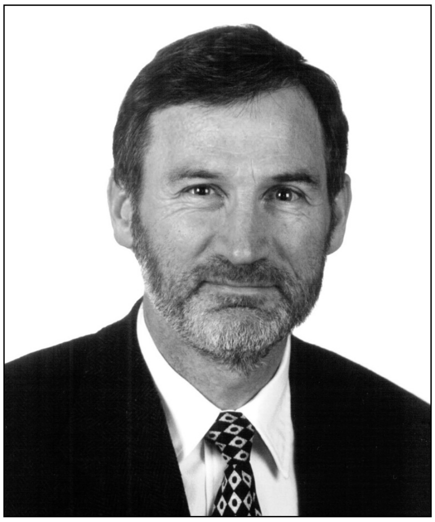
## *MATERIALS, MINERALS AND MINING – INNOVATION, CONSERVATION AND WEALTH CREATION*

### *MEETING OF THE PARLIAMENTARY AND SCIENTIFIC COMMITTEE ON MONDAY 4TH DECEMBER*

The recent surge in the value of primary raw materials, such as minerals and metals is partly due to increased industrialisation in emerging economies such as China and India. This has concentrated the focus on the finite availability of these commodities and the increasing difficulty in discovering new economic reserves in the near surface of our planet. Innovative research in the conservation of resources and in cost reduction has therefore also increased; these include recycling, the development of novel materials, using smart and nanotechnologies for example, and extended asset and material lifetimes through effective protection against degradation and corrosion. However, the attraction to young people of science and engineering is diminishing, despite attractive average lifetime career earnings for graduates. Thus, at a time when the demand for innovation in materials has never been higher, the number of students of materials science, and in mining and mineral engineering in our Universities is at an all-time low. It is true that almost all engineering and technological advances depend on new developments in the science and technology of materials. The list includes new, efficient light sources, electronic materials in computation, materials for the hydrogen economy, including batteries and fuel cells, and lightweight corrosion-resistant materials for transportation. Materials science is a key growth area that underpins the knowledge-based economy. The challenge now is to improve public perceptions so that our lead in this technology helps to create the next generation of materials scientists.

# The Importance of Mining Engineering[1] in Providing Primary Raw Materials



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In our everyday needs for materials and energy our resources are either grown or “mined”. Historically the UK has played a leading role in the discovery and exploitation of mined resources including coal, iron, building products and a variety of metals and minerals. While the scale of UK mining and quarrying is not large by global standards it is still significant and likely to be more so with pressures to source raw materials locally. This will be driven by our responses to Climate Change and consequent reduction in energy usage. However, in the UK as a whole the importance of mining and quarrying is not fully appreciated and largely negative perceptions predominate. For example, obtaining planning permission for new or extended quarries, while not as demanding as for land fill or waste incineration sites, is very difficult and affected by the same societal attitudes. Other perceptions of mining and quarrying include bad environmental legacy from abandoned sites – unfortunately true – but the record is improving rapidly, and a rather low-tech uninspiring industry – completely untrue.

For the reasons summarised above, which occur in most of the developed world, there is a crisis in attracting young people to the extractive industries (oil and gas, mining, quarrying) and the age profile is highly skewed to 45-plus. It has been estimated by the major mining companies that they are short of 600 graduates per year, to replace retirees and other leavers, and this figure can easily be doubled by including the smaller operators. In addition many of the equipment suppliers to the industry, mining finance houses and consultants need large numbers of professionals with mining engineering skills. The industry leaders recognise that they have to solve this problem largely themselves and the solutions include better industry performance and consequent reputation; higher salaries; more attractive on-site packages (eg fly-in/fly-out patterns); better consideration of family issues; outreach to the public at large and to schools in particular.

However there is an underlying problem that is critical in the UK and very serious in many developed countries. The number of students in schools who are studying mathematics and science has declined rapidly and this has inevitable knock-on effects for universities. There have been some high profile examples recently in chemistry and physics, but the effects are felt throughout

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[1] in the current context mining engineering also includes specialist disciplines such as mineral processing, applied geology and quarrying

science and engineering. There are now only two universities in the UK who offer mining engineering courses, Exeter (CSM) and Leeds. At the Camborne School of Mines we are currently pleased if we can attract 25 students per year into mining engineering. To do this we need good publicity, generous scholarships, an attractive package with good facilities and effective research and teaching. Our recent graduates typically can pick and choose between many job offers many of which are outside the mining industry. This is good for the graduates but not healthy for the industry. We need more applicants and the UK political/education system must address the underlying problems. There have been some encouraging initiatives in the past year but it requires a sustained effort to be effective.

