A Strategy for Innovation in the UK chemistry-using industries

June 2013
The Technology Strategy Board is the UK’s innovation agency. Its goal is to accelerate economic growth by stimulating and supporting business-led innovation. It provides support and funding to both the Knowledge Transfer Networks and the Catapult Centres.

Chemistry Innovation is the Knowledge Transfer Network with the responsibility to stimulate product and process innovation delivering growth for the UK chemistry-using industries.

The Centre for Process Innovation is one of seven Centres within the High Value Manufacturing Catapult and works with companies to develop, prove, prototype and scale up the next generation of products and processes. Its capabilities are aligned with the needs of the process, chemical and chemistry-using industries.

The way forward

Smart Manufacturing Processes

Design for Functionality

A Comprehensive set of Focus Areas

Successful Innovation

The way forward

Key Sources
Foreword

Chemistry is at the heart of UK manufacturing. Every manufacturing sector uses chemical products and processes. So, the road to the UK’s economic recovery and growth depends on nurturing and sustaining a differentiated chemical industry, built from:

- great ingredients manufactured at lowest imaginable cost
- advanced functional materials and formulated systems designed to give performance advantages in application, e.g. lightweight composites, electrochemical storage devices and advanced pharmaceuticals
- an active community of SMEs manufacturing chemicals and using chemistry

For the UK to prosper, it is crucial that the chemistry-using industries can deliver sustainable and differentiated innovation. Innovation, the conversion of new science, technology and concepts into commercial success, can be achieved in a number of ways. In its simplest form it involves the development of new products which can be brought successfully to market. It might be a new manufacturing process which can offer significant benefits in cost, quality or environmental impact. Or it might be clever technology which can be applied anywhere in the world, perhaps through licensing or joint venturing with global partners. These can all deliver value, growth and jobs to the UK economy.

The UK’s SMEs have a critical role to play in the national drive for sustained growth. In the value chains of all the UK’s priority growth sectors – aerospace, automotive, construction, energy generation and supply, life sciences, consumer products, and chemical production – SMEs provide essential product and service links in a complex web of supply and demand. The more that the supply requirements of the downstream sectors can be met from within the UK – at competitive price and quality – the more value is created and retained to benefit the UK economy.

Chemical and Chemistry-using Companies in the UK – like many others – have suffered decline since the global economic downturn began in 2008. The UK now has a timely opportunity to create strong businesses with growth potential. This will require a continuous focus on innovation, which will inevitably involve partnerships and collaboration. The result will be new jobs created and the long term future of the chemistry-using industries secured. At the same time we will also make positive contributions to many of the global issues facing us.

This innovation strategy has been developed as a key component of the UK’s Chemistry Growth Strategy. Whether you are based in industry, academia or the public sector I hope you find it informative and stimulating. Please work with Chemistry Innovation to pursue any opportunities that will help to create a prosperous future for your organisation.

Graeme Armstrong
President and Managing Director
Surface Chemistry and
Country Director for North America
AkzoNobel
Chair of the Chemistry Innovation
Knowledge Transfer Network
Member of Supervisory Board of the
High Value Manufacturing Catapult

Executive Summary

An Innovation Strategy for Growth

The world is facing some major challenges. In particular the world population is expected to grow from around 7 billion today to over 9 billion by 2050. All these people will require food, energy and water – and on average they will live longer. The expanded population will expect a higher standard of living. All of this will place an even greater demand on supplies of energy and scarce metals.

Chemistry can help in the quest to find solutions to these challenges. In addition the chemical and chemistry-using industries face their own specific challenges: the availability of sustainable raw materials, secure and competitive energy, and meeting the UK’s climate change targets. And UK industry needs to continuously find ways to compete successfully in an increasingly global economy.

In order to rise to these challenges, the UK Chemistry Growth Strategy is making a number of recommendations to the UK Government. Critical amongst these is a reinforcement of the need to accelerate innovation. Where companies in the UK can develop successful businesses in high value products or processes with clear differentiation, demonstrable sustainability improvements and with a market in one of the UK’s other key manufacturing sectors, there is a recipe for success and growth.

This strategy analyses the projected requirements for chemical products in seven of the key manufacturing sectors in the UK. Currently these sectors purchase many of their chemicals and intermediates from abroad, sometimes because of price but often because they are simply not available within the UK. This strategy proposes some innovation opportunities where there is potential for UK companies to enter the supply chain and fill some of those gaps.

In addition, the strategy uses the sector information to define some focus areas where public intervention should significantly accelerate innovation. These cover the availability of raw materials, how these are converted into chemical products and finally how those chemicals are transformed into products that the general public would recognise and use. In all these areas, public intervention will enable innovation significantly faster and better, and deliver faster growth to the UK.
Introduction

The global economy has struggled to recover from the financial crisis which began in 2008. In this context the UK has failed to achieve sustained growth and has experienced two recessionary dips. The Government has maintained its commitment to industrial innovation and “rebalancing the economy” since it is clear that sustainable and sustained industrial innovation provides the only viable route to growth and prosperity. Companies which continuously innovate and differentiate themselves with respect to global competition will be essential for the future success of the UK.

Innovation drives economic growth. It can involve technology developed in one part of the world, implemented in another, for sale in yet another, with commercial value derived from:

- sales of new products
- operation of new manufacturing processes
- implementation of an alternative business model

Innovation often results from the combination of new and existing technologies and usually benefits from collaboration in order to access new or complementary capability.

The chemistry-using industries can be described in three levels of criticality:

- those industries which manufacture chemical products and pharmaceuticals, where the discipline of chemistry is absolutely fundamental;
- those industries which are critically dependent on chemistry to operate their business, such as agrochemicals, coatings, lubricants, home and personal care, food and drink, and mining;
- industries where chemistry is a key part of the value chain, including for example, transport, construction and energy generation; this group includes most industrial manufacturing sectors.

“Companies which continuously innovate and differentiate themselves with respect to global competition will be essential for the future success of the UK.”

Together these industries generate over £900 billion of revenue and contribute £195 billion Gross Value Added (GVA) to the UK economy (see diagram opposite). The critical contribution that chemistry and chemicals make to the downstream manufacturing sectors is perhaps less obvious. Without modern chemicals it would be impossible to manufacture cars, aeroplanes, mobile phones and electronic displays. Chemistry is also critical to the energy and construction sectors, and the management and quality of our water supplies.

