Inspirational chemistry for a modern economy

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Foreword from the President

Scientific research is a vital driver of the UK economy. Growth and productivity rely heavily upon both technological advances and the skills forged by a scientific education, which in turn are supported by investment from government and the private sector.

Our science and innovation system is world-leading; it produces 15.9% of the world's most highly cited publications, with only 4.1% of the world's researchers and 3.2% of the global research and development (R&D) investment. Every pound invested by the government in R&D returns 20–30p annually, driving a knowledge economy which supports a third of our businesses and pays 40% higher than the average wage. The UK chemical sector alone has an annual turnover of £60 billion, and sustains 500,000 jobs throughout the country.

Chemistry plays a fundamental role in these broad economic benefits, but it also transforms our everyday lives for the better. The case studies in this booklet show how chemical scientists across the UK are designing drugs that improve human health, building diagnostics to improve the efficiency of healthcare, revolutionising materials, and developing new clean-energy technologies. We have limited ourselves to only a few, but there are many more in the Research Excellence Framework (REF) database online, and many new success stories in the making right now.

Chemistry is often referred to as 'the central science', but rather than point to protectionism, this signifies the importance of collaboration across the sciences. The innovations presented within this booklet all began in university chemistry departments – often with fundamental origins – but their impact is delivered with contributions from physics, biology, physiology, computer science, engineering, and many other disciplines. Collective strength helps us all achieve more.

It's important that we do not become complacent, but this booklet – launched alongside similar work from the Institute of Physics – shows where things have gone well. Focus must be maintained to ensure sustained and stable funding and a ready supply of highly-skilled scientific workers, but if it is then the UK will be on the path to maintain its crown as a world-leading knowledge economy.

Professor Dominic Tildesley CBE FRSC

President, Royal Society of Chemistry

Chemistry transforms drug discovery

Researchers at the University of Cambridge develop a ground-breaking new method for drug discovery, new drugs and a spin-out company worth £100 million.

What is the problem?

New drugs are constantly needed. Whether it be new antibiotics to fight the rise of antimicrobial resistance, a cure for a previously untreatable disease, or the next step in winning the fight against cancer, scientists from a broad range of disciplines are constantly developing new strategies and innovative treatment methods to identify solutions for healthcare challenges.

Developing a new medicine from initial concept to successfully deployed drug is lengthy and extremely costly. It has been estimated that, on average, bringing a new drug to market costs \$2.6 billion and takes 10–15 years, and with the last new class of antibiotics having been developed in 1987, innovative methodologies are desperately needed.

What was the solution?

In the 1990s, Professor Chris Abell and Professor Sir Tom Blundell at the University of Cambridge, funded by the BBSRC, began investigating enzyme inhibition in relation to drug development. An interest in developing a structure-based approach to enzyme inhibition led to a collaboration with Dr Harren Jhoti, former head of structural biology and bioinformatics at Glaxo Wellcome (now GSK).

The novel approach to drug discovery involved looking at the way small parts of drug molecules behaved. Drugs work by binding to proteins in the body and activating or inhibiting their behaviour, resulting in a beneficial therapeutic effect. However, due to their size, studying this interaction in a typical drug molecule is complex and time consuming. The researchers focused their attention on much smaller fragments of the drug-like molecules, drastically increasing the efficiency of the design process.

The collaboration led to the establishment of the company Astex Technology Ltd in 1998, backed by City investors interested in supporting biotechnology start-up companies. Astex built upon the university's fundamental research by combining fragment-based drug discovery with high-throughput methods and roboticised data collection.

What was the impact?

Since their formation Astex has created 8 potential drugs that have progressed to clinical development; 4 being developed in-house and 4 through collaborations with Janssen, Novartis and AstraZeneca. Between 1999 and 2011, Astex signed contracts in excess of £1 billion, and received over £100 million in investment. Over the last decade Astex has secured constant employment for between 70 and 120 workers.

In 2011 Astex was sold to SuperGen Inc for £100 million, creating Astex Pharmaceuticals with an estimated value in excess of £320 million. In 2013 the company was in turn acquired by Otsuka Pharmaceuticals for $886 million.