Taking the global view, the mining industry has some important strategic considerations to address, in which mining engineering will play a key role.

The (shallow) easily mined world-class deposits of valuable metal and other ores have mostly been taken already, or have been located and mining has commenced. The industry must be increasingly innovative in finding and exploiting more marginal resources and in mining underground at depth, where it was previously possible to mine in large open pits. For example it is estimated that within 10 years the world supply of copper ore will be 90% from underground block caving operations, whereas currently it is 90% from open pits. This requires a step change in technology, a significant research effort, and retraining at all levels of operation. A short example of some of the computer modelling being developed in the UK for the simulation and design of block caving was demonstrated.

The impact of the rapidly growing economy of China has had a profound effect on the global flow of raw materials and their prices and on energy consumption (mostly coal-powered). The non-energy prices will probably moderate in due course but at the recent conference in London "Mines and Money 2006" it was predicted that the current high index value of base metal prices would continue to rise for a year or so, then decline to approximately current (late-2006) prices. These are historically very high. There are several consequences here – the increased prices will lead to more efficient usage (but not always immediately); there will be some substitution of cheaper alternatives; there will be concerns about security of supply of strategically important materials (including energy materials such as uranium) and recycling will become increasingly important (eg about 80% of lead comes from recycling, but not nearly as good for other valuable metals). Mining technology has a potentially critical role to play in reducing net $CO_2$ emissions in China and worldwide, with clean coal burning, in-situ gasification and sequestration. The UK has a significant capability in these areas and, in a related project, the planned Peterhead power station, will have $CO_2$ sequestered under the North Sea.

The impact of global warming and consequent need to reduce greenhouse gas emissions will affect the mining industry as much as others. The industry will increasingly need to reduce unit energy inputs per tonne mined, processed and shipped. For high value materials the market will remain global. For low value materials such as aggregates and some industrial minerals (gypsum, carbonates, potash) the energy cost of transport will increase pressure for local resourcing. In the UK this could mean opening currently abandoned quarries.

The global mining industry is rightly under increasing pressure to address the social, environmental and economic impacts of their operations on affected local communities. It is recognised by all responsible mining companies that they need a well-planned post-closure programme with adequate financing to meet future/unforeseeable needs, as a condition to have "permission to mine". This approach is now embedded in the Equator Principles to be applied by signatory financial institutions (eg World Bank) as conditions for approving project financing. Further, the Extractive Industries Transparency Initiative (EITI) is the (currently UK Government led) effort to address transparency and corruption.

The mining industry is truly global and has a direct impact on virtually every country in the world. The turnover of each of major companies (eg Anglo American, BHP Billiton, Rio Tinto, Xstrata) is typically in the tens of billions of dollars. The turnover of the whole industry is in the hundreds of billions of dollars. Typically the large mining companies and suppliers each have tens of thousands of direct employees and hundreds of thousands of closely dependent employees and their families.

The UK extractive industry is very significant if oil and gas are included, with an annual turnover of about £25 billion per year, of which over £20 billion is in oil and gas. Coal accounts for about £1 billion and quarrying for aggregates about £2.5 billion. There are small but significant mining and quarrying operations, which produce industrial minerals such as limestone, potash, gypsum, salt and clay. There are tens of thousands of employees. The UK quarrying industry, like others, has much international ownership. Although this may affect investment decisions within Europe, eg if UK becomes relatively difficult in which to operate, the energy saving agenda should favour local sources.

## To conclude:

The global mining industry is key to future supplies of materials and minerals, which are essential for development. The industry has a major role to play in the transition to more sustainable patterns of development – and this needs top-quality skills. High prices and the need to reduce energy consumption at all stages will lead to profound changes in practice.

The UK has major roles to play in Mining Engineering domestically and globally. In the UK, reduced energy consumption should lead to more local sourcing of aggregates. Globally the community of UK-based mining finance specialists and technical consultants play major roles of importance to UK earnings and influence.

