OXFORD ECONOMICS

The economic benefits of chemistry research to the UK

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FINAL REPORT

Contents

Foreword

Our future is dependent on the fruits of research in engineering and the physical sciences, such as chemistry, which play a critical role in developing economic growth and improving our quality of life.

Many of the life-improving breakthroughs of the last century in areas such as health and medicine, food and agriculture, energy and the environment have been heavily dependent on advances in chemical knowledge. Not so obvious is the essential role of chemistry in many wider applications, such as aerospace or electronics. It was the application of molecular science to some of the biggest questions facing science as a whole that gave us the silicon chip and unlocked the secret of the genetic code.

New developments in nanotechnology and materials have chemistry at their core. This multi-disciplinary research holds the key to tackling many of the challenges we face as a society and is the breeding ground of the knowledge-based industries of the future.

This independent report uses a combination of robust econometric analysis and qualitative illustrations to reveal a story of dedication, ingenuity and enterprise in UK chemistry research. It tells the story of high quality research performed by chemical scientists in our universities, recognised as internationally excellent by scientists across the world. It is these standards that have attracted the brightest minds, creating opportunities for innovation and bringing high levels of foreign investment to the UK.

Chemistry research will help to provide solutions to all the major challenges facing our society today, such as creating and securing supplies of energy and food, improving and maintaining accessible health, and developing and ensuring the sustainable management of water and air quality. It will also help us solve the unknown challenges that will face us in the future. Our strength in chemistry research is an asset we must nurture by encouraging a fascination with science amongst our children and leading our brightest students into scientific careers. Only by increasing the visibility of our research and ensuring that strong partnerships and pathways are embedded across the UK can we provide business and government with the partners and results they need to keep the UK at the forefront of technological and economic success.

Professor David Delpy FRS

Chief Executive

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Highlights

Total Economic Contribution of Chemistry

- The UK's upstream chemicals industry and downstream chemistry-using sectors contributed a combined total of **£258 billion in value-added in 2007**, equivalent to 21% of UK GDP, and supported over **6 million UK jobs**.
- Workers in the UK's chemicals industry are highly productive - at £83,500 per employee (2007) the sector has a **labour productivity more than double the UK average**.
- The UK's chemicals industry is **a major source of UK exports**, accounting for 15% of the goods exported by UK companies.
- UK chemists are **internationally renowned** for their quality and are shown to be a significant factor in causing companies to locate in the UK, or retain a UK-based research presence.

Other Findings

- The chemistry research benefits we enjoy today reflect the fruits of many years of investment. **On-going fundamental research is essential,** not only to ensure a continuing flow of scientific and technological breakthroughs, but also to ensure that the UK **maintains a highly skilled and innovative workforce** and is well placed to adopt and advance new ideas, to successfully exploit new technologies, and to develop new and better products and services. This will fuel economic activity, and is a necessary condition for attracting inward investment to the UK.
- Fundamental chemistry research remains indispensible to the search for solutions to some of the most important technological and societal challenges facing both the UK and the wider world. Examples identified in this report include:
    - **Climate change** - chemistry research is developing sustainable alternatives to fossil fuels and lowering carbon emissions by increasing energy efficiency in areas ranging from domestic electronic products to nuclear power stations;
    - **Energy** – chemistry research leads to improvements in the generation, transmission and use of energy in all forms. Airbus' next-generation A350 XWB aircraft will have significantly improved fuel economy in part because they will be over 50% (by weight) built from lightweight composite materials derived from chemistry research;
    - **Security** – chemistry research has resulted in faster, smaller and more sensitive devices able to detect microscopic levels of explosives;
    - **Food Supply** – Azoxystrobin, an extremely successful agricultural fungicide developed by UK-based chemists between 1981-96, has increased yields of more than 120 types of crop in over 100 countries; and,
    - **Health** - Amlodipine (one of many blockbuster drugs underpinned by UK chemistry patents) has reduced the number of days a patient visits hospital, cutting costs to both patient and the health service.

Executive Summary

The products of chemistry research are all around us, from the water we drink and the food we eat, to the clothes we wear, the cars we drive and the energy used to heat and light our homes, chemistry research has changed our way of living and increased our quality of life.

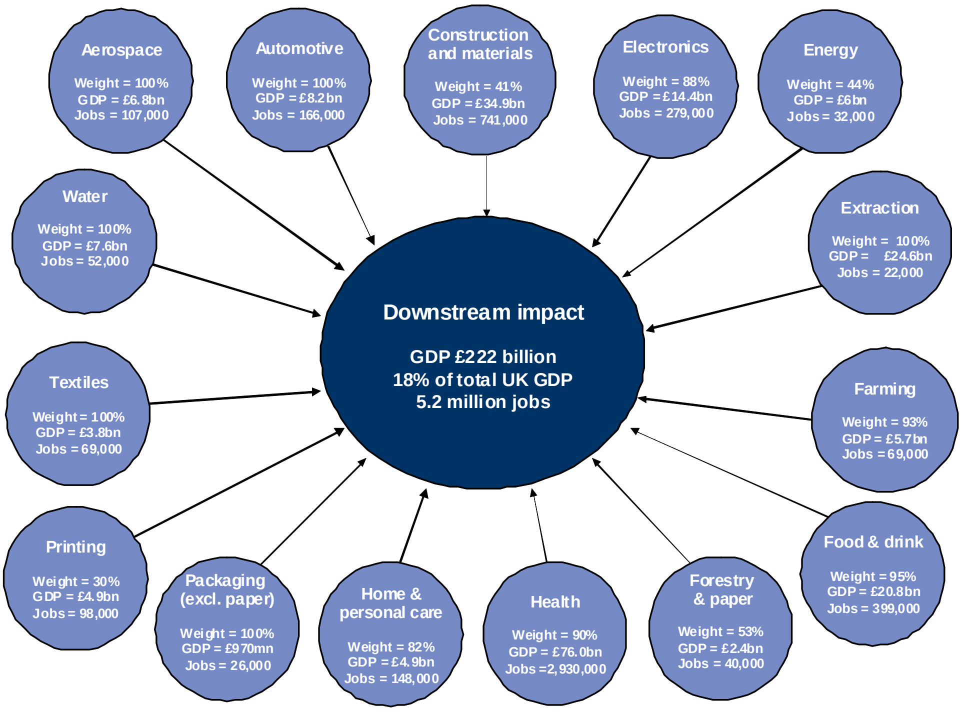
This study has been commissioned by the Engineering and Physical Sciences Research Council and the Royal Society of Chemistry to examine the many channels through which chemistry research contributes to the UK economy and to provide a quantitative and qualitative analysis of just how much it benefits the UK. The evidence presented in this report shows that **the direct and indirect ('spillover') benefits from fundamental chemistry research are significant to the UK**. More crucially, it will be the outcomes of this fundamental research that will be a vital ingredient to help answer important technical and societal challenges facing the UK over the years ahead.

Chemistry-reliant industries contributed £258 billion value added to the UK economy in 2007 - equivalent to 21% of UK GDP - and supported 6 million jobs, accounting for at least 15% of the UK's exported goods and attracting significant inward investment.

- Today the UK's upstream[1] chemicals industry supports **over 800,000 jobs**, including those in its supply-chain, **contributing £36 billion** to the UK's economy in 2007.
- The 15 identified downstream industries, in which chemistry research is a necessary but not sufficient condition for their operation, support an additional **5.1 million jobs** and directly **contributed £222 billion** to the UK's GDP in 2007.
- The upstream chemicals industry is one of the UK's highest exporters, accounting for **15% of the UK export of goods**, comparable to UK's transport equipment sector, which includes famous global brands such as Rolls-Royce aerospace and Bombardier trains. The chemistry research reliant pharmaceuticals industry is the **third largest exporting sector** in the UK. Trade performance is a key determinant of economic growth and prosperity. Innovative exploitation of fundamental research discoveries enables UK industries to improve their price and product competitiveness in a global market.
- The **quality of UK chemists** and the **reputation for excellence** of the UK's science base significantly influences companies choosing to locate in the UK, or to retain a UK-based research presence. For example a Japanese health care firm, Eisai, has invested £100 million in its 'European Knowledge Centre' at Hatfield.

[1] The UK's chemistry-reliant industries can be split into two categories: the 'upstream', consisting of chemical-producing industries; and 15 identified 'downstream', chemical-using industries (which include e.g. aerospace, automotive, electronics, health and textiles).

The direct contribution of the downstream chemistry-using industries to UK GDP and employee jobs, 2007 (constant 2005 prices)



Fundamental chemistry research has a crucial role to play in generating future economic benefits for the UK economy…

- The economic and social returns we enjoy today reflect the fruits of many years of investment in chemistry research, and **on-going fundamental research is essential** to ensure a continuing flow of scientific and technological breakthroughs. Undertaking this research in universities, research centres and in industry ensures that the UK **maintains a highly skilled and innovative workforce** and is well placed to adopt and advance new ideas, successfully exploit new technologies and develop new and better products and services. This will fuel economic activity, and is a necessary condition for attracting inward investment to the UK.

…and is indispensible to the search for answers to some of the most important technological and societal challenges facing both the UK and the wider world

- ***Climate change*** – underpinning on-going research to identify the best ways to reduce our impact on the climate and support the Government's climate change agenda (e.g. technologies to deliver cleaner fuels and reduce carbon emissions).

- ***Energy*** – chemistry research to improve the efficiency with which energy is generated, transmitted and used is a critical aspect of securing future energy requirements. For example, advanced materials research is helping to produce more efficient photovoltaic products, to enable conventional vehicles to operate with improved fuel economy, and to increase the longevity, safety and efficiency of nuclear reactors.

- ***Food supply*** – agricultural and bio-chemistry research leading to increased yields is critical to securing future global food supplies.

- ***Security*** – increasingly sophisticated 'Lab on a chip' technology is leading to improved public safety through enabling the development of faster, more accurate methods to detect and measure potentially harmful chemical compounds. Forensic chemistry research is leading to improved detection rates by increasing the ability to generate information from a crime scene (e.g. DNA profiling and advanced fingerprint technology)

- ***Health*** – chemistry research helps to improve the quality of life, and to save lives, not only through new or more effective medical treatments, but also by enabling improvements to products ranging from healthier foods to safer fire resistant materials used in clothing and buildings

Chemistry research helps to enhance the performance of the wider UK economy in ways that extend beyond simple economic and financial metrics by maintaining and enhancing the reputation of the UK science base, providing a skilled, innovative and highly productive workforce and generating vital non-economic benefits that will improve quality of life.

- The UK has **many world leading chemistry research departments** and specialist research centres. The latest (2008) Research Assessment Exercise classed 12 chemistry / chemistry related departments as world-leading or internationally excellent, while the 2009 International Review of UK Chemistry Research highlighted world-class and often world leading research areas including chemical biology, materials and supramolecular chemistry.

- UK chemistry PhD programmes are recognised by industry as **providing an innovative workforce** able to pose and answer difficult questions. Stakeholder interviews suggest that UK post-graduate training in chemistry provides an edge in the corporate world: a remarkable number of UK-trained chemistry PhDs either occupy senior positions in leading multi-national companies such as BP and Novartis, or have set-up successful spin-out companies to exploit their PhD research.

- The UK's upstream 'chemicals industry' workforce is the 4th largest in terms of the proportion educated to at least degree level, and generated a **labour productivity in 2007 of £83,500 per worker** – **more than double the UK average** (£37,500). By comparison, the industry is more productive than the UK motor industry and produces more than 80 per cent more output per worker than across manufacturing as a whole.

- Products and services derived from chemistry research underpin every aspect of modern life, ranging from plastics used in domestic appliances and car dashboards, polyester used in packaging, clothing, home furnishings and carpets, through to medicines, clean drinking water, sewage disposal, paints, rubber compounds for tyres, automotive lubricants and even the food we eat. Examples cited in the case studies include:

- Fire resistant glass, one of the most chemistry intensive products marketed by Pilkington, reduces both the human and economic cost of fire by reducing the speed at which a fire/smoke can spread.

- Azoxystrobin, an extremely successful agricultural fungicide developed by UK-based chemists between 1981 and 1996, is now used to increase yields of more than 120 types of crop in over 100 countries.

- Healthier foods – by supporting their development chemistry research is playing a critical role in the transformation needed to deliver a sustainable response to obesity in the UK

- Amlodipine – a drug developed at Pfizer, is used to treat hypertension and angina and shown to have reduced the number of days a patient visits hospital, reducing costs to both patient and the health service.

Maximising the impact of chemistry research for the benefit of UK plc requires publicly-funded, multidisciplinary teams of scientists and high levels of collaboration between academia and industry.

- In the process of research, discovery and innovation, chemistry works in tandem with other science disciplines including physics, biology, biotechnology and material science.

- Collaborative and strategic partnerships between academia and industry are crucial to enhance the two-way flow of knowledge between academia and industry. They accelerate the speed with which new products can get to market, and thus help assure the UK has ‘first-mover advantage’.

- Conducting fundamental research is both costly and risky. The benefits from research often translate into impact only years or even decades later; they are also rarely confined to the firm or research institution conducting the original research (even in the presence of patents), but instead spillover to society at large. For these reasons private sector investment in fundamental chemistry research will be sub-optimal for the economy as a whole. This is often referred to as market failure, and justifies continued support from the public purse.

This report utilises different methodologies for estimating the impact of the upstream and downstream chemicals industries:

Upstream – defined as the manufacture of chemicals and chemical products, in accordance with the Standard Industrial Classification (SIC), the economic impact of the upstream industry is calculated using multiplier analysis based on UK input-output tables from ONS. The result is direct, indirect and induced impacts, which in total encompass the entirety of the upstream industry's supply chain.

Downstream – to assess the downstream industry three steps were required. It was first necessary to define the downstream. This was conducted by using a UK input-output table to analyse which industries purchased the most from the upstream chemicals sectors, and other chemical-using sectors. This process led to the identification of 15 sectors. The unadjusted economic impact of these sectors was the total GDP and employment within these sectors.

The second step was to adjust the GDP and employment totals on the basis of how important chemistry research is in enabling the sector to operate. Using information from the UK input-output table, together with discussions with stakeholders, suitable weightings were determined for each of the fifteen sectors. Multiplying the GDP and employment in each sector by the associated weighting provides a chemistry-related GDP and employment figure for each sector. The total of these represents the direct impact of the downstream industry on the UK's economy (indirect and induced are not calculated due to the complex interrelationship between sectors to ensure that double counting does not occur. Consequently, the results produced are conservative.

1. Introduction

1.1. Purpose of study

Determining the economic impact of science research has gained particular focus in recent years; particularly following the publication of the 2006 Warry report[2]. In line with this, the purpose of this report is to demonstrate more clearly the economic benefits of chemistry research to the UK economy and to illustrate some of the many wider social and environmental benefits of such research.

This independent study has been prepared by Oxford Economics[3] and was commissioned by the Engineering and Physical Sciences Research Council (EPSRC) and the Royal Society of Chemistry (RSC). The EPSRC is the UK Government's leading funding agency for research and training in engineering and the physical sciences, investing more than £800 million a year in a broad range of subjects – from mathematics and material sciences, to information technology and structural engineering. The Physical Sciences programme remit encompasses a wide range of scientific areas including those that relate to chemistry research: organic and inorganic chemistry; physical, analytical and biological chemistry; and synthetic chemistry.

The RSC is the largest organisation in Europe for advancing the chemical sciences. Supported by a worldwide network of over 46,000 members and an international publishing business, its activities span education, conferences, science policy and the promotion of chemistry to the public.

1.2. Study methodology

The report quantifies the economic benefits of chemistry research in terms of both the 'upstream' impact (jobs and contribution to UK GDP by chemicals and chemical-product producing industries) and the 'downstream' impact (jobs and contribution to UK GDP for 15 sectors of the economy identified as reliant on inputs that depend on chemistry research to produce their products and services).

To do this, a methodological framework was developed to determine the extent of dependence on chemistry research of different sectors across the economy. The key features of this approach involved:

- Identifying the key industries using chemistry research in the UK by drawing on earlier work by the Chemistry Innovation Knowledge Transfer Network (CI-KTN);
- Applying a weight to each industry according to their dependence on chemistry research based on consultations with industry stakeholders and desk-based research;

[2] Increasing the economic impact of Research Councils: Advice to the Director General of Science and Innovation, DTI, from the Research Council Economic Impact Group, 14th July 2006, page 5. http://www.berr.gov.uk/files/file32802.pdf
[3] www.oxfordeconomics.com

- Combining the weights with publicly available data from the UK Office for National Statistics (ONS) to produce a 'weighted' estimate of the economic importance of chemistry research to the UK economy.

The quantitative analysis was supported by a qualitative assessment, based on a literature review, stakeholder contributions and case studies, as a means of exploring and illustrating the routes to economic impact. This approach enabled the study to illustrate the wider contribution of chemistry research in delivering positive benefits to the UK, in terms of accumulation of a highly skilled and innovative workforce that improves productivity, promotes inward investment, creates the basis for competitive advantage and international trade, and facilities conditions favourable to scientific breakthroughs that improve quality of life.

Within our approach it is important to note that:

- The study recognised that there are different interpretations of the definition of fundamental research (sometimes known as pure or basic research) depending on context and that the boundary between fundamental research and applied research is often blurred[4].
- While the study focused at UK level benefits, it was clear from our analysis that UK-based chemistry research has significant international benefits;
- We have addressed exclusively the question of what are the economic returns to the UK population and the UK economy from UK based chemistry research. We recognise that UK chemistry research benefits other countries, just as our analysis recognises that the UK benefits from research from the rest of the world. Indeed, some chemistry research is undertaken in the UK with the expectation that it will predominantly or exclusively benefit health care in other countries (for example research on tropical diseases/technologies for developing nations). However, benefits to countries other than the UK are outside the scope of this study;
- Despite the study focusing on quantifying the benefits of chemistry research to the UK today; it was very clear that chemistry research has a crucial role to play in generating economic and social benefits for the UK economy in the years ahead.
- The study is specifically not restricted to research funded by any particular donor (e.g. EPSRC).

Annex 1 provides further details of the methodological approach utilised in the study.

1.3. Report structure

The report is structured as follows:

- Chapter 2 quantifies the economic benefits of the chemistry dependent upstream sector;
- Chapter 3 considers the role of chemistry research in the 'downstream' chemistry-using

[4] Fundamental research is often defined as research carried out to gain knowledge and understanding of the physical world with no immediate application, while applied research is often defined as research carried out in order to discover a solution to a practical problem.

industries and quantifies the extent to which their economic contribution is dependent on chemistry research;

- Chapter 4 outlines the wider impact chemistry research can have on the UK ;
- Chapter 5 presents detailed downstream results, using UK case study evidence to illustrate the role of UK chemistry research in facilitating the successes of 15 key chemistry-using industries.
- The annex at the end of this report contains:
    - Examples of current collaborative projects
    - Lists of the highly ranked chemistry institutions and key research centres
    - Information on the skills and productivity of the upstream chemistry industry workforce
    - A description of how the upstream chemistry industry contributes to UK trade
    - An explanation of how R&D and chemistry R&D benefits the whole UK economy

1.4. Acknowledgements

Oxford Economics' gratefully acknowledge the help that we have received from all the individuals and organisations that assisted with this report.

2. The economic impact of chemistry research to the upstream industry

Key Points

- The upstream chemicals industry is an enabling industry, helping provide technological solutions to many challenges faced by other parts of the economy – it underpins sustainability in downstream industry such as healthcare, electronics, and textiles.

- On that basis, chemistry research in the upstream industry contributes £17 billion in GDP directly, providing 200,000 jobs. The wider impact of the upstream chemicals industry, incorporating indirect and induced effects is £36.5 billion in GDP and 824,000 jobs.

- The upstream chemicals industry is defined as the sectors that manufacture chemicals and chemical products, this includes: basic chemicals, such as dyes and pigments, rubber, plastics, and fertilisers; pesticides; paints, varnishes and mastics; pharmaceuticals; soap and detergents; and, man-made fibres.

- Without chemistry research many products would not exist, or would not be as effective as they are today. Examples of chemistry research's impact range from the latest breakthroughs in medicines to improvements in the performance of washing detergents.

- Interviewees reported that chemistry research is essential in keeping their businesses competitive through innovation, meeting evolving customer needs, and responding to market pressure from regulatory and environmental concerns.

- Fundamental research is the foundation stone of applied research, which some stakeholders regard as the process of rearranging the fundamental 'building blocks' in order to find new commercial applications. However, today's fundamental research is also essential in ensuring that the knowledge base is continually expanded.

- Collaboration between industry and academia/research centres is key to effective research in the upstream industry, by providing a detailed understanding of the fundamental outcomes of research and expertise that may not be possessed in-house by industry.

- It is concluded that the upstream chemicals industry is 100% dependent on chemistry and chemistry research.

2.1. Introduction

This chapter demonstrates the importance of chemistry research to the chemical and chemical-products producing industries (i.e. the upstream industry), by drawing from a series of structured interviews with businesses operating within the industry, academia and specialist research centres. This is then followed by quantification of the contribution of the upstream industry chemistry research to UK GDP and employment via the upstream industry. The impact is presented in terms of direct, indirect and induced impacts.

However, before establishing the importance of chemistry research to the upstream chemicals industry, it is important to provide an exact definition of the upstream chemicals industry *as used in this study*.

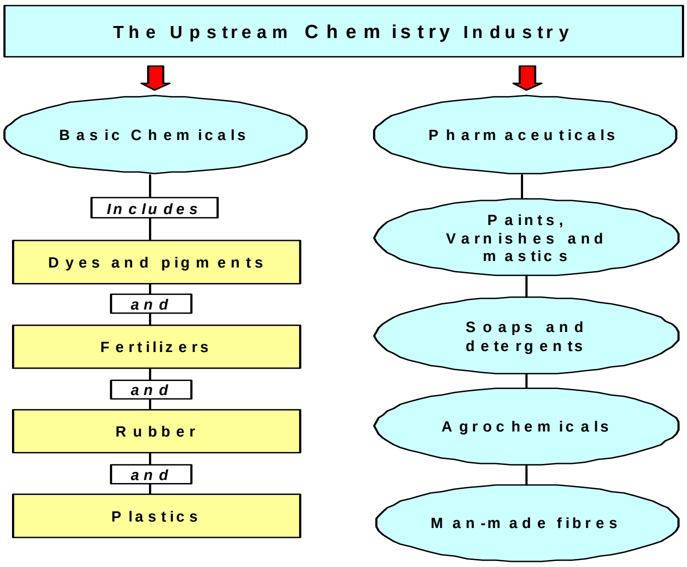
2.2. Definition of the upstream chemicals industry

The upstream chemistry industry, as defined in this study, comprises the companies that manufacture chemicals and chemical products. It is defined using the standard government industrial classification (SIC) as used in the Annual Business Inquiry survey by the Office for National Statistics. The UK Standard Industrial Classification of economic activities is used to classify business establishments by the type of economic activity in which they are engaged[5]. The broad SIC code matching the activities of the upstream chemistry industry is:

24: Manufacture of chemical and chemical products

Within this broad definition are a magnitude of products that are used by both industry and consumers as illustrated in Figure 2-1.