Fragment-based drug discovery is recognised as one of the most important developments in drug discovery in the last 20 years. Astex have made a significant change to how the pharmaceutical industry approach drug discovery, and most pharmaceutical companies now use fragment-based methods in early discovery including Johnson & Johnson, GSK and AstraZeneca. The use of fragments may lead to totally new classes of therapeutic agents designed to meet the medical needs of the 21st Century.

> // As a consequence of Astex's success, fragment-based approaches are commonplace throughout pharma and biotech. //

Dr Simon Campbell
former Head of Worldwide Discovery at Pfizer

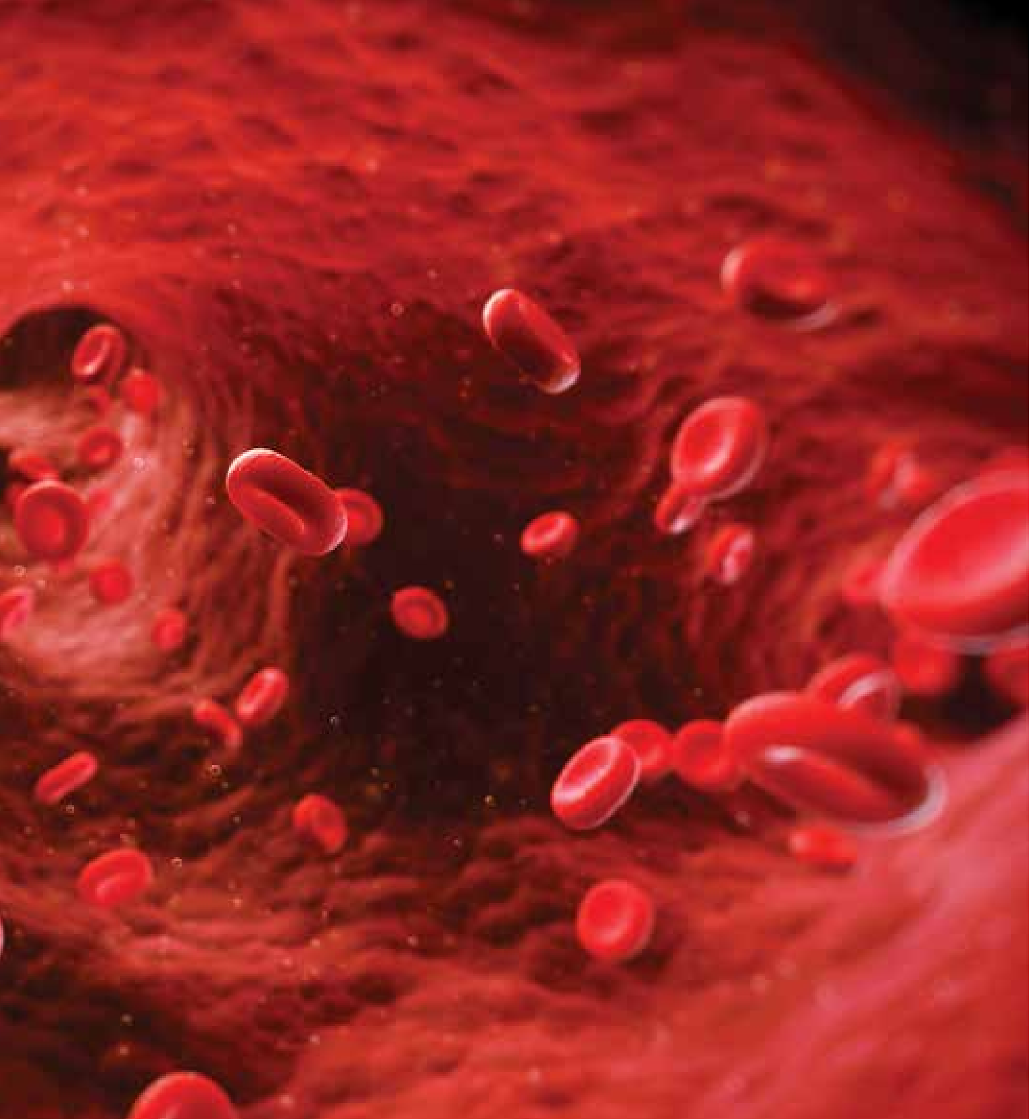
$886 million
Value of Astex Pharmaceuticals sale to Otsuka in 2013

£1 billion
Value of contracts signed by Astex 1999–2011

8
Number of cancer drugs developed by or with Astex

120
Number of employees

8.2 million
Number of annual deaths worldwide due to cancer



Chemistry analyses blood in 30 seconds

Measurement of salts in blood leads to development of point-of-care device used in hospitals, ambulances, and war zones.