There is a serious global shortage of mining engineering professionals, which could get worse. UK universities are playing a small but significant role in meeting demands.

UK science and engineering university courses are undermined by the shortage of school students studying suitable subjects. Government policy and industry support are vital to redress the problem.

# The Role of the Science of Corrosion in Extending the Useful Life of Materials

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## Introduction and History

The International Standards Organisation (ISO) definition of corrosion is “A physico-chemical interaction between a material and its environment which results in changes in the properties of the material and which may often lead to impairment of the function of the material, the environment, or the technical system of which these form a part". This is, essentially, a statement of the thermodynamic tendency for materials to react with their environment, an understanding of which has clearly been around since at least the Bronze and Iron Ages. However, the application of corrosion protection dates from Humphrey Davy (of the Miners’ Lamp). Known as “Father of Electrochemistry”, the Admiralty commissioned Davy in 1823 to investigate the corrosion of copper sheathing on the hulls of wooden vessels. In 1824 he instigated the first known application of cathodic protection (CP) by utilising iron or zinc ingots attached to the copper sheathing. Unfortunately, while this was a technical success, and effectively prevented the corrosion of copper, it was a practical failure as it eliminated the anti-fouling properties of the copper hull! Today, CP (using zinc or aluminium anodes) is the preferred method of protection of almost all marine (and many other) structures.

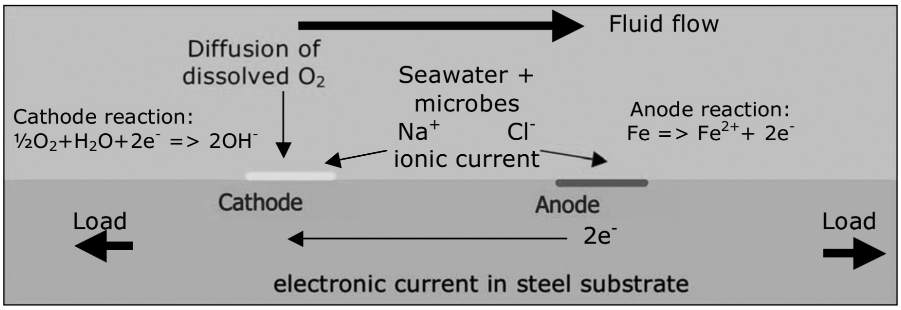

*Figure 1.*

## Corrosion Processes

Following on from Davy, corrosion was first understood as (and proven to be) an electro¬chemical process by Ulick Evans (known as the “Father of Corrosion”) in the Goldsmiths’ Laboratory at The University of Cambridge in a research career lasting over 60 years from 1919 to 1980.

What Evans discovered was that corrosion consists of two reactions that happen at the same time, and at the same rate but not in the same place. These are exactly the same reactions that occur in a standard dry cell battery, where corrosion of zinc (at one terminal) is supported by an oxidant such manganese dioxide or oxygen from the air (at the other terminal) causing an electrical current to flow. Thus, all corrosion reactions involve the flow of electrical current and are affected by a range of materials and environmental influences, some of the complexity of which is indicated in the cartoon (Fig 1) showing steel corroding in seawater.

Corrosion is thus fundamentally multi- and inter-disciplinary that requires knowledge of:

Materials science (polymers, ceramics and metals), solid-state physics, organic chemistry, electrochemistry, mechanical chemical and civil engineering, microbiology, tribology, surface science, surface engineering, etc;

Engineering appreciation of applications and functions, etc;

Resource conservation, asset management, lifetime extension, recycling, etc.

With the key drivers being: engineering application, cost reduction, safety, legislation, etc, together with genuine scientific endeavour.

## Costs of Corrosion

The costs of corrosion to industrialised economies are very significant. The Hoar Report, commissioned in 1969 by Tony Benn and reporting in 1971, put this cost to the UK economy at between 3.5-4.5% of GNP. A more recent UK survey, reporting in 2000, estimated the cost as somewhat less at between 2.5-3.5%. The significance of this amount is hard to grasp, so another way to consider it is that if the monies currently spent on maintenance and other repairs due to materials degradation were NOT spent, then the entire physical infrastructure of the country, (eg machinery and buildings, etc) would cease to function, or lose ALL economic value, in about 30-40 years. Similar surveys in USA, Japan and Germany, have come to essentially the same conclusions.

