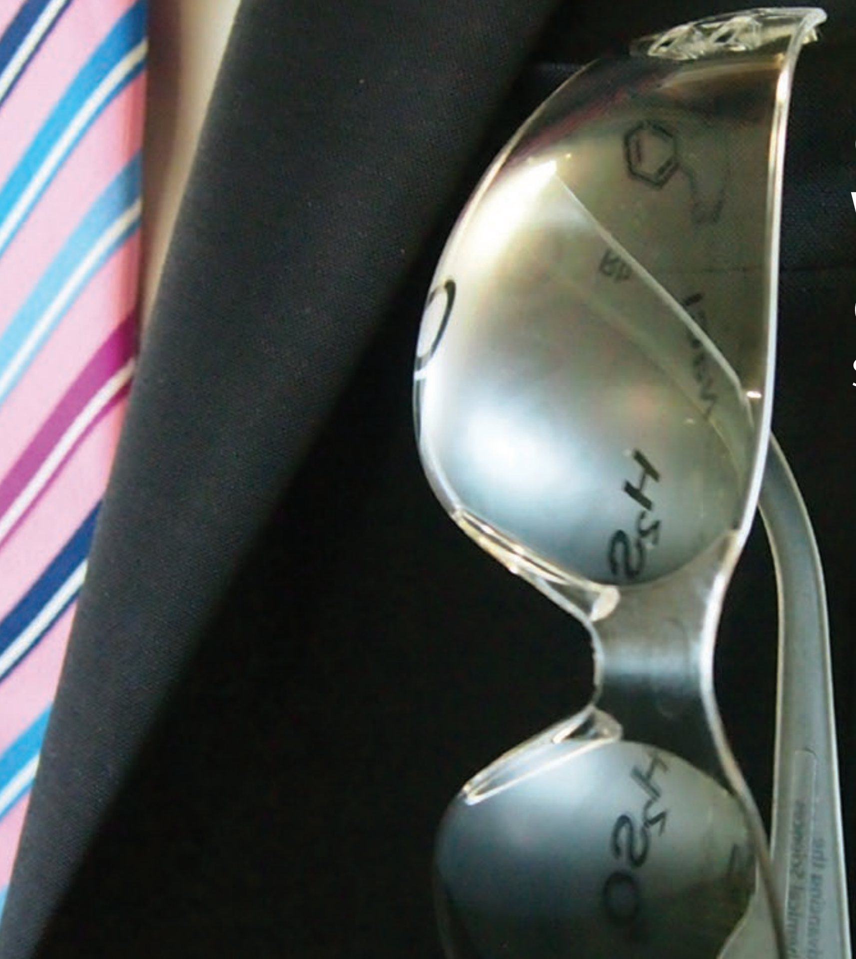

Chemistry: We Mean Business

Creating growth by staying ahead in science

RSC | Advancing the Chemical Sciences

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Creating growth by staying ahead in science

The UK needs a long term commitment to our knowledge economy if we are to stay ahead in the global race. Our world leading science produces growth and jobs, but we are in danger of falling behind our global competitors. To prevent this, the government should commit to a long-term plan to fund science at internationally competitive levels, consolidate innovation mechanisms to convert research into growth, and ensure people have the skills to take up new jobs in the innovation economy.

As well as driving growth, science and innovation provide solutions to challenges faced by our society. This document presents five case studies that show how the chemical sciences contribute significantly to economic growth and help address global challenges in energy, food production, water, healthcare and scarce natural resources.

Britain's world-leading science base creates growth and jobs. According to Nesta[1], innovation drove 63% of UK growth between 2000 and 2008. Chemistry-using sectors contribute significantly to the economy. Government figures show that the chemicals and pharmaceuticals sectors alone made up 1.9% of gross value added to the UK economy in 2011 (reaching £27bn).[2] The flourishing industrial biotechnology industry, for instance, is predicted to contribute £4-12bn by 2025.[3]

UK science has a record of punching above its weight internationally. The UK's combined public and private spend on R&D represents only 3% of the global total, but it is home to 4% of the world's researchers and contributes to 6% of published papers.[4]

However, we are in danger of falling behind our global competitors. The USA and Germany currently invest around 2.5% of GDP in research and others, such as Korea at 3.7%, invest even more. By comparison, the UK currently invests only around 1.7% of GDP.[5] There is growing evidence to suggest that the UK science base is at its limit of efficiency. Serious and irreversible damage will result if we do not re-invest now.