What is the problem?

Professor AP de Silva, Queen's University Belfast, was inspired to develop a blood analyser whilst caring for his grandmother who was suffering from hypertension. Hypertension is a chronic condition, affecting 30% of people in England, in which the blood pressure in the arteries is elevated. Hypertension can be caused by increased levels of water in the blood, meaning that the heart has to work harder to pump blood around the body. Salts such as sodium hold on to water, and de Silva's doctor taught him that if salt levels could be monitored easily and accurately a diuretic could be administered to remove the water and excess sodium from the system, decreasing the load on the heart.

Monitoring blood pH and concentrations of ions such as sodium, potassium and calcium is critical in most medical contexts. Previously, analysis of analytes present in the blood required external analysis on expensive equipment and was slow. Apart from this being inconvenient for the patient, it can literally mean life or death in situations where time critical diagnostic testing is needed, for example in accident and emergency departments or intensive care units.

What was the solution?

de Silva began pioneering research into fluorescent PET (photo induced electron transfer) sensors in 1985. By understanding the rates of electron transfer reactions, de Silva was able to design a sensor containing two parts: a fluorescent unit and a receptor unit.

When electrons within molecules are energised with light they are able to transfer from one unit to the other, stopping a fluorescent response. However, if the receptor captures a suitable cation, such as sodium, then electron transfer is prevented and fluorescence occurs. Using a specific combination of units, researchers were able to create a device that could measure blood pH, as well as calcium, sodium and potassium ion concentrations.

What was the impact?

Based on the seminal research undertaken at Queen's University Belfast, a blood analyser was developed which has been the market leader in point-of-care analysers ever since.

Researchers at global healthcare company Roche read about de Silva's research and quickly recognised its commercial potential; the result was a collaboration with Optimedical Inc to develop the sensor.

After testing in collaboration with AVL Bioscience Corporation, Roswell GA, the OPTI blood analyser was created with a disposable, single-use cassette to carry out the measurement. Diagnostic cassettes worth over $50 million were sold from 2008–2013.

The device can be used in a range of settings including GP surgeries, hospital critical care units, ambulances and veterinary practises. Blood test results can be available in less than 30 seconds, enabling rapid medical responses such as administering a particular blood type with the correct salt levels.

As well as being rapid, the device is also easy to use. In Japan, doctors are able to immediately provide patients with test results in their surgeries, and paramedics in Sri Lanka and Libya were able to use the device in conflict situations. Furthermore, the technology has been adapted for veterinary surgeries.

1985
Research into fluorescent PET sensors started at Queen's University Belfast

1998
Collaboration with Roche began

10 million
Sensors sold in the past 5 years

30 seconds
Time taken to analyse blood sample

$50 million
Sales of diagnostic cassettes used in the OPTI device

Chemical engineering increases pharmaceutical productivity

Researchers develop new manufacturing technology to increase industrial productivity and reduce waste.

What is the problem?

Manufacturing fine, speciality and pharmaceutical chemicals requires high precision and large energy costs, and can result in significant amounts of waste. Batch technologies are typically used during high volume production, but there remain a number of inefficiencies. The properties of crystalline products (which represent 80% of pharmaceuticals) are tightly controlled, and any product not meeting the required specification needs modifying, increasing energy usage, operational costs and the amount of waste. For example, for every 1 kg of active pharmaceutical ingredient created in a batch process 50–200 kg of waste is produced, and the typical cost of raw materials for a single batch is £1–5 million.

Such a large-scale problem resulted in a nine-year EPSRC funded project – Chemicals Behaving Badly – designed to identify and address the root issues. In particular it was found that cooling and mixing needed to be controlled with a level of precision beyond any current industrial systems.