All such surveys have consistently estimated that 25-30% of corrosion losses could be eliminated by the application of effective corrosion control systems and procedures and that research in reducing such losses is highly cost-effective. The main outcomes of the Hoar Report were the establishment, at the former UMIST (now The University of Manchester), of The Corrosion and Protection Centre and, as a campus company CAPCIS Ltd. These currently comprise world-leading centres of excellence in, respectively, academic research into corrosion science and in the control of corrosion and in corrosion advice and consultancy to industry.

## Lifetime Extension of Materials

The science of corrosion is vital for the successful application of many modern engineering and technical systems. Such applications include those that use positive aspects of the corrosion process to develop (or engineer) particular desired functions on material surfaces. A well-known example of this is titanium, the surface of which can be treated using a corrosion process (anodising) to give attractive coloured finishes used in jewellery. Some other examples are tabled below (Fig 2).

| Beneficial Corrosion Process | Technological Application |
|---|---|
| Passivation of semiconductors | Micro-electronics |
| Surface treatment of aluminium | Adhesive bonding of structural alloys |
| High-temperature protective coatings | Efficient gas turbines (e.g. aero-engines) |
| Acid etching of aluminium | Lithographic printing plates |
| Corrosion of zinc | Dry cell batteries |
| etc. | etc. |

*Figure 2.*

An important example of the beneficial application of corrosion is in the surface treatment on the aluminium alloy. In aerospace and automotive applications, increasingly adhesive bonding of structures (as opposed to welding) is being carried out. This can be seen in the electron micrographs (Fig 3), which provide visualisation of the position of joint failure (b), showing that the presence of the pre-treatment (a) has **prevented** failure, at the metal-adhesive interface.

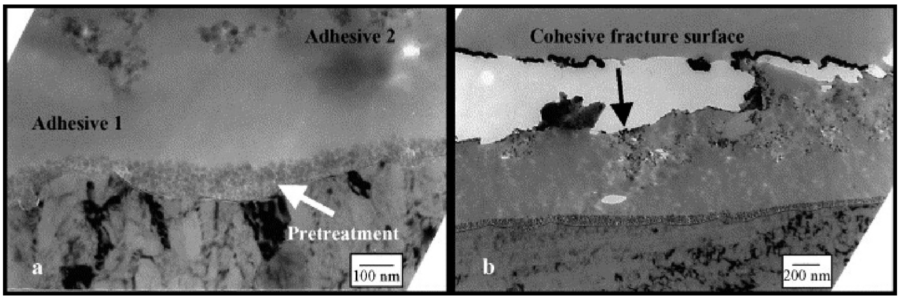

*Figure 3.*

Conventionally, the main reason for the application of corrosion control technology (of which protective coatings, including paints, are the most familiar) is to extend the economically useful life, or to increase the performance, of a material; hence, to reduce the cost of the technical system. Although, corrosion can never be completely stopped, it **can** be effectively controlled for a longer or shorter time by interfering with the material or environment in some way. In total, there four main methods of corrosion control:

Electrochemical modification (eg cathodic protection)

Chemical modification of the environment (eg inhibition of corrosion)

Application of a protective coating (eg paint, galvanising, etc)

Appropriate selection and design of material (eg selection of the correct type of stainless steel – there are probably over 100 different specifications).

## Skills Training and Certification

One important message is that a significant fraction of corrosion costs (up to 25%) can be saved by correct application of current technologies. For example, modern paints, if correctly applied to properly blast-cleaned bare steel, can have lifetimes exceeding 20-25 years before re-coating is required. This compares with 5-7 years for conventional paints applied as touch-up over existing paint. For something like the Forth Bridge, where the painting proverbially never ends, a significantly longer life translates into tens of millions saved in maintenance costs over the coating lifetime. However, this can only be achieved with a properly trained and skilled workforce together with professional inspection of the finished coating. A new scheme, pioneered by the UK Institute of Corrosion, and developed with partners such as Network Rail and The Highways Agency, is intended to upgrade the status in the industry from painters (who handle commercial decorating) to industrial coaters (trained to apply correctly industrial coatings to structural steelwork). It would greatly assist this introduction if, as in some other countries, training in corrosion control was compulsory.