Figure 2-1: The upstream chemistry industry



[5] This study utilises the 2003 Standard Industrial Classifications, the more recent 2007 classifications were not used as data were not available at this level at the beginning of the study. More information on the 2003 classification of individual activities can be found at: http://www.statistics.gov.uk/methods_quality/sic/downloads/UK_SIC_Vol2(2003).pdf

To put the upstream industry in context, the UK is home to over 3,700 chemical and pharmaceutical companies which produce a broad range of commodity, speciality and consumer chemicals. Large multinational companies in the sector include well known businesses such as: BASF, BP, Dow Chemicals, Du Pont, GlaxoSmithKline, Merck & Co, Procter & Gamble, Syngenta and Unilever. But not all activity in the sector is large scale, with the sector containing approximately 3,500 small and medium sized companies (SMEs) employing fewer than 200 people. The economic activity of many of the SMEs and indeed some of the larger companies within the chemical and pharmaceutical industries is classified as R&D (SIC 73), rather than manufacturing of chemicals (SIC 24). However, although the R&D sector is clearly significant to the UK economy it is **not** included in this report in the calculation of the upstream industries impact on GDP and employment. This is because it is not possible to separate out 'chemistry' R&D from the R&D sector as a whole which includes other disciplines such as mathematics, physics, astronomy, and earth sciences.

2.3. The upstream industry's dependence on chemistry research

Without the accumulated results of many decades of chemistry research many of the everyday products and services we take for granted would not exist or would be less effective. The upstream industry is the area where this is more apparent than most, for example chemistry research has led to the development of products in the areas of:

- Medicinal and biological chemicals – e.g. pharmaceutical and veterinary drugs, antiseptics and disinfectants
- Consumer chemicals – e.g. soaps, detergents, perfumes and cosmetics
- Speciality (or fine) chemicals – e.g. coatings, catalysts and lubricants
- Commodity (or basic) chemicals – e.g. petrochemical and polymer products (such as rubbers, plastics and adhesives) and inorganic chemicals (such as salts and acids).

It should be noted that although the upstream chemicals industry is heavily reliant upon the products of the extractive and refining industries, this report treats the extraction and refining sector as being a downstream chemistry-reliant industry. This is due to a high level of chemistry usage within the sector.

Case studies, such as Box 1, provide illustrations of how UK fundamental chemistry research impacted on the outputs of this sector.

Box 1: Chemistry research in the chemistry of cleaning

The UK houses Procter & Gamble's (P&G) global research centre for laundry. It employs over 350 people, many of whom are chemistry graduates engaged in R&D or in process and chemical engineering. The centre runs several hundred research projects each year involving a vast range of chemistry inputs. These projects are split into two broad areas:

Sustainable innovation, involving existing products (e.g. using a fundamental understanding of surfactants, polymers and enzymes to get better cleaning results at lower wash temperatures (15^{o}C), enabling consumers to save energy).

Disruptive innovation*,* where chemistry is used to produce completely new products or product categories. A well known example of this is the revolutionary idea of using synthetic laundry chemicals to improve wash characteristics compared to soap flakes. P&G's discovery and subsequent use of surfactants revolutionised the laundry industry and transformed P&G from being a soap company to a technology business[6] .

The outputs of chemistry research in both sustainable and disruptive innovation are critical for P&G to maintain market competiveness from two perspectives. Firstly, the consumer market for laundry detergents is a competitive area, with products competing for consumers who have evolving taste and preferences, and so requires the development of new products of superior quality and value. Secondly, it offers the opportunity to discover more affordable and cost effective ingredients. For example, the company buys about 1 million tonnes of surfactants each year. These are largely oil based so their cost can fluctuate, making it important to look for substitute ingredients (e.g. enzymes produced through biotechnology) or to add polymers, for example, to make the surfactant work more efficiently, thereby requiring less of that material.

Our assessment of the dependence of the upstream industry on chemistry research is augmented by consultations with businesses operating in the upstream industry and academic research groups who conduct research to support the business needs of these companies.

2.3.1 The role of fundamental chemistry research to upstream industries

Stakeholders consulted as part of this study judged chemistry research as crucially important for the continued success of their businesses. Though the manner in which chemistry research is accessed and/or applied varies across the sectors - both by industry and by the strategy followed by business - there are a number of common themes from the interviews that show that businesses rely on a number of aspects of chemistry research to:

- Keep their businesses competitive through innovation;
- Meet evolving customer needs; and
- Respond to market pressure from regulatory and environmental concerns

A common theme from the interviews was that the outputs of fundamental research provide a platform or set of building blocks[7] that are rearranged in novel ways to "deliver the science" and create value-added products and processes thereby generating significant benefits for both the company and the UK economy as a whole from the initial fundamental research. This was particularly prevalent in the pharmaceuticals industry where the re-examination of existing knowledge is reflected in the commonly held view that the scarcity and high cost of developing new 'blockbuster' drugs has meant that progress has been more incremental in recent years and reliant on re-profiling active compounds;

[6] Rising Tide: Lessons from 165 Years of Brand Building at Procter & Gamble, Davis Dyer, Frederick Dalzell, Rowena Olegario - 2004.
[7] One interviewee reinforced the building-block theme using the analogy of the way that the alphabet can be used to create an infinite number of different lines of text.

the short/medium term prospects for new blockbusters were seen as slim by interviewees in the sector. As such, there is a perception in the pharmaceuticals industry that fundamental chemistry research is becoming relatively more important as the stock of new ideas to develop and exploit is thinning out.

Most stakeholders judged that chemistry and chemistry research is crucial to the success of the overall R&D activity of businesses operating in the upstream industry, but that chemists and the outputs from chemistry research is only one piece of the jigsaw – R&D activity that is seen by many as the life-blood of businesses operating in the upstream industry often involves multidisciplinary teams of chemists, biologists, physicists and engineers who all contribute to bringing a new or improved product to market (see Box 2).

Box 2 – Pharmaceuticals Company

The UK is one of the major hubs of this leading global pharmaceuticals company. This company recruits more chemists than any other type of scientist. The chemists are a big enabler of what the company does, impacting across their entire supply-chain from ***Discovery***: (*fundamental research* involving synthetic chemists, physicists and biologists), through ***Process R&D*** (taking lab discoveries and working with chemical engineers to ramp up the speed and quantity of production , then into ***Chemical manufacturing***.

Chemists working at the company are also involved in ***Formulation***, where they look to discover new and improved active pharmaceutical ingredients that they pass onto manufacturers. Given the strengths within the UK's chemistry based SME's, often this will involve forming a strategic collaboration with a smaller, specialist company to gain access to important intermediate skills/inputs or to use the SME to manufacture the product.

Throughout the entire supply chain there is a need for chemists with different but highly valued skills. This ranges from the core disciplines of synthetic and organic chemistry, through analytical chemistry to more interdisciplinary areas such as materials chemistry, biological chemistry and chemical engineering.

2.3.2 The use of academic research by upstream industries

Businesses in the upstream industry conduct chemistry research in-house, but are also closely connected to academic chemistry and draw heavily from academic research centres. Academic research of all types is widely valued, but the means of accessing the research varies by the strategy of the business.

Some businesses rely on simply scanning academic journals and following up potentially interesting leads with their in-house teams of chemists. One speciality chemical manufacturer bases its business model on being a fast developer of interesting process ideas to gain a lead and a short-term cost advantage on competitors. In the context of agrochemicals the case study on Azoxystrobin (section 5.7) demonstrates the path from academic publications to the development of the world's biggest selling fungicide. This translation of the fundamental research produced important investment, employment and trade benefits for the UK in addition to significant impacts on crop yields and food production globally.

Other mechanisms for interaction between industry and academia include the outsourcing of research to academia. This is more common where the academic institutions hold reputations for excellence in specific areas. AstraZeneca, for example, regularly outsources chemo-catalysis research to the University of Bristol.

2.3.3 Collaborative research between academia and upstream industries

Other businesses work actively with academia and research institutes throughout their development processes. Businesses conducting research in collaboration with academia and/or research centres stressed that this approach is crucial for translating the results of fundamental research into impact. The level of knowledge gained by the chemists involved in the fundamental research is difficult to match when taking a product or process from the bench through to commercialisation. Greater knowledge of the fundamental science enables researchers to have a deeper understanding of the potential to exploit the outcome. Although not always the case, the business can bring commercialisation perspectives and constraints, as well as funding, to the collaboration.

A number of interviewees also commented positively on developments in collaborative research driven by government funded initiatives. For example one valued the EPSRC's involvement simply for the access it gives to UK academics, while a second, from a multinational company with a global network of research centres, said that the value of the structures for collaborative research now in place in the UK was recognised at the most senior levels of management and was helping to drive research activity and funding to the UK. In addition, the Chemistry Innovation Knowledge Transfer Network, which was established in 2006, has helped to raise almost £80 million of project funding to stimulate and support product and process innovation and to drive value for the UK economy[8].

Annex 2 provides examples of current collaborative projects between industry and academia.

2.6.1. An example of total economic impact from the upstream pharmaceutical industry

The pharmaceutical sector is the largest segment of the upstream chemical industry and as a single industry, in 2006, employed 16 % of first degree and doctoral chemistry graduates entering full time employment[9]. Each year the pharmaceutical industry invests around £4.5 billion in research and development in the UK, representing a quarter of all private sector R&D investment. The industry contributes £17 billion to exports, resulting in a £6 billion net contribution to the balance of trade. With figures like these, the pharmaceutical industry is the single biggest research investor in the UK and a significant contributor to the balance of trade[10].

AstraZeneca, the subject of this case study (Box 3), is the UK's second largest pharmaceutical company. Although similar analyses could certainly be made for other businesses in the

[8] Chemical Industries Association publication: Chemicals – the UK advantage, http://www.cia.org.uk/newsRoom.php?id=97; and http://www.innovateuk.org/deliveringinnovation/knowledgetransfernetworks.ashx
[9] Meeting industry's need for chemistry graduates RSC Policy Bulletin 4, Autumn 2006, www.rsc.org/ScienceAndTechnology/Policy/Bulletins/Issue4/Meetingindustry.asp
[10] ABPI publication. Health and Wealth March 2010 http://www.abpi.org.uk/publications/pdfs/HealthWealth_March2010.pdf

pharmaceutical and other sectors, this example illustrates the impact that a single business in the upstream industry can have.

Box 3 – AstraZeneca: How outputs of chemical research contribute to the UK economy

AstraZeneca was formed in 1999 from the merger of Astra of Sweden and Zeneca of the UK. In 2007, AstraZeneca recorded global sales of £14.8 billion[11] making it the world's fifth largest pharmaceutical company[12]. AstraZeneca has a major presence in the UK, which is the location of the Company's corporate head quarters and major R&D and manufacturing centres.

In 2009, AstraZeneca published a report detailing their economic impact on the UK economy[13] in which it is estimated that during 2008 AstraZeneca directly generated a GVA worth £3.1 billion in the UK, with a further £1.0 billion in indirect and induced contributions. Another key financial metric is the payment of £620 million to the Exchequer in direct tax contributions (inclusive of corporation tax, employer's NI contributions and employee's PAYE and NI contributions). This figure stood at £936 million when the indirect and induced contributions were included.

Though these figures are impressive, the impact on the economy is far wider ranging than just the contribution to the Exchequer. AstraZeneca's supply chain is a further source of economic impact. In 2008 it spent an estimated £679 million on external purchases of goods and services from the UK, on items such as computer services; market research and consultancy; pharmaceuticals; and medical and precision instruments. Perhaps most importantly, in the context of this report, the UK AstraZeneca business spent £1.1 billion on R&D, with activities in discovery; process R&D; pharmaceutical and analytical R&D and clinical trials. Their R&D portfolio involves extensive interactions with the UK academic sector, biotech and pharmaceutical companies and the clinical healthcare sector as well as with international colleagues and collaborators. In 2008, AstraZeneca directly employed 11,000 FTEs, although supporting a further 19,000 with indirect and induced contributions. Approximately 16% of those directly employed are educated to postgraduate level and the average gross salary (excluding pension and other employment benefits) paid to UK employees in 2008 was £46,000, (the UK average was £30,000 in 2008). In terms of the GVA per employee, this was estimated to be in the region of £280,000 compared to £56, 000 for the UK as a whole. Like many of the other industries within the upstream chemicals sector, the pharmaceutical industry also makes a significant investment in education, reaching teachers and students in schools as well as at university. AstraZeneca have funded and supported many initiatives and programmes in science education. In 2007, AstraZeneca spent around £6 million in UK universities. This access to skills and knowledge in the workforce is one of the reasons that the UK has attracted significantly more investment in this field than its market size would suggest. However this must be sustained and improved upon, along with a good regulatory climate, a competitive cost base for collaborative research and a market that supports innovation, to realise the vision of an innovation led economy[14].

[11] Based on an exchange rate of $1 = £0.50
[12] Based on global sales; source: ABPI ranking (www.abpi.org.uk/statistics/section.asp?sect=1)
[13] Investing in the UK Economy (2009) AstraZeneca
[14] ABPI Response to House of Commons Science and Technology Committee Inquiry, Strategic Science Provision in English Universities http://www.abpi.org.uk/information/industry_positions/science_englishuniversities_05.doc

Dependency of upstream industry to chemistry research

Based on interviews with stakeholders and supplemented with desk-based research, ***the upstream chemical industry is assumed to be 100% dependent on fundamental chemistry research.*** *While it is not possible to isolate the impact of UK-based fundamental research in this conclusion, it is clear from the consultations that the academic base is highly significant in delivering the research needed by businesses operating in the upstream sector.*

2.4. GDP and Jobs

Having identified the dependence of the upstream industry on chemistry research, we now quantify the impact of that industry on UK GDP and jobs. However, before doing so it is worth drawing attention to the coverage of the data used in this analysis. The Annual Business Inquiry (ABI) is the main source of data used in this study for the number of workers in a given industry, and only measures employees rather than employment in an industry. As employment figures capture those people that are self-employed, and employee figures only capture those who are employed by a company, this means that the estimates of job numbers included in this report are by definition, conservative.

A further source of conservatism in the estimates produced within this study is the way multi-activity businesses are classified within the Standard Industrial Classification (SIC) system. This usually stems from a business being active in several areas, but is classified by the SIC based on their principle area of activity. For example, if a rubber and plastics company is predominantly involved in the manufacture of products, but also has a small fundamental research section, all of the businesses activity may be reported under the rubber and plastics manufacture SIC code, leaving total UK research under reported. The same could be true for SMEs conducting chemistry research and recorded in the R&D sector (SIC 73) under the SIC system and not included in this study as stated above. Unfortunately this is unavoidable, although the likely impact on the numbers produced will be small.

The standard method for calculating the direct contribution of an industry or a company to GDP is to measure its so-called gross value added (GVA) – that is, to calculate the difference between the industry's total pre-tax revenue (i.e. turnover) and its total bought-in costs (i.e. costs excluding wages and salaries) adjusted for any changes in stocks.

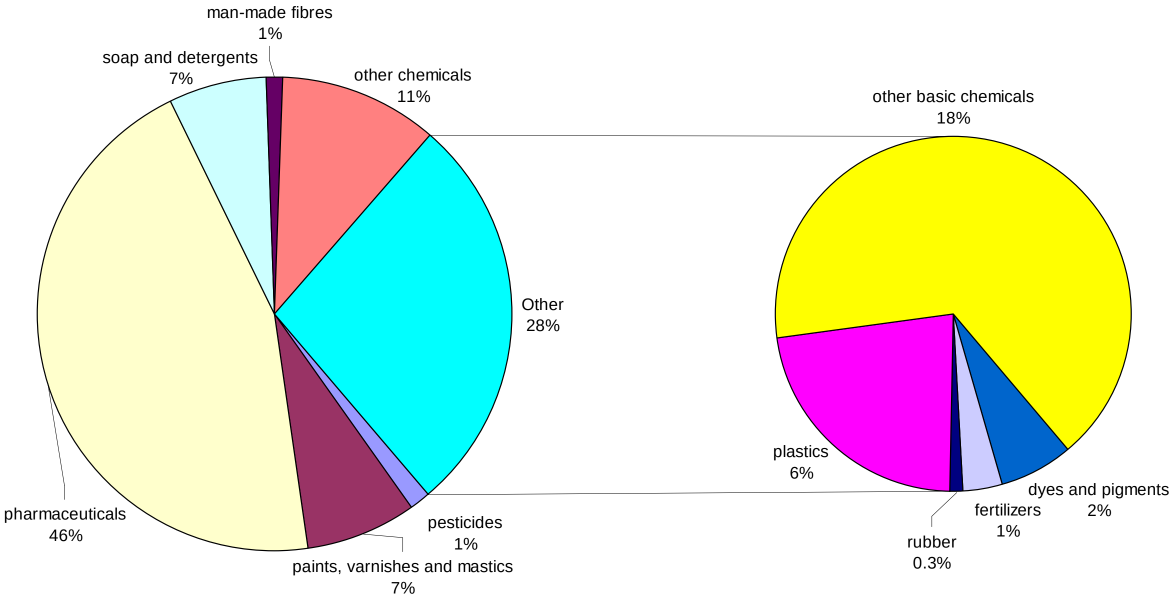
Based on the information from the 2009 ONS Blue Book, the upstream chemistry industry contributed £17 billion directly to UK GDP in 2007, from a turnover of £63 billion[15]. The upstream industry represents around 11 % of value added in manufacturing, equivalent to 1.4 % of UK GDP. It employs approximately 205,000 workers.

The largest segment in the upstream industry is pharmaceuticals, which includes companies such as

[15] Annual Business Inquiry (ABI) – Release date 16/06/2009. See www.statistics.gov.uk/abi/subsection_dg.asp, scaled to Blue Book 2009 constant 2005 prices

Pfizer, GlaxoSmithKline and AstraZeneca, and accounts for 46 % of upstream GVA, equivalent to a 0.7 % contribution to UK GDP in its own right (Figure 2-2)[16].

Figure 2-2: Upstream industry, GVA, 2007



Source: Annual Business Inquiry (ABI) – Release date 16/06/2009. See www.statistics.gov.uk/abi/subsection_dg.asp

2.5. Indirect and induced impact

The upstream industry has a wider impact on the UK economy than simply the activity and jobs in those companies directly part of the industry. Companies in the upstream industry source goods and services from other companies, thereby generating activity in the rest of the UK economy. These industries themselves will in turn source goods and services from suppliers and so on. This multiplier effect is known as the 'indirect effect' of the upstream chemicals industry. In addition, economic activity is supported by the spending of people who work in the upstream chemicals industry and its supply chain: this is termed the 'induced effect'. These multiplier impacts depend on the extent of domestic linkages between industries.

Multiplier effects that arise from further economic activity associated with additional income and supplier purchases are calculated by applying a methodology consistent with the HMT 'Green Book'[17] and English Partnerships guide to additionality[18].

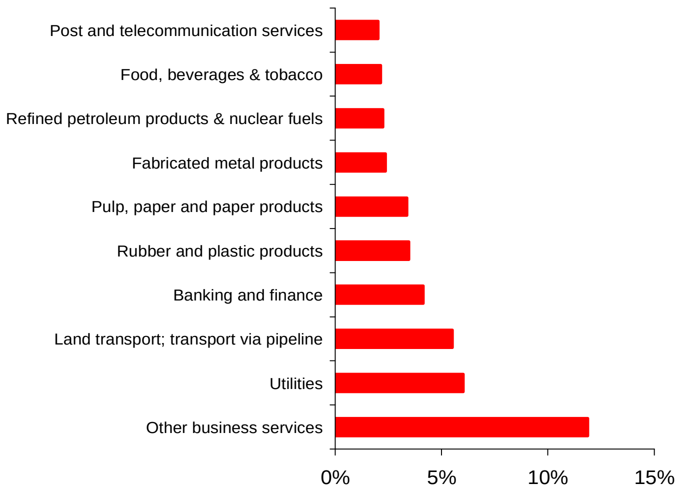
[16] In the figure, Other Chemicals includes the manufacture of glues, essential oils, and photographic chemical material. Other Basic Chemicals includes the manufacture of industrial gases, and organic and inorganic chemicals.
[17] HMT Treasury (2003), 'Appraisal and Evaluation in Central Government'.
[18] English Partnerships (October 2008), 'Additionality Guide (Third Edition): A standard approach to assessing the additional impact of interventions'

(a) Indirect impacts

The indirect multiplier for the upstream chemicals sector in the UK is estimated to be 1.71. This means that for every £1 million of value added output generated by the upstream chemicals industry, another £0.71 million of value added output is generated indirectly in its supply chain. The indirect multiplier is calculated from the Input-Output Tables prepared by the ONS[19], which provide output multipliers for different Standard industry Classification (SIC) codes. From these we have used the Industrial code SIC 24, 'The manufacture of chemical and chemical products'. This is the same code used to define the 'upstream' chemicals industry.

Figure 2-3 shows the key UK-based sectors that supply the upstream industry[20]. The largest is the so-called 'other business services', which includes activities such as legal, accounting, labour recruitment and industrial cleaning services. Other important sectors in the supply chain of the upstream chemicals industry include utilities (electricity, gas and water supply), rubber, plastics and paper products and refined petroleum products - these are very much the core inputs into many if the products manufactured in the upstream chemicals sector.

Figure 2-3: The upstream chemicals sector's supply chain



Source : Oxford Economics, ONS

[19] UK Analytical Tables – Output multipliers, Source: Office for National Statistics (2000)
[20] This analysis excludes purchases by the upstream sector from itself. This accounts for around 25 % of the sector's UK purchases. The analysis also includes purchases from the wholesale sector as the I-O tables do not provide sufficient detail to identify the precise nature of the products bought by the upstream chemicals sectors from the wholesale sector.

(b) Induced impacts

Estimates based on Oxford Economics' detailed econometric model of the UK economy[21] suggests that the induced multiplier is 1.25 – i.e. for every £1 million of output generated by the upstream chemicals industry and its supply chain a further £0.25 million of output is generated in the economy as workers spend their earnings on other goods and services.

(c) Employment impacts

The employment multiplier for the upstream chemicals industry is estimated to be around 3.0[22]. This means that for every 10 jobs directly supported by the UK upstream chemicals industry, another 20 in total are supported indirectly in the supply chain and from induced spending of those directly or indirectly employed by the upstream industry. The employment multiplier is higher than most other industries. This reflects the above average productivity of those employed in the upstream industry, and hence above average wages paid to employees in the upstream industry (mean annual gross earnings in the upstream industry was £33,991 in 2008, 30 % higher than the whole economy average of £26,020)[23].

Indirect jobs supported by the upstream industry include those employed in industries listed in the sector's supply-chain highlighted in Figure 2-3. Induced jobs supported by the industry will include jobs in retail, leisure and across a broad range of service industries.

2.6. The contribution of the upstream sector to GDP and employment

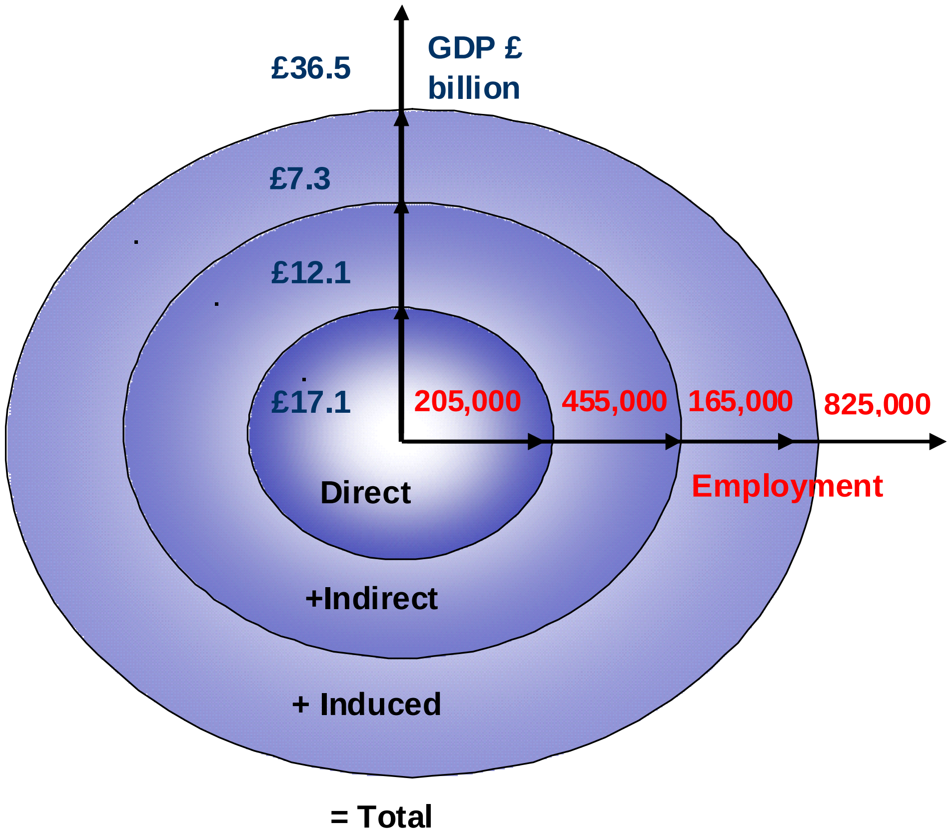
In total, including both direct and multiplier (indirect and induced) impacts, Oxford Economics estimate that the UK upstream chemicals industry supported 824,000 jobs in 2007, with a value added contribution to GDP of £36.5 billion (Figure 2-4). This is equivalent to 3.1 % of UK GDP. But that is only a one-year impact. The industry has been contributing to UK economy for many years. For example, the ten largest-selling UK drug discoveries have a combined peak-year global sales value of £16 billion, and the cumulative impact of these global sales have generated substantial revenues for the Exchequer via corporation and sales taxes.