What was the solution?

Building upon the findings of this investigation Professor Xiong-Wei Ni at Heriot-Watt University, supported by the EPSRC among others, was able to develop a new reactor. This reactor provided much improved levels of mixing and firmer control of crystallisation conditions, leading to significant waste reduction. This type of reactor allows laboratory monitoring tools to be implemented on industrial scales without modification, enabling a fast knowledge transition from laboratory to production.

What was the impact?

A spin-out company formed attracting over £3 million in investment. NiTech® Solutions Ltd was launched in 2004 with support from a Scottish Enterprise SMART award. Trials with over 60 chemical, food and pharmaceutical compounds resulted in consistent product quality with significant reductions in levels of waste, energy usage, inventory costs, and, importantly, over 90% reductions in process time.

Previous processes would result in inconsistencies in particle size and so require several refining stages with capital costs of around £1 million for just a single piece of equipment. NiTech's technology was able to remove this step and has an overall cost of c.a. £500,000, thereby saving time, money and energy.

Genzyme (now Sanofi) were first to adopt the technology for the production of a biopharmaceutical drug worth several £100 million per year. Implementation led to a production rate 40 times faster than a traditional batch reaction.

Product quality is higher and continuous monitoring has resulted in a zero rejection rate at the reaction stage, contributing to a competitive commercial advantage. NiTech's continuous crystallisation technology is also being used in the development of one of AstraZeneca's blockbuster drug ingredients, reducing crystallisation time by a factor of 50 from almost 10 hours to just 12 minutes.

NiTech's technology was the starting point for the Continuous Manufacture and Crystallisation consortium, launched in 2010, which has attracted over £90 million investment and support from industrial partners including GSK, AstraZeneca and Novartis. The consortium aims to accelerate the introduction of new process-intensification technologies such as those developed by NiTech.

// We were able to supply the market many months earlier than would have been the case with conventional batch processing. This was one of the best investment decisions that I have made! //

Senior Manager of Sanofi

80%
Pharmaceuticals produced in crystalline form

2004
NiTech Solutions Ltd launched

90%
Reduction in process time

2010
Continuous Manufacture and Crystallisation consortium launched to exploit NiTech's technology

£90 million
Investment in Continuous Manufacture and Crystallisation consortium

Chemistry revolutionises DNA sequencing

Research on proteins leads to new DNA sequencing technology and a spin-out company valued at $3 billion.

What is the problem?

DNA sequencing, the decoding of an individual organism's DNA, is central to the development of personalised medicine and has considerable utility in agriculture and crop science, food safety, security, and defence.

However, existing methods of DNA sequencing are comparatively expensive and time-consuming. Therefore rapid and reliable, 'new generation', sequencing technologies are required.

To address this, the US National Human Genome Research Institute introduced grants to support research that aimed to sequence the human genome for under $1,000 and reduce the time associated with prevailing sequencing technologies.

What was the solution?

Professor Hagan Bayley joined the University of Oxford in 2003 to conduct fundamental research into membrane proteins. The work perfected techniques to engineer membrane protein pores so that they became capable of sensing individual molecules, which altered a current passing through the pore.

This research underpins the development of engineered nanopores capable of accurately detecting, or 'reading', the sequence of individual nucleic acid molecules (DNA or RNA) that pass through them at high speed.

What was the impact?

In 2005 Oxford Nanopore Technologies Ltd was formed, aiming to develop disruptive technologies based on Bayley's and collaborators' research, and Bayley's laboratory received a grant of $10 million from the US National Human Genome Research Institute. By 2012 Oxford Nanopore was valued at $2 billion, increasing to $3 billion in 2015.

To date the GridION, PromethION and MinION devices have been developed.

GridION is a nanopore-based system able to efficiently sequence DNA and RNA strands in terms of both cost and time; using 20 GridION nodes together an entire human genome could be sequenced in 15 minutes, at relatively low cost.

The GridION has since been superseded by the PromethION device, which can process multiple samples and enables greater workflow capability and scalability.

MinION is a miniaturised DNA sequencer, and is a portable device smaller than a mobile phone that plugs into a computer. MinION measures single molecules directly, without a need for the numerous processing stages prior to analysis required by traditional sequencing technology.