## Challenges to Wealth Creation

Despite the undoubted economic importance of corrosion and the corrosion control industry to life extension and resource minimisation, the main challenge lies in the poor image that corrosion has. Nevertheless, images can and must be challenged and changed by education and upskilling of companies and individuals at all levels.

As a branch of materials science, we in the UK are world-leading in the science and engineering application of corrosion. We must acknowledge this lead and should not relinquish it to emerging or more vibrant economies. Thus, future wealth creation relies on technical, engineering and educational services predicated on retaining an indigenous talent and knowledge base. We must not "outsource" our strategic knowledge in a knowledge-based economy.

# How Materials can help solve Major World Problems

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## Introduction

It is no accident that the intelligent use of materials is one of the fundamental characteristics by which the development and impact of the human species on the planet is identified and described from archaeological records. Indeed it is this special ability to utilise materials that has made a relatively comfortable human existence in an otherwise hostile environment what it is today, to the extent that current living standards are widely accepted as an attainable norm for much of the human species. We are entirely dependent on materials to satisfy our desire for improved standards of living. The extra demand from growth in the human population and our increasing longevity don't make this any easier. There is also an urgent requirement to manage and minimise the detrimental impacts of increasing human activities on the global ecosystem.

Major world problems that are of particular concern relate to the improvements demanded in human health where elderly people have come to expect to be able to maintain healthy and active lifestyles for as long as feasibly possible. This inevitably contributes to demands for the provision of reliable and relatively inexpensive energy supplies that are required to underpin the economy and lifestyle of the human population. Fossil fuels are an essentially finite resource and unless managed in a more environmentally-friendly manner worldwide could precipitate a hostile global warming event never previously experienced by humanity. It is therefore essential to minimise the negative impacts of increased atmospheric concentrations of $CO_2$ and develop alternative fuels and energy sources. Hence an innovative range of new materials technologies using new materials will have a key role to play in providing a sustainable future for humanity in the planetary environment.

## Biomaterials

The wide range in the application of biomaterials to human health[1] is clearly demonstrated in Fig 1[1], where artificial hips enable the lame to walk and artificial arteries bring new life to the dying and thereby greatly improve the quality of life of many people. Many of these recent developments arise from UK successes in developing biomedical materials.

**UK Successes in biomedical materials**
Development of first successful joint replacements in 1960's
Ceramic coatings exported around the world
UK development of novel polymers and degradable materials
Artificial organ research UK led

**Biomedical Implants**
**1970**
Only joint replacements
1,000 operations per year
Implants
- Metal
- Polymer

Non-reactive materials
Artificial joint life – 10 years

**Today**
Soft and hard tissue replacement
External and internal systems
250,000 operations/year
Artificial bone materials
Joints perform longer and better
Corneal lenses - hydrogels
Skull – polymer/ceramic composites
Heart valves - polymers
Stents –shape memory alloys
Plates and screws – biodegradable polymers
Hips – ceramic coated metal
Knees – metal & polymer

## Global Warming and the coming Energy Crisis

A portfolio of new materials science measures is now required:

- to improve the efficient use of the energy that we currently generate but utilise in a wasteful manner;
- to help with an innovative generation of safe and reliable nuclear reactors, such as the Pebble Bed Reactor, for example, which can be modularised and conveniently located within the community requiring electricity and heat from such a source; and
- to help increase the efficiency and reliability of electrical power from renewable sources, such as wind and wave. Materials science also has a key role to play in improving solar cells, fuel cells, and in developing nuclear fusion.

## Next Generation Lighting

This is an example of an innovative project that I am involved in by application of materials science to next generation lighting. The project clearly demonstrates the urgent need for a new UK National Programme on next generation lighting which is entirely consistent with and underpins our national goals and targets for reduction of $CO_2$ from the generation of electricity.

Lighting is one of the biggest causes of greenhouse gas emissions, creating 1,900Mt of $CO_2$ emissions annually from power stations, which is 70% of the global $CO_2$ emissions of all cars and three times more than emissions from aviation (International Energy Agency Report, 2006). Currently the US consumes 30 times as much lighting per person as India and 1.6 billion people have no access to electric light. The projected global demand for lighting will be 80% higher by 2030 (IEA Report, 2006).