[21] The Oxford Model is widely used. Oxford's clients include international organisations (such as the IMF and World Bank); government departments in the US and Europe (including HM Treasury and BIS – formally the DTI - in the UK); central banks around the world; as well as a large number of blue-chip companies in the US, Europe and the UK across the whole industrial spectrum.

[22] In the terminology this is a 'Type II' multiplier and in formula terms is equal to (direct impact + indirect impact + induced impact) / direct impact. The number of dependent jobs in the supply chain is computed by calculating how many workers would be required in the supply chain to produce the amount of goods and services demanded by the upstream industry. To calculate the number of jobs supported through the induced impact, we model the additional effect on domestic demand in the UK economy that salaries generate through consumer spending. This is then converted into jobs using average productivity across the economy.

[23] http://www.statistics.gov.uk/downloads/theme_labour/ASHE_2008/tab4_7a.xls

Figure 2-4: Direct, indirect and induced contribution of upstream chemicals



3. The economic impact of chemistry research to the 'downstream' industries

Key Points

- The downstream chemicals industry is defined as 15 major chemistry-using industries (i.e. aerospace, automotive, construction and materials, energy, electronics, extraction and refining of petroleum products, farming, food and drink, forestry and paper, health, home and personal care, packaging, printing, textiles, water.)
- Chemistry research impacts on the downstream sector indirectly through the inputs it purchases from the upstream industry but also directly as businesses in the downstream sector conduct chemistry research often in collaboration with academic research centres.
- Akin to the upstream industry, the downstream industries utilise chemistry-based research to remain competitive through innovation, to meet evolving customer needs, and to respond to market pressure from regulatory and environmental concerns.
- To achieve these objectives downstream businesses employ UK-trained chemists to help facilitate the two-way transfer of knowledge between the academic research base, research centres and industry.
- A methodological framework is used to determine the extent of dependence on chemistry research of different sectors across the economy. This involved applying a weight to each industry according to their dependence on chemistry research based on consultations with industry stakeholders and desk-based research.
- Applying the weighting shows that the chemistry-dependent share of the downstream industries contributes a value added of £222 billion, equivalent to 18% of UK GDP. Within the downstream industries chemistry research supports 5.2 million jobs.
- This approach does not consider the indirect and induced impact of these industries as this would lead to double-counting – so the overall impact could be much greater (e.g. aerospace industries supports travel agents and facilitates international trade, among others).

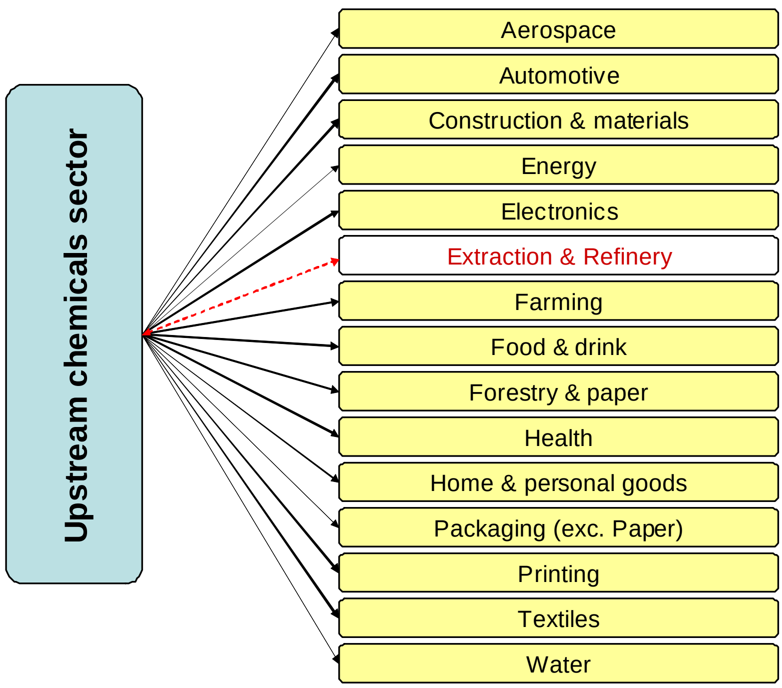
3.1. Introduction

This section highlights the key economic benefits that were identified in the fieldwork and gives an overview of the economic impact of chemistry research on 15 major chemistry-using industries – hereafter referred to as 'downstream' industries (Figure 3-1). The economic impact is presented in terms of the direct contribution to employment and GDP in the UK by the downstream industries.

The 15 downstream industries selected for the analysis are based on a list of industries provided to the study team by the project steering group. That list, in turn, is based on the Chemistry Innovation KTN Roadmap[24], which shows how chemistry underpins much of the UK economy through important disciplines such as process technology, chemical engineering, product development and formulation.

Each of the key downstream industries reviewed as part of this chapter are detailed in full in Chapter 5, which also provides examples of how UK-based chemistry research has added to the science base and resulted in novel or enhanced products. Where it has been possible to do so, the benefits for the downstream industries arising from UK-based research have been included.

Figure 3-1: The chemistry-using 'downstream' industries[25]



The extraction and refining industry is highlighted as it can be considered either upstream (i.e. as a supplier of basic chemical products to the downstream industry) or downstream (i.e. as a user of upstream chemical products). **However, within this report it is treated, and its contribution quantified, as a downstream chemistry-using industry.**

3.2. The role of chemistry research to the downstream industries

Over many years, research activities carried out in the upstream chemicals sector have resulted in a

[24] http://www.chemistryinnovation.co.uk/roadmap/sustainable/roadmap.asp?previd=10&id=75
[25] The extraction and refining industry is highlighted as the industry is an important supplier of inputs to upstream industries as well as itself being a 'downstream' chemistry-using industry.

large number of products that either would not exist or would be less effective without the results of chemistry research. Many of the these products form vital inputs into many other industries that in turn provide products and services that touch every area of our everyday lives - examples range from vital medicines, life saving operations, foods and clothing, through housing and transport, to cosmetics and electronic goods; indeed, computers and telecommunications systems could not function without essential chemicals produced by the upstream sector.

But the role of chemistry research does not stop at providing the critical inputs that enable many downstream industries to operate; it provides indispensible support for the development of technologies across many areas of manufacturing, transportation, waste management and information technology, among others. The demand for chemists and chemistry research extends into many of the chemistry-using downstream industries. The key drivers of this requirement are akin to those in the upstream chemistry industry, namely to:

- Keep their businesses competitive through innovation;
- Meet evolving customer needs; and
- Respond to market pressure from regulatory and environmental concerns

Through stakeholder interviews it was discovered that there is less emphasis on conducting fundamental research in-house by businesses operating in the downstream industries. Instead, businesses access this knowledge by building strategic relationships with upstream companies, academia and research centres, but also less formally by monitoring academic publications and attending conferences, the latter viewed as a useful way to keep on top of the latest developments in fundamental chemistry research and with a view to spotting commercial applications.

Much of the chemistry-based research effort conducted by downstream businesses involves using fundamental principles of chemistry to ‘tweak’ existing products to meet more immediate needs. Downstream businesses emphasize the value of the skills available in the UK workforce as a result of training in chemistry research to facilitate this work. It is these researchers who are best placed to make the small incremental changes in processes and materials that can give their companies an advantage over their competitors. This common approach is best illustrated by way of two examples from the stakeholder consultations (Box 4).

Box 4: Chemistry research by downstream companies

An aerospace company

The majority of research conducted in the aerospace industry is about taking chemistry research and shaping it towards the more immediate needs of the industry. In most instances this involves using chemists and chemistry research, as a part of multidisciplinary teams (with physicists, engineers and materials scientists) to adapt existing materials to improve their performance. This work is predominantly carried out in the research centres of the major aerospace companies, but these centres maintain close links with the research centres of upstream companies who provide the key material inputs. More step-change impacts, such as the use of carbon composites, involved engineers learning more about the physical and chemical properties of new materials including their stress-bearing capabilities in comparison to aluminium. This knowledge then fed into the manufacturing and assembly of aircraft using new methods, techniques and materials that will lower the weight of aircraft and have big implications for fuel and emission savings (See Section 5.1 for more details of this case study).

A cables and cable accessories company

This company provides cables and cable accessories for a multitude of industries:

- Energy transmission (National Grid) and Distribution (Electricity companies);
- House wiring, construction industry, hospitals, fire alarms, telecoms (networks);
- Accessories – joints/terminators

Their products contain chemicals (mainly plastics and resins). They buy-in chemical ingredients and re-formulate to meet specific product needs. This involves organic and polymeric material research by chemists and engineers at their UK R&D facility. A key driver of their chemistry research is to develop products with higher performance and quality. Chemistry knowledge is also used to formulate products that adhere to strict health and safety guidelines as set out in the European Community Regulation on the Registration, Evaluation, Authorisation and restriction of Chemicals (REACH). (E.g. reducing the amount of toxic and/or corrosive gas emitted during combustion).

3.3. Methodology

To quantify the impact of chemistry research to the downstream industries, the approach sought to identify and quantify the extent of dependence on chemistry research across different downstream sectors of the economy. A four-stage approach was followed.

(i) Analysis of expenditure on upstream chemicals by the downstream industry

The first step involved identifying the level of purchases made by the downstream industry directly from the upstream sector. These are based on information in the UK supply-use tables available from the ONS[26]. This analysis is carried out to validate the selection of the key chemistry-using industries. For example, the purchase of direct inputs to farming from the upstream chemicals sector (e.g. fertilisers and pesticides) cost the industry £1.4 billion, over 11 % of total inputs used.

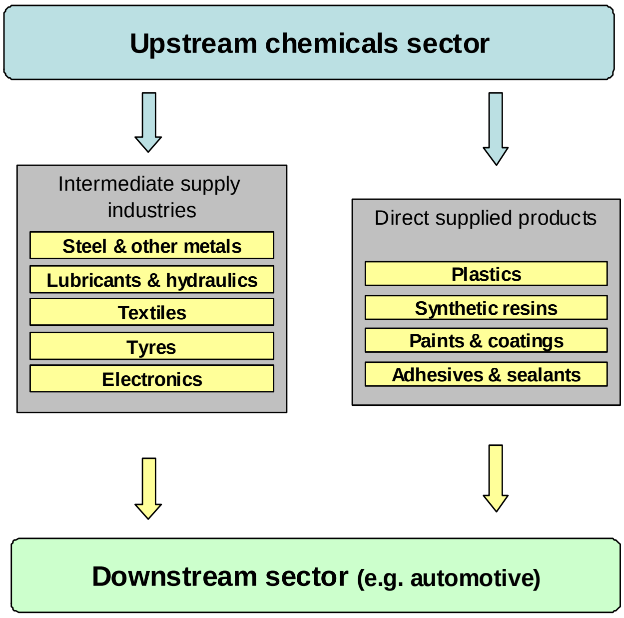
(ii) Analysis of expenditure on chemistry-using industries by the downstream industry

Analysing the purchase of inputs made directly from the upstream chemicals industry is only part of the story. Downstream chemistry-using industries also purchase inputs from a range of industries that in turn are chemistry-using. By way of illustration, the automotive industry purchases inputs from a wide range of industries where chemistry is an important contributor to innovation, product quality

[26] ONS supply and use tables are constructed directly from survey and other data sources where the Supply table provides estimates of the output of a large number of differentiated products by each industry and the Use table provides estimates of the inputs (of goods and services) used by each industry to produce their own output. The Supply and Use Tables are the basic building blocks; all other Input-Output analyses are derived from them.

and cost (e.g. tyres, textiles, electronics and fuel). Today the automotive industry buys £1.1 billion of tyres and other rubber products from the industry 'rubber and rubber products' industry (SIC 25.1), £1.6 billion of manufactured plastic products (SIC 25.2) and £1.7 billion of insulating wire and electrical equipment from the electrical machinery industry (SIC 31). This represents 20 % of purchases made from companies outside the automotive industry; hence the automotive industry is clearly dependent on chemistry-using inputs. Figure 3-2 illustrates how chemistry-using industries are used within the automotive industry.

Figure 3-2: The chemistry-using 'downstream' industries



The first two steps provide a guide of the *value* of chemistry inputs utilised by each industry, and are the minimum requirement for this analysis. However, they do not provide an insight into the *importance* of chemistry inputs; this is obtained in the following two steps.

(iii) Weight the dependence on chemistry-research of the downstream industry

Having identified the value of the chemistry-using industries that supply each downstream industry the next step is to weight the dependence of each downstream industry on chemistry research. To do this it is necessary to not only consider the inputs used, but also their importance, and any chemistry related R&D conducted internally within the industry. The water distribution and electronics industries both present examples as to why determining the dependency on chemistry is important:

- The water distribution industry purchases just 3 % of its inputs from the chemicals sector, suggesting a low level of dependence on chemistry research. However, these chemicals are used for purification, without which there would be little demand for distributed water.

Therefore, the water distribution industry is deemed to be entirely dependent upon chemistry research.

- The electronics industry purchases 7% of its inputs from the chemicals sector, again suggesting a low level of chemistry research dependence. However, modern electronics is underpinned by semiconductors and their substrates which are all highly dependent on the results of chemistry research (see case study in Section 5.4 on electronics for further details and also the role of chemistry in the development of Organic Light Emitting Diodes (OLEDs) in Section 5.13)

Once the importance of chemistry is determined for each industry, a score is assigned based on a weighting system below:

- 1 = fully dependent on chemistry research;
- 0.6 = highly dependent on chemistry research;
- 0.3 = moderately dependent on chemistry research; and
- 0 = not dependent on chemistry research.

The weight is based on stakeholder views of the role of chemistry in today's goods and services, collected during interviews with businesses that operate in the upstream and downstream chemistry-using industries. In addition, desk-based research of third-party sources has been used to complement or validate stakeholder views where possible.

The weighting system above is applied at the most detailed disaggregation for each downstream industry available in the Annual Business Inquiry dataset - this is typically at the level of either a 3-digit SIC code for an industry group or a 4-digit SIC code for an industry class. This helps with the weighting process described in (iv), below.

(iv) Derive the size of the chemistry-dependent downstream industry

The final step involves multiplying the chemistry dependency score for each industry group (or class) by the total GDP of that group (or class) within the downstream industry. This produces an estimate of GDP (and employees) for each downstream industry that is 'weighted' by its dependence on chemistry-research. A dependency level percentage derived from the ratio of the weighted GDP to the non-weighted GDP is stated at the beginning of each case study. It should be noted that the dependency upon chemistry is a necessary but not sufficient condition in the generation of activity in a sector, as this is also dependent upon other factors, such as a flexible and innovative financial system. Furthermore, due to productivity differentials between sub-sectors the implicit employment weighting might be slightly different to that produced for GDP. In all sectors we have used the overall GDP weighting as the indicator for a sector's dependency on chemistry research.

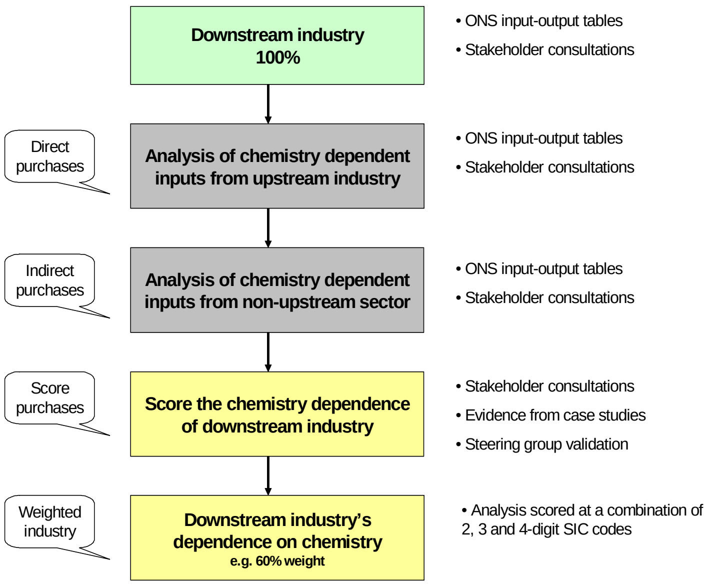
Figure 3-3 provides the calculation used for the energy industry – full details of the justification for each chemistry dependence score are set out in Chapter 5.

Figure 3-3: Weighting the energy industry

SIC code	Description	Examples	Score	GDP 2007 (current prices, £m)	Weighted GDP 2007 (current prices, £m)
40.11	Production of electricity	Nuclear processes - dependent on uranium purified using chemical processes	0.3	7,261	2,178
40.12	Transmission of electricity	chemistry in wires	1.00	3,703	3,703
40.13	Distribution and trade in electricity	chemistry in wires	0.3	7,074	2,122
40.2	Manufacture of gas; distribution of gaseous fuels through mains	Use of chemical processes and additives	0.3	*	0
40	**Total Energy**		**0.44**	**18,038**	**8,004**

Figure 3-4 summarises the four main components of the methodological approach.

Figure 3-4: Methodological approach

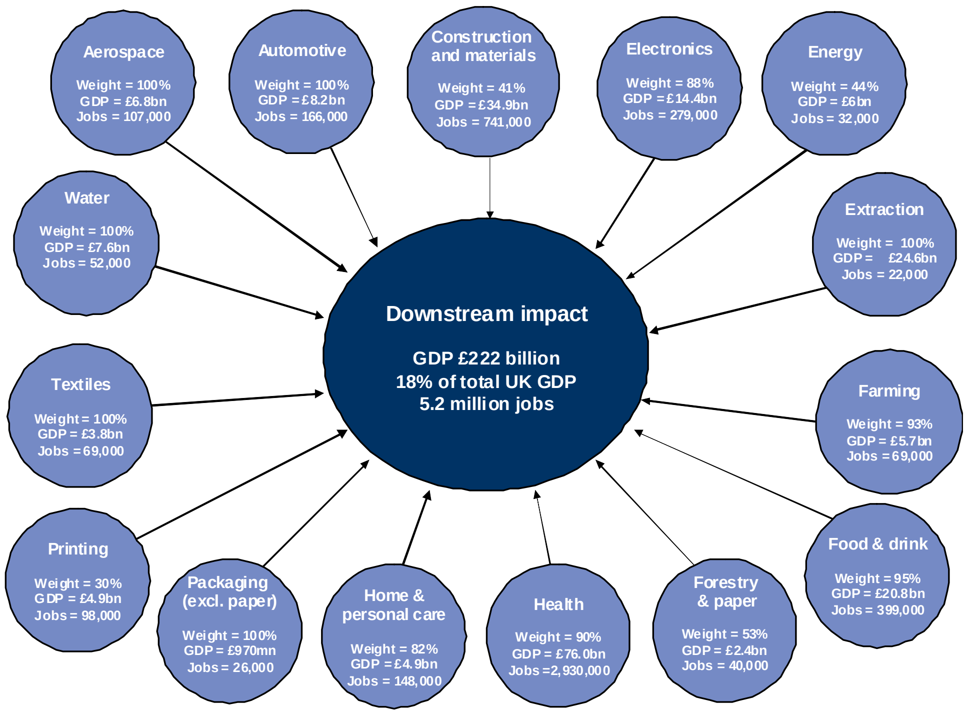


3.4. Summary results

The downstream chemistry-using industries make a substantial direct contribution to UK GDP and employment. Based on the methodology set out above, Oxford Economics estimate that the **UK downstream chemistry-using industries supported 5.2 million jobs in 2007, with a value added contribution to UK GDP of £222 billion** (See Figure 3-5). This is equivalent to 18% of UK GDP.

The results presented here provide a ***lower bound estimate***. This is due to two factors. First, the contribution by each downstream industry to employment and GDP in the UK is based wholly on their direct contribution – it does not seek to explore economic activity supported in their supply-chain[27], or the wider 'catalytic' effects that each downstream industry has on the economy. Second, the data covers only employees – it excludes the activities of the self-employed.

Figure 3-5: The direct contribution of the downstream chemistry-using industries to UK GDP and employee jobs, 2007 (constant 2005 prices)



3.5. Downstream industry summaries

The downstream chemistry sector impacts multiple industries throughout the economy. This section provides a summary of a number of exemplar industries of economic importance to the UK, for which chemistry research provides significant benefits. There will, of course, be other industries which

[27] We do not quantify the supply-chain (indirect) impacts of the downstream industry as this would lead to double-counting of economic impact.

utilise the outputs of chemistry research that are not considered here. While it is impossible to cover every single area of impact within each industry, this summary offers examples of the diverse outputs of chemistry research and also the potential of chemistry research to provide for a more sustainable future, in the face of global societal challenges. Some of the research highlighted herein is explored in greater depth in the case studies within Chapter 5. In addition, the rationale for each weighting attached to each industry considered in Chapter 5 are presented therein.

Aerospace – The modern aerospace industry depends on high-performance products that are lightweight, yet strong enough to take harsh loading conditions, and it is indeed the fruits of chemistry research which have given rise to advanced materials such as the polymers and composite materials now used in tails, fuselages and propellers. Chemistry research also impacts this industry through the development of coatings (e.g. to inhibit corrosion) and fuel additives to enhance performance. The aerospace industry also relies on computational chemistry to better understand combustion and the impact of elevated temperatures on the stability of various components e.g. metal oxide surface coatings and catalysts. Finally, key to the continued success of the aerospace industry are the advances that chemistry research has provided in security in aviation. The devices which safeguard the security of passengers, workers and cargo in airports and during transit are heavily dependent upon chemistry research (i.e. metal detectors, x-ray systems, trace explosives and narcotics screening devices, and, more recently, biometric passports). The future of aerospace is based upon the ability of researchers to provide solutions which lessen the environmental impacts of aviation with examples including the continued development of lightweight materials. Such materials enable new wing designs aimed at increasing efficiency and reducing drag and thereby fuel consumption, which would not be possible with traditional materials. In addition, the role that functional coatings can have in helping to improve the performance maintainability of the aircraft should not be underestimated.