Oxford Nanopore Technologies' MinION is the only near-market technology set to break the $1,000 target set by the US National Human Genome Research Institute.

$3 billion
Value of Oxford Nanopore Technologies in 2015

£180 million
Funds raised since 2005 to support research and development

300
Patents issued to the company

15 minutes
Time to sequence human genome using 20 GridION nodes

$7.6 billion
Expected global market for 'next generation' sequencing by 2018

Chemistry creates next-generation materials

Research revolutionises the ability to create and characterise new materials, with applications in batteries, fuel cells and green safety technologies.

What is the problem?

The UK Government is committed to lowering greenhouse gas emissions, and with 27% of UK energy consumption used for road transport alternative vehicle technology is high on the radar. At present electric vehicles are improving, but uptake is hindered by high initial costs and concerns about the performance constraints of current battery technologies.

The feasibility of other future energy sources, such as hydrogen, depends on development of new materials for storage; current solutions consume large amounts of energy and raise safety concerns. Materials chemistry enables the creation of new solid-state materials that address these current limitations, with additional applications across a range of technologies.

What was the solution?

Researchers at the University of Southampton, led by Professor Mark Bradley, Professor Brian Hayden and Dr Samuel Guerin, established a Combinatorial Centre of Excellence in 2001 with £6 million funding from the UK Joint Infrastructure Fund. Combinatorial chemistry is the rapid and automatic production of large numbers of compounds in a single process. The technique was typically used by pharmaceutical companies, however, the team recognised it could be used to develop new approaches to solid-state materials discovery.

By depositing a thin film of a new material on silicon it could be rapidly characterised and its properties considered for various applications. Work was undertaken with several industrial partners, including Johnson Matthey and General Motors, with support from the EPSRC.

What was the impact?

A much wider range of materials could now be produced, and a spin-out company – Ilika Technologies plc – was rapidly created in 2004 to aid development; by 2010 it had achieved a market capitalisation value of £18.7 million. At the time of publication in 2015, the market value had increased to almost £50 million.

Ilika has increased the energy capacity of solid-state lithium-ion batteries, a market set to be worth $32 billion annually by 2018. Toyota has contributed £4 million to this research, with the technology used in the development of batteries for next generation Toyota electric and plug-in hybrid vehicles.

A range of materials have also been developed for other applications. Platinum-free fuel cell catalysts have been developed with the Carbon Trust to significantly reduce the cost of fuel cells. Recyclable hydrogen storage materials have been developed and commercialised in collaboration with Shell and Sigma Aldrich. Environmentally-friendly, lead-free materials are being developed with CeramTec for use in vehicle fuel injection systems and when triggering airbags.

// Ilika's high through-put techniques are essential to overcome some of the technological barriers we face in the development of leading-edge technologies. //

Mr Okajima
Project Manager, Toyota's Frontiers & Advanced Engineering Strategy Department

27%
UK energy consumption used for road transport

£4 million
Investment by Toyota

83%
Revenue from international companies

2010
Ilika Technologies plc floated on the main London Stock Exchange

£47.2 million
Market capitalisation value in 2015

Chemistry protects soldiers, footwear and smartphones

Research into nanocoating techniques leads to development of a widely used industrial coating process, and three valuable start-up companies.

What is the problem?

Surface functionalization techniques such as waterproofing and antibacterial coatings are highly valued and used in a range of sectors including materials, engineering, electronics and healthcare, with an estimated value of $50 billion per year.

However, most high-performance coatings tend to be relatively thick and either manufactured by energy intensive 'wet' solvent-based processes using chemicals detrimental to the environment, or 'dry' vapour-deposition techniques unsuitable for industrial-scale production. Most methods are also substrate-specific so cannot be easily adapted for different materials.

A technique needed to be developed that created ultrathin, high-performance super-repellent surfaces for a range of different materials on a commercial scale in a single step without the use of solvents.

What was the solution?

Since 1989 Professor Jas Pal Badyal at Durham University has been developing surface functionalization techniques that use low-cost materials and are better for the environment than conventional solvent-based processes. The research was funded by industry including DuPont, British Gas, Proctor & Gamble, and DSTL, and focuses on reactions that occur at the interface between a plasma and a solid.