The Tungsten light bulb, which accounts for 79% of global lamp sales by volume, is only 5% efficient – 95% is lost as heat which stays near the ceiling. It has been suggested (Letters, The Times, 17 July 2006) that the sale of filament light bulbs be banned, hastening a changeover to the low-wattage, long-life fluorescent variety. However, compact fluorescent tubes are only 15% efficient and the efficiency of long fluorescent tubes is only 25%.

There is a need for ultra-efficient lighting: 20% of all electricity consumption in the UK is for lighting and in Thailand over 40% is for lighting. There is a new man-made material, Gallium Nitride, first used in 1993, which emits a bright light of any desired colour if mixed with Indium and UV light if mixed with Aluminium. The efficiency of GaN-based white LEDs in normal conditions is currently 25%, though in the lab we can achieve 40%, and the target is 50-80%. According to a US Department of Energy report if 50% of lighting in the USA is replaced by GaN-based LEDs (White) 41 GW of Electricity will be saved and 41 power stations can be closed.

Ultra-high efficiency white GaN-based lighting gives perfect colour rendering – like sunlight. Its use would reduce $CO_2$ emissions by over 10%, giving savings of £1.7 billion in annual energy costs. We could close about 8 power stations in the UK. It operates on a 4V circuit for lighting which is ultra-safe and cheap. In the developing world it can be powered by solar cell batteries. A single light lasts for 10 years continuously and for 60 years at 4 hours per day. There are national programmes in Solid State Lighting in Japan, China, Korea and the USA but there is no national programme in the UK.

## Summary Overview of Materials in the UK

The UK undertakes world class research in many areas and manages world class industries in some areas. University-industry links are good and the organisational structure is good. However, there are manpower problems for industry and universities, and there are also funding problems for universities. I visited Rolls Royce Submarines last week. They employ 980 scientists and engineers, many of them materials scientists and engineers. They are mainly aged between 40 and 60 years and the MoD requires all their employees to be of UK origin. There are recruitment difficulties for industry, especially for the smaller SMEs, who find the supply chain has been sucked dry by the primary industries they are working to support. For example, Thomas Swan Scientific Equipment Ltd wishes to recruit 2 materials engineers for exports. They have found one from China but have been unable to find another after nine months.

Manpower problems also exist in universities. For example, one university in Singapore produces more materials graduates than all UK universities combined. All of my post-doctorate students are from overseas – with usually not a single UK applicant, while 80% of my first year research students are from overseas.

## Conclusions

The HEFCE grant per undergraduate needs to be increased for Engineering and Physical Sciences students, if necessary by a redistribution of existing funds. Materials is a key subject for our wealth, health and for reducing global warming. It is a high priority topic in the USA, Japan, China, and needs higher priority in UK with increased funding for Materials allocated to EPSRC and the DTI.

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[1] Full figure available at http://www.scienceinparliament.org.uk/sip.asp

## *In discussion the following points were made:*

Depletion of the professional base results from the lack of a clear career prospect ahead of potential students of materials science. Graduates are increasingly seeking financial reward from their studies of metallurgy through employment in finance houses. The annual trawl around universities by companies seeking graduates for employment focuses on graduates with 2-3 years' experience, with less interest shown by companies in recent graduates due to the inherent costs involved in their training. Everyone wants experience, but no one is prepared to pay. Support for graduate apprentices should be restored. SMEs have the greatest difficulty in recruiting, as the defence-related industries that require UK nationals have had first pick. Students are not all hungry for money, but it is important. You cannot require someone to work as a post doc for 10 years without the prospect of permanent employment. No one wants to be a temporary worker for ever. Starting salaries should be raised and a reasonable career path should be offered. In some schools students are steered by their teachers into easier A levels to improve overall ratings. Universities must also play their part and recognise the importance of recruiting students taking hard subjects and cease seeking students with A grades from soft subjects just to improve their overall intake ratings. Every university makes a loss on training engineers and scientists due to the inadequacy of the current funding system when paying for laboratories as well as lecture halls. Finland, however spends 4% of GDP on research in science and engineering, compared with 2% in the UK, and boasts a world class company, Nokia, that provides high quality employment in materials science for Finnish scientists and engineers, based on the mobile phone, the original technology for which was developed in the UK.