Automotive – Although it is clear that many of the materials currently used in cars are the products of chemistry research (e.g. plastics, rubbers, coatings and fluids such as fuels, oils and lubricants), chemistry research is key to guiding this industry to a sustainable future. In particular, chemistry research underpins the development of advanced materials technology (e.g. energy absorbing lightweight materials for safety, platinum group metal catalysts for anti-pollution applications), the use of sustainable materials (e.g. the manufacture of biocomposites used in car door panels and parcel shelves), battery chemistry offering improved performance and capacity, hydrogen fuel cells & alternative fuels. For example, by enabling increased biodiesel usage, UK chemistry is directly contributing to efforts to reduce global warming. The future of the UK automotive industry is relying on cutting edge science and engineering research, in fields such as electrochemistry, to provide new materials and technologies for energy generation and storage as well as polymers with applications in engine oils (e.g. as viscosity modifiers) and new components.

Construction/Materials – Chemistry research has played a role in the development of many of the materials used in construction. This includes, but is not limited to, the widely used low maintenance plastic uPVC, plasticisers for concrete and the development of specialised glass products. Research collaboration between universities and industry in the UK has led to various improvements in the properties of glass used for construction, with fire-resistant glass demonstrating how chemistry research can generate a clear safety benefit. In addition, environmental advances are driving the development of future construction materials. Examples include low carbon cements and concrete, which require spectrometry for characterisation. The development of lightweight, high strength composite materials and more energy efficient materials are heavily reliant on chemistry-based enabling technologies such as nanotechnology. Finally, the ambition to produce construction materials with novel functional surfaces (e.g. which decompose VOCs and other pollutants) will only be realised with input from chemistry research.

Electronics – Chemistry research has contributed towards many of the advances in the electronics industry, not least the development of semiconductor materials which are the foundation of modern electronics, including radio, computers and telephones. Consumers are looking for progressive miniaturisation and mobility of devices but at the same time demand faster processing speeds and denser storage capacity. UK-based chemistry research is enhancing the future of electronic technologies. Quantum dots, a particular class of semiconductors, are the result of fundamental research in the UK and have applicability in lighting, display technology, photovoltaics and biomedicine, and offer the advantage of extremely low energy use. The future of these devices lies in the ability of chemists who are able to manipulate molecules leading to the development of self-repairing ‘molecular machines’ and nano-sized factories fuelled by chemical and light energy, offering for example the prospect of reaching past wireless communication to devices powered from the material used in their casings. Other aspects of chemistry research which have potential electronic applications in the future include chemical nanowires and carbon nanotubes, which are able to address many of the limitations (due to metals) which cause premature device failures in contemporary electronics. Chemistry-based advances will also reduce the dependence of electronics upon finite metal resources and precious metals, as well as increase the ability to recover and recycle metals from e-waste.

Energy – Chemistry research is vital in helping society move from an economy based on fossil fuels to a more sustainable energy mix. With respect to nuclear power, 90 % of the UK’s nuclear power is dependent upon chemistry, with one example being UK-based fundamental research into graphite moderators allowing increased reactor longevity and safety. As we strive for a more sustainable energy mix in the future, it is vital that we enhance renewable energy use. The scope for innovative UK-based chemistry research in developing the full potential of renewable energy technologies is considerable. Chemistry research is also providing solutions in the form of solar photovoltaic devices (that convert sunlight into electricity) and the development of sustainable biofuels (e.g. through optimisation of biochemical conversion processes as well as thermochemical conversion and gasification processes). Advances in supercapacitors and fuel cells hold the promise of energy storage and conversion technologies for the future. Hydrogen, coupled with fuel cell technology, offers a further alternative for transport and power generation. In addition, chemistry is not only developing sustainable energy solutions but also more efficient ways of producing, refining and using fossil fuels during the transition (e.g. chemical approaches to maximise current fossil fuel reserves). Carbon capture and storage (CCS) research is being carried out in the UK and will play a vital role in meeting the targets for carbon dioxide reduction as part of the drive towards a low-carbon future.

Extraction and manufacturing of petroleum products – The petroleum products industry is enhanced by chemistry research throughout the entire supply chain. Analytical chemistry has played an important role in the exploration and discovery of oil reserves. Chemicals have aided drilling and extraction, from the use of lubricants for the machinery, through chemical additives to prevent corrosion (and other chemical effects) within the pipes, to chemical and radioactive tracers which are used to gauge fluid flows in the reservoir. In the future, the industry will rely more heavily on innovations, such as the Bright Water® polymer, to significantly improve the recovery of oil from reservoirs, a feature that is of increased importance as reserves diminish and the price of oil rises. It is without doubt that the conversion of crude oil (e.g. through distillation, cracking and subsequent treatments) to marketable products, would not be possible without the knowledge and development of chemistry research. The conversion of diverse sources of hydrocarbons into different fuels and products will also require chemistry input to become more energy efficient in the future; examples include technologies to monitor and prevent fouling of heat exchangers, development of membranes and novel technologies for low energy hydrocarbon separation.

Farming – With a strong history in agriculture and farming, the UK has produced world leading agricultural products from its chemistry research; outputs that have dominated the world agricultural landscape, with significant impacts on crop yields. These achievements include the development of the pyrethroid class of insecticides, fungicides such as azoxystrobin and many world-class herbicides. The development of azoxystrobin demonstrates how UK-based chemists can draw from the natural world for inspiration and transfer knowledge from academic literature to a finished product, capable of delivering crop yield increases of up to 20%. Chemistry has not only contributed to increases in crop productivity; it is also clear that veterinary medical care via the use of vaccines, antibiotics, parasiticides, hormones and enhanced nutrition strategies has lead to production enhancement in terms of greater output per animal. In the future, chemistry research has the potential to further enhance agricultural productivity through developments such as in situ sensor devices which can monitor a wide range of agricultural parameters (e.g. soil quality, nutrients, disease and water availability). These will allow farmers to pinpoint nutrient deficiencies, target applications and improve the quality and yield of crops. Better understanding of formulation chemistry will aid the development of more efficacious and less environmentally detrimental agrochemicals and further drugs for treatment of livestock and aquaculture. Basic understanding of chemical cycles throughout the food chain will underpin the development of enhanced feed and food production.

Food and Drink – Chemistry research underpins many aspects of the healthy, safe, flavoursome food and beverages that we consume in the UK today. This ranges from the detection of contaminants to the development of flavours and additives and the introduction of nutritional enhancements. Without chemistry research to synthesise and extract natural food components, the foods we consume today would be far less enjoyable. UK-based interdisciplinary collaboration between academia, industry and government research has led to commercially successful reduced fat and reduced salt foods, against a backdrop of increasingly demanding consumers. Not only does chemistry research allow product developers to understand the reactions that take place within the foods during processing, cooking etc, it is changing the face of food products to ensure a sustainable food supply in the future. This ranges from processing developments (e.g. novel, sustainable packaging materials and cost effective sensors throughout the supply chain) to improved understanding of the consumer: food interaction (e.g. nutrigenomics and personalised nutrition). Chemical strategies will also enable technologies which will help producers and consumers alike to minimise waste as well as re-use any waste that is produced (e.g. production of energy).

Health – UK based chemistry research has significantly impacted on the health of the nation in many ways. From the development of diagnostic devices, through the discovery and development of highly effective drugs for treating disease (an exemplar case study described in this report being the use of Amlodipine in cardiovascular disease), and of substances that enable medical procedures to be accomplished (for example, anaesthetics) to advanced materials for use in prosthetics and regenerative medicine. These developments, which are used widely in the health sector, significantly enhance the lives of patients and their families, and make a major contribution to the UK economy through a healthier workforce and reduced morbidity rates. In the future, not only will healthcare solutions have less of a negative impact on the patient and the environment, they will be more targeted and efficacious as chemistry rises to the challenges in human health. Research in chemistry will be critical to improve the quality of life for an ageing population. Chemistry will play a role in developing technology which enables earlier diagnosis and improved methods of monitoring disease. Treatment and prevention of diseases and acquired infections will be enhanced, not only through medical interventions and pharmaceuticals but by an increased understanding of the chemistry of disease onset. Chemistry-based research will further exploit materials and prosthetics to enhance and sustain function as well as accelerate tissue regeneration strategies. Finally, novel chemical-based approaches are vital in the transformation of the drug discovery landscape to deliver new therapies more efficiently and more effectively and the development of personalised medicine programmes which could deliver specific, differentiated prevention and treatment programmes on an individual basis.

Home and Personal Goods - Although the impact of chemistry research is somewhat less obvious in the downstream home and personal goods industry when compared with industries, such as energy or healthcare, chemistry remains a vital contributor to current and future developments. For example, furniture utilises textiles and coatings (with stain resistance or safety features) which rely heavily on chemistry research. In future applications, chemistry research is important for the development of strategies for increasing the re-use of materials, production of biodegradable/home-compostable textiles, and the development of synthetic fibres from sustainable sources. In addition, the low energy digital and electronic devices which are expected to be the mainstay of future technologies are being developed at the confluence of UK electrochemistry, chemical engineering and materials science research. The home and personal goods industry encompasses many additional goods to those described above, not least those which enhance our leisure time. Good examples of this include alloys for use in musical instruments and composite materials in high performance sport (e.g. coatings for playing surfaces/running tracks, lightweight high-strength materials for use in racquet sports or field athletics and materials with protective qualities such as supports, braces and clothing which do not hinder performance). Developments such as these have contributed to increased accessibility to and enjoyment of high tech sports for both athletes and the public alike.

Packaging – Chemistry research has provided numerous types of plastic packaging, from single-use food packaging containers, to high strength protective packaging. UK-based fundamental research that would not have occurred without EPSRC funding has lead to the development of the world's first self-reinforced 100% polypropylene composite offering high levels of impact resistance, light weight, high stiffness. The research has led to a series of very successful commercial applications including reusable packaging. Chemistry research is also giving packaging a more sustainable future through the development of biorenewable plastics such as Polylactic acid (PLA) and more recently, biomaterials from non-food crops using low-energy and low-water processes. As the products that require packaging (e.g. food, medicines) transform in the future, it is inevitable that packaging will become smarter to ensure that the product remains in optimal conditions and is able to indicate this to the consumer, these advances will require various aspects of chemistry research (e.g. analytical, materials chemistry, nano-technology) to deliver cost-effective interactive packaging.

Printing and Publishing – The traditional printing and publishing industry has used the outputs of chemistry research to move the industry to a more environmentally sustainable position, with advances ranging from reductions in the volatile organic chemicals (VOCs) in inks, to increased recyclability of the materials used. These measures have had the effect of lowering chemical waste and energy input while at the same time lowering costs. As this industry moved towards digital printing and publishing processes, further innovations followed such as in the development of novel ink systems (e.g. UV curable inks) and moves to integrate printing and electronics (e.g. using conductive inks with applications in radio frequency identification (RFID) printing). UK multidisciplinary research is now paving the way for the next generation of commercial display and advertising media through academic research which led to discovery of organic light emitting diodes (OLEDs). The adoption of this technology is used in new technologies such as e-readers.

Textiles – Chemistry research has been pivotal in the development of numerous chemicals for the textiles industry. The case study herein details how polyester, which was developed by UK researchers in the 1940s and has since become the most widely used synthetic material in the textiles industry, has also, through continuous innovation, become used in many other diverse applications. The continuing evolution of the textile industry embraces both the high-performance technical textiles sector and the traditional apparel market. The multi-disciplinary nature of textiles with associated innovation, leads to cutting-edge products such as clothes which react to climate changes, clothing with mobile communication systems built in and medical textiles (such as artificial ligaments and wound management materials). Advanced textiles are incorporated into an array of medical, consumer, industrial and military products with critical performance requirements. Outputs include advanced materials which will enable controlled delivery of active compounds, high strength construction materials (such as carbon fibre) and the embedding of textiles with nanoparticles for flexible high-strength, light-weight body armour. Chemistry research has also helped to develop approaches for the recycling, reuse and conversion of recovered fibres for industrial processes. These advances are the products of the future, enabling better use of environmental and economic resources e.g. self-cleaning textiles.

Water – Chemical processes are exceptionally important in the treatment and delivery of drinking water and the treatment of wastewater. Analytical techniques (including the development of associated portable devices) are critical in verifying the quality of water, and where required chemicals and membranes are employed in the treatment, ranging from simple disinfection to multi-stage advanced treatment. In this report, one case study demonstrates the role UK chemistry research plays in addressing global water demand, through an alternative process for the desalination of seawater, which offers the potential to significantly change the economic and performance characteristics of water related industries. A second case study details how UK chemistry-based research in electrochemical water-treatment systems (electrocoagulation) has been commercialised to provide a process for the removal of dissolved and suspended contaminants from waste water streams ensuring that wastewater is not harmful to the environment. Finally, chemical research is helping to find solutions to developing energy-neutral waste water treatment (e.g. membrane, catalytic and photochemical processes) and the approaches for the beneficial re-use of the associated by-products.

4. The wider impacts of chemistry research to the UK

Key Points

- Chemistry research is playing a hugely significant role in answering the important technological and societal challenges facing the UK. This chapter and the preceding analysis provides a strong quantified evidence base outlining a strong case for on-going financial support for fundamental chemistry research, both in funding and coordination to maximise the hugely significant impact on UK plc.
- Fundamental chemistry research delivers positive benefits to the UK economy as a whole that extend beyond simple economic and financial metrics. It helps enhance the performance of the wider economy in a number of ways by:
    - maintaining and enhancing the reputation of the UK science base;
    - providing a skilled and innovative workforce (e.g. over 40% of chemistry doctoral leavers entered the manufacturing sector over the period 2003-07)
    - attracting inward investment and creating trade benefits; and
    - generating vital non-economic benefits that improve quality of life.
- And just as today's economic and social returns reflect the fruits of many years' investment in fundamental chemistry research, on going fundamental research is essential to ensure a continuing flow of future scientific and technological breakthroughs.
- Both fundamental and applied research will be vital in our efforts to address some of society's big challenges including climate change, sustainable food, water and energy supplies, and saving lives.
- Universities will play a crucial role in maintaining the UK science base and training chemistry researchers, who will have the knowledge to answer the important questions facing the UK today and in the future.
- In order for the UK to maximise the benefit of its science base, collaboration and strategic partnerships between academia and industry are required. This is crucial to enhance the two-way flow of knowledge transfer between academia and industry. It will also accelerate the speed that new products can get to market and support first-mover advantage for UK industry.
- The benefits from fundamental research are rarely captured by the institution conducting the initial research and instead spillover to society at large. This means that private sector investment in fundamental chemistry research will be sub-optimal for the economy as a whole.

4.1. Introduction

The contribution that fundamental chemistry research makes to the UK extends much wider than the impacts from the upstream industry and downstream chemistry-using industries discussed in chapters 2 and 3. Fundamental chemistry research helps enhance the performance of the wider economy in a number of ways by:

- maintaining and enhancing the reputation of the UK science base;
- providing a skilled and innovative workforce
- facilitating early adoption of new technologies and first-mover advantage;
- attracting inward investment;
- creating trade benefits; and
- generating vital non-economic benefits that improve quality of life.

In the remainder of this chapter we consider each of these wider impacts in turn, before moving on to illustrate the crucial role that chemistry research will play in generating future benefits for the UK economy and the important features which will maximise the impact of chemistry research. We conclude by drawing together the evidence from the previous chapters to set out the case for Government intervention and support for fundamental chemistry research, both in funding and co-ordination.

4.2. The wider benefits of fundamental chemistry research

4.2.1. Maintaining and enhancing the reputation of the UK science base

As well as resulting in a large number of new or improved products, cutting-edge chemistry research positively contributes to the UK's reputation by maintaining the UK's science base and the ability of universities to compete for staff, (international) students and research contracts. The UK research base now ranks second only to the USA, with Oxford and Cambridge acknowledged as two of the world's top three universities[28].

This leading-edge chemistry research takes place in place in a number of settings, including academia and specialist research centres, alongside the specialist research departments of businesses in industry.

Research conducted by academia

Chemistry research is a key component of the UK's academic research base and its research output, particularly in relation to the size of the UK economy, is demonstrably high in international terms[29] The

[28] CIA publication, Chemicals : the UK advantage, http://www.cia.org.uk/newsRoom.php?id=97
[29] Using industry-standard metrics, including bibliometrics, share of global PhD students, proportion of the workforce engaged in research work, and the productivity of research in terms of published papers and PhD awards relative to overall GDP or research spending

second International Review of UK Chemistry Research[30], published in 2009 supports this view, highlighting world-class and often world leading areas such as chemical biology, materials and supramolecular chemistry, synthesis & theory.

Bibliometrics – i.e. the analysis of the extent to which published research cites and is cited by other research – can be used to measure and compare the relative impact of that research. A recent study shows that despite producing only around 6% of the world output of Chemistry research papers, the UK was ranked second only to the USA among G8 countries in terms of overall citations per paper (a fairly crude measure) and in terms of the share of papers in the world's most highly cited papers (a much more discriminating indicator)[31]. These measures are clear evidence of the 'impact' that UK chemistry researchers have globally.

Furthermore, the UK has many world leading chemistry research departments. According to the latest (2008) Research Assessment Exercise (RAE), the UK has 12 higher education institutions whose chemistry and chemistry-related departments classed as world-leading or internationally excellent. These institutions employ over 600 top-level research staff, slightly over half such staff spread across all UK university chemistry departments. (See Annex 2 for more details).

Research conducted by specialist research centres

In addition to chemistry departments in universities, there are also a number of specialist chemistry research centres. These are typically linked to university departments, often leveraging off the expertise and research focus of more than one university. Supported by Government finance and by contract research, these research institutions are a key part of the UK's chemistry research community. Box 5 uses The Polymer Interdisciplinary Research Centre (Polymer IRC) to illustrate the aims and objectives of such research centres, while Annex 3 lists the most prominent of these centres and describes their core areas of expertise.

Box 5: The Polymer Interdisciplinary Research Centre (Polymer IRC)

The Polymer IRC is formed from a core partnership of four Universities - Bradford, Durham, Leeds and Sheffield. The IRC was established using substantial funding from the EPSRC, conditional on all research conducted at the Centre being fundamental and novel.

With over one hundred full time academic research staff covering the fields of chemistry, engineering and physics, the IRC has the strength in depth and multidisciplinary knowledge required to tackle the largest problems in polymer science. The scale of the IRC provides the resources to develop purpose built facilities, and provide their staff with the tools necessary to carry out research to the highest standards.

The Polymer IRC acts as an important focal point in UK polymer science and "soft nanotechnology", organising meetings, workshops and collaborations that bring industry, Government and academics together.

The co-operation and interdisciplinary working skills needed to deliver solutions to scientific and technical problems have been honed within the IRC through ongoing integrated studies requiring participation of all member institutions. As a consequence of

[30] Chemistry for the Next Decade and Beyond - International Review of UK Chemistry Research 19-24 April 2009
[31] Internal evidence paper, EPSRC, 2009

its organisation, the Polymer IRC can offer the scientific and engineering skills required for a wide range of projects, without being limited by geographic location.

The centre is an evolving organism that permits scientists and engineers to get together to solve some of the larger problems in the science. Their success in developing an effective approach to managing interdisciplinary research in polymer science has resulted in the IRC being used as a model for other interdisciplinary ventures funded by EPSRC, and led Europe, for example as the model for the Dutch Polymer Institute.

The research conducted at the IRC has led to two different technologies which have been, or are in the process of being, commercialised: ionically conducting polymers, to be commercialised in a lithium-ion battery, and self-reinforcing polymers (see case study in Section 5.12).

Although out of the scope of this study it is worth stating that chemists are also conducting research within many other institutes, departments and centres (such as chemical engineering, biomolecular sciences, biomedical engineering, schools of pharmacy and other interdisciplinary research centres).

4.3. Providing a skilled and innovative workforce

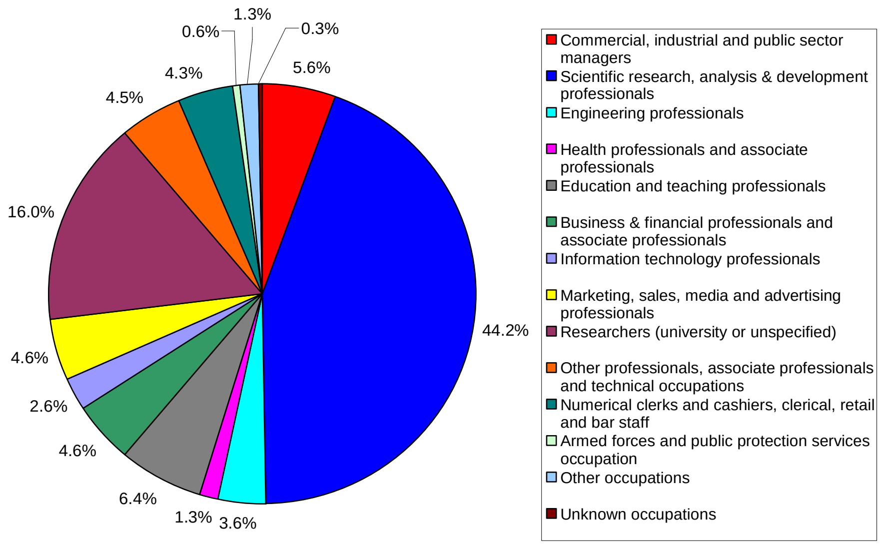
Research by Vitae (2009) showed that the UK's universities produced more UK-domiciled chemistry doctoral graduates than any other subject, with the exception of clinical and pre-clinical medicine. Analysis of the first destinations of this group[32] shows that research remains an important occupation once study is completed, with 60% of doctorate leavers entering research-based jobs, half of whom enter research outside of academia (Figure 4-1). For comparison 43% of all doctoral leavers in engineering and physical science remained in research-based positions.

The most popular sector of the economy for chemistry doctoral leavers is the manufacturing sector, which encompasses pharmaceuticals, accounting for 43% of all leavers – the highest proportion for all subjects. 33% of leavers remained in the education sector, which was the second lowest of all subjects.

Reflecting the movement of doctoral leavers into manufacturing, many of the 200,000 workers in the upstream industry are highly qualified scientists and engineers. Within the UK economy, the upstream industry is in the top five industrial sectors in terms of the proportion of the workforce who are educated to at least degree level. Almost 40% of employees in the upstream industry hold a first degree or higher, which is almost 50% higher than the equivalent figure for employees across the UK economy as a whole[33].

[32] Based on the type of job role defined using Standard Occupational Classification (SOC) codes
[33] Labour Force Survey (LFS April-June 2008)

Figure 4-1: Types of work entered into by UK-domiciled respondents employed in the UK, graduating in 2003-2007 in chemistry[34]



Source: DLHE surveys

An industry employing a highly qualified workforce is typically placed among the most highly productive industries. Highly productive industries and productivity growth are crucial to the UK economy. The upstream industry meets both criteria.

Labour productivity in the upstream industry in 2007 was around £83,500 per worker, which was more than double the UK average (£37,500). Furthermore, productivity growth in the upstream industry has been faster than for the UK economy, averaging 5.5 % a year in real terms, almost three-times the rate of productivity growth for the UK economy as a whole.

Industries that are highly productive generate more economic activity per worker for the economy and, hence, raise living standards and are key to wealth creation in the future.

> **"…high value added, high tech, high skilled, science-driven products and services are the key to wealth creation in the future" Gordon Brown[35]**

A number of interviewees said that the reason why their businesses continued to operate in the UK was significantly dependent on the availability of talent – either for solving specific problems or as a pool of skilled workers from which they could source staff for key positions within their businesses.

[34] Vitae report: What do researchers do? http://www.vitae.ac.uk/CMS/files/upload/Vitae-WDRD-by-subject-Jun-09.pdf

[35] Speech by the then Chancellor of the Exchequer, Gordon Brown, at the Advancing Enterprise Conference, QE2 Conference Centre, London, Jan 2004

This extended to the general feeling that there is something particular about post-graduate training in the UK that provides an edge to UK-trained chemists in the corporate world, with the prominent global roles played by UK chemists in a number of multinational pharmaceutical companies cited as a specific instance of this effect. The ***EPSRC Industrial CASE award programme*** was often cited by stakeholders as a very useful tool to gain exposure to the UK science base.