Badyal developed methods that allowed plasmas to selectively protect the surfaces of a range of different materials. This work resulted in the development of a quicker, single-step process that was selective, cheaper, and lower energy.

What was the impact?

Badyal's research led to the formation of three start-up companies: Surface Innovations Ltd (2001), Dow Corning Plasma Solution Ltd (2001), and P2i Ltd (2004). Through P2i's Ion Mask™ brand the surfaces of 100 million pipette tips and 3 million pairs of footwear have been protected, as well as 50 million mobile phones and 60% of the world's hearing aids under the Aridion™ brand.

P2i Ltd is a growing company with an estimated turnover of £19 million in 2014, and 93% of revenues generated in geographic markets outside of the UK. It has led to the establishment of subsidiaries in China, Hong Kong, Singapore and the USA.

P2i Ltd originated from a project with DSTL, with the challenge to make soldier's protective clothing more effective against mustard gas whilst maintaining comfort in hot and dehydrating conditions. It commercialised research into liquid repellent nanocoating technology, raising over £40 million in investment, and over 150 commercial plasma coating units have been manufactured and installed globally. The intellectual property held by Surface Innovations Ltd was sold to P2i Ltd in 2010.

Dow Corning Plasma Solution Ltd was created through corporate venturing following an initial investment of €3.3 million from Dow Corning. Invexus (USA), who supplies to the £2 billion global market for antibacterial surfaces, is a current licensee of the technology.

Badyal is also leading the Global Biomimetic Water Harvesting Project, which aims to collect drinking water from air using functionalised surfaces, for example through fog harvesting. Several patents have already been filed, and this is seen as the biggest potential impact of the research, as 1 billion people are currently without clean water.

> The Aridion™ coating, which we believe to be a game-changing innovative moisture management technology, has helped us to substantially reduce warranty failure and repair costs in our hearing aid range.

Tim Schnell
Hearing Lab Technology

39
Functional surfaces patents filed by Badyal's research laboratory

3
Start-up companies

£40 million
Investment from industry

50 million
Smartphones protected

60%
Of the world's hearing aids protected

Chemistry creates efficient electronics

Development of quantum dots leads to spin-out worth £384 million and technology allowing energy efficient lighting and televisions.

What is the problem?

Quantum dots are crystals around 1/1000th the width of a human hair made of semiconductor materials. These dots can be designed to emit light, and by changing the size of the dot you can change the colour of light. A wide spectrum of colours can be produced relatively simply, with potential applications in backlighting for LCD displays, LED lighting, biological imaging and thin-film solar cells.

The synthesis of high-quality quantum dots themselves, however, was relatively complex, and only achievable using a limited range of materials, many of which were toxic and required specialist handling. Therefore production was limited to expert organometallic chemistry laboratories, only small quantities could be produced at a time, and techniques were not reproducible in terms of the stability, size or colour of the quantum dots produced. Of these, the main hurdle to overcome for commercialisation was scalability.

What was the solution?

Whist working for Professor Paul O'Brien at the University of Manchester, Dr Nigel Pickett developed a method to effectively scale up the synthesis of quantum dots using a 'molecular seeding' method. In this process molecules act as a template for nanoparticle growth, removing the need for the high temperature nucleation step used in 'hot-injection' nanoparticle synthesis. The process could be easily scaled-up to produce batches of quantum dots on the gram and kilogram scale.

The molecular seeding process was first used to produce cadmium-based quantum dots, but has since been developed to prepare quantum dots free of cadmium and other toxic heavy metals.

What was the impact?

In 2001, O'Brien and Pickett founded Nanoco Technologies Ltd in order to progress the development of quantum dot technology. Since 2004, Nanoco has focussed on the development of heavy metal-free quantum dots that comply with hazardous substances legislation. By 2013, Nanoco had a market capitalisation value of £384 million.

Nanoco has been working to develop quantum dots for display applications. Quantum dot-containing components can be incorporated into LCD backlight units (BLUs), improving the energy efficiency and range of colours that can be emitted compared to BLUs with conventional white LEDs. In 2013, Nanoco entered into an exclusive licensing agreement with Dow Electronic Materials for the sale, marketing and manufacture of their quantum dots for use in electronic displays.