Chemistry can provide the solutions to some of the world’s greatest challenges: climate change, energy supply and demand, and coping with an increasing world population with changing demographics. Partnerships between chemists, engineers, biologists, the design community and other key players will be necessary to ensure that new products meet the demands imposed by a responsible society for recovering, recycling and re-using materials wherever possible.

The UK has a number of strengths which it should exploit to secure sustainable growth:

- a strong industry base with companies ranging from micro-SMEs to large multi-national corporations;
- manufacturing and R&D capabilities which could support innovation within the right climate;
- a strong science and technology base in industry and academia, both fundamental and applied, which ranks with the best in the world.

It is therefore critical that UK chemistry is nurtured and encouraged to develop new products and manufacturing capability. In this way, value is realised and, where possible, retained within the UK, either through manufacturing in the UK or through licensing of leading edge technologies.

How this strategy will be used

The main purpose of the strategy is to identify the major business growth opportunities for the UK chemistry-using industries, to indicate the key emerging and enabling technologies required to support and nurture these opportunities, and to highlight any issues and barriers to innovation. This enables the definition of the key themes and topics where there is potential for value-adding intervention to support companies in building new sustainable business. A partnership between industry and government in these areas will help to accelerate the delivery of growth to the UK economy.

The strategy will have a number of additional spin-off benefits, including:

- highlighting the requirements of key strategic downstream industry sectors, including Energy, Construction, Aerospace, Automotive, Life Sciences and Food, which depend on the products of the chemical and related industries;
- helping deliver the UK national competencies outlined in "A landscape for the future of high value manufacturing in the UK" commissioned by the Technology Strategy Board;
- guiding the UK Government, the Technology Strategy Board and the Research Councils on the topics which would benefit from public investment;
- assisting other stakeholders, including the professional bodies and industry groupings in developing complementary strategies and plans;
- identifying the critical skills and capabilities needed to maintain and develop a strong industry base;
- providing guidance for Chemistry Innovation to prioritise its efforts and resources.

The strategy also forms the innovation component of the broader strategy being developed by the UK Chemistry Growth Strategy Group. Innovation sits as a key theme alongside energy and rebuilding the UK supply chains.
Our Approach
Basis for the Innovation Strategy

Innovation succeeds when it is motivated by opportunities which address the needs of users and customers. Based on this premise, the approach taken for identifying the elements of the strategy for innovation in the UK chemistry-using industries begins with those who might benefit from the innovation.

We have examined a number of industry sectors, looking to identify the challenges which face each of them within the context of the global trends and drivers which impact their activities. The challenges in turn point to opportunities against which innovation activity will deliver economic growth. We have focused on the opportunities which can be enabled by the application of chemistry; these are plentiful.

The global trends and drivers which face all industries are well articulated. The world population continues to grow, expected to exceed 9 billion by 2050. At the same time, the demographics are changing: the middle class in developing countries and an emerging well-off middle class in developing countries. Meanwhile, the resources of our earth remain the same, one earth to support us all. This constraint on traditionally used resources is evidenced in price increases and volatility in supplies. Added to this constraint, concern is increasing about the environment and the impact we have on it: this includes pollution, contamination and climate change.

The trends apply universally but how each industry sector is impacted by them, and has chosen to respond to them, differs. The impact and the opportunity for response inform this strategy. Once the opportunities for each of the sectors were indicated, common threads were identified which led us to a number of chemistry related Focus Areas around which the strategy has been written.

Eight industry sectors have been considered in the development of the strategy. These include priority sectors indicated in a recent BIS (Department for Business, Innovation & Skills) report: Aerospace, Automotive, Construction, Energy, and Life Sciences. To these we added three sectors which are particularly relevant for chemistry and chemicals: Food, Home & Personal Care, and Chemicals Manufacturing.

It is important to recognise that chemistry is relevant to other sectors and the innovation strategy will apply to these. The identified Focus Areas, although motivated from examination of eight sectors, are applicable more broadly.

The BIS report which identifies the priority sectors was one of many documents relied upon to inform this work. Consulted documents include Government strategies, for example the Technology Strategy Board’s High Value Manufacturing strategy; sector strategies, for example aerospace and life sciences; and European roadmaps including SPIRE and BRIDGE. Further input was obtained from relevant strategic documents prepared by the Royal Society of Chemistry and the Institution of Chemical Engineers, from the work of various Special Interest Groups, industry sector representatives and many other organisations and individuals active in this area. The key sources are indicated at the back of this report.

The UK aerospace industry holds the number 2 position in the world and number 1 position in Europe. The industry leads with technology and manufacturing capability in wings, engines, aircraft systems and structures. In a world where the developing economies in the Far East and South America will be increasingly active, the need for air travel will increase.

This growth takes place against a background of concern about the impact of aviation on the environment, including CO2 and NOx emissions and noise pollution. The industry’s response is through more efficient air travel. Three levers have been identified to achieve this: 1) reduction in aircraft weight both in the body and engines, 2) better efficiency of aerodynamics and engines, and 3) improved control through electronics.

Chemistry has a great contribution to make towards addressing these challenges, creating opportunities for the UK industry. During manufacture, advanced composite materials comprising polymers, fibres, metals and ceramics enable weight reduction while retaining performance within aircraft structures and engines. These materials can be bonded using adhesives in a way which reduces weight but also allows for easier end-of-life disassembly and reuse. In the interior, polymers, foams and fabrics are used to produce fire safe panelling and seating. In addition, lighter electronic components and displays reduce the overall weight of control and in-flight entertainment systems.

In use, engine efficiency is aided by advanced lubricants while fuels sourced from bio-renewable raw materials provide a reduced impact on the environment. Better aircraft and flight management providing improved operational efficiency is facilitated by faster electronics and displays which consume less energy. Within these devices, chemistry provides the materials which enable display screens, organic light emitting diodes, conductive coatings and semi-conductors, not to mention the materials used in manufacturing integrated circuits and electronic chips.

In the aerospace sector, the evolution of advanced composite materials has been driven by miniaturisation of electronic components, weight reduction and integration of systems. This has been achieved through the use of lightweight, high performance composite materials. Aerospace technology is putting pressure on the industry to find more cost effective and simpler ways of producing composites.

Within these devices, chemistry provides the materials which enable display screens, organic light emitting diodes, conductive coatings and semi-conductors, not to mention the materials used in manufacturing integrated circuits and electronic chips.