More generally, chemistry graduates with PhDs also contribute significantly to some of the UK's largest research discoveries. For example, section 4.8 of this report sets out the involvement of UK PhD trained chemists in the discovery of many blockbuster drugs in the UK over the past 40 years that have led to peak year 'global sales' of over $25 billion[36].

4.4. Spin-out companies

UK-trained chemists are also contributing to new firm formation by setting up successful spin-out companies off the back of their research and so supporting economic development in the UK. Box 6 illustrates two example spin-out companies that have developed out of fundamental chemistry research, while a third example, that of Surrey Aquatechnology Ltd, a University of Surrey spin-out company formed to commercialise the IP and research outputs of the Centre for Osmosis Research & Applications, is explored in more detail in Section 5.15.

Box 6: Spin-out companies

Example 1: Owlstone Ltd

Owlstone Ltd, set-up in 2004, has developed a chemical detection system one hundred times smaller and one thousand times cheaper than the existing technology. Rapid, accurate detection and measurement of chemical compounds is of particular importance in security applications. Their detector can be programmed to detect a wide range of chemical agents that may be present in extremely small quantities.

The EPSRC supported the development of Owlstone Ltd in a number of ways:

- EPSRC studentship funding supported Ashley Wilks, Chief Systems Officer (R&D) during his MSc and PhD studies in the Department of Instrumentation and Analytical Science at the University of Cambridge. The **fundamental chemical research** into Remote Millimetre Wave Sensing conducted by Wilks as part of his PhD was directly relevant to the Owlstone business, which he joined in 2005, a year after its formation.
- In the subsequent 4 ½ years the Owlstone team has grown from 6 to 35 in the UK.
- Today the company employs six EPSRC-supported PhD students (including Wilks) out of a total staff of 35, based at their new 10,000 sq/feet facility on the Cambridge Science Park, UK.
- Owlstone products have been taken up by SELEX Galileo, Agilent and the US Dept. of Defence and so these sales directly contribute to the UK's trade performance.

Conclusion: Owlstone Ltd provides a tangible example of how the EPSRC generates economic impact by supporting both training and fundamental chemistry research.

[36] http://www.rsc.org/chemistryworld/Issues/2009/September/Educationandwealth.asp

Example 2: Cambridge Display Technology (CDT)[37]

Professor Sir Richard Friend's research group at the University of Cambridge Cavendish Lab was investigating the potential use of conducting polymers in semiconductor devices, the research team believing that polymers had the potential to complement silicon by providing new and cheaper manufacturing, and new, distinct and useful semiconductor device properties.

The science had developed to the point that EPSRC funding was obtained which allowed Dr Andrew Holmes, Paul Burn and Arno Kraft in the University of Cambridge's Department of Chemistry to work on producing a family of polymers with potentially better performance. Through this fundamental research the teams were able to show novel properties of polymeric semiconductors resulting in the development of polymer organic light-emitting diodes (P-OLEDs) – thereby launching the field of so-called 'plastic electronics'.[38]

Realising the significance of this discovery it was decided that a series of patents should be filed including the chemical modification of the polymeric materials exploited by Andrew Holmes' group. Support for the patent filing costs was provided by Cambridge Research and Innovation (a Cambridge-based 'seed corn' venture fund) and these activities developed to the point where Cambridge Display Technology Limited was formed in 1992 including an initial investment from the University Venture Fund.

P-OLEDs are now being developed by the university spin-out company Cambridge Display Technology (CDT), their collaborators and licensees and major display manufacturers, including for example Samsung.

CDT Ltd has so far raised over £250 million through investments and sale of stock, including its acquisition by Sumitomo, a Japanese company, in September 2007. It currently employs around 150 people in the UK, including a team of over 80 scientists with PhDs or other higher degrees based at their technology development centre in Godmanchester, UK.

4.5. Attracting inward investment

A recent report by the Chemical Industries Association (CIA) highlights some of the key figures in the UK's strong track record in attracting inward investment in R&D[39].

- The UK is ranked top within Europe and sixth globally for 'ease of doing business' according to a World Bank survey covering several legal issues including the ability to enforce contracts and overall business protection
- The UK remains the number one inward investment destination in Europe, with almost one-fifth of the total accumulated stock of foreign direct investment
- R&D investment into the UK increased by 83 % in 2007/08
- In 2007/08, the UK attracted 1,573 foreign direct investment projects from 48 countries, a record-breaking performance.

When consulted, stakeholders reported that the quality of UK chemists was a significant factor in

[37] University of Cambridge Press Centre, http://www.enterprise.cam.ac.uk/successstories.php?key=86
[38] For a further discussion of the economic impact of plastic electronics refer to www.parliament.the-stationery-office.com/pa/cm200809/cmselect/cmdius/50/50i.pdf, or www.berr.gov.uk/files/file45988.pdf
[39] Chemicals – the UK advantage: Adding value for global investors and industry, http://www.cia.org.uk/newsRoom.php?id=97

causing companies to locate in the UK, or to retain a UK-based research presence[40].

Examples from the case studies include Propex Fibres, an international company which licensed intellectual property from the Polymer Interdisciplinary Research Centre and made an investment of £10m; the newly discovered material is now exploited in a range of premium brand consumer products. Similarly, a major international company with a global reach continues to invest heavily in its UK-based research group, partly because the UK is a centre of excellence in chemistry research with academia providing highly trained staff. Eisai (see Box 7) has recently strengthened its drug discovery group in the UK, reflecting this appreciation of the (chemistry) science base[41,42].

Other companies which have made significant investments in the UK Chemicals sector include:

- Saudi Basic Industries Corporation (SABIC), which has invested £300 million acquiring the world's largest polyethylene plant in the North East of England
- Ensus, which is investing £200 million in building Europe's largest bioethanol refinery (also in the North East)
- Victrex's £32 million polymer manufacturing plant in Lancashire
- Brunner Mond's £10 million new sodium bicarbonate manufacturing facility in Cheshire.

Box 7: Impact of the UK science base on inward investment

Eisai

Japanese health care firm Eisai made Hatfield its 'European Knowledge Centre', in a major £100 million investment that demonstrates the UK's appeal for big pharmaceutical companies.

The UK's impressive record in the field of life sciences and its strategic position in the European market are cited by Mr Haruo Naito CBE, President and CEO of Eisai, as main reasons for the move.

The Centre, which opened in June 2009, is made up of a manufacturing plant, research laboratory, office building, and shared facilities, and will employ more than 500 staff, half of whom will work in newly created positions.

Novartis UK

Novartis UK is the UK affiliate of Swiss-based Novartis AG – one of the largest pharmaceutical companies in the world.

Novartis UK employs over 3,500 people on 9 sites. In the UK the Novartis sites are involved in manufacturing, packaging, customer service and marketing for products used in the UK and worldwide

The Respiratory Research Centre at Horsham is the Novartis global research centre for respiratory and gastro-intestinal research, employing over 300 scientists (about a third of whom are organic, synthetic, medicinal and formulation chemists) in a £42 million purpose-built centre.

The Novartis Vaccines facility in Liverpool is the UK's only large-scale producer of influenza vaccines and the company is still

[40] Note, recent changes in the business models of pharmaceutical companies have led to job losses in the UK pharmaceutical industry. For example, since 2005, well over 300 medicinal chemists from Merck, GlaxoSmithKline and AstraZeneca have been laid off. Further details of the 'strategic' and 'financial' drivers of these new business models is available in *'Nature Review: Drug Discoveries'*, Volume 8, June 2009, page 435

[41] www.eisai.co.jp/enews/enews200922.html

[42] www.eisai.co.jp/enews/epdf20060221.pdf

investing heavily in new manufacturing facilities at the site.

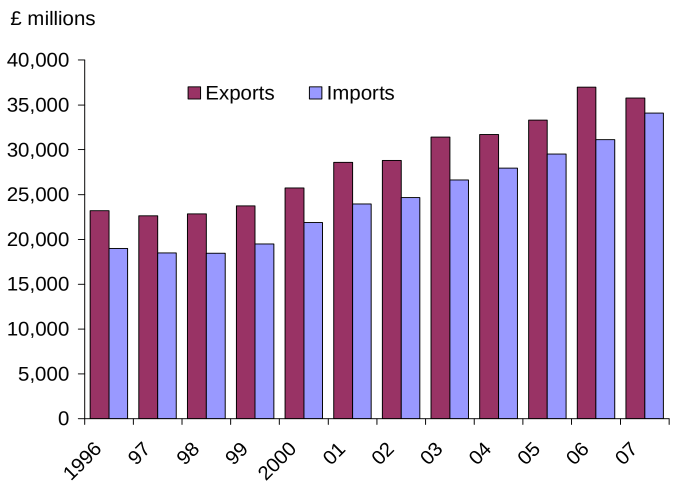
Novartis has invested over £600 million in their Grimsby manufacturing site over the last 15 years

4.6. Impact on trade

Trade performance is a key determinant of economic growth and prosperity. Over the last 40 years, the countries that have grown fastest have typically been those that have also seen the fastest growth in international trade (see Annex 5)

The chemistry-dependent upstream industry has made a positive contribution to UK trade performance over many years. This is shown by a trade surplus in the upstream industry, i.e. the UK's exports from the upstream industry exceed the industry's imports (Figure 4-2)[43].

Figure 4-2 Trade performance of the upstream chemicals industry, 1996-2007



Source: Oxford Economics, uktradeinfo.com

Within the UK, the pharmaceuticals industry is consistently in the top three industrial sectors in terms of trade surplus[44], while over the past two years it has ranked at number 1 (see Annex 5). The chemical materials and products industry, another component of the upstream chemicals industry, also features highly. Industries that are internationally competitive are more likely to show a trade surplus. An industry with a trade surplus will also make a positive contribution to the UK's balance of trade and hence UK GDP.

4.7. Improving quality of life

The products and services underpinned by chemistry research improve the average quality of life not

[43] List of UK Trade by Industry Annually, https://www.uktradeinfo.com/index.cfm?task=annualTrade
[44] http://www.abpi.org.uk/statistics/section.asp?sect=2#29

only in the UK, but also across the globe. Our case studies illustrate examples of how the quality of life of people in the UK and further afield have been improved over many years as a result of UK chemistry research that has built upon the foundations of fundamental chemistry research.

- Foods with a lower fat or salt content but which maintain the taste, texture or performance of the product have been developed - meeting the demands of consumers and policy-makers alike (See food and drink case study in Section 5.8);

- A fungicide such as Azoxystrobin has led to higher yield crops, lowering the global and UK prices of key agricultural products – including meat and dairy products, where cereals are used as feed for the livestock – and so increases the discretionary spending power for consumers, particularly for poorer households where food accounts for a bigger proportion of the overall shopping basket – (See farming 'agriculture' case study in Section 5.7);

- The UK pharmaceutical industry has discovered, developed and commercialised numerous medicines and treatments that have enhanced or saved the lives of hundreds of thousands (if not millions) of lives across the globe. For example, the list below illustrates just some of the 'blockbuster' drugs discovered in the UK over the past 40 years, alongside peak-year 'global sales', of which if just a small percentage of the global sales figures returns to the UK in taxes, then the impact on the Exchequer is significant, and even more so when the cumulative impact over many years is calculated[45].

    - Cimetidine (Ulcers) > $1 billion
    - Ranitidine (Ulcers) > $3 billion
    - Salmetrol (Asthma) > $5 billion
    - Fluticasone (Asthma) > $5 billion
    - Atenolol (Heart disease) > $1 billion
    - Amlodipine (Heart disease) > $5 billion (See case study Section 5.10)
    - Sildenafil (Erectile dysfunction) > $1 billion
    - Anastrozole (Cancer) > $2 billion

4.7.1. Supporting R&D investment

R&D is central to the UK's knowledge economy. R&D investment enhances the productivity of the firm or sector that invests in it.

The upstream industry is a substantial investor in R&D. According to the Department for Business, Innovation and Skills (BIS) R&D scoreboard, in 2007, the 130 UK pharmaceutical and biotechnology businesses among the UK850 invested £7.9 billion in R&D making the sector the largest investor in R&D by someway, accounting for 37 % of total R&D spend[46]. A further £660 million of expenditure on R&D can be added to this figure to cover R&D performed in the UK by businesses in chemicals and chemical products industry excluding pharmaceuticals, giving a total R&D spend in the upstream

[45] Sudden Impact – David Lathbury, unpublished.
[46] This report summarises the latest data on investment in R&D and financial performance of the 850 most active UK companies (including foreign-owned companies whose R&D is conducted and reported in the UK850.

chemicals sector in 2007 of £8.6 billion[47].

But not all of the returns to R&D spending are 'private' – i.e. captured by the firm or sector that makes the investment. Some of the technological advances and innovations that come from R&D spill over into other businesses and sectors, boosting their productivity as well – termed 'social returns'. Academic studies show that 'spillover benefits' of R&D can be very large, with R&D investment generating a social return of around 50-100 %. They show that for every £100 million invested in R&D one can expect – after a period of around ten years – an increase in GDP of £50-100 million each and every year.

Annex 7 discusses in detail the linkages between R&D expenditure in the upstream chemicals industry and underlying productivity in the upstream industry, as measured by Total Factor Productivity (TFP). The results of that analysis show that the upstream chemicals sector has the highest private rate of return of the seven sectors analysed[48] reflecting the strong patenting system operating within the sector to help businesses retain the benefits from their own R&D expenditure. The pharmaceuticals sector creates a high level of spillover returns of 40 % to generate a social rate of return of 65 %, just behind the precision equipment and aerospace sectors.

On the basis of that study, R&D investment in the upstream chemicals industry generates a social return of 65 % (i.e. for every £100 million invested in R&D one can expect – after a period of around ten years – an increase in GDP of £65 million each and every year). That means the upstream chemicals industry helps to generate £34 billion a year of GDP in the UK (0.4 x £8.6 billion x 10 years[49]) due to the spillover effects of its R&D, in addition to £36.5 billion direct and multiplier contribution.

4.8. The wider benefits of chemistry research - the future

Just as today's economic and social returns reflect the fruits of many years' of investment in chemistry research, support for an ongoing mix of fundamental and applied research is essential to ensure a continuing flow of future scientific and technological breakthroughs.

Not only will chemistry research continue to play a vital role in helping to answer some of the most important technological and societal challenges facing both the UK and the rest of the world; it also enhances the reputation of the UK's science base, and the process of conducting fundamental research ensures that the UK maintains a highly skilled and innovative workforce that is well placed to adopt and advance new ideas and successfully exploit new technologies. This will fuel economic activity as new and better products and services are developed, and provide a necessary condition for attracting inward investment to the UK.

[47] Source ONS www.statistics.gov.uk/StatBase/tsdataset.asp?vlnk=568&Pos=&ColRank=1&Rank=422
[48] Aerospace, machinery & equipment, motor vehicles, pharmaceuticals, radio & television equipment, precision equipment and manufacturing.
[49] Calculation assumes 10 years of accumulated R&D activity is required before private and social benefits accrue from that R&D investment – this is in line with examples provided during stakeholder interviews and reported in the BIS 2008 R&D scoreboard (see section 2.3 for further details)

4.8.1. Impact on climate change

Indeed, it was fundamental chemistry research that developed into the field of molecular spectroscopy that has been the basis for the understanding of climate change that is now of such concern to society. The measurement of subtle variations of chemical species in the atmosphere, and the detailed characterisation of such molecules, was initiated before the economic or societal applications were known. However the cumulative knowledge developed by physical chemists over the last 70 years has been essential to the modern world.

On-going research is necessary to find the best ways to reduce our impact on the climate and support the Government's climate change agenda (e.g. lower energy use technologies, cleaner fuels, more effective home insulation). Examples set out in the report provide evidence of how chemistry research is contributing towards:

- extending the longevity and safety of the UK's advance gas reactors that provide almost 20% of the UK's power capacity (see case study on energy in Section 5.5);
- improving the efficiency and lowering the running costs for users of biodiesel that will benefit the environment by reducing the level of toxic emissions from automobiles (Section 5.2); and
- reducing the fuel consumption of the world's shipping fleet and so lowering the adverse effects of CO_2 emissions (see Box 8 below – The Economics of Bio-fouling).

As well as understanding the anthropogenic activities which impact on climate change, it is critical that the fundamental chemistry of the atmosphere is also well understood. This will enable the prediction of the impact of climate change and further enable the development of strategies to prevent and mitigate against further changes.

To achieve this, chemical research in the following areas will be critical:

- development of novel techniques for studying reactive molecules that occur at ultra-low concentrations in the atmosphere and are the agents of chemical change;
- study of geo-engineering solutions to climate change – such as ocean fertilisation to draw down CO_2, or increasing the Earth's albedo by enhancing stratospheric aerosols to modify the Earth's climate in response to rising greenhouse gas levels;
- development of new modelling methodologies for treating the enormous chemical complexity that occurs on regional and global scales.

This must be coupled with development of novel analytical techniques, such as low-cost sensors for the detecting of atmospheric pollutants, which can be dispersed throughout both developed and developing urban areas for fine-scale measurement of air quality, and can be used in developing atmospheric models.

Box 8: Case study - The Economic and Environmental Impact of Bio-fouling

Bio-fouling is the accumulation of unwanted micro-organisms, plants and animals on man-made surfaces- such as those exposed to the marine environment. Huge sums of money are spent annually to combat the consequences of biological fouling in marine and freshwater environments.

- The commercial shipping fleets of the world consume approx. 300 million tonnes of fuel annually. **Without antifouling measures that fuel consumption would increase by as much as 40%, equivalent to an extra 120 million tonnes of fuel annually.** The economic cost of this was estimated as Euro 8 billion in 2000[50]:
- Control of fouling of water intakes, piping systems and heat exchangers in desalinization and power plants, costs over Euro 10 billion per year
- Control of fouling on membranes used in wastewater and desalinization systems costs over Euro 1 billion per year
- Fouling of aquaculture systems in fish farms costs an average producer Euro 100,000 per year

Fouling has been controlled traditionally by antifouling paints that contain biocides (i.e. compounds that are toxic to the organisms). But, regulations now require that antifouling paints must not cause adverse environmental effects.

A UK-based paints, coatings and specialty chemicals company provided chemistry-based research into new marine coating products. The products provided a more environmentally friendly way of preventing marine life from attaching to the hull of a vessel; the product was also commercially very successful.

4.8.2. Access to healthy, nutritious food

Chemistry will play a critical role in achieving a sustainable food supply and supporting the development of new food products that can contribute to improving health and wellbeing. Examples from the case studies include:

- Azoxystrobin (Section 5.7) – a fungicide developed by UK-based chemists that treats more than 120 types of crop in over 100 countries, raising food yields and so increasing the supply of land for other uses;
- Development of low fat foods (Section 5.8) – on-going UK chemistry research to deliver a sustainable response to obesity in the UK.

In the future, chemistry will play an even more important role in securing the global future food supply. A rapidly expanding world population, increasing affluence in the developing world, climate volatility and limited land and water availability mean that there is no alternative but to significantly and sustainably increase agricultural productivity to provide food, feed, fibre and fuel. Chemistry research will feed into all aspects of the food supply chain. Examples of ways in which agricultural productivity will be enhanced include:

- new high-potency, more targeted agrochemicals with new modes of action that are safe to use, overcome resistant pests and are environmentally benign; and
- better understood formulation technology for the controlled release of macro- and micro-nutrients and removing unhealthy content in food.

[50] Source www.ambio.bham.ac.uk/about/what%20is%20biofouling.htm

Some of the most critical developments will come in the form of advances in conserving water and energy in agriculture. Chemical strategies will also play a role in developing more energy and resource efficient (food) factories of the future, through development of routes for by-product and co-product processing to reduce waste and recover value as well as through the development of new surface coating technologies to minimise fouling and to minimise energy requirements for cleaning.

With respect to the level of wastage in the food supply chain, polymer chemistry research is at the forefront of development of new biodegradable, recyclable or multifunctional packaging materials, to reduce environmental damage and the quantity of packaging used in the supply-chain. In addition, 'green-chemistry' research paves the way to add economic and environmental value to food waste, through the isolation and extraction of fine chemicals from biomass[51].

4.8.3. Enhancing health, safety and wellbeing

Global health is inextricable from chemistry research, which will continue to help to save lives not only through new or more effective medical treatments as illustrated by the role of amlodipine to treat hypertension and angina (Section 5.10), but also through the development of a wide range of chemistry-enhanced goods such as fire resistant glass (Section 5.3), other fire resistant materials used in the construction and building industry, and fire-retardant clothing (Section 5.14).

Fundamental research at the chemistry-biology interface, e.g. into nucleic acids, carbohydrates and proteins, enables the understanding of the basic building blocks of life. Research into the reactions and manipulation of sugars and proteins, which have fascinated organic chemists for over a century, is culminating today in a host of new drugs with the potential to treat, for example, microbial infection, cancer and inflammation. In addition to the pharmaceutical aspects of human health, chemistry is in continued demand for developing advanced materials for use in orthopaedic implants (e.g. hips, knees, ankles, etc, and traditional prosthetics) and new materials for cost effective, high functional prosthetics, for example, artificial organs, tissues and eye lenses.

The challenge is to ensure replacement organs provide full functionality over a sustained period of time. Materials breakthroughs will be required in polymer and bio-compatible material chemistry for surgical equipment, implants and artificial limbs, developing smarter and/or bio-responsive drug delivery devices for diabetes, chronic pain relief, cardiovascular disease and asthma, and in researching the basic building blocks for fabricating new (nano) materials and devices. This must be supported by an increased understanding of the chemistry at the interface of synthetic and biological systems. In addition, repairing, replacing or regenerating cells, tissues, or organs will require further research into soluble molecules, gene therapy, stem cell transplantation, tissue engineering and the reprogramming of cell and tissue types.

Finally, the development of advanced analytical devices will be critical in the future. Quick and accurate diagnosis not only benefits individual patients by improving their treatment, it also ensures more efficient use of resources and helps limit the spread of infectious diseases. Screening and early

[51] C Eckert *et al.* Tunable solvents for fine chemicals from the biorefinery (2007), Green Chem. 9, pp. 545 - 548

detection of breast, cervical, colorectal and possibly oral cancers can reduce mortality. Technology breakthroughs in detection include identifying relevant biomarkers and developing sensitive analytical tools for early diagnostics, which require smaller samples and will deliver more complete and accurate data from a single non-invasive measurement. Further advances could ultimately lead to information-rich point-of-care diagnostics resulting in a reduction in the need for (and associated costs of) diagnosis and subsequent treatment in hospital. Improved bio-monitoring techniques and an increased focus on chemical genetics could result in personalised treatment and medication tailored to the specific needs of the individual.

In addition to detection, the chemical sciences have a role to play in monitoring the effectiveness and safety of therapies and medication. An understanding of the chemistry of disease progression is required to achieve this and research should be done to enable the continuity of drug treatment over the disease life cycle. Point-of-care diagnostics can also be used to monitor disease progression and treatment efficacy enabling responsive treatment, such as changes of drug dose, thus reducing hospital hours. It is possible that technological breakthroughs in diagnostic techniques and therapeutic devices could lead to combined devices that detect infection *and* respond to attack.

4.8.4. Energy for the future

The chemical sciences have a wide role to play in securing future energy requirements by improving the efficiency with which energy is generated, stored, transmitted and used. The case study herein highlights how research conducted by UK-based chemists in the field of nuclear chemistry is delivering increased longevity and safety within nuclear reactors. Increased efficiency in nuclear energy generation resulting from this research, coupled with additional chemistry research into photovoltaics increasing the efficiency of solar power, contributes to efforts to reduce global warming.