TVs containing Nanoco's heavy metal-free quantum dots were showcased by LG at the Consumer Electronics Show in January 2015. The quantum dot and quantum dot display market is anticipated to be worth $6.4 billion by 2019.

Other areas of Nanoco's research and development include lighting, biological imaging and thin-film solar cell applications. Quantum dots can be incorporated into high-efficiency LED lighting with a tuneable colour temperature. Nanoco is working in collaboration with University College London, as part of an Innovate UK-funded project, to develop cadmium-free quantum dots for cancer diagnostics. Nanoco has also developed a range of copper indium gallium diselenide/disulphide (CIGS) nanoparticles for use in thin-film solar devices that can be deposited using low-cost printing techniques.

> The launch of LG's Ultra HD TV at the Consumer Electronics Show in Las Vegas is a major milestone for Nanoco as it represents the first commercial product to incorporate our cadmium-free quantum dot technology.

Michael Edelman
Nanoco's CEO

2009
Initial 'molecular seeding' patent granted

2013
Worldwide licensing agreement with Dow Electronic Materials

£384 million
Market capitalisation value of Nanoco in 2013

$6.4 billion
Anticipated quantum dot and quantum dot display market value by 2019

60%
Efficiency of quantum dot lighting compared to 5% for traditional light bulbs

Chemistry enables zero emission energy production

Fuel cell technology research leads to a company floated on the London Stock Exchange and employing over 350 people around the world.

What is the problem?

The UK Government aims to reduce greenhouse gas emissions by at least 80% from the 1990 baseline by 2050. Combustion of fossil fuels such as diesel or gas contributes to atmospheric carbon dioxide levels, but other technologies, such as fuel cells, have higher efficiency and limited pollution.

Typical fuel cells convert a fuel, such as hydrogen, into electricity through a chemical reaction with an oxidising agent. Solid oxide fuel cells were among the first to be developed in the mid twentieth century, but required expensive materials and high operating temperatures, and their large size limited them to stationary uses. The first proton exchange membrane (PEM) fuel cells were then developed and used in the NASA Gemini spacecraft, however, they also used expensive materials and required very pure oxygen and hydrogen so had limited applications.

PEM fuel cells needed to be more cost effective to enable their use in everyday situations.

What was the solution?

In 1988 the Fuel Cell Group at Loughborough University was formed in a collaboration between the Departments of Chemistry and Aeronautical and Automotive Engineering.

The focus of the group's research was to improve PEM fuel cell performance and scale up the technology. This resulted in the UK's first 1 kW PEM fuel cell stack in 1995, optimisation of PEM fuel cell design to save space and reduce weight, and a 33% efficiency gain as part of a project funded by the EPSRC.

What was the impact?

The spin-out company Advanced Power Sources (APS) Ltd was founded in 1995 by Dr Paul Adcock, Dr Phil Mitchell, Dr Jon Moore and Anthony Newbold, and was the first company in the UK formed specifically to address the development and commercialisation of PEM fuel cells.

Intelligent Energy was established in 2001 and acquired APS Ltd, together with its personnel and fuel cell related intellectual property that originated from research conducted by both APS and Loughborough University into PEM fuel cell technology. This triggered investment and enabled the company to grow its business activities. In 2005, it launched the ENV, the world's first purpose-built fuel cell motorbike which gained the company recognition as a Technology Pioneer by the World Economic Forum in 2006.

Intelligent Energy has partnered with a number of leading companies to develop their fuel cell power systems. These have led to the inaugural flight of the first fuel cell powered aircraft in 2008 in collaboration with Boeing; the world's first fuel cell motorbike approved for manufacture and sale with Suzuki, with whom it has formed a joint venture in Japan, and the production of a fleet of zero emission London fuel cell taxis that were used by VIPs during the 2012 Olympics.

The company was ranked 27th in The Times 100 Fastest Growing Technology Companies 2013 and 15th in the Deloitte 2013 Fast 50 companies driven by technology innovation, and in 2014 it was voted the Most Successful Company by the UK Science Park Association. Intelligent Energy floated on the main London Stock Exchange in July 2014 and employs over 350 people across the UK, US, Japan, Singapore and India.