Composites are being more widely used in the Aviation industry. Composite materials are structurally stronger and lighter weight than their metal counterparts resulting in better fuel efficiency of composites aircraft. The composite wings of the A380 enable 17% lower fuel use per passenger than comparable metal based aircraft. Boeing’s 787 Dreamliner will be the first commercial aircraft in which major structural elements are made of composite materials rather than aluminium alloys. Formation of composite materials (where one material acts as a supporting matrix, while another component as a reinforcement material) can be an expensive and complex process. The recent increased adoption of the technology is putting pressure on the industry to find more cost effective and simpler ways of producing composites.

There is enormous scope for innovation, in the basic components of the composite, the fabrication process and the development of stronger adhesives, critical in the final assembly process.

Opportunities
- Lighter materials for structure, interior and engines
- Sealants and adherives to facilitate assembly and disassembly
- Coatings and flame retardants to protect the structure and passenger
- Lubricants and additives to enhance engine efficiency
- Bio-based fuels to increase renewable content
- More capable electronics for better control and flight management
- Lighter electronics and displays to enhance the passenger experience
The Automotive Sector

Low carbon vehicles with improved driver experience

The UK has a strong and active automotive sector. There is significant development of automotive technology in the UK. Meanwhile, design and manufacture of engines and vehicles is thriving. Furthermore, at the high end of motor sport, Formula 1, many of the participating teams are based in the UK developing and implementing advanced technologies which ultimately appear in everyday vehicles.

The sector benefits from the increasing world population, with a growing middle class who need, desire and aspire to owning automobiles. Furthermore, the aspiration for individualised vehicles drives mass customisation. This increase in vehicles coincides with constrained availability of fossil based fuels and increased concerns for the environment including CO₂ emissions. These global trends pose challenges and offer opportunities mainly in enhancing efficiency and reducing environmental impact.

Opportunities for innovation to improve vehicle efficiency abound including lighter materials comprising polymers and fibres, possibly natural, as well as foams and sandwich panels. Incorporating these multi-component materials needs to accommodate ease of end-of-life dismantling and recycling. In the engine and drive train, lubricants and fuel additives can enhance running efficiency. Already many vehicles use fully synthetic oils formulated with the help of chemistry.

While fossil fuels will continue to dominate for some time, bio-based fuels offer an alternative. This together with electric, fuel cell and hybrid engine vehicles can contribute to an inherently cleaner drive. New improved catalysts can, in the meantime, reduce harmful emissions. Within the vehicle, electronics will continue to improve engine and journey management, not to mention providing a better user experience. Here, chemistry has the potential to enable lighter and more effective displays as well as faster processing power with lower energy consumption.

Opportunities

- Lightweight materials for body, drive train and trim
- Polymer based composites with natural and synthetic fibre reinforcement
- Coatings to protect and to enhance aesthetics
- Lubricants and additives for efficient running engines
- Catalysts to reduce vehicle emissions
- Bio-based fuels and alternative energy drives: battery, fuel cell, solar
- Electronics for engine and journey management and a better user experience
- Design for end-of-life recyclability

Case Study

Debondable Adhesives

The Challenge

The End of Life Vehicle Directive aims to reduce the amount of waste from scrapped cars and vans. Currently piano wire or electric knives are used to separate bonded parts (e.g. windscreen and frame) raising issues of safety, wastage and breakages.

One Innovative Response

Recsol Technological Centre developed Indar debondable adhesive for car parts. Debonding is a heat-triggered clean break of any adhesive bond between two surfaces and is achieved quickly under an infra-red lamp. This is caused by thermooxpansible microspheres expanding to over 100 times their volume, applying pressure to cleanly break the bond at the interface, and the cohesive structure. Microspheres can be applied to an adhesive, cleaner or primer, or directly applied at the interface between two layers. They will remain dormant (for up to 10 years or more) until the precise heat range is applied. The debonding process can be carried out by an individual operative and is much safer and efficient than traditional methods. It leaves clean surfaces and intact windscreen dramatically increasing recyclability of the components.

Opportunities

- Construction of residential and commercial buildings together with infrastructure requires a significant proportion of the UK economy with the resulting structures greatly influencing our daily lives.

The Construction Sector

Sustainable, low carbon buildings delivered through the whole value chain

Construction of buildings, whether residential or commercial, was estimated to account for 40% of the UK’s total energy consumption in 2012. Given the scale and profile of the project, Philips brought forward its development of 7W LED lighting which has been installed. Independent calculations show that across the 2,818 dwellings of the Athletes Village, the energy efficient lighting is predicted to save 5,317 tonnes of CO₂ annually, representing an 85% reduction on standard 60W lighting. Dwelling occupants in the future will also benefit from reduced energy bills. This energy efficient product is available on the market earlier than Philips originally planned because of the demand by such a major client as the Games. The development, early engagement with the product manufacturer to discuss technological innovation and availability enabled the supplier to accelerate its research and development programme.

Case Study

Renewable building material

The Challenge

Construction and use of buildings accounts for over 50% of the carbon dioxide produced in the UK. Studies have shown that up to 200 kg of CO₂ is emitted in the production of each square metre of walling alone equating to 40 tonnes for the walls of a typical house.

One Innovative Response

Lime Technology has developed Tradical Hemcrete, a unique blend of specially prepared hemp shiv and a lime based binder; which together form a bio-composite building material. The hemp shiv forms the key element in these products, is grown and harvested in the UK and is a low energy input crop. The Hemcrete is mixed on site and is applied by spray providing an airtight coating with very high insulation. The coating has excellent air tightness and vapour permeability and can produce savings of over 50 Tonnes of CO₂ in total emissions for a typical house.

Opportunities

- Materials for fast and sustainable construction
- Coatings with basic and added functionality
- High performance insulation materials
- Thermal management materials and systems
- Low energy, longer life lighting
- Recycling and full utilisation of waste materials
- In-situ energy generation and storage systems
- Control systems for building and environment management

*Case study courtesy of Construction Products Association

In 2006 when concept designs for the Athletes Village were first being developed, consultants would have tended to specify 50w halogen light bulbs. However Lend Lease (the Athletes Village developer) engaged with the manufacturer Philips to assess technological developments in energy efficient lighting that were likely to be coming to market for domestic properties by 2012. Philips predicted that wattages of 7w rather than 50w could be achieved around 2012. Given the scale and profile of the project, Philips brought forward its development of 7W LED lighting which has been installed. Independent calculations show that across the 2,818 dwellings of the Athletes Village, the energy efficient lighting is predicted to save 5,317 tonnes of CO₂ annually, representing an 85% reduction on standard 60W lighting. Dwelling occupants in the future will also benefit from reduced energy bills. This energy efficient product is available on the market earlier than Philips originally planned because of the demand by such a major client as the Games. The development, early engagement with the product manufacturer to discuss technological innovation and availability enabled the supplier to accelerate its research and development programme.