Major opportunities exist for improving the conversion of primary energy for transport, industrial energy use and in buildings and domestic applications. Innovation in these areas will be underpinned by the chemical sciences. For example, materials chemistry has a significant role to play in meeting future requirements:

- using nanotechnology to increase the strength to weight ratio of structural materials;
- developing better insulating materials and more efficient lighting for buildings
- through improving fuel economy and reducing CO_2 emissions by developing advanced materials and components that can be used in conventional vehicles.

Chemistry research has elevated the importance of hydrogen as a potential energy carrier over the last decade due to rapid advances in fuel cell and other energy storage technologies. Fuel cells are a key energy technology for the future, due to their inherent advantages - particularly their high efficiency and environmental friendliness. However, a number of scientific and technological challenges must be overcome if fuel cells are to become commercially viable[52]. Although chemistry research has already seen the development of improved energy systems, there is much fundamental research still required to underpin the future. Examples include more detailed investigations of

[52] Oxford Future Energy source: http://www.futureenergy.ox.ac.uk/home

photosynthesis[53] and the properties/ behaviours of microbial systems and enzymes (such as those which can be used to catalyse the generation of hydrogen).

4.8.5. Enhancing Security

Chemistry research conducted by companies such as Owlstone (see Box 6) provides an example of how chemistry is contributing to significant security benefits. Sensors providing rapid, accurate detection and measurement of harmful chemical compounds have wide scope in security applications. Advances in electrochemistry and nanotechnology are enabling the detection of an increasing number of chemical components selectively. Future developments for public safety and homeland security will bring sensing systems that can act on this information in real time. Chemical and biological sensors that are remote, rapid, miniaturised and reactive will lead to the development of sensor networks such as a chemical analogue of CCTV that could trace chemical and biological threats, narcotics, explosives and potential pandemics. Similar technologies could be adapted for use as home security networks. The ability to detect potential threats must be coupled with the development of decontamination and remediation technologies.

Not only do chemical sciences have a role in developing high performance protective materials for those involved in civil protection, chemistry research is also key to advances in detecting crime. Chemistry research is already widely recognised for its underpinning role in the work of forensic teams; technological breakthroughs that can provide evolutionary, real-time information-rich crime scene profiles are now required. Such work must be coupled to advances in chemical biometrics (for example DNA profiling and fingerprint technology), and advances in ‘Lab on a chip’ technology. Increases in the amount of information generated from a crime scene will also require advances in methods of data storing and handling.

Finally, the growth and proliferation of counterfeit products, which are of inferior quality and are potentially dangerous, pose an additional threat to society. Chemical based solutions will help to identify counterfeit products, including pharmaceuticals, money and high value products. The foundations of these advances will come from analytical and materials chemistry.

4.9. Maximising the impact of chemistry research

To maximise the benefits of the UK science base requires that there is a backwards and forwards flow of research between academia and industry. However, if the linkages between academia and industry are impeded this will mean that companies cannot take full advantage of the UK research base. This undermines both their performance and the performance of the UK as a whole. This section summarises the key messages from the stakeholder interviews to explain how the UK can maximise the benefits of the UK’s science base.

[53] Artificial Leaf source: http://www3.imperial.ac.uk/energyfutureslab/research/grandchallenges/artificialleaf

4.9.1. Training

It is clear from the stakeholder consultations that universities play a crucial role in maintaining the UK science base and training chemistry researchers who will have the knowledge to answer important questions facing the UK today and in the future.

As part of this, the UK PhD program (including CASE awards described in the next section) was viewed as working particularly well and providing positive benefits for the UK. This period of training was recognized by industry as giving UK-trained chemists a "fundamental understanding of the processes and mechanisms of how molecules interact", and teaching and developing the skills needed to pose and answer difficult questions. It will be well-trained scientists with a fundamental understanding of chemistry who can "manage the molecule" and who will be pivotal to answer the key societal challenges facing the UK over the years ahead.

Such research will also help maintain the UK's thriving research community, both within academia, but also with industry research departments. This in turn will attract the best international researchers to the UK and in doing-so further establish the UK as a place to conduct research; indeed there are an increasing number of non-UK nationals coming to the UK to be part of this community.

And following on from this, ensuring that the UK has a highly skilled research base will help facilitate high quality R&D activity in the UK, and so maximize the spillover or 'social' returns from R&D activity in the UK, particularly within the upstream R&D intensive industry.

4.9.2. Collaboration

For the UK to maximise the benefit of this training involves forming strategic partnerships to enhance the two-way flow of knowledge transfer between academia and industry.

Collaboration between academia and industry will be absolutely vital in ensuring that the new knowledge will be translated into positive economic impact. There were mixed opinions on the most effective way to organize the collaborations and the emphasis of the research conducted by each party suggesting that several different forms of strategic relationships are required, rather than a one-size fits all strategy.

Industry emphasised that academic research should focus on finding knowledge, or answering specific technical questions that industry can exploit, rather than inventing new products themselves, This view is reinforced by the findings of a recent report on the future of the pharmaceutical industry, whereby much of drug discovery is now being outsourced from big pharmaceutical companies to universities, Charities (e.g. Medical Research Council, Cancer Research UK), or small niche research companies.[54]

A further and often cited reason for the distinction in research activity between academia and industry is that industry uses universities to work on fundamental research as a means to avoid patenting problems, and will instead purchase a license from academia to exploit patents.

[54] '*Nature Review: Drug Discoveries*', Volume 8, June 2009, page 435

What is clear from the interviews with both industry and academia is that there was strong recognition that the link between both groups requires people in both establishments to have a background and knowledge of the fundamental principles in chemistry to make the collaboration work effectively. The use of CASE awards and more general funding of post graduates is viewed as an effective way to facilitate this transfer and benefits both parties in a number of ways:

- **CASE awards**[55] – these were highly valued by companies and researcher alike and seen as a great strength and distinguishing feature of UK chemistry. In particular CASE awards are viewed as:
    - a very useful method for researchers to build on their fundamental understanding in a more practical way but also to widen their skills set in a more commercial manner and facilitating the formation of spin-out companies;
    - offering a valuable means of recruitment as the research is effectively a three-to-four year job interview;
    - supporting the transfer of individuals from academia to industry, the latter accelerating the speed to which new products can get to market and supporting first-mover advantage of UK industry;
    - offering a low cost environment for industry to conduct more risky research, particularly exploratory first looks which are often difficult to sign-off in a commercial organisation that need to shows proven ‘bottom-line’ benefits of research expenditure.

Outside the CASE award system, industry collaborates with academia through the direct funding of graduates and post-graduates but there is concern that UK Universities are not cheap. A post-doc in a UK university costs around £130,000, a much higher fee than to fund a similar training scheme abroad. This is leading industry to employing researchers in-house and then seconding them back to universities to maintain these important linkages.

4.9.3. Summary – the importance of on-going financial support for fundamental research

There is a strong case for on-going support for fundamental chemistry research, both in funding and the coordination of linkages between academia and industry, in order to maximise the hugely significant benefits to UK plc.

Conducting fundamental research is both costly and risky. For example, only 1 in 5,000 compounds researched in pharmaceuticals moves to the development phase[56]. Moreover, the benefits from the research often translate into impact only years or even decades later, often in wide-ranging and unrelated products. Examples illustrated in this report include the 10 to 12 year time lag between a drug entering initial clinical trials and it receiving approval from regulatory agencies for sale to the

[55] The main aim of Industrial CASE is to allow industry to drive the research project of their choice according to their business needs. Industrial CASE provides funding for PhD studentships where businesses take the lead in arranging projects with an academic partner of their choice.
[56] BBC Radio 4, *US Health Reform: Beware of Side Effects!*, broadcast 11/10/2009 13.30.

public, at a cost of about £550 million[57,58], while the self-reinforced polymer case study (section 5.12), shows that a fundamental chemistry research discovery in 1989 took over a decade to get to market and is now being applied in applications as diverse as reusable packaging, travel suitcases, sporting shin-guards and loud speaker cones - an application of true serendipity.

But rarely are the benefits of the initial research investment confined to the firm or research institution conducting the original research, and instead spillover to society at large.

Because the benefits of fundamental research are rarely captured by a single entity (even in the presence of patents), private sector investment in fundamental chemistry research will be sub-optimal for the economy as a whole. This sub-optimal outcome is often referred to as market failure.

The evidence presented in this report shows that the direct, indirect and wider spillover benefits from fundamental chemistry research are significant to the UK. More crucially, it will be the outcomes of this fundamental research that will be a vital ingredient to help answer important technical and societal challenges facing the UK over the years ahead. Accordingly, and on the basis of such evidence, the authors of this report have identified that **on-going support for fundamental chemistry research, both in funding and the coordination of linkages between academia and industry is crucial to ensure that fundamental chemistry research continues to lead to significantly high levels of benefits to UK plc.**

57 http://www.pharmaceutical-technology.com/contractors/materials/aesica/press9.html
58 The 2008 R&D Scoreboard. Pharmaceuticals and Biotechnology: Sector Summary, page 3.

5. The Case Studies

5.1. Aerospace industry

This section presents a case study from the aerospace industry to illustrate the role of UK chemistry research in facilitating success downstream of the chemical industry.

Dependence on chemistry research: entirely dependent (100%)

- *Chemistry research directly enables the aerospace industry to contribute **£6.8 billion** to the UK economy and supports **107,000 jobs** in the UK aerospace industry.*
- *Inputs from chemistry into the aerospace industry range from chemicals and solvents to plastics, synthetic resins and rubbers through to reinforcing fibres, paint, insulated wiring and metal compounds, with a total value of £1.2 billion per year.*

Case study – Composite materials

- *UK-based research into composite materials, such as carbon fibre and polymer matrices, has its foundations in fundamental chemistry research in the areas of synthetic polymers, and produces materials with properties far in advance of available metals.*
- *Composite materials have played a prominent role in raising the efficiency and reducing the environmental impact of flying, by reducing the weight of aircraft and allowing innovative engineering design to improve overall performance. Composite materials have long been used in many parts of an aircraft, such as interior fittings, trailing edges and the tail section, but are now being used for load carrying parts of its structure, including the wings and fuselage.*
- *In Airbus planes for example, composite material as a proportion of the overall structure weight has increased from less than 10% in the mid-1980s, to over 20% today, while over 50% of the A350 XWB family of aircraft will be made from composite materials[59].*
- *It is estimated that new aircraft are 20% more fuel efficient than those made 10 years ago, helped by the use of carbon fibre reinforced composites which exploit toughened epoxy resin and thermoplastic to deliver up to 20% improvement in strength-to-weight ratio compared to competing metals.*
- *The UK continues to play a central role in the development of new lightweight materials for aircraft, both through industrial research and EPSRC funded academic research.*

[59] http://www.eads.net/eads/special/investor/Streams2008/GIF_2008/pdf/41889725.pdf

5.1.1. Chemistry research and the aerospace industry

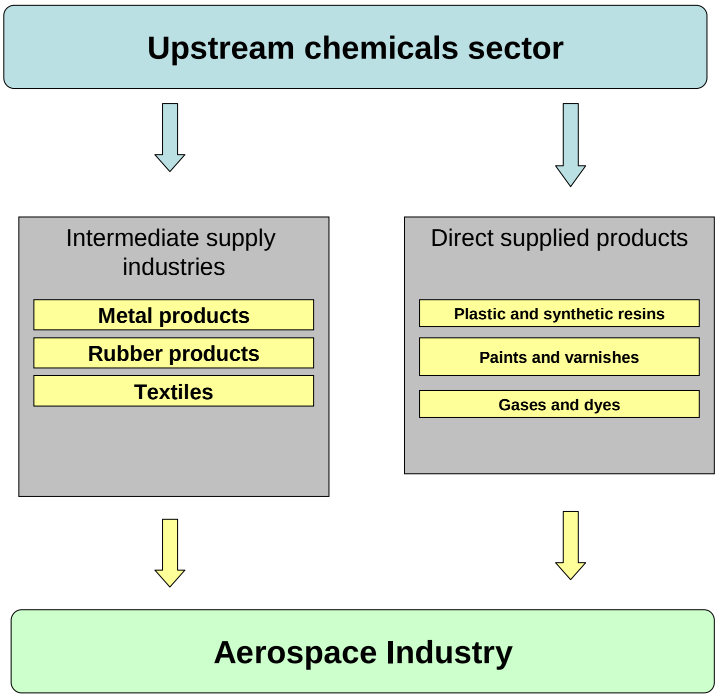
Aerospace is one of the UK's most dynamic industries. To meet the challenge of producing lighter, more fuel-efficient aircraft with lower operating costs, the industry has been increasing its use of composite materials for the manufacture of key aircraft components. The use of these composites is largely based on the chemistry-based breakthroughs in the processing of carbon fibres made at the Royal Aircraft Establishment in the 1960s, but the story is also one of continuing innovation and development of epoxy resin formulations and thermoplastics and, in particular, epoxy/thermoplastic blends which are used to bind the carbon fibres together. Chemistry research continues to play a crucial role in this process of innovation by developing more effective composite materials (see section 5.1.2, below) but also more generally in terms of producing more fuel-efficient aircraft.

Aerospace industries also source inputs from a wide range of industries where chemistry is an important contributor to innovation, product quality and cost. The list includes plastics and synthetic resins (composite materials and engineering adhesives); rubber; metal castings (titanium); non-ferrous metals; paints and varnishes; and insulated wiring (Figure 5-1). In total the UK aerospace industry bought £1.2 billion of inputs from sectors very dependent on chemistry in 2007[60]. This represents 17% of the total purchases of inputs of £7 billion made from companies outside the aerospace sector. **However, due to the crucial nature of chemistry research-based inputs to aircraft, aerospace is deemed to be wholly dependent upon chemistry research**.

In particular the outputs from chemistry research have helped change the structure of aircraft wings. Fibrous composite materials began to be used in a minor way in military aircraft in the 1960s, followed by civil aviation in the 1970s and 1980s. Initially the composites were used for interiors and secondary wing and tail fin components such as trailing edges and rudders, but over time are accounting for an increasing proportion of aircraft weight. In Airbus planes for example, composite structures as a proportion of overall weight has increased from less than 10% in the mid-1980s, to over 20% today, while in the next generation of aircraft (the A350 XWB family), composite materials account for over 50% of the overall weight of the aircraft[61]. Today, the Airbus A380 – the largest passenger aircraft – uses composite materials for load-carrying parts of its structure, including parts of the fuselage. This design allows the A380 to boast 17% less fuel consumption per passenger mile than comparable aircraft, helping to lower the carbon cost of flying[62].

[60] Source: ONS input-output tables 2007, http://www.statistics.gov.uk/about/methodology_by_theme/inputoutput/latestdata.asp
[61] http://www.eads.net/eads/special/investor/Streams2008/GIF_2008/pdf/41889725.pdf
[62] Source: W S Atkins, Ingenia, September 2008

Figure 5-1: The chemistry-using 'aerospace' industry



While most of the research activity on composites is devoted to learning how to use the new materials, substantial effort continues to be devoted to developing new composites or improving existing materials, with aircraft manufacturers and supply chain industries employing a significant number of chemists. Examples of this work include research on thermoplastics to create materials that:

- can if necessary be re-heated and re-formed at a later stage of the production process
- have better damage resistance than thermosets
- will process more quickly than thermosets
- do not require an autoclave for processing
- can be recycled into high value products
- can in principle self-heal if cracked or damaged

New chemistries are needed for the development of out-of-autoclave irradiation technologies, including the use of microwave, radio frequency and electron beam. Also, chemistries which will give additional functions such as electrical energy storage, lightning strike protection, damage detection and improved fire, smoke and toxicity properties are high priorities for the aerospace industry. Self-assembling chemistries may well have a role to play in the development of fully recyclable composites which will become very important in the future.

Air transport makes a large contribution to the UK and global economies. Oxford Economics estimated[63] that the air transport industry supported over 520,000 jobs in the UK in 2004 via its direct value added and the demand created in its supply chain and by its employees.

Yet this industry impact is dwarfed by the catalytic effects aviation has on the economy. By improving connectivity air transport drives productivity growth by promoting trade, investment, innovation and tourism. In particular air transport is very important for growth sectors on which the UK's future economic success will depend, such as high-tech companies and financial & business services, with air transport improving competitiveness of almost all aspects of companies' operations, including sales, logistics and customer support. For example, 55% by value of the UK's manufactured exports to countries outside the EU are transported by air and visitors arriving by air supported a further 170,000 jobs in 2004.

However, without the input of chemistry research that has helped boost aircraft fuel efficiency and so lower fares, air transport would be less accessible for individuals and businesses alike and these catalytic economic benefits would be much smaller. Oxford Economics[64] research suggests that if growth in business use of air transport (both passenger and freight) was held back by just 1 % age point a year over a 30 year period there would be a loss in potential GDP of 1.8% a year by the end of the period.

5.1.2. Case study - Composite materials and air transport

Though the initial steps in developing carbon fibre composite materials were taken abroad, the three-stage process used to create high-performance carbon fibres was developed at the Royal Aircraft Establishment at Farnborough in the early 1960s. Fundamental chemistry is crucial to the development of composite materials, such as carbon fibre, as materials are synthesised from chemical precursors and assembled using chemical transformations. This process involves using a man-made fibre – typically polyacrylonitrile (PAN) - as the base material. The resulting filaments of pure carbon graphite are extremely strong and stiff, and around 5 times as strong as aerospace grade aluminium alloys. Since carbon composites are only 60% of the density of aluminium and immune from the fatigue that shortened the lives of the first commercial jets – such as the de Havilland Comet – these composites are ideal for use in a diverse range of settings, including aircraft wings and fuselages, jet engines and rockets. Carbon fibre composites are also used in the braking systems of aircraft where their ability to withstand very high temperatures is important.

Carbon composites are manufactured from sheets or tapes of carbon fibres that have been pre-impregnated with resin that is processed by the application of heat, while high pressures are used to ensure that no spaces form in the final product.

The carbon fibre epoxy: thermoplastic blends that are typically used in aerospace improve on the strength-to-weight ratio available from competing metals by up to 20%. With composite structures requiring fewer riveted joints there are further efficiencies in both the manufacturing process and from

[63] The Economic Contribution of the Aviation Industry in the UK, Oxford Economics, October 2006
[64] ibid

better aerodynamic properties. And, this story of innovation is continuing with aero engineers now able to choose the stiffness characteristics of the material they are using and to explore the possibilities of aero-elastic tailoring for wings to reduce the impact of increased loads on the rest of the aircraft's structure.

Generating further fuel and load efficiencies is crucial to the future of the air transport industry. According to IATA[65] new aircraft are 70% more fuel efficient than 40 years ago and 20% better than 10 years ago – with the latest large passenger airliners more fuel efficient per passenger mile than a compact car. Nevertheless IATA affiliated airlines have adopted the goal of reducing fuel consumption and CO_2 emissions per revenue tonne kilometre by 25% from 2005 levels by 2025. IATA expects continuing weight reductions and new wing and fuselage profiles to play a major role in these reductions[66]. Without the contribution of chemists in the development of appropriate composite materials these goals are unlikely to be achievable.

For example, the UK's Next Generation Composite Wing programme brings together 17 industrial partners – led by Airbus to ensure the UK maximises the use of weight-saving composite materials in future wing design and development. The press release[67] announcing the programmes stated "the skills and capability to design and manufacture in composite materials is vital in the aerospace industry today, helping to improve efficiency and performance while lowering both operating costs and gaseous emissions through burning less fuel."

In parallel to this, the EPSRC and the Defence Science and Technology Laboratory are funding research at Imperial College and the University of Bristol into 'Crack Arrest' and 'Self-Healing Composite Structures'[68]. The research is seeking to develop tailor-made composite materials which arrest the development of cracks, and heal themselves, which could be used with confidence to build lightweight, safe, damage-resistant components. This would overcome the concerns that existing composites could be susceptible to defects and damage, and so engineered to withstand a 40% loss of strength during use, leading to additional weight and fuel consumption that the new components will eliminate.

[65] http://www.iata.org/whatwedo/environment/fuel_efficiency.htm, accessed on 4th September 2009
[66] Aviation & Climate Change, presentation to GIACC ICAO, Montreal, 2008
[67] Innovative Aviation Research and Development to be Co-funded by Technology Strategy Board, Technology Strategy Board, May 2008
[68] Arresting and Self-healing Cracks: Paving the Way for Next Generation Composite Materials, Science Daily, August 4th 2008

5.2. Automotive

This section presents a case study from the automotive industry to illustrate the role of UK chemistry research in facilitating success downstream of the chemical industry.

Dependence on chemistry research: Entirely dependent (100%)

- *Chemistry research directly enables the automotive industry to contribute **£8.2 billion** to the UK economy and directly supports **166,000 jobs** in the UK automotive industry.*
- *The use of chemistry has permeated every aspect of the automobile industry, ranging from the plastic used for car dashboards and polyester for trimming, through to paints, rubber compounds for tyres and, fuel additives and lubricants.*

Case study – engine lubricants for biodiesel engines

- *Chemistry research is playing a crucial role in the development of future technologies to be applied in the automotive sector. By creating engine lubricants that enable biodiesel to be utilised efficiently at higher volumes, uptake of biodiesel as a fuel type increases, and so, therefore, does the potential market.*
- *The new engine lubricant developed will ensure that biodiesel does not result in increased engine maintenance costs for the users. It is estimated that global demand for biodiesel will be over 19 million metric tonnes in 2010. However, these cost savings will not be restricted to biodiesel users, as cost savings are passed down the supply chain.*
- *Increasing the usage of biodiesel will benefit the environment, by reducing the level of carbon emissions from automobiles. This development represents a way in which chemistry is central to the method of tackling society's issues.*

5.2.1. Chemistry research and the automotive industry

Despite recent troubles, the UK's automotive industry remains a considerable sector in the economy, with a GVA of £8.2 billion contributing 1.1% of UK GDP. The automotive industry directly supports 166,000 jobs, equivalent 0.7% of total employment in the UK[69].

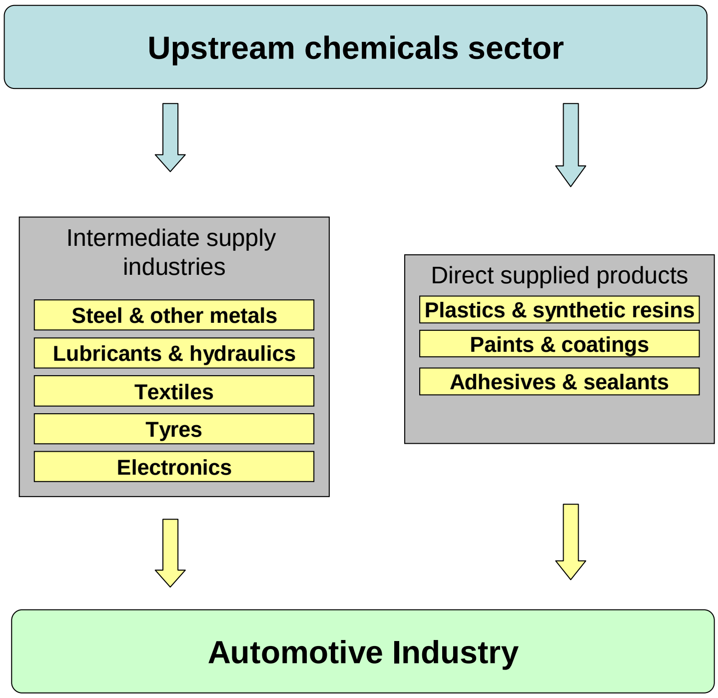
The UK automotive industry is ***entirely dependent*** on inputs that either would not exist or be less effective without the results of chemistry research. Products of the chemicals sector – including, paints and varnishes, plastic and other synthetic resins, and organic chemicals – account for 5.2% of the direct inputs into the automotive industry, costing the industry £1.7 billion, out of total inputs of £21.8 billion[70]. In addition to inputs from the chemicals sector, other intermediate industries supply numerous goods that are produced on the back of chemistry research; between them, plastic, iron

[69] Annual Business Inquiry (ABI) – Release date 16/06/2009. See www.statistics.gov.uk/abi/subsection_dg.asp, scaled to Blue Book 2009 constant 2005 prices.
[70] ONS input-output tables 2007, www.statistics.gov.uk/about/methodology_by_theme/inputoutput/latestdata.asp

and steel, and rubber products accounted for 19% of automotive inputs, valued at £4.2 billion (Figure 5-2).