When ranked by the capacity to convert invention into economic growth, the UK is scored as an 'Innovation Follower' within the EU, lagging behind the EU's 'Innovation Leaders',[6] which include Germany and Sweden.

To continue to make its important contribution to the economy, scientific research and the components of the economy using scientific skills require a continuous supply of talent. However, it is predicted that we are far from capable of meeting our future needs. Cogent, the Sector Skills Council, has estimated that chemistry-using industries require 33,000 apprentices and 37,000 graduates by 2020, yet projected supply is only 21,000 and 18,000 respectively. Unless something is done to address this shortfall areas as diverse as pharmaceuticals, energy, materials science, nanotechnology, industrial biotechnology, process engineering, the life sciences, and agriculture, will struggle to meet our national need.

To secure and maximise economic growth through science and innovation, we need a long-term commitment to our knowledge economy to win the global race.

To achieve this, the government should:

1. **Commit to a long-term plan to return science funding to internationally competitive levels:**
   - Set a goal to raise UK Government research spending to 0.7% of GDP (the current EU average) by the end of the next Parliament in 2020.

2. **Consolidate innovation mechanisms to help convert research into growth:**
   - Broaden the Technology Strategy Board's (TSB) role to cover coordination across innovation.
   - Carry out a strategic review of the current capacity, deficit and opportunities within each of the 'Eight Great Technologies'.
   - Expand Knowledge Transfer Partnerships to further increase their engagement with small and medium enterprises (SMEs).
   - Provide tax incentives for SME research activities, and financial support for SMEs to take on industrial placement students.

3. **Ensure people have the skills to take up new jobs in the innovation economy:**
   - Commit to continuing the Initial Teacher Training (ITT) scholarship scheme for chemistry teachers beyond 2013/14.
   - Establish a science specialist in every primary school.
   - Increase investment in and recognition of vocational routes to employment in science.

Commit to a long-term plan to return science funding to internationally competitive levels

The UK is not in a position to be truly internationally competitive whilst R&D funding is at a level significantly lower than that of its competitors. Long-term investment in science will ensure that the UK is not left behind in the global race, and will provide a secure research ecosystem to attract business investment and top-class researchers.

Investment is needed from both public and private sources, but academic research[7] and international comparisons[8] show that government funding encourages additional input from business.

The UK's public spending on R&D has long been declining relative to competitors, and now lies at only 0.57% of GDP, noticeably lower than the averages of 0.7% for the EU-27, and 0.8% for the G8 and the OECD.[8]

The 2010 Spending Review and 2013 Spending Round both resulted in a cash freeze for the science budget. This amounts to a real-terms cut of greater than 10% up to 2016. The full effect of these decisions is yet to be seen, but there are already reduced numbers of grants being awarded by research councils – narrowing the research base upon which innovation can prosper – and reduced numbers of PhD students being funded – decreasing the number of 'coal face' researchers.

Returning capital to 2010 levels and protecting it with respect to inflation until 2020 were positive signals from the government, but real term increases in both capital and revenue are needed to ensure our competitiveness.

To restore confidence and attract business investment, a long-term commitment to R&D support is needed. **The UK should set a goal to raise government spending on R&D to 0.7% of GDP (the current EU average) by the end of the next Parliament in 2020.** This is not an insignificant rise, but is achievable, requiring only a 3% year-on-year increase in spending relative to GDP.