Case Study

LED Lighting at the London Olympics
The Energy Generation & Supply Sector
Delivering secure, economical, sustainable energy

Global demand for energy continues to increase as populations grow and adopt more energy intensive lifestyles. This demand is affecting both price stability and availability of fuels at a time when UK oil and gas imports are expected to increase to 50% of needs by 2020. Meanwhile, concern about the environment and climate change is also increasing and becoming more vocal. These factors are driving a number of changes in the approach to generating and using power.

Dependency on fossil fuels will continue for the foreseeable future, it is the basis for much of the current infrastructure. The need to access more difficult oil and gas reservoirs and unconventional sources, such as shale gas, presents opportunities for enhanced oil recovery and fracturing technologies which are enabled by chemistry. At the point of use, these fuels can also be made cleaner by using carbon capture technologies.

Renewable energy sources need to be developed further. Bio-based fuels provide one recognised alternative which demands attention and exploitation. Increased use of wind and solar power can be aided by the development of new materials. Composite materials can make turbine blades lighter and stronger, coatings can protect installations in harsh offshore environment, and lubricants can make gears boxes run more efficiently. Another source of electricity, nuclear, remains a controversial necessity. Chemistry has a great enabling role in ensuring safe nuclear power generation as well as later decommissioning.

Chemical formulations for enhanced oil recovery
Fracturing fluids for shale gas extraction
Carbon capture technology for clean burn of fossil fuels
Bio-based fuels
Materials for wind turbine structures
Functional materials for photovoltaic cells
Decommissioning technologies for nuclear power
Energy storage and release capability

Case Study

Electricity from Low Grade Heat

The Challenge
Capturing and converting waste energy and making it useful is key to approaching optimum energy efficiency and zero emissions. Whilst the recovery of waste heat from high temperature sources is achievable by raising steam, recovery and use of low grade heat is less straightforward.

One Innovative Response
Redcar based DRD Powers have developed an innovative approach to capturing and converting low grade (low temperature) heat to electricity. It has the added benefit of producing zero CO2. The approach uses Organic Rankine Cycle (ORC) technology for a cost effective way to produce a transportable, modular unit capable of operating in the temperature range of 90-130 °C. ORC employs an organic, high molecular mass fluid with a liquid-vapour phase change, or boiling point, occurring at a lower temperature than the water-steam phase change.

The overall market size for ORC applications within the UK is estimated to be at least €100m, representing around 120 MW of generating capacity. The technology can also be applied to the renewable energy sectors such as geothermal, solar and biomass applications which could represent an additional energy market of at least €50m. The world market potential is in excess of €1bn.

Case Study

Novel anodes for Lithium ion batteries

The Challenge
Modern devices are increasingly demanding more from rechargeable batteries in terms of higher capacity and longer lifetimes. Lithium ion (Li-ion) batteries are most commonly used due to their light weight, high open-circuit voltage and low self-discharge rate with less toxic metals than comparable alternatives. However, they have a poor cycle life as well as some safety concerns if overcharged. The use of silicon to replace graphite as the anode material has been limited by its tendency to expand and contract leading to fracture.

One Innovative Response
Nexeon have produced silicon anode materials with structures that mitigate the volume expansion issue. These materials have up to ten times higher capacity for lithium than carbon and only a quarter of the amount is used compared to graphite. The graphite currently used in Li-ion battery production can simply be replaced with Nexeon materials and used in combination with conventional polymer binders and current collectors. The silicon anodes provide increased longevity and consistent performance, together with many operational benefits.

The Life Sciences Sector
Personalised treatments requiring niche, high value products with improved delivery

The UK life sciences industry covering, among other things, pharmaceuticals, medical diagnostics and devices, and synthetic biotechnology, has a significant global presence. As such this sector is impacted strongly by global trends.

The world’s ageing population, particularly in the developed world, is both a driver and a consequence of activities in this sector. People are living longer with a desire to stay active and healthy at an advanced age. In developing countries, a growing middle class can increasingly afford a healthier lifestyle. Amongst both these groups, there is increased awareness of the possibilities afforded by healthcare with a growing expectation for cure and repair. The proliferation of information, mainly on-line and through social networks, is also increasing demand for wellbeing consumer products and nutraceuticals as an aid to prevention.

Within this environment, opportunities abound for innovation, enabled by the application of chemistry. Pharmaceutical actives, chemically and biologically derived, delivered more effectively are in demand within a growing market. New antibiotics are needed to tackle evolving difficult-to-treat infections. Treatment can be further aided by the application of better diagnostics to target treatments where they are most effective. Meanwhile, newer treatments using techniques such as cell therapy and regenerative medicine are enabling more capable treatment and repair. Furthermore, quality of life and improved wellbeing can benefit from remote health monitoring and care and diagnostics in the home.

Case Study

Stem Cell differentiation for Regenerative Medicine

UK SME Plasticell is working in partnership with EMD Millipore to deliver technology for differentiating human stem cells into osteocytes. The formulation used produces more consistent and potent osteogenic differentiation than other available alternatives, enabling a more reproducible, efficient method for creating bone tissue and advancing research in bone disease and healing (e.g. osteoporosis). Plasticell’s proprietary technology, Combinatorial Cell Culture or CombiCult®, allows testing of cell culture variables in millions of combinations to discover optimal protocols for the differentiation and expansion of stem cells. Results are obtained rapidly at lower cost than the alternative - each screen can produce many dozens of protocols which are ranked using bioinformatics.

In addition to discovering optimised stem cell differentiation protocols, CombiCult® can be used to produce high-value cell types for drug development and cell therapy applications, improving yields and decreasing cost of goods for bio-processing.

Case Study

Nutraceuticals for improved wellbeing

The proliferation of information, mainly on-line and through social networks, is also increasing demand for wellbeing consumer products and nutraceuticals as an aid to prevention. Within this environment, opportunities abound for innovation, enabled by the application of chemistry. Pharmaceutical actives, chemically and biologically derived, delivered more effectively are in demand within a growing market. New antibiotics are needed to tackle evolving difficult-to-treat infections. Treatment can be further aided by the application of better diagnostics to target treatments where they are most effective. Meanwhile, newer treatments using techniques such as cell therapy and regenerative medicine are enabling more capable treatment and repair. Furthermore, quality of life and improved wellbeing can benefit from remote health monitoring and care and diagnostics in the home.