The use of chemicals has permeated every aspect of the automotive industry. The interior of a vehicle is overflowing with aspects reliant on chemistry research – textiles used for interior furnishing are likely to include polyester[71], a car airbag is entirely made of polyester[72], the dashboard and steering wheel are likely to be made of a form of plastic. Similarly, the exterior of the car is also covered with chemical products – the paint used, the coating given to the windscreen to increase visibility[73] and induce crack resistance, and the shell of the car itself which, along with all the other metal components, is likely to be an alloy displaying the properties of strength and lightness. Finally, the 'working parts' of the car are also dependent upon chemistry – the tyres are a combination of rubber and polyester, and the brake fluid and lubricating oils are engineered to meet both safety and operating targets.

Figure 5-2: The chemistry-using 'automotive' industries



Growing calls for action in order to contain greenhouse gas emissions and increase environmental sustainability have focused on the automotive industry as one of the prime GHG emitters. Chemistry research can play an important part in the industry's answer by increasing the sustainability of the resources used. For example, the environmental impact of vehicle construction has been reduced by using more recyclable plastic in tyres and joining a closed-loop recycling network[74], cutting solvent

[71] See Section 5.14
[72] Airbag Patent, http://www.freepatentsonline.com/5073418.html
[73] Windscreen Patent, http://www.freepatentsonline.com/7475932.html
[74] See Section 5.14

and paint usage and related VOC emissions[75] and capturing those emissions that cannot be avoided.[76] Low-emission vehicles have also been developed, utilising emissions control systems, advanced engines or hybrids, and bio-fuels to offer the potential to reduce environmental impact.

Research in UK universities is looking to the future through the development of advanced materials technology, sustainable materials, enhanced battery chemistry, hydrogen fuel cells & alternative fuels. Fundamental chemistry underpins all of these areas. This research can indeed be derived from the advances in a number of other fields but is now being applied to benefit the automotive industry. For example, advances in composite materials for aircraft also find applications in this industry (see case study 5.1) and energy storage and conversion technologies such as those considered in section 5.5.1. Recently, a UK consortium, partially funded by the technology strategy board, announced plans to develop high energy density batteries for use in plug-in electric vehicles. Applied research led by Professor Peter Bruce at the University of St Andrews into solid state chemistry and electrochemistry is providing new electrode materials which will be further developed by the industrial partners. This development enhances the UK's reputation in low carbon vehicle technology and will strengthen the UK's automotive industry**.**

5.2.2. Case Study: Engine lubricants for biodiesel engines

(i) Background

The increasing utilisation of biodiesel as an alternative, renewable fuel for vehicles has presented the automotive industry with several challenges. Manufactured from a wide range of vegetable oils and even animal fats, biodiesel is blended with conventional diesel at levels from 5% up to 100%. The biodiesel components are biodegradable and renewable, with the mixture having similar combustion properties to conventional diesel. The chemical structure of biodiesel differs significantly from diesel, leading to challenges to the effectiveness of traditional engine lubricants when used in engines running biodiesel blends. A principal issue with biodiesel blends is that as a result of incomplete combustion the biodiesel component can build up in the lubricant. This happens also with conventional diesel, but the difference with biodiesel is that it has a narrower and higher boiling range and hence stays in the lubricant. It is also prone to oxidation and therefore has a negative effect on the chemical stability of the lubricant and its performance additives. This leads to increased viscosity of the lubricant, sludge formation, poor engine cleanliness, and the risk of unacceptable component wear[77]. Consequently, dependent on the level of the biodiesel component in the fuel, vehicles running with biodiesel may require more frequent oil changes, at a higher cost to the consumer, and also may have poorer long term engine durability.

Infineum International is conducting in-house research involving chemists to identify, develop, and commercialise solutions to the impact of biodiesel on lubricants. With corporate headquarters in the UK, Infineum International is a global leader in the production of performance additives for lubricants and fuels, with a global manufacturing and marketing reach. Their strap line is "Performance you can

[75] http://www.chemistryinnovation.co.uk/roadmap/sustainable/roadmap.asp?id=169
[76] http://www.chemistryinnovation.co.uk/roadmap/sustainable/roadmap.asp?id=231
[77] Infineum (2007) "How biofuel tolerant will lubes have to be?", *Infineum Insight*, 34.

rely on", and a major element of their success is the development of innovative chemistry for their lubricant and fuels customers, who are in the main the major oil companies.

In addition to in-house research and development, Infineum International also has a large number of active university programmes within the UK, including at the Universities of Bristol and Leeds, and has been involved in collaborative research projects funded by EPSRC. These research partnerships have resulted in significant advances in fundamentals that underpin lubrication understanding, development of fuel additives that contribute to emissions reduction, and understanding of 'cold flow' issues in biofuels that can result in wax and deposits at low temperatures.

Research in these areas can have a significant impact within the automotive industry, providing a tangible contribution to reduced vehicle maintenance costs, increasing fuel efficiency, and ultimately may facilitate the use of higher levels of biodiesel. Together these translate to significant efficiency gains for the automotive industry and higher vehicle reliability for the vehicle end user.

(ii) Impact of research outside of automotive industry

Biodiesel is likely to be the second most important biofuel after ethanol in the short to medium term, with global biodiesel demand increasing rapidly from 8.2 million metric tons in 2006, to an estimated 19.7 million in 2010[78]. These numbers are dominated by demand from Europe, however demand from North America and Asia Pacific is growing rapidly; a recent report by LECG estimated that biodiesel generated US$ 4.1 billion for US GDP in 2007[79].

In addition to the light vehicle and truck industry, this demand may come from other transport segments. Heavy diesel engines, such as those found on trains, and marine engines can run on biodiesel; the UK's Royal Train has already been converted to run on B100 biodiesel[80].

The scope for an effective lubricant for engines running on biodiesel is, therefore, extremely large, particularly as we can expect the levels to rise in due course from around 5% near term to up to 15% longer term with a proportion of captive fleets running at even higher biodiesel levels. There is of course continuing debate about the real benefits of biodiesel (including food vs. fuel land use), but in order to meet emerging targets for sustainability and renewability we can expect to see increasing use of it as a fuel. The work outlined above facilitates the capture of some of these environmental benefits, and represents one way in which chemistry is contributing to the achievement of social goals.

[78] Marsh, S and Corradi, M (2007) "The effect of biodiesel on engine lubricants", *Lubes'n'Greases Magazine*, June
[79] LECG (2007) *Economic Contribution of the Biodiesel Industry*
[80] http://www.green-fuels.co.uk/royal_train.htm

5.3. Construction/materials

This section presents a case study from the construction industry to illustrate the role of UK chemistry research in facilitating success downstream of the chemical industry.

Dependence on chemistry research: moderately dependent (41%)

- *Chemistry research directly enables the construction and materials industry to contribute **£34.9 billion** to the UK economy and supports **741,000 jobs** in the UK construction and materials industry.*
- *The construction and materials sector utilises chemistry in a wide range of final products, such as plastics and paints. In addition, the sector also uses chemistry to improve materials with additives.*
- *The developments made through chemistry research lead not only to new products, but also result in higher safety standards. Chemistry research is making buildings safer and playing a vital life-saving role.*

Case study – fire-resistant glass

- *Research collaboration between universities and industry in the UK has led to various improvements in the properties of glass used for construction.*
- *These breakthroughs include fire-resistant glass and photovoltaics, both of which carry a high value-added for producers, and have supported UK glass producers throughout the current recession, as traditional automotive and construction orders declined.*
- *The fire-resistant properties that can be incorporated into glass through chemistry research have a clear health and safety applicability.*

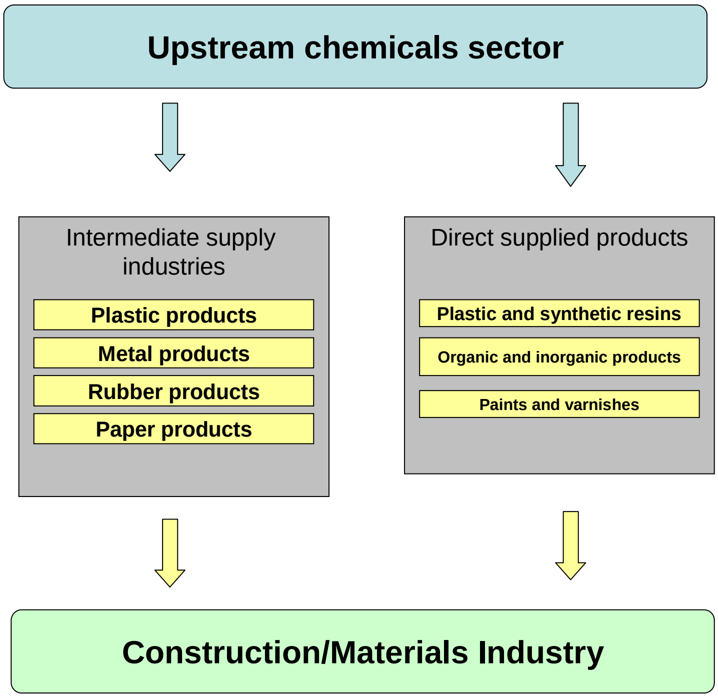
5.3.1. Chemistry research and the construction/building materials industry

The construction and building materials (hereafter referred to simply as construction) industry is one of the largest in the UK, with GVA of £85 billion accounting for 7.2% of UK GDP in 2007. Unsurprisingly given its size, the industry is one of the major employers in the UK, with employment totalling 1.7 million in 2007.

In generating this GVA, the industry consumed inputs valued at £70.7 billion, of which £5.9 billion, or 8.4%, were sourced from the chemicals industry. The predominant chemical input consumed by the construction industry is plastic and synthetic resins, valued at £3.9 billion; other sizeable chemical inputs were organic and inorganic chemicals, and paints and varnishes – each valued at around £750 million. Furthermore, the construction industry consumes chemical goods indirectly from other sectors, the two largest of which, plastic and metal products, accounted for 16.8% of inputs consumed

(Figure 5-3). As a consequence of the level of chemistry-related inputs consumed, Oxford Economics have judged the construction industry to be ***moderately dependent*** on chemistry research.

Figure 5-3: The chemistry-using 'construction/materials' industries



Many of the products used within construction stem from chemistry research, such as paints, varnishes, metal alloys and plastics. Polyvinyl chloride, or PVC, is one such material. A thermoplastic resin, PVC is one of the most used plastic materials in the world, with consumption in Europe accounting for 15% of all plastics[81]. Application of PVC in the construction industry is wide due to its durable, lightweight, and strong properties, with pipes, fittings, flooring and cables commonly manufactured using PVC.

The progress made by chemistry research has led to changes in the building regulations implemented by the UK's Health and Safety Executive. Historically, the cables in fire alarms could withstand the heat and flames of a fire for up to one hour. However, chemistry research into heat resistance led to the development of wires that can withstand a fire for up to three hours. In light of this new development, the British Safety Standard now requires that all fire alarms are constructed using wires incorporating the new heat-resistant coating.

In addition to being used to produce final products, chemistry research is also used to improve materials, for example concrete. Among the many additives that can be used to augment the properties of concrete are water reducing agents, a form of super plasticizer which reduces the water required for producing concrete, shrinkage reducing agents, which reduces shrinkage while drying,

[81] European Council of Vinyl Manufacturers, www.pvc.org

and set retarders, which provide greater time for texturing[82].

Chemistry also plays an important role in the development of new glass compositions. Employing around 3,000 people, Pilkington United Kingdom is the UK's largest flat glass manufacturer, and a part of NSG group's global business. Traditionally, the company has supplied the automotive sector, supplying both original equipment and replacement glass, and the building sector. However, recently the business has moved towards higher value added products, supplying glass for photovoltaic panels and solar collectors for buildings and fire resistant glass (see the case study below). This diversification has been particularly necessary in the current recession, which has seen demand from both the automotive and buildings sectors fall leaving the company more reliant on demand from the electronics sector for photovoltaics.

In addition to the above, Pilkington UK also have developed glass which helps to make homes more energy efficient (i.e. reduce the amount of heat lost through windows and allow more heat from the sun in) and self cleaning glass, which utilises the photocatalytic properties of titanium dioxide coatings.

5.3.2. Case Study – Fire-resistant glass

Different aspects of chemistry research are utilised within Pilkington's glass production, depending on the required properties of the glass. During the production process, organometallic coatings are applied to a 4 metre ribbon of glass at 700℃. Chemistry is required twice in this process, first to develop the correct compound, which differs depending upon the property required, and, second, surface chemistry is required to ensure that the coating remains even and only a few nanometres thick over the entire ribbon. The initial research that led to the development of Pilkington K-glass was focused on coatings that include an undercoat to suppress colour and increase light transmission, this research was conducted in-house by Pilkington in the UK in collaboration with Harvard University. The product range has been extended through work with Imperial and Queen Mary Colleges, UCL and the University of Bath. Pilkington regularly uses EPSRC for collaboration purposes, taking on several new CASE collaborations each year. However current compounds used are a hybrid of both Pilkington's UK research and the research of a US company purchased by Pilkington; the US research was conducted simultaneously to that undertaken by Pilkington in the UK. As the scale of production expands, to provide compounds in larger quantities production is outsourced to specialist companies within the UK.

One of the most chemistry intensive product lines marketed by Pilkington is fire resistant glass. By taking two panes of glass and filling the cavity between them with intumescent material the resultant glass can provide fire resistance for periods up to 120 minutes; the exact resistance time is determined by the specific intumescent compound utilised. During normal conditions the glass is just like any other pane of glass, however when exposed to a fire, the pane facing the flames fractures but remains in place, the intumescent filling then turns opaque, creating an insulating shield blocking the

[82] Sakai, E., Ishida, A., and Ohta, A. (2006), "New trends in the development of chemical admixtures in Japan", *Journal of Advanced Concrete Technology,* 4(2):211-223

heat of the blaze.

Chemistry is heavily used in the manufacturing process to ensure that the intumescent material has the correct properties to maintain the correct level of integrity and insulation during a fire. Fire resistant glass of this type has a clear application in the construction of fire escape routes, which with the use of glass doors and walls can remain free from smoke and fire during an emergency for long enough for evacuation, and provide safe fire-containing corridors.

The manufacture of fire resistant glass clearly illustrates another of the ways in which aspects of chemistry research contribute to providing a safe and healthy society. By reducing the speed at which a fire/smoke can spread, enabling safer evacuation routes and areas from which fire-fighters can operate, both the human and economic cost of fire is reduced.

5.4. Electronics

This section presents a case study from the electronics industry to illustrate the role of UK chemistry research in facilitating success downstream of the chemical industry.

Dependence on chemistry research: highly dependent (88%)

- *Chemistry research directly enables the electronics industry to contribute **£14.4 billion** to the UK economy and supports **279,000 jobs** in the UK electronics industry.*
- *Chemistry plays an important role within the electronics industry. Fundamental research conducted by chemists impacts on the electronics sector through conductive polymers and various insulating plastics.*
- *Desire for generating energy from renewable sources has led to demand for photovoltaics of increasing efficiency. Consequently, fundamental research in both UK industry and academia into photovoltaics is extremely active.*

Case study – Quantum Dots

- *Fundamental research at the University of Manchester led to the development of a new method of manufacturing quantum dots in an efficient and large scale.*
- *Quantum dots have a large potential market, with applicability in lighting, display technology, photovoltaics, and biomedicine – by way of example, the global market for display technologies today is already in excess of £55 billion and is estimated to exceed £65 billion by 2011[83].*
- *Nanoco, the owner of the IP, continues to conduct research in the UK, with the backing of major international manufacturers.*

5.4.1. Chemistry research and the electronics industry

The UK electronics industry generated £16.4 billion of value added in 2007, accounting for 1.4% of UK GDP. Activity in the electronics industry supports 322,000 jobs, across areas including the manufacture of computers, electronic valves, lighting equipment and watches[84].

To generate a value added of £16.4 billion, the electronics industry consumed £12.3 billion of inputs, of which £908 million, or 7.4%, came directly from the chemicals industry[85]. The majority share of these inputs were in the form of plastic or synthetic resins, which amounted to £547 million, however, inputs of both organic and inorganic chemicals, and man-made fibres were not insignificant, being

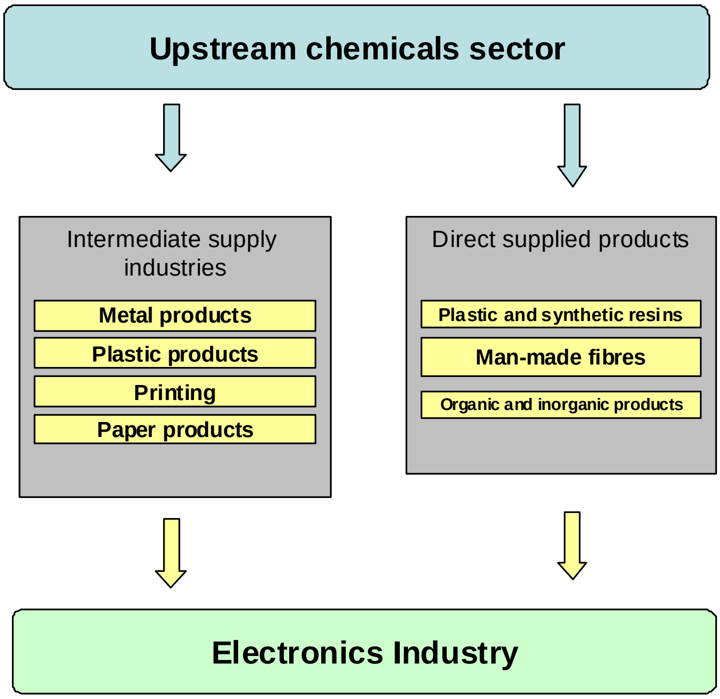
[83] 'BERR 'Flat Panel Displays in the UK – A guide to UK capability 2008/09'. Uses data and projections supplied by iSuppli Corp
[84] Annual Business Inquiry (ABI) – Release date 16/06/2009. See www.statistics.gov.uk/abi/subsection_dg.asp, scaled to Blue Book 2009 constant 2005 prices.
[85] ONS input-output tables 2007, www.statistics.gov.uk/about/methodology_by_theme/inputoutput/latestdata.asp

valued at £137 million and £144 million respectively (Figure 5-4). Stakeholders have deemed that the electronics industry is ***highly dependent*** (88%) on chemistry research because of the importance of these inputs which are dependent upon chemical research. In 2007, spending on two product groups that are highly dependent on chemistry – metal and plastic products – by the electronics industry amounted to £3.8 billion, or 31% of all inputs into the industry. As this figure only considers two products, actual spending on all chemistry-related products will be considerably higher.

Semiconductors lie at the foundation of modern electronics and are found in a wide range of devices from computers and mobile phones to solar cells. Usually based fabricated from silicon they are reliant on chemistry research: when placed together, a group of semiconductors, each formed of silicon doped with phosphorus, arsenic, boron or gallium, can be used to form a microprocessor. More recently it has been found possible to create polymer-based semiconductors - while often seen as being a branch of physics, the origin and development of underpinning conductive polymers is based upon chemistry research – the 2000 Nobel Prize for Chemistry was awarded to Heeger, MacDiarmid and Shirakawa for the discovery and development of conductive polymers[86].

Once again, a wide array of polymers and plastics produced through chemistry research find a use within the electronics industry. The casing used for almost every electronic appliance will be made out of some form of plastic, with different polymers chosen depending upon the desired finish.

Figure 5-4: The chemistry-using electronics industries



The role chemistry research plays in electronics has not stopped with the discovery of

[86] Nobel Prize website, http://nobelprize.org/nobel_prizes/chemistry/laureates/2000/index.html

semiconductors. Given the demand for alternative energies, the photovoltaic characteristics of semiconductors, first discovered by Bell Laboratories in 1954, provide potential for increasing the share of energy generation held by solar power. However, before replacing more traditional forms of energy generation, photovoltaic cells need to improve in efficiency to reduce the cost difference between hydrocarbon fuels and solar energy[87]; further chemistry research could create these increases in efficiency. Major work in the field of materials chemistry can be used to substantially enhance the efficiency of photovoltaic cells. The future of such research requires the development of a new generation of semiconductors, more flexible substrates and low cost printing technology. The Printable Electronics Technology Centre, PETEC[88], in the North East of England is an example of a facility that it tackling these challenges. PETEC is a design, development and prototyping facility. The centre offers facilities and expertise to help to bring new printable electronics products to market quickly (an example of printable electronics products are conductive inks, which are discussed as the case study within the Printing and Publishing section of this report). PETEC are working across disciplines and linking the applications of the electronics industry with the technologies of the printing industry e.g. conductive inks as described in case study 5.13. The printed electronics market is viewed as a sector with great growth opportunities for companies that innovate. Printed electronic products can be used in end-user industries such as consumer electronics, healthcare, power generation, military, logistics and the manufacturing sector.

5.4.2. Case Study – Quantum dots

Quantum dots (QD) are small particles of material with electro-optical properties, traditionally manufactured on a small scale through ‘high temperature dual injection’, which involves the injection of organometallic alkyls into a hot reactor solution. The process suffers from harsh reactor conditions, hazardous starting materials, and quality issues upon scaling-up.

Using EPSRC funding, fundamental chemistry research led by Professor Paul O’Brien based at the University of Manchester resulted in a new method of manufacturing quantum dots in a cost-effective manner on an industrial scale. Professor O’Brien’s group were able to create a quantum dot manufacturing process that overcame a key factor limiting the possible scale of production. The new process removes the need for high temperature nucleation by producing nanoparticles from chemical precursors in the presence of a molecular cluster compound, which acts as a seed nucleation point.

The discovery by Professor O’Brien’s group has led to a platform technology with numerous potential applications of QDs:

- **Lighting** – QDs can be used as a lighting solution in the form of LED lamps. LEDs created from QDs offer improved performance in converting electricity into light over both incandescent and fluorescent energy saving bulbs. Furthermore, the operational life span of QD LEDs ranges between 25,000 and 50,000 hours, considerably larger than those of fluorescent energy-saving and incandescent bulbs, which have lifespans of 3,000 and 500 hours respectively.

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[87] RSC (2009) *Chemistry for Tomorrow’s World: a roadmap for the chemical sciences*
[88] http://www.uk-cpi.com/3_pages/focus/petec/about/

- **Screens** – QD technology represents the next-but-one generation of display technology. By incorporating organic light emitting diodes (OLED) with quantum dot technology, future displays will utilise less energy than current technologies, and will be printable, enabling flexible and very large displays.

- **Photovoltaics** – Using QDs in photovoltaics provides easy manufacture of photovoltaic units, as printing is the primary method of construction.

- **Biomedical imaging** – Future developments of a coating for QDs will render them soluble, and reduce toxicity. Potential applications in the field of biomedicine include tissue mapping, drug delivery, real-time detection of cellular events, tracking cell migration, and *in vivo* whole animal clinical imaging.