Consolidate innovation mechanisms to help convert research into growth

The UK's innovation landscape is complex: ownership is distributed across the research councils, the Technology Strategy Board (TSB), Higher Education Funding Council for England (HEFCE), Local Enterprise Partnerships (LEPs) and the EU. This makes it difficult to have a coherent strategy, difficult for other bodies to support government initiatives, and difficult to monitor and assess progress holistically.

To maximise the impact of existing innovation support, a more joined-up approach is needed. **The government should broaden the TSB's role to cover coordination across innovation.** It would implement processes to follow up investment with specific, nationally-comparable success metrics, allowing optimisation of the various innovation mechanisms and, consequently, maximum economic growth.

The government's 'Eight Great Technologies' also offer an opportunity to bring coherence to our national innovation policy. **The government should carry out a strategic review of the current capacity, deficit and opportunities within each of the 'Eight Great Technologies', performed under a similar set of criteria as the Synthetic Biology Roadmap.**[9]

Bringing businesses together with universities offers substantial economic value, so academics should be helped to develop the skills to take research to the marketplace. Charitable initiatives can help – for example, the Royal Society of Chemistry has established the Linked Fellowship Exchange Scheme, which encourages researchers working in drug discovery to engage with adjacent sectors and disciplines. The TSB's Knowledge Transfer Partnerships (KTPs) have also been successful, and **the government should expand KTPs to further increase their engagement with small and medium enterprises (SMEs)**.

UK SMEs are a great potential source of innovation, but they need support to nurture this value. Many innovations produced by SMEs do not make it to market because of a lack of capital and skilled personnel. **The government should provide tax incentives for SME research activities, and financial support for SMEs to take on industrial placement students.**

Ensure people have the skills to take up new jobs in the innovation economy

Sustainable research and innovation require a strong and steady supply of talented people.

At the secondary school level more skilled teachers are needed. The Royal Society of Chemistry is a partner in the government's chemistry Initial Teacher Training (ITT) scholarship scheme for secondary teachers, for which £2.7m funding is planned this year. **This type of investment must be sustained, so the government should commit to continuing the ITT scholarship scheme for chemistry teachers beyond 2013/14.** The Royal Society of Chemistry will work with the government to further develop the programme.

The shortage of primary school teachers who have a science background also needs to be addressed. The Department of Education plans to provide financial incentives for primary specialist trainees with good A-levels in science, technology, engineering, and maths. However, only 3% of qualified primary school teachers in England have science degrees.[10] **To ensure the availability of high quality primary science education, a science specialist should be established in every primary school in the UK.**

Apprenticeships in science should be supported to build a diverse talent pipeline and offer an alternative to higher education for entry into science-based industries. The Royal Society of Chemistry (in partnership with the Science Council) accredits science apprenticeships and awards professional recognition for apprentices, technicians and technical scientists, and would like to see the government take a similar proactive stance on vocational routes to careers in science. **The government should ensure that the initiatives to support vocational routes to employment in UK sectors provide further support to science-based industries.**

1997

first paper on the use of nanopores as sensors published

2005

Oxford Nanopore set up

>£105m

investment raised from private funders

>140

people employed across four locations

>350

patents/patent applications owned or licensed by the company

Personalised medicine

Personalised medicine involves selecting the best treatments for individuals on the basis of their genetic make-up and an understanding of how proteins interact with pharmaceuticals. Achieving this requires better access to molecular information about DNA, RNA, proteins and a range of other molecules. It is important to analyse these molecules in a research setting to understand disease, and in a clinical setting to direct treatment of patients.

Oxford Nanopore Technologies Ltd is in the final stages of developing devices to provide fast access to molecular information to a wide range of researchers and clinicians.

Oxford Nanopore Technologies Ltd is developing the devices GridION™ and MinION™, using nanopores to analyse single molecules such as DNA, RNA or proteins. A nanopore is a very small hole, or channel, in a cellular membrane that is one-billionth of a meter wide. This diameter is about the same size as the width of DNA molecules, meaning the DNA can thread through the hole. When this happens, unique electrical signals are generated by the individual units that make up DNA. These signals can be decoded and the DNA sequence determined. In this way, the device is designed to determine the make-up of whole genomes from plants, humans or small organisms.