Case Study

Pharmaceutical actives, chemically and biologically derived

Antibiotics for difficult-to-treat infections

Regenerative medicine to enable organ and limb replacement

Better diagnostics to target treatments where most effective

Systems enabling care and diagnostics in the home

Nutraceuticals for improved wellbeing
The world population continues to grow; expected to exceed 9 billion by 2050. Meanwhile, there is increased concern from the public about the impact of food production intensification. This includes worries about contamination of soil and habitat, care for the welfare of animals, and nervousness about modification of the food itself. In response to these concerns, stringent regulations apply which pose both threats and opportunities to the industry. Providing for everyone requires more effective utilisation of the food producing resources of our earth. Opportunities exist to develop better and safer fertilisers, crop protection products, and animal feeds.

At the same time, in many of the developing countries, an emerging middle class is acquiring the means and desire to purchase better food with increased interest in nutritional value and an enjoyable eating experience. This drives opportunities for food manufacturers to offer more nutritious food with ingredients, flavourings and additives from natural sources, formulated and processed to address the emerging needs.

In developed economies, on the other hand, where people are increasingly money-rich and time-poor, demand is increasing for ready-made meals having high quality and good flavour. Preparation of these products presents opportunities to develop ingredients tolerant of factory processing while retaining texture and flavour with extended shelf-life.

The global market for home and personal care products is benefiting from the increasing world population and, in particular, a growing proportion with disposable income. These positive trends are countered by the need to increasingly demonstrate responsiveness and environmental friendliness. Better informed consumers demand more sustainable, “greener”, products without sacrificing functional effectiveness, and they want an ever changing offering of new products. Meanwhile, regulations such as REACH constrain the ability to introduce new chemicals.

This context presents opportunities for innovation in ingredients and products as well as in the methodology used to develop these. Bio-derived natural ingredients offer a huge potential for new products; they offer both real and perceived advantages. More advantageous is the potential to address the consumer demand through formulation using existing ingredients. Formulation can deliver new products to market in a short timescale with tailored effect and benefit. The highlighted challenge here becomes developing the capability to design and manufacture new formulated products effectively to accelerate time to market.

### Opportunities
- Agrochemicals for safe intensification and crop protection
- Animal feeds for nutrition and welfare
- Ingredients allowing robust food processing and extended shelf-life
- Ingredients offering added nutritional value
- Flavourings and additives naturally based and naturally processed

### One Innovative Response
ADM and Novozyme jointly developed an enzymatic interesterification process (an alternative to hydrogenation) using immobilised lipases. This produces zero trans-fatty acids and is extremely efficient. It is simpler than both hydrogenation and chemically catalysed interesterification, and produces very little waste. It gives food manufacturers a wider range of options for specifying the exact triglyceride that can be extracted, and leads to a host of benefits such as poor reproducibility and poor shelf life stability.

### Case Study
#### Healthy Food using enzymes
**The Challenge**
Edible oils are triglycerides; three fatty acid chains linked to a glycerol backbone. Many contain significant amounts of mono-unaturated and poly-unsaturated fatty acids. For many applications the oils need to be hydrogenated or hardened to reduce the degree of unsaturation. Hydrogenation was traditionally carried out using a nickel catalyst (producing nickel-containing waste) and a high hydrogen pressure (turning cis-fatty acids into trans-fatty acids, a strong risk factor in heart disease).

**One Innovative Response**
ADM and Novozyme jointly developed an enzymatic interesterification process (an alternative to hydrogenation) using immobilised lipases. This produces zero trans-fatty acids and is extremely efficient. It is simpler than both hydrogenation and chemically catalysed interesterification, and produces very little waste. It gives food manufacturers a wider range of options for specifying the exact triglyceride that they want without concerns for human health.

### The Challenge
Concentrated washing liquids

**The Challenge**
Liquid fabric washing detergents are a very popular product, especially in the US. The bulk ingredient in washing liquids is water, not an active component, an increasingly precious resource worldwide. The large amounts of packaging required, and transport fuel, add substantially to the carbon footprint of detergents.

**One Innovative Response**
Unilever produced the UK’s first double concentrated liquid detergent in the form of Persil Small & Mighty. This detergent is twice as concentrated as previous versions, requiring considerably less water during the manufacturing process. Other benefits of this product include various pre-treating agents allowing it to work optimally at 30˚C, and it using 40% less packaging than other Persil liquids. Wal-Mart, the major US retailer, expects to sell over 300 million bottles of concentrated detergent per year saving 40 million pounds of plastic resin, 150 million gallons of water, 200,000 gallons of diesel fuel and 50 million pounds of cardboard packaging.

**Case Study**
**Concentrated washing liquids**

**Opportunities**
- New functionality offered to consumers
- Natural, bio-derived ingredients, for greener products
- Formulation of new products using pre-registered ingredients
- New ingredients such as nanomaterials, giving novel effects
- Increased speed-to-market through formulated products
- Science-based formulation design capability
- New technologies for reproducible manufacturing of formulated products
The Chemicals Manufacturing Sector

Manufacturing chemicals more competitively and sustainably from a variety of feedstocks

Chemicals are key to the make-up and manufacture of most things in regular daily use. Consequently, the chemicals manufacturing sector is driven by the usual trends which impact other sectors. However, this sector has its own challenges with which it must deal. The two most critical challenges facing the sector are the increasing cost and volatility of energy and traditional feedstocks, and the growing pressure to be greener and more sustainable.

Many opportunities arise from these challenges such as the potential to increase use of alternative feedstocks including bio-based ingredients and recovered waste materials. Furthermore, the transformation processes used can be diversified to include more biologically based processes while traditional chemical processes can be made more flexible and more resource efficient. Where possible, more direct transformation processes can make for a more efficient industry as well as offering the potential to manufacture better differentiated end products. More broadly, opportunities exist to alter the business model in a way which increases industrial collaboration for mutual benefit. This can involve more complete utilisation of feedstocks, increased recycling and reduced transport of chemicals.