2012
Fleet of zero emission hybrid fuel cell taxis launched for London Olympics

2014
Intelligent Energy Holdings plc floated on the main London Stock Exchange

350
People employed by Intelligent Energy

900
Patents granted and over 1000 pending

$230 million
Company value in 2015

Chemistry extends nuclear reactor lives

Research into the properties of graphite results in a £40 million saving to date and helps to significantly increase nuclear reactor lives.

What is the problem?

Energy security is a priority for the UK Government who recognise the need to establish safe, low-carbon, renewable energy sources. The need to move away from finite fossil fuel resources has revitalised interest in developing a long-term nuclear strategy. In 2012, nuclear energy supplied 19% of the UK's electricity and by 2050 up to 49% of the UK's electricity could be provided by nuclear power.

The mainstay of the UK reactor fleet is the Advanced Gas-cooled Nuclear Reactor (AGR), which has graphite at its heart. Graphite moderates nuclear reactors, slowing down neutrons to make them more efficient for nuclear fission (splitting the uranium nucleus). Although a resilient material, it is susceptible to damage that affects its structure and functionality.

The engineering of reactors caters for these changes using an experimental approach based on Materials Test Reactor (MTR) data. These irradiate graphite samples at between ten and one hundred times that of commercial reactors, thereby accelerating their ageing and enabling predictions of future behaviour.

To compare test data with normal operating conditions the relatively rapid MTR experiments had to be conducted at a higher temperature, with the equivalent temperature concept used to correct for the difference.

Reliable estimates of the condition of the graphite are critical for management decisions for ageing reactors and contribute to assuring their safety.

What was the solution?

The nuclear graphite programme at the University of Sussex ran from 1997–2012, headed by Professor Malcolm Heggie and funded by EDF Energy Generation's Plant Life Extension (PLEX) project and EPSRC. Heggie investigated how atoms in graphite layers bonded together by creating mathematical models that generated projections into future graphite behaviour, independent of the existing experimental models.

Radiation damage was known to affect graphite properties, changing the size and shape of graphite crystals and displacing atoms. Displaced atoms formed new sheets of graphite between existing layers, leaving behind vacant areas.

However, researchers at the University of Sussex indicated that the mobility and properties of the displaced atoms and vacant sites inferred from experiments were incorrect, and therefore previous theories of graphite radiation damage were producing erroneous results.

Heggie and colleagues showed that, following exposure to radiation, changes to the graphite structure arose from displaced atoms binding layers together, causing them to buckle. However, above 250°C the atoms became mobile, and the buckling effect was removed.

What was the impact?

The buckling concept was a major shift in the science of radiation damage; the concept of equivalent temperature was no longer used, it guaranteed the £30 million MTR experiments were run at the correct temperature, and the models of graphite behaviour that assessed reactor lifetime and condition were revised.

If the flaws in the MTR data had not been corrected the £30 million programme, used to assess reactor lifetime, would have continued to produce incorrect data and significantly reduce anticipated reactor lifetimes.

Improved understanding of the rate of graphite damage and the properties of irradiated graphite have contributed savings of £40 million to date, in studies that support EDF Energy Generation's PLEX project, by extending the lifetime of current nuclear reactors.

As a whole EDF Energy's project aims to achieve an extra 100 reactor-years from existing AGRs, equating to £60 billion of additional power output.

> // If the fourteen UK operating Advanced Gas-cooled Nuclear Reactors closed unnecessarily early, by perhaps one year, it could lead to losses running into billions of pounds, threaten the UK's carbon dioxide emission targets and widen the nation's energy deficit. //

EPSRC

14
Number of operating Advanced Gas-cooled Nuclear Reactors in the UK

25 years
Design life of an Advanced Gas-cooled Nuclear Reactor

£3.3 billion
Annual contribution to UK GDP from the nuclear industry

£40 million
Sussex contribution to EDF Energy Generation's PLEX project to date

48 years
Total extended reactor life achieved by EDF Energy Generation's PLEX project to date

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