The company was founded on the basis of years of publically-funded fundamental research carried out by Hagan Bayley, a professor of chemical biology based at Oxford University, and colleagues at other institutions. The company has since amassed intellectual property (IP) collaborations that include Cambridge University, Harvard University, Brown University, University of California and Boston University.

Initial investigations into the behaviour of nanopores were carried out by Hagan's research group, which at the time was based in the USA. In 2003, Hagan moved back to the UK, encouraged by the construction of the Chemistry Research Laboratory (CRL) at Oxford University. The state of the art facility was supported by an injection of capital expenditure by the UK Government and from funds raised from other donors.

"The state-of-the-art CRL building was a huge enticement. Indeed, it has provided both world-leading research facilities, and an attractive location and environment, which are a big plus as I've spent most of my waking hours in the place!"

Professor Hagan Bayley FRS, FRSC

In 2005, Hagan began investigating the idea of setting up a spin-out company. Locating the company at Oxford made sense because of easy access to a nearby university and well-equipped science parks. Today, Oxford Nanopore Technologies Ltd is a world leader in nanopore technology and employs >140 people. The company aims to deliver devices for molecular analyses, one of which (MinION™) will be disposable and will connect to a computer USB. New research taking place at Oxford will contribute towards the new and exciting era of personalised medicine allowing people increased access to rapid, cheap and accurate health information.

>$2bn

cost of sequencing the first human genome

>$5000

current cost of sequencing a full human genome

>3bn

DNA base pairs in the human genome

£60m

funding committed by the Medical Research Council over four years towards personalised medicine initiatives

Solar energy

1 hour
time in which more energy from the Sun falls on the Earth's surface than we currently use in a year from fossil and nuclear fuels and all renewable energy sources combined

170%
potential growth in global PV market by 2017

3rd
largest renewable energy source in terms of global installed capacity

>100 GW
electricity produced by globally installed PV, equivalent to the energy needs of over 30m European households

~€58bn
value of European PV market

In December 2012 the Department of Energy & Climate Change identified solar photovoltaics as a key technology in the UK Renewable Energy Roadmap for the first time. The UK is in a particularly strong position to be a global leader in next generation photovoltaic (PV) technologies.

Chemistry will play a key role in improving current solar energy technologies and in developing new ones.

Chemistry is involved in the development and improvement of current wafer and thin-film technologies through:

- the development of lower energy, higher yield and lower cost routes to silicon refining;
- creating more efficient or environmentally benign chemical etching processes for silicon wafer processing; and
- supporting the development of processes to improve deposition of transparent conducting film onto glass.

In addition, chemical science research is crucial for new technologies by:

- providing alternative materials and materials recovery techniques to reduce dependence on critical raw materials or high energy manufacturing processes; and
- improving efficiency of organic and dye-sensitised solar photovoltaic devices, which are potentially lightweight, cheap and made of abundant materials.

An audit in 2011 revealed more than 70 companies in the UK – ranging from SMEs to large multinationals – that are involved in photovoltaics manufacturing at different points of the supply chain. Their involvement ranges from materials production to assembling arrays of solar panels.

Multinational companies with solar-related R&D centres in the UK include Merck, Sharp, NSG Group and Cristal Global.

The UK also has notable academic research expertise in next-generation photovoltaics, including organic photovoltaics and dye-sensitised solar cells. There is also substantial photovoltaics-associated university spin-out activity through companies such as Eight19 (Cambridge), Molecular Solar (Warwick), Ossila (Sheffield), Oxford Photovoltaics, Solar Press (Imperial).

In 2012, Cardiff-based G24i Power launched the world's first light-powered tablet PC keyboard, which presents the first major application of dye-sensitised solar cells.

Tata Steel Europe and Australian company Dyesol are undertaking a flagship project in Wales to integrate dye-sensitised solar cells onto steel roofing. Tata Steel supplies 100m m^2 of roofing and wall material annually, illustrating the tremendous potential of building-integrated photovoltaics in the UK.