Opportunities

- Technology enabling production with high atom efficiency and minimum waste
- Scalable and flexible manufacturing processes close to supply or market
- Increased use of bio-based feedstocks
- More complete utilisation of feedstocks with reduced waste
- Using recovered and recycled materials as feedstocks
- Deploying alternatives to catalysts that use scarce metals
- Upgrading chemical processes to increase efficiency
- Reducing the use of energy and water in chemicals manufacture
- Utilising bio-based transformation processes
- Encouraging cross industry collaboration for mutual benefit

The Challenge

Propylene oxide (PO) is one of the biggest volume industrial chemicals in the world. It is a building block for a vast array of products including detergents, polyurethanes, de-icers, food additives, and personal care items. Traditional PO production uses chlorohydrin or one of a variety of organic peroxides which, in addition to producing a substantial amount of waste, lead to co-products such as t-butyl alcohol, styrene monomer, or cumene.

One Innovative Response

Dow and BASF developed the Hydrogen Peroxide to Propylene Oxide (HPPO) process, based on the reaction of hydrogen peroxide and propylene, using a modified ZSM-5-type zeolite catalyst. It has high yields and produces only water as a co-product. Production facilities are up to 25% cheaper to build because there is no need for equipment to collect and purify the co-product. The process, now fully operational, has resulted in a 70% reduction in waste water and a 35% reduction in energy use. It also has lower capital requirements and substantially lower negative impacts.

Case Study

Manufacture of propylene oxide

Innovation Focus Areas

Examination of the eight priority industry sectors has highlighted a number of challenges which can be addressed with chemistry enabled solutions. These opportunities for innovation share common threads which allow them to be grouped into areas of focus, each of which merits attention and action.

Focus areas have emerged where it is evident that some intervention could accelerate the pace of innovation, leading to growth in the UK economy. The required intervention could simply involve increasing awareness of issues throughout industry; it might involve other specific initiatives by one or more KTNs; or, in key topics, it might require targeted funding from UK public funds (probably through the Technology Strategy Board) or the European Commission. It is especially important to encourage UK companies to collaborate with one another with academia and across sectors.

In order to achieve the desired growth, activity within these focus areas must meet some critical prerequisites. Activity must be based on sustainability principles such that the outcome can generate growth without threatening limited resources or causing objectionable damage to our world. Furthermore, the intellectual property resulting from the activity must be protected in a way that provides a compelling advantage to the UK. The outcome cannot be the result of simple incremental development effort which is easily replicated by others.

The three focus areas which have emerged from this study are:

1. Raw Materials for the 21st Century
2. Smart Manufacturing Processes
3. Design for Functionality

In each of these focus areas there are a number of themes which require additional definition. These are discussed in the following pages.
Raw Materials for the 21st Century

The raw materials used as input materials for the production of energy, chemicals, and components and structures

Opportunities to identify, secure and exploit alternative raw materials were highlighted in several industry sectors. This call is driven by increased demand for conventional raw materials which is raising prices and increasing volatility of supply, together with the desire to increase usage efficiency and renewable content.

Three distinct themes require attention:

Renewable feedstocks

Fossil hydrocarbons continue to play a role both as feedstock for the production of chemicals and as a source of energy, in particular as transportation fuels. Exploiting new oil and gas reserves will require production from deeper wells where production fluids need to tolerate higher temperatures. Exhausted fields can benefit from Enhanced Oil Recovery treatments. And gas trapped in shale deposits can be extracted by using fracturing technologies. Companies directly involved in the extraction of fossil hydrocarbons have been active in these areas for some time together with their suppliers of chemistry enabled solutions. However it is only recently that government policy has drawn attention to this area as a potential intervention focus. The opportunities and benefits of intervention will need to be articulated next.

Unconventional oil and gas

Fossil hydrocarbons continue to play a role both as feedstock for the production of chemicals and as a source of energy, in particular as transportation fuels. Exploiting new oil and gas reserves will require production from deeper wells where production fluids need to tolerate higher temperatures. Exhausted fields can benefit from Enhanced Oil Recovery treatments. And gas trapped in shale deposits can be extracted by using fracturing technologies. Companies directly involved in the extraction of fossil hydrocarbons have been active in these areas for some time together with their suppliers of chemistry enabled solutions. However it is only recently that government policy has drawn attention to this area as a potential intervention focus. The opportunities and benefits of intervention will need to be articulated next.

Scarcity of raw materials and minerals

Metals and minerals are used in many emerging technologies including electric vehicles, energy efficient lighting and wind turbines. They are also present in everyday devices such as mobile phones and computers and in established manufacturing processes. Increasing demand for these metals and minerals is making us more dependent on limited sources which are subject to geopolitical pressures and control. To continue to enjoy the benefits of the products to which we have become accustomed, our usage of scarce materials must be addressed. Increased supply is required, possibly through more efficient extraction and recycling, or reduced demand through substitution. A number of activities are already ongoing in this area, particularly the Materials Security SIG and the CRM InnoNet project. Efforts need to continue, in particular to identify opportunities specific to the UK and to initiate actions to address them.

Opportunities to identify, secure and exploit alternative raw materials were highlighted in several industry sectors. This call is driven by increased demand for conventional raw materials which is raising prices and increasing volatility of supply, together with the desire to increase usage efficiency and renewable content.

Three distinct themes require attention:

Renewable feedstocks

Fossil hydrocarbons continue to play a role both as feedstock for the production of chemicals and as a source of energy, in particular as transportation fuels. Exploiting new oil and gas reserves will require production from deeper wells where production fluids need to tolerate higher temperatures. Exhausted fields can benefit from Enhanced Oil Recovery treatments. And gas trapped in shale deposits can be extracted by using fracturing technologies. Companies directly involved in the extraction of fossil hydrocarbons have been active in these areas for some time together with their suppliers of chemistry enabled solutions. However it is only recently that government policy has drawn attention to this area as a potential intervention focus. The opportunities and benefits of intervention will need to be articulated next.

Unconventional oil and gas

Fossil hydrocarbons continue to play a role both as feedstock for the production of chemicals and as a source of energy, in particular as transportation fuels. Exploiting new oil and gas reserves will require production from deeper wells where production fluids need to tolerate higher temperatures. Exhausted fields can benefit from Enhanced Oil Recovery treatments. And gas trapped in shale deposits can be extracted by using fracturing technologies. Companies directly involved in the extraction of fossil hydrocarbons have been active in these areas for some time together with their suppliers of chemistry enabled solutions. However it is only recently that government policy has drawn attention to this area as a potential intervention focus. The opportunities and benefits of intervention will need to be articulated next.

