knowledge-based expertise.

Global demand is rising steadily and in the US the demand for goods exceeds that for services: sales of durable goods in the US have nearly doubled since 1990. However, the goods people are buying are high-tech products and we need to ensure that we have the skills and technologies to produce them.

I believe there is a future for manufacturing in the United Kingdom if we retain early-stage production capability and go beyond the value of patents so that we are in a strong position to offer that all-important process of production. We must strengthen our production knowledge and capability and develop a sector-by-sector understanding of the role of production in the economy. If we can achieve this, we will be well on the way to ensuring a healthy future for our manufacturing industry. ❐

Recent lectures and dinner/discussions organised by the Foundationin the past year are listed below. Sponsors to whom we are very grateful for their support, are shown in italics, below the event. Summaries of these and other events are available on the web at www.foundation.org.uk

26 May 2004

How can science improve the performance of the Home Office in crime detection, immigration control, counter-terrorism, prison management and cybercrime?

John Gieve CB, Permanent Secretary, Home Office
Paul Wiles, Chief Scientist, Home Office
Peter Neyroud QPM, Chief Constable, Thames Valley Police
Alasdair Rose MBE, Crime Detection & Prevention Technologies Programme Manager, EPSRC

Engineering and Physics Research Council, Medical Research Council, National Grid Transco Foundation, QinetiQ

12 May 2004

North-South Capacity Building - How can the developed nations support the developing world to build science capacity?

The Rt Hon Hilary Benn, Secretary of State for International Development at the Department of International Affairs
Professor Silas Lwakabamba, Rector, Kigali Institute of Science, Technology and Management, Rwanda
Sir David King FRS ScD, Chief Scientific Adviser to the UK Government and Head of the Office of Science and Technology, DTI

CABI Bioscience

28 April 2004

What is the countryside for: food production or amenity value?

The Rt Hon Alun Michael MP, Minister of State for Rural Affairs and Environmental Quality, DEFRA
Professor Chris Pollock, Director, Institute of Grassland and Environmental Research
Oliver Walston, Farmer, Thriplow Farms, Royston

Biotechnology and Biological Sciences Research Council, DEFRA, RCUK – Rural Economy and Land Use Programme

24 March 2004

Training Teachers — Have we got it right?

Mr Ralph Tabberer, Chief Executive, Teacher Training Agency
Dr Derek Bell, Chief Executive, Association for Science Education
Mr Mike Tomlinson CBE, Chair, The Learning Trust

Comino Foundation, SEMTA and Teacher Training Agency

25 February 2004

Is a fundamental review of university funding required?

The Lord May of Oxford OM AC PRS FMedSci, President, The Royal Society
Professor Sir Graeme Davies, Vice Chancellor, University of London
Dr Mark Walport FMedSci, Director, The Wellcome Trust
Professor Nick Cumpsty FREng, Chief Technologist, Rolls-Royce

EPSRC, QinetiQ, Rolls-Royce and Royal Commission for the Exhibition of 1851

2 December 2003

The Lambert Review and the DTI Innovation Review

Mr Richard Lambert, Chairman, HM Treasury - Lambert Review
Dr David Hughes, Director General, Innovation, Department of Trade and Industry
Sir Colin Lucas, Vice-Chancellor, University of Oxford
The Lord May of Oxford OM AC FRS FMedSci, President, the Royal Society

BTExact, Fugro GEOS, Momenta, QinetiQ and Particle Physics and Astronomy Research Council

25 November 2003

Energy policy: the renewables targets

Dr Bernie Bulkin, Chief Scientist, BP
Dr Malcolm Kennedy, Chair, Energy Working Group, The Royal Academy of Engineering
Ms Claire Durkin, Director, Energy Innovation and Business Unit, Department of Trade and Industry

BRIT, National Environment Research Council, The Royal Academy of Engineering

18 November 2003

Nanotechnology: threats and opportunities

The Lord Sainsbury of Turville, Minister for Science and Innovation, Department of Trade and Industry
Professor Samuel Stupp, Professor of Materials Science, Chemistry and Medicine, Northwestern University, USA
Professor Stephen Holgate FMedSci, MRC Clinical Professor of Immunopharmacology, School of Medicine, University of Southampton
Professor Ann Dowling CBE FRS FREng, Chair, Royal Society and Royal Academy of Engineering Study of Nanontechnology, University of Cambridge

Council for the Central Laboratory of the Research Councils and QinetiQ

11 November 2003

Does manufacturing have a future in the UK?

The Lord Haskel, House of Lords
Mr Simon Edmonds, Director, Material and Engineering Sector Unit, Department of Trade and Industry
Mr Tim Woodbridge, Chief Executive, Web Dynamics
Professor Mike Gregory, Director, Institute for Manafacturing, University of Cambridge

Aerial Facilities Limited, SEMTA and the Textile Institute

6 November 2003

Visit to Addenbrooke's Hospital

Sir Keith Peters FRS PMedSci, President, The Academy of Medical Sciences
Dr Mary Archer, Chairman, Addenbrooke's NHS Trust Hospital
Professor Krishna Catterjee FMedSci, Professor of Endocrinology and Director of Wellcome Trust Clinical Research Facility
Professor Alastair Compston, Professor of Neurology
Professor Bruce Ponder, Professor of Oncology
Professor John Pickard FMedSci, Professor of Neurosurgery and Chairman and Clinical Director of Wolfson Brain Imaging Centre
Dr Robert Winter, Medical Director, Addenbrooke's NHS Trust
Dr Richard Henderson FRS FMedSci, Director MRC Laboratory of Molecular Biology

28 October 2003

The GM debate

Professor Howard Dalton FRS, Chief Scientific Adviser, Department of Environment, Food and Rural Affairs
Mr Ian Coates, Strategy Unit, Cabinet Office
Professor Malcolm Grant CBE, Chair, GM Public Debate

Biotechnology and Biological Sciences Research Council, Natural Environment Research Council and the Natural History Museum

23 October 2003

Fish stock assessment and the CFP

Sir David Smith FRS FRSE, Chair, RSE Inquiry into the crisis in the Scottish fishing industry, Royal Society of Edinburgh
The Earl of Selborne KBE FRS, House of Lords
Ms Maja Kirchner, Member of Cabinet of Commissioner Fischler, European Commission

Fishmongers' Company and The Royal Society of Edinburgh

7 October 2003

The Lord Lloyd of Kilgerran Lecture

Mr Tim Smit, Chief Executive, the Eden Project

Aerial Facilities Limited and Southampton Oceanography Centre

16 July 2003

The Research Assessment Exercise Review: how should university research quality be measured?

Sir Gareth Roberts FRS, Chairman, RAE Review
Sir David Watson, Vice Chancellor, University of Brighton
Dr Chris Henshall, Group Director, SEB, Office of Science and Technology, DTI

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