2012
Department of Energy & Climate Change identified solar PV as a key technology in the UK Renewable Energy Roadmap for the first time

£12.7bn
planned investments in UK renewable energy from 2011-2012

270,000
UK jobs supported by the renewable energy sector

400,000
UK jobs in renewable sector estimated by 2020

53m
tonnes of CO_2 saved annually by total globally installed PV

Food production

9bn
expected world population by 2050

2
number of people 1 hectare of land fed in 1960

6
number of people 1 hectare of land will need to feed by 2050

>40%
drop in global crop yields would occur without the use of crop protection chemicals

90%
growth in demand for field crops predicted by 2050

Providing enough food for a growing population is a major global challenge. By 2050, the world's population is expected to reach 9bn and it will be essential to:

- raise agricultural productivity;
- use water, nutrients and land more efficiently; and
- protect crop yields.

Chemistry has a clear and central role in meeting these demands, feeding into a variety of related areas ranging from crop protection and soil science to veterinary medicine.

Crop protection chemicals – mainly herbicides, fungicides and insecticides – provide farmers with a cost-effective way of improving the yield and quality of their crops. The chemical sciences are required to invent and develop these products.

Invented in the UK, Azoxystrobin is the world's number one fungicide. Its design was inspired by the structure and activity of a family of naturally occurring fungicides, and it is now used in a wide variety of crops around the world. It is selective, stable, easy to apply and safe for consumers and the environment.

"A reliable supply of food for the growing world population is critically important. Agricultural fungicides, of which Azoxystrobin is the leading example, make a key contribution to the yield and quality of numerous crops."

Professor John Clough, Chemist at Syngenta, MRSC

UK-based chemists at Syngenta discovered and developed Azoxystrobin. The project directly supported jobs and investment in the UK. Syngenta is a global company and employs more than 2000 people across six UK sites. They manufacture several of their leading products in the UK. The global supply of Azoxystrobin, for example, is manufactured at Grangemouth in Scotland.

By increasing yields under different climatic conditions in many parts of the world, Azoxystrobin also optimises land use and the costs of crop production. It takes chemists and other scientists many years to invent and bring a new product to market. There is always scope for further research, aimed at identifying new and improved products. Chemistry and the skills of chemists will continue to be essential in the discovery of new products designed to 'feed the world'.

50%
of UK arable farming area is wheat crop

9yrs
estimated time to develop and register a new crop protection product

120
types of crops can be protected by Azoxystrobin

100
countries where Azoxystrobin is available

$1bn
annual global sales of Azoxystrobin

2000
people employed across six UK sites

Critical raw materials

£4.72bn
worth of minerals were imported into the UK in 2010

£150m
worth of precious metals in 90m unused mobile phones in UK households

15%
of gold and 10% of platinum from electronics are recycled

€1.32tn
the value to the EU economy of sectors dependent on access to raw materials

5%
of known metal reserves are found in Europe

The supply of a number of elements and minerals essential to modern technology is at high risk. Whereas this does not necessarily mean that they are geologically scarce, their supply might be geographically concentrated or they might be produced as a by-product of another mineral that is subject to fluctuations in demand.

Making the most of valuable materials and reducing our dependence on expensive critical raw materials will support the businesses that rely on them.

The chemical sciences make a vital contribution to improving material efficiency through reusing, recycling, and reducing the use of expensive or critical elements and materials through:

- processes for recycling raw minerals;
- the development of alternative materials that avoid the use of critical raw minerals;
- improved extraction and processing of raw minerals; and
- a reduction in energy consumption in industrial and manufacturing processes.

Chemistry can also drive improvements in resource efficiency by characterising the physical and chemical properties of existing materials. A thorough understanding of such properties enables substitution with alternative materials.