Scarcity of raw materials and minerals

Materials which are economically important and at high risk of supply disruption; scarce metals and minerals; heavy rare-earth elements; platinum group metals

Materials used in chemical processing such as catalysts

Materials used in products with growing markets, for example in LCD displays and in energy efficient lighting

Devising technologies and approaches to reduce usage and for recovery and recycling

Identifying technologies and approaches for substitution with sustainable alternatives

Securing, extracting and refining additional supplies with minimal environmental impact
Biological transformation

Biological transformation as a route to making chemicals offers an alternative to chemical based processes. Bio-transformation can be applied to both natural and fossil feedstocks. Applying these processes can enable new, different chemicals to be made or offer more efficient manufacture of existing chemicals. This area has been at the heart of the activities of the Industrial Biotechnology Leadership Forum (IBLF). Facilities for trial and scale up have already been established at the Centre for Process Innovation within the High Value Manufacturing Catapult. Also, several calls for collaborative projects have been initiated. This activity needs to continue towards demonstrating delivery of the £12 billion benefit already indicated by a study commissioned by the IBLF.

Resource efficiency

A number of traditional chemical plants are big users of resources such as water and energy. This heavy use impacts the cost of manufacture. More significant is the impact on the environment of using resources in a wasteful way. The SPIRE European roadmap has identified the opportunity to change this and a number of manufacturers are already taking steps to become more efficient in resource usage. However, more needs to be done, starting with a SPIRE UK roadmap which identifies some clear actions. This in turn prompts the examination of technologies which can contribute to better resource efficiency, often through enhanced management of existing plants and processes.

Chemical processes

Manufacturing chemicals by traditional chemical transformation processes is the norm. These processes can be made more efficient by applying process improvements and bolt-on upgrades. More radical are opportunities to modify the processes so that they become more flexible and use less of any scarce metals and resources. Process intensification, novel scalable processes, continuous rather than batch processes, and microfluidics are some of the options available. New processes can be developed to make use of bio-based feedstocks and to manufacture better differentiated end products. The issues and opportunities are well understood and communicated but realisation can benefit from further focus on identifying specific solutions and providing access to facilities for trials and scale-up.

Using bio-transformation where it offers better efficiency compared to chemical processes

Applying biological transformation to enable manufacture of previously unattainable chemicals

Using bio-transformation for both fossil and bio based feedstocks

Succinic acid is emerging as one of the most competitive of the new bio-based chemicals. It has a range of applications, including as a raw material for polyurethanes, coatings, adhesives, sealants, and personal care ingredients. BASF and Purac collaborated to develop a sustainable and highly efficient process for manufacturing succinic acid, using their complementary strengths in fermentation and downstream processing. The new process combines high efficiency with the use of renewable substrates and the fixation of the greenhouse gas CO₂ during the production. This results in a positive eco-footprint and makes bio-based succinic acid an economically and ecologically attractive alternative to petrochemical substitutes. The employed microorganism巴斯夫 suciniciproducens is a natural producer of succinic acid and can process a wide variety of C3, C5 and C6 renewable feedstocks, including biomass.

Improving the efficiency of existing chemical manufacturing processes including more efficient synthesis and catalysis; process intensification

Devising and adopting processes for synthesis and catalysis which are bio-based processes

Adopting new chemical processes, for example continuous in place of batch processes and micro-reactor technologies

Topics in this Focus Area include:

Case Study

Green route to succinic acid

Succinic acid is emerging as one of the most competitive of the new bio-based chemicals. It has a range of applications, including as a raw material for polyurethanes, coatings, adhesives, sealants, and personal care ingredients. BASF and Purac collaborated to develop a sustainable and highly efficient process for manufacturing succinic acid, using their complementary strengths in fermentation and downstream processing. The new process combines high efficiency with the use of renewable substrates and the fixation of the greenhouse gas CO₂ during the production. This results in a positive eco-footprint and makes bio-based succinic acid an economically and ecologically attractive alternative to petrochemical substitutes. The employed microorganism巴斯夫 suciniciproducens is a natural producer of succinic acid and can process a wide variety of C3, C5 and C6 renewable feedstocks, including biomass.

Improving the efficiency of existing chemical manufacturing processes including more efficient synthesis and catalysis; process intensification

Devising and adopting processes for synthesis and catalysis which are bio-based processes

Adopting new chemical processes, for example continuous in place of batch processes and micro-reactor technologies

Resource efficiency, especially for manufacturing chemicals which are energy and water intensive

Technologies and processes for reducing the use of resources which are heavily consumed in chemicals production such as energy and water

The processes used in the manufacture of chemicals

Chemicals can enable the solution to many challenges facing the chemistry-using industries. The manufacture of these chemicals faces its own challenges. Improving process efficiency in order to reduce costs and reduce impact on the environment is the most accessible opportunity. The ability to manufacture different, and more effective, chemicals by using new processes offers a second innovation opportunity. A third opportunity is to achieve a step change reduction in using certain resources which are consumed intensively within traditional chemical plants. More broadly, opportunities exist to alter the business model in a way which increases industrial collaboration for mutual benefit. This can involve more complete use of feedstocks, increased recycling and reduced transport of chemicals.

Three distinct themes require attention:
Novel materials and their creation

 Opportunities to develop ‘new’, ‘advanced’, ‘novel’ materials abound. These can be magnetic materials for wind turbines; they can be sensor materials or semi-conductors for electronics; or they can be lightweight fibre reinforced composites for aircraft; the definition is broad. Increasingly, the act of creating the material and the system is one and the same. Additive manufacture, layer deposition and 3D printing are some of the new approaches creating materials. Because of its breadth, this area is represented by a number of organisations and working groups. Most recently, the Materials Chemistry SIG was formed. Going forward, this focus area would benefit from better understanding and analysis of what interventions are required to ensure maximum benefit to UK plc.

Formulated products

 Formulated products, combining several ingredients, are indicated in most of the industry sectors as critical routes to delivering desired effects and functionality. Coatings, lubricants, pharmaceuticals, foods, home cleaning and personal care products are just some examples which were highlighted in the sector analysis. Opportunities for innovation are plentiful but perhaps the most effective intervention will be establishing the capability and facility to assist industry in designing, evaluating and developing formulations, quickly and effectively. While the application knowhow differs between sectors, the underlying science and technology which enable formulation are commonly applicable across the sectors. The Formulation SIG has already been active in specifying such a capability with well advanced plans to establish a National Formulation Centre. The next task, once the centre has been opened is to demonstrate value from it by securing strong engagement and commitment from industry.