Durham Graphene Science

Graphene is a promising new material for energy, electronics and structural composites. The global market for its products is predicted to be worth £650m by 2022 and graphene research has secured £50m recent public funding in the UK, which provided the capacity for up to £1bn more in funds from the EU. The majority of graphene produced so far originates from the critical mineral graphite. One of the biggest challenges facing the application of graphene is producing enough high-quality material to supply the growing demand. As an alternative to sourcing graphene from graphite, Durham University spin-out Durham Graphene Science has developed a process to synthesise graphene from ethanol. This process can produce tonnes of high-purity graphene per year.

Metalysis

Tantalum is an important metal used in high-value electronics, ranging from mobile phones to pacemakers. Metalysis, a spin-out from the University of Cambridge, developed a new way to produce tantalum from metal oxide using electrolysis. The resulting process is cleaner, cheaper and easier to use than currently available methods. The same technology can also be applied to titanium production and is expected to be applied to rare earth metals in the future. This process reduces the costs of metal powder production and will open up new markets for advanced manufacturing, including 3D printing.

1 in 3

UK manufacturers cite limited access to raw materials as a top business risk

14

critical raw materials identified by the EU in 2010 and examples of their uses

Antimony:	Battery
Beryllium:	Loudspeaker
Cobalt:	Paint
Fluorspar:	Camera lens
Gallium:	Microwaves
Germanium:	Fibre optic
Graphite:	Steel
Indium:	LCD screen
Magnesium:	Photocopier
Niobium:	MRI scanner
Platinum group metals:	Car
Rare earth elements:	Laser
Tantalum:	Mobile phone
Tungsten:	TV

Water treatment

11bn
litres of wastewater produced in the UK every day

71%
of the Earth's surface is covered by water

1%
of the world's water can be used for drinking

1.4m
children die every year from drinking unsafe water

9bn
projected global population by 2050

Water treatment and reuse are vital to ensuring that we have sufficient water to support a growing global population. Emerging UK companies like Arvia are developing innovative technologies to treat water in more cost-effective and energy- efficient ways.

With increasing concern about the scarcity of water supplies for drinking, sanitation, agriculture and manufacturing, there is a growing need to use water more efficiently, including the development of new methods for water treatment and reuse.

In the UK, the sewer network extends over 340,000 km and collects more than 11bn litres of wastewater every single day. This water has a wide range of contaminants that need to be removed, involving processes that are currently highly energy intensive. A key challenge for securing future clean water supplies is to make wastewater treatment energy-neutral and to enable the beneficial reuse of treatment by-products.

The global water treatment market was worth approximately £12bn in 2010 and is predicted to grow to £18bn by 2015. With the global population, and therefore demand, set to rise to 9bn by 2050, it is a market that will continue to grow for the foreseeable future.

Chemistry is vital in understanding and mitigating the effects of water contamination and its subsequent impacts on both the environment and human health. Chemistry can also support the development of more efficient desalination processes, purification technologies and portable technologies for analysing and treating contaminated groundwater.

Arvia

One example of a recent technological advancement in the removal of wastewater contaminants is the method used by Arvia, a University of Manchester spin-out company. Initial chemical and chemical engineering research supported by public funds was critical in developing this process.

Arvia's method is designed to completely remove carbon-based contaminants such as oils, dyes and fertiliser, which represent significant sources of impurity. The Arvia treatment cell contains the proprietary material Nyex™, which collects all carbon-based material. When an electrical current is applied, the Nyex™ destroys these chemical compounds by turning them into water and carbon dioxide. Once this process is completed the Nyex™ can be reused.

An additional benefit of this technology is that it is not specific to any type of carbon-based material. The method can therefore be applied to other markets, and Arvia has already carried out substantial work on deploying the system for the cheaper disposal of radioactive carbon-based material in nuclear waste. With this market expected to exceed £70bn in the UK alone, Arvia's cheaper method could give the UK a significant edge.

£12bn
value of the global water treatment market in 2010

£17.5bn
projected value of the global water treatment market in 2015

<£1m
of public funding invested (from EPSRC, NWDA grant, TSB grant)

18
full time staff members employed by Arvia

15
patents granted to Arvia in several countries

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