Design for a circular economy

The Circular Economy model challenges businesses to adopt sustainable practices, where resources are circulated within the economy whilst retaining their value for as many cycles as possible. This presents a dual opportunity for businesses to reduce costs, mitigate supply risks and generate value, whilst contributing towards a resource-efficient and low-carbon economy. Products designed for disassembly in a way which facilitates material recovery and re-use can result from better education and collaboration. Alternative business models, such as leasing, enable businesses to recover valuable products and components or even retain ownership to enable re-use. The Materials Security SIG has been active in this area. Further activity is required to highlight this opportunity to UK business, and to produce plans and processes which encourage collaboration between disciplines, in particular with designers, to enable circular principles to be adopted.

Perhaps the richest area for innovation is that of outputs at the end of value chains; these can be materials, systems, components or end products. Functionality can be delivered to the user which matches their needs exactly. Opportunities exist in creating new ingredients and materials; there is room for these. However, tailoring functionality by combining several existing ingredients and base materials within formulations, composites and materials systems is a more likely route for innovation. Further opportunities for beneficial intervention exist in developing and creating the capability to design, evaluate and manufacture the end products in a way which optimises their use and impact. Three distinct themes require attention:

- Net shape manufacture, self-reinforcing and developing novel materials and systems through additive manufacture, 3-D printing, layer deposition, net shape manufacture, self-assembly, and other such processes
- The fundamental application of physical chemistry and other sciences, design methodologies, numerical and experimental, production approaches
- Provision of the component ingredients to create formulated products by combining several ingredients

Business models, design concepts and materials which enable an economy in which waste materials are put to use and where materials and products are recycled and reused at end of life
A Comprehensive set of Focus Areas

Focus Areas enable innovation in the Industry Sectors

Table 1 indicates the relevance of the innovation focus areas to the various industry sectors. It is evident that intervention to drive activity in each focus area will deliver benefit across a number of sectors. Further benefit would be expected within other sectors not examined in detail during the development of this strategy.

Focus Areas support the HVM Strategy National Competencies

Table 2 demonstrates the correspondence between the innovation focus areas and the national competencies identified in the Technology Strategy Board’s High Value Manufacturing Strategy. Efforts to progress the innovation focus areas will concurrently support the national competencies.

Successful Innovation

The process of innovation is complete when added value is generated for the innovator. The process is about converting technology and knowhow into commercial value. This can be done by launching and selling a product, implementing and operating a production process, or adopting and commercialising a business model.

This strategy indicates the areas within which the chemistry-using industries have opportunities to innovate successfully; we have the capability to address these. The Innovation Focus Areas identified in this strategy can guide towards the science, technology and knowhow required to deliver.

In addition, to innovate successfully, teams representing all business functions must work together towards the innovation goal. Organisations need to create and nurture a culture which encourages innovation. Establishing this culture needs to be led from the top of the organisation. Managing innovation is a skill and a discipline which need to be acquired and developed; attention needs to be paid to these at all levels of industry.

Beyond the boundaries of any single organisation, additional enablers can improve chances of innovation success. It is said that the UK is not very effective at commercialising technology; we are not the best at innovating. To change this, it is necessary for us all to pay attention to the environment within which we operate. There are interventions which Government could introduce which would enable more innovation success. These interventions could be in policy or simply to provide support and information to companies.

Organisations need to create and nurture a culture which encourages innovation.”
The Way Forward

This strategy has identified a number of opportunities for the chemical and chemistry-using industries to innovate and grow new business to satisfy the supply requirements of the other major manufacturing sectors in the UK. Many of these opportunities will be accelerated with carefully considered intervention. This strategy will not only deliver more value for the UK economy but will also enable our companies to compete successfully in a global economy.

The activities going forward are expected to take a number of forms. For example there may be opportunities for funding competitions to fill critical gaps in science and technology; we may identify specific needs for demonstration facilities, networks, events and dissemination; or to address more complex issues it may be appropriate to establish a limited term Special Interest Group.

The following topics will be addressed initially, with the aim of developing detailed plans with specific objectives and targets before the end of 2013.

- Report on the sourcing of renewable feedstocks, including technical, logistic and economic implications, and technology requirements for handling them
- Identify innovation opportunities for the safe extraction and use of shale gas
- Identify and prioritise the challenges and opportunities associated with the consumption of critical metals and minerals

In order to progress these strategic opportunities, a programme of activity will be initiated by Chemistry Innovation and the Centre for Process Innovation. This will involve collaboration and joint activity with a number of other partners, in particular:

- Technology Strategy Board
- Centres within the High Value Manufacturing Catapult
- UK Research Councils
- EPSRC Centres for Innovative Manufacturing and Doctoral Training
- BBSRC Institutes and Centres
- KTNs representing both manufacturing sectors and specific areas of science and technology
- European Technology Platforms, especially SusChem
- The Chemical Industries’ Association and other Trade Associations representing the chemistry-using industries
- Relevant professional organisations, particularly the Royal Society of Chemistry, the Institution of Chemical Engineers and the Society of Chemical Industry

Key sources

Many documents inform this strategy particularly the following:

- Industrial Strategy: UK Sector Analysis, September 2012
  BIS/12/1140

  https://www.innovateuk.org/documents/1524978/213968/Hg+h+Value+Manufacturing+Strategy+2012-15/66765f6c-e09a-4efc-89e5-59d132be477

  http://www.eurosfaire.prd.fr/7pc/July_2012_Spire2012_SpireRoadmap_FINAL.pdf


- BRIDGE - Biobased and Renewable Industries for Development and Growth in Europe
  http://bridge2020.eu/

- Chemistry for Tomorrow’s World, RSC, July 2009
  http://www.rsc.org/images/Roadmapfull_tcm18–221545.pdf

- Chemical Engineering Matters, IChemE, February 2013

- Reach for the Skies: a Strategic Vision for UK Aerospace, July 2012
  BIS/12/954

- Lifting off: Implementing the Strategic Vision for UK Aerospace, March 2013
  BIS/13/723

- Learning legacy – lessons learned from the London 2012 Games construction project

- Strategy for UK Life Sciences, December 2011
  BIS/11/1429

- Strategy for UK life sciences: one year on, December 2012
  BIS/12/1346

- Science and innovation strategy 2012, April 2012
  DECC/12D/073

- Nuclear Industrial Strategy, March 2013
  BIS/13/629

- Nuclear Industrial Vision Statement, March 2013
  BIS/13/629

- UK Oil and Gas Industrial Strategy, March 2013
  BIS/13/748

- European chemistry for growth – Unlocking a competitive, low carbon and energy efficient future
  www.CEFIC.org

- HORIZONS Sustainable Economy Framework
  http://horizons.innovateuk.org