To exploit this technology commercially, Nanoco Technologies was founded in 2001 by Professor Paul O'Brien and Dr Nigel Pickett as a spin-out of the University of Manchester. Since 2001, Nanoco has raised £4.1 million of private equity funds to continue the development and manufacture of quantum dots. The company has successfully floated on AIM, is currently valued at £130 million, and employs between 30 and 35 people. Nanoco conducts all research in-house and attracts development funds from major Japanese manufacturers.

5.5. Energy

This section presents a case study from the energy industry to illustrate the role of UK chemistry research in facilitating success downstream of the chemical industry.

Dependence on chemistry research: moderately dependent (44%)

- *Chemistry research directly enables the energy industry to contribute **£6.0 billion** to the UK economy and support **32,000 jobs** in the UK energy industry. This supports the oil, gas, nuclear and renewable energy sectors in providing energy for electricity, heating and transport.*
- *The provision of electricity is significantly dependent upon chemistry research. New technologies enable electricity to be generated and transmitted in more efficient and environmentally-friendly ways, drawing on improved technologies for conversion (from the energy sources) and the handling of waste materials.*
- *The role of chemistry in the UK's energy sector is likely to increase in the coming years, through both the pursuit of alternative energy sources, such as hydrogen and solar power, and the Government's planned scaling-up of power obtained from nuclear sources.*

Case study – Graphite moderators in advance gas reactors

- *90% of the UK's nuclear power relies on graphite moderators – the material which slows neutrons and hence improves fission. The science of moderators is heavily dependent upon chemistry, particularly through UK-based fundamental research.*
- *This research underpins assessments of reactor longevity and safety, ensuring that plants are not unnecessarily closed down prematurely, which would cost billions of pounds of lost production.*

5.5.1. Chemistry research and the energy industry

The production and distribution of electricity, and the distribution of gas, generated £13.6 billion in value added in 2007, equivalent to 1.53% of total UK GDP. The UK energy sector employs 82,000 people[89].

The chemical products sector supplies relatively little, in terms of consumables to the UK energy sector, with chemical inputs valued at £48 million representing only 0.16% of total inputs of £31 billion. Of the chemicals that are purchased by the energy industry, organic and inorganic compounds account for £37 million, with industrial gases and dyes being the remainder. The energy sector also purchases little by way of inputs that are dependent upon chemistry; the three largest indirect chemical inputs into the energy sector – printing and publishing, paper products and electronic

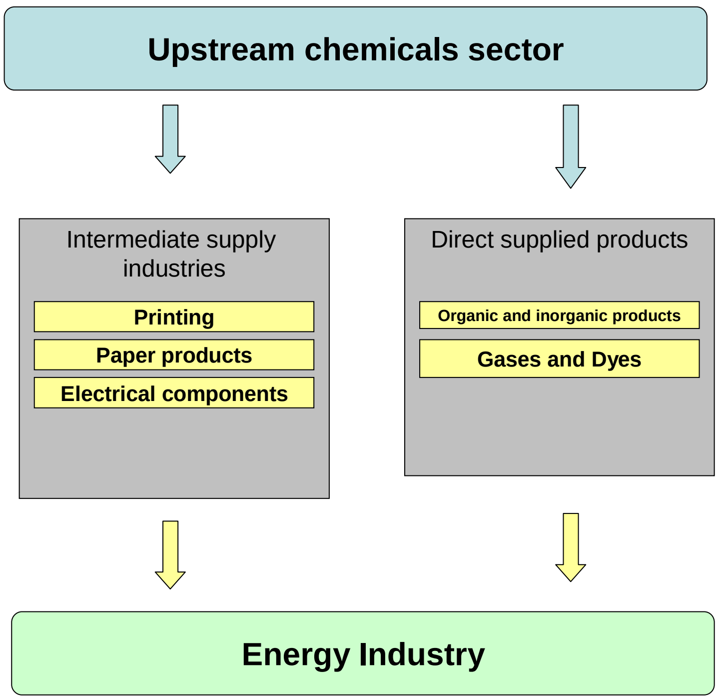
[89] Annual Business Inquiry (ABI) – Release date 16/06/2009. See www.statistics.gov.uk/abi/subsection_dg.asp, scaled to Blue Book 2009 constant 2005 prices

components – account for only 1.1% of total inputs (figure 5-5)[90].

However, the industry is extremely capital intensive, requiring chemistry expertise in providing the appropriate materials and operating guidelines for boilers, nuclear reactors, pipe-work, transmission cables, turbine technology and the handling of nuclear and non-nuclear waste.

Given the relatively low level of inputs of chemistry related products into the energy sector, the assigning of a dependency on chemistry research of 44% (***moderately dependent***) to the energy sector could be questioned. However, the rationale for this level of dependency is driven not by the purchases made by the industry, but rather the application of chemistry research to fundamental technologies within the sector, specifically within the national electricity grid.

Figure 5-5: The chemistry-using 'energy' industries



The generation and distribution of power nationally is central to the sector's operation and revenue generating capacity. Just one example shows how chemistry research has led to significant change in the industry over time. When the national grid was originally built the transmission cables were packed with paper and used an oil-based solution to stop water impregnation. Unfortunately, such cables have a tendency to leak oil, which becomes a major issue with underground cables. Chemistry research has provided a solution to this problem in the form of cross-linked polymers such as polyurethane. The use of polymers in transmission wires has many advantages – the product is cheaper and more effective as it is easier to maintain and does not leak, it does not require the oil to be 'topped up' or re-pressurised and the new cable is more resilient than the old paper and oil

[90] ONS input-output tables 2007, www.statistics.gov.uk/about/methodology_by_theme/inputoutput/latestdata.asp

combination. Finally it allows up to 20% more current to flow through the wire[91]. Without this input from chemistry research, the ability of the national grid to deliver electricity to consumers would be diminished.

The desire for improved efficiency in the energy sector leaves considerable scope for future chemistry research. Demand for greener power production, and the likely exhaustion of hydrocarbons - particularly rapidly in the UK - opens the path for research into alternative generating techniques and methods to 'clean up' and increase efficiency in existing processes. For example, as discussed in the previous chapter, further research into photovoltaic cells could result in increased green energy production. Additionally, there will be improved efficiency through the gasification of coal[92].

Chemical research will be critical to creating a future sustainable energy mix. In collaboration with other science and engineering disciplines, chemists are providing solutions to the existing technological barriers. Examples include developing technologies and approaches to maximise the useable fraction of known fossil fuel reserves, increased process efficiencies and the development of cleaner products (e.g. ultralow sulphur diesel). As long as fossil fuels remain in use a key challenge is the development of some means of capturing and safely storing carbon dioxide on a large scale so that targets for carbon dioxide reduction can be met through carbon capture and storage (CCS).

The conversion and storage of energy are critical areas of development for the future. The UK Energy Storage Consortium has developed from collaboration between electrochemists, materials chemists, chemical engineers and electrical engineers and has the objective to develop new nanostructured materials to improve the performance or capabilities of lithium ion batteries and electrochemical supercapacitors. In addition, the Consortium aims to develop new batteries/supercapacitors for applications including interfacing with power grids and automotive power (see section 5.2). Fuel cells (combined with hydrogen) offer a significant advantage over traditional combustion-based thermal energy conversion, in that they have the potential to provide higher efficiencies of electrical power supply whilst causing very low levels of pollutant emission. Although a highly attractive technology, further transition to a sustainable hydrogen economy will require reliable and efficient means of creating, transporting and storing hydrogen, all of which will require chemistry research. Hydrogen will need to be produced using renewable energy and a sustainable feedstock (rather than from yet more fossil fuels). A wide variety of current research is addressing this need, for example in one research strand bio-hydrogen is being produced from a green alga that is closely related to higher plants using a chemical process which mimics the water oxidation enzyme of plant photosynthesis[93].

Furthermore, following the UK Government's recent announcements to pursue a more nuclear-orientated energy policy[94], the role of chemistry within the UK's energy sector will undoubtedly increase in the future through the expanded use of nuclear fission (as detailed in the case study below) and through continued investment in nuclear fusion which, although still a long way from

[91] From stakeholder interview
[92] World Nuclear Association, http://www.world-nuclear.org/info/inf83.html
[93] Energy Futures Lab (Imperial College) source: http://www3.imperial.ac.uk/energyfutureslab/research/grandchallenges/solarhydrogen
[94] http://www.direct.gov.uk/en/Nl1/Newsroom/DG_182294

commercial viability, potentially offers a long term energy solution.

5.5.2. Case Study – Graphite moderation in advanced gas reactors

Nuclear power plays a prominent role in the UK, accounting for around 15% of the UK's electricity generating capacity. A large proportion of this capacity comprises two generations of nuclear reactor, the first generation Magnox reactor and the second generation Advanced Gas-cooled Reactor (AGR)[95].

The AGR design uses the circulation of carbon dioxide gas to transfer heat from the nuclear reactor to heat exchangers that convert water to steam. This in turn, drives steam turbines to generate electricity.

The older Magnox reactors are either in decommissioning or are approaching the end of their operational lifespan and so the importance of AGRs to the UK is increasing; currently AGRs provide about 75% of the UK's nuclear energy generating capability, although this will increase to around 90% within the next five years.

The ability to continue to operate reactors, such as the AGRs, is improved by better understanding of the fundamental processes occurring within them. Thus, appropriate studies in areas of chemistry, physics and materials science are highly beneficial.

A key component of an AGR is the graphite moderator. The most important role for this component is to slow (or "moderate") neutrons, thereby improving the efficiency with which the uranium fuel undergoes fission. A clearer understanding of the effect of these neutrons on the structure and properties of graphite should provide substantial support both for ongoing safety assessments and for assessments of remaining reactor lives. Similarly, the chemistry of the coolant is important since the gamma rays from nuclear reactions can split carbon dioxide molecules into carbon monoxide and oxidising species, and the latter can corrode the graphite, increasing its porosity and so reducing its strength and ability to moderate.

The life expectancy of the moderator is likely to be the main determinant for AGR longevity. Chemists at the University of Sussex, with funding from British Energy, conducted calculations to obtain in-depth understanding of the atomic displacement caused by neutron impacts in the moderator material. The science behind these phenomena was previously unknown and fills what would otherwise still be a major gap in the existing theory of radiation damage.

The funding to the department from British Energy to conduct this fundamental research is substantial, supporting several PhD students in graphite sciences, in addition to further post-doctoral study. Accordingly, the work at the University of Sussex on graphite as a moderator in AGRs is contributing to the better definition of reactor longevity and safety. If the fourteen UK operating AGRs 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 (linked to reducing fossil fuel dependency)

[95] The UK also has one third-generation pressurised water reactor (PWR) at Sizewell B.

and widen the nation's energy deficit.

The methods developed at the University of Sussex have also been applied to estimate the long-term scale of nuclear decommissioning. The Chemistry Department received funding from the EPSRC between 2000 and 2003 to predict the atomic structures which exist in the graphite within Pile 1 of the Windscale accident site, and the implications for decommissioning; the EPSRC rated this research as internationally leading and outstanding.

Due to the high level of secrecy many countries place on their nuclear reactors, there has been little by way of international application of the modelling developed by Sussex, however there have been suggestions of collaboration with the Idaho Nuclear Laboratory. Domestically, the importance of the work done in the Sussex Chemistry Department will increase up to and including the decommissioning process. Looking towards new generations of nuclear reactors, graphite moderators will remain applicable to the proposed generation IV reactors (Pebble Bed Modular, High Temperature Reactors (HTR) and Very High Temperature Reactors (VHTR)). These reactors have the potential to catalytically produce hydrogen from water, for use as a clean transport fuel. Graphite is also utilised as the first wall in designs of fusion reactors, as it is very durable and stable up to high temperatures.

5.6. Extraction and manufacturing of petroleum products

This section presents a case study from extraction and manufacturing of petroleum products industry to illustrate the role of UK chemistry research in facilitating success downstream of the chemical industry.

Dependence on chemistry research: highly dependent (100%)

- *Chemistry research directly enables the extraction and refining of oil within the petroleum products industries to contribute **£24.6 billion** to the UK economy and directly supports **22,000 jobs** in this sector.*
- *The petroleum products supplied by the industry are crucial for the upstream chemicals industry. Making the industry a 'special case' through the two-way reliance between it and the upstream chemicals sector.*
- *The refining of crude oil into petroleum products involves many chemical processes; aside from the distillation of crude oil and subsequent cracking into simpler molecules, every drop of fuel used anywhere in the world has been treated with a number of additives and catalysts to ensure quality.*

Case study – Bright Water™ Polymer

- *Chemistry is playing an increasing role in the extraction of oil, as industry seeks to recover as much oil as possible from reservoirs. Developments such as the Bright Water™ polymer enhance traditional methods of extraction, enabling more efficient and complete drainage of oil from reservoirs.*
- *The benefits of developments such as the Bright Water™ polymer offer enormous potential: a single percentage point increase in extraction from BP wells worldwide would generate an additional 2 billion barrels of oil, over the lifetime of the fields.*

5.6.1. Chemistry research and the extraction and manufacturing of petroleum products

The extraction and manufacture of petroleum products is one of the UK's major sectors, accounting for 2.6% of the UK's GDP, with a value added of £24.6 billion. The sector is characterised by being extremely capital intensive and a high productivity per employee and consequently employs only 22,000 people, 9,000 of whom work in the manufacture of petroleum products[96].

The petroleum industry includes the global processes of exploration, extraction, refining, transportation, and marketing, and petroleum products produced by the industry are key inputs into the upstream chemicals industry. This places the industry in a unique position within the economy, as it is both reliant upon, and essential for the upstream chemicals industry.

[96] Annual Business Inquiry (ABI) – Release date 16/06/2009. See www.statistics.gov.uk/abi/subsection_dg.asp, scaled to Blue Book 2009 constant 2005 prices.

Throughout the entire supply chain, this industry requires a range of chemicals and a significant understanding of chemical science. For example, analytical chemistry is essential to the investigation of rock samples to discover oil and gas (e.g. through the use of chemical and/or radioactive tracers to gauge fluid flows in the reservoirs).

Currently, the bulk of oil extraction is affected through primary and secondary recovery processes. These involve both natural mechanisms (e.g. natural water displacing oil upward into the well, expansion of the natural gas in the reservoir) and through the input of external energy (e.g. injection of fluids or using pumps) respectively. There is also an increasing impact of chemistry research through tertiary recovery processes, in which surfactants and biocides are injected into the reservoir to improve oil recovery. These fruits of chemistry research are employed to keep the oil flowing through flow improvers, gel treatments, chemicals which inhibit cementing, corrosion, wax deposition and hydrate crystallisation. In addition to these chemicals, this industry also relies on improved lubricants for machinery and oil well and production facilities require plant and pipe-work to be injected with anti-corrosion, demulsifying, anti-foaming, and emulsifying agents at a range of different locations. Many of these are needed to facilitate the separation of fluids into oil, gas and water. Additionally, electrochemistry is deployed to control the external corrosion of pipe-work and vessels (figure 5-6).

Petroleum refining involves distillation and subsequent cracking to turn crude oil into a variety of useful products and fuels, such as petrol, diesel and kerosene. While distillation is a physical process, cracking is a chemical process.

Crude oil comprises a complex mixture of numerous hydrocarbon liquids and dissolved gases; distillation separates these into well defined “cuts” or streams. These streams are further modified through the cracking process, which both breaks down the larger molecules into smaller sized, more marketable chemical products, and removes sulphur. The modified streams can then be blended to form a range of products and fuels, such as propane/butane gas, fuels for heating, road, air and marine transport, electricity generation and lubricating oils[97].

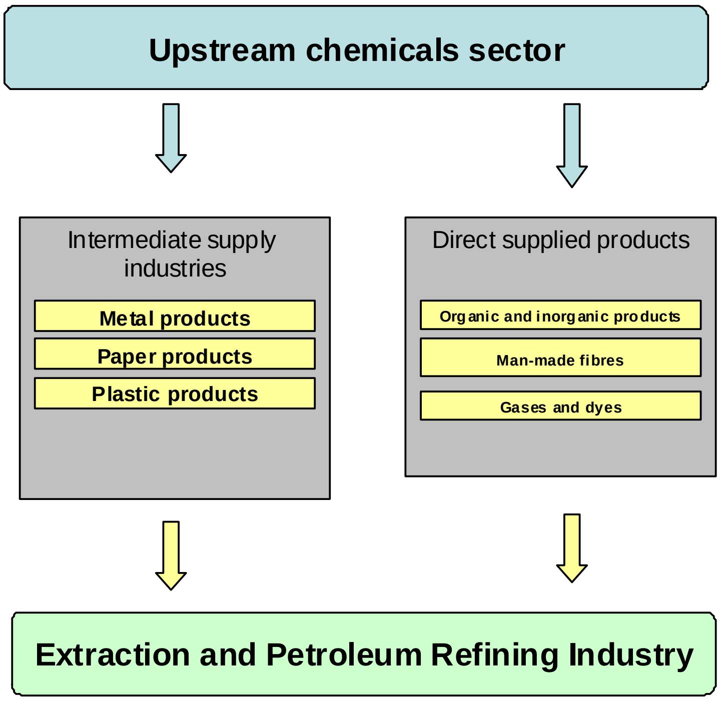
These examples highlight the importance of chemistry and chemical research throughout the petroleum industry. Consequently the industry is assigned a **high (100%) level of dependency on chemistry research**.

Discussions with stakeholders have highlighted that the role chemistry plays in the extraction of oil will increase, as easily accessible reserves diminish. Currently, the industry recovers on average less than 35% of the available oil from a reservior, although there is considerable variation in this. This figure is determined largely by the interfacial properties of the oil in the pores of the reservoir, the reservoir geometry and the porosity and permeability of the rocks. However, if the degree of extraction were increased by 1% the impact would be enormous. BP estimates that extracting an additional 1% oil from its reservoirs over the production lifetime would amount to 2 billion extra barrels of oil with a gross pre-tax value of ca. $150 billion at current oil prices. That chemistry has a crucial

[97] http://science.howstuffworks.com/oil-refining.htm

role to play in the effort to increase the level of hydrocarbon recovery from reservoirs is revealed in the following case study.

Figure 5-6: The chemistry-using 'extraction and petroleum refining' industries



5.6.2. Case Study – Bright Water™[98] polymer

- One of the most promising methods of increasing extraction rates is the application of Bright Water™ polymer to the water injected into oil reservoirs.
- Water is pumped into reservoirs to displace oil, a process known as water flooding. However, the water soon finds channels of least resistance, colloquially called thief zones, through which the bulk of the water flows, leaving the majority of the oil untouched.
- Using polymer chemistry research, collaboration between several extraction companies has led to the development of the Bright Water™ polymer. Bright Water™ polymer is added to the water injected into a reservoir and reacts to a change in temperature in the thief zones. This causes the polymer particle to expand (this 'popping' has resulted in this polymer being informally known as the popcorn polymer'), thereby filling the channels, diverting the water to areas that would otherwise be poorly swept, and increasing the amount of oil forced out into the production wells.

[98] Bright Water is a registered trade mark of Nalco for waterflood sweep efficiency products

5.7. Farming (agriculture) industry

This section presents a case study from the farming/agriculture industry to illustrate the role of UK chemistry research in facilitating success downstream of the chemical industry.

Dependence on chemistry research: highly dependent (93%)

- *Chemistry research directly enables the farming industry to contribute* ***£5.7 billion*** *to the UK economy and directly supports* ***69,000 jobs*** *in the UK farming industry.*
- *Chemistry provides farming with many of the tools it requires to produce yields at modern levels, including fertilisers and pesticides.*
- *The process of researching and developing a new product is neither cheap nor short. It has been estimated that the development and registering of a new plant protection product takes at least 9 years and costs upwards of £150 million.*
- *A weighting of 95% is based on an adjustment to account for organic farming practises, which keep use of chemicals to a minimum.*

Case study - Azoxystrobin

- *The development of the fungicide Azoxystrobin demonstrated how chemists can draw from the natural world for inspiration and transfer knowledge from the academic literature to a commercial product.*
- *Developed by UK-based chemists, Azoxystrobin is used to treat more than 120 types of crop in over 100 countries, raising beet yields by over 20%.*
- *Increasing crop yields allows for extra land to be set aside for wilderness and woodland, both of which have recreational and environmental value, which in one study has been valued at over £300 million in the UK.*

5.7.1. Chemistry research and farming

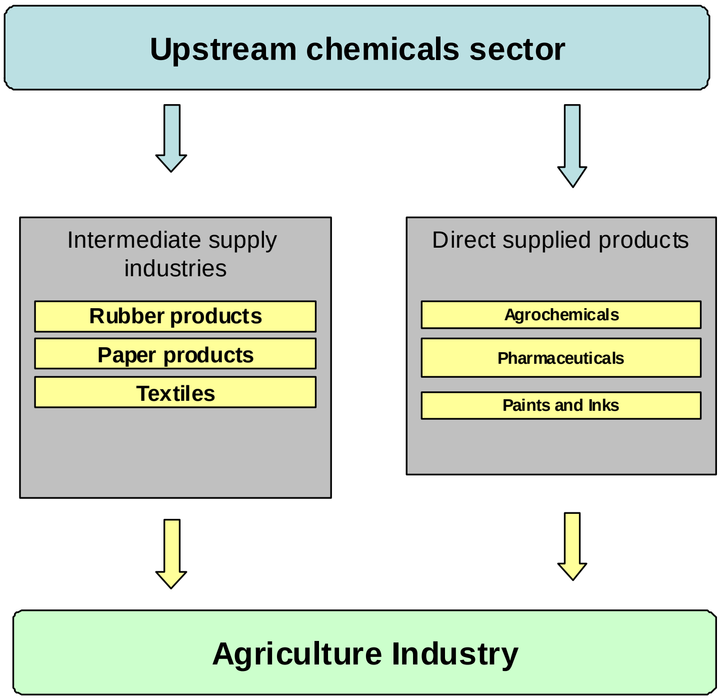
Agriculture in the UK is heavily dependent on inputs that either would not exist or would be less effective without the results of chemistry research (figure 5-7). This linkage has a long heritage with landmark developments such as the synthesis of ammonia for the manufacture of fertilisers early in the last century including ICI's ammonium phosphate based fertilisers.

Today direct inputs to farming in which chemistry plays a crucial role – fertilisers, pesticides, veterinary medicines and plastics – cost the industry £1.4 billion, over 11% of total inputs used[99]. These direct inputs play a crucial role in boosting and maintaining yields, ensuring that UK agriculture

[99] Source: ONS input-output tables 2007, http://www.statistics.gov.uk/about/methodology_by_theme/inputoutput/latestdata.asp

is economically viable and maintaining affordable food. A further £145 million was spent by the animal feeds industry on pharmaceutical ingredients, such as veterinary medicines.

Figure 5-7: The chemistry-using 'agricultural' industries



It is without doubt that the development of inorganic fertilisers has boosted agricultural productivity significantly. It has been estimated that 48% of the world's population are currently fed as a result of the use of manufactured nitrogen fertilisers[100]. Though the production of inorganic fertilisers is a long-established industry, there are continuing pressures on the industry for further innovation and development. These include the search for more energy efficient ways of manufacturing common fertilisers, which will reduce associated CO_2 emissions, and the development of slow or controlled-release fertilisers that result in more efficient delivery of plant nutrients. For example, new catalytic technology for the nitric acid sector provides significant potential for reducing the fertiliser industry's N_2O emissions in the medium term[101].

The UK has a strong history in development of globally significant crop protection chemicals. In addition to azoxystrobin, the fungicide considered in the case study below, the UK has developed many world leading crop protection chemicals. In the 60's and 70's the pyrethroid insecticide family was discovered and developed at Rothamsted Research. At the time of development, pyrethroids had a number of advantages over other products in the market place: they were more effective at lower application rates than other classes of insecticides; less persistent in the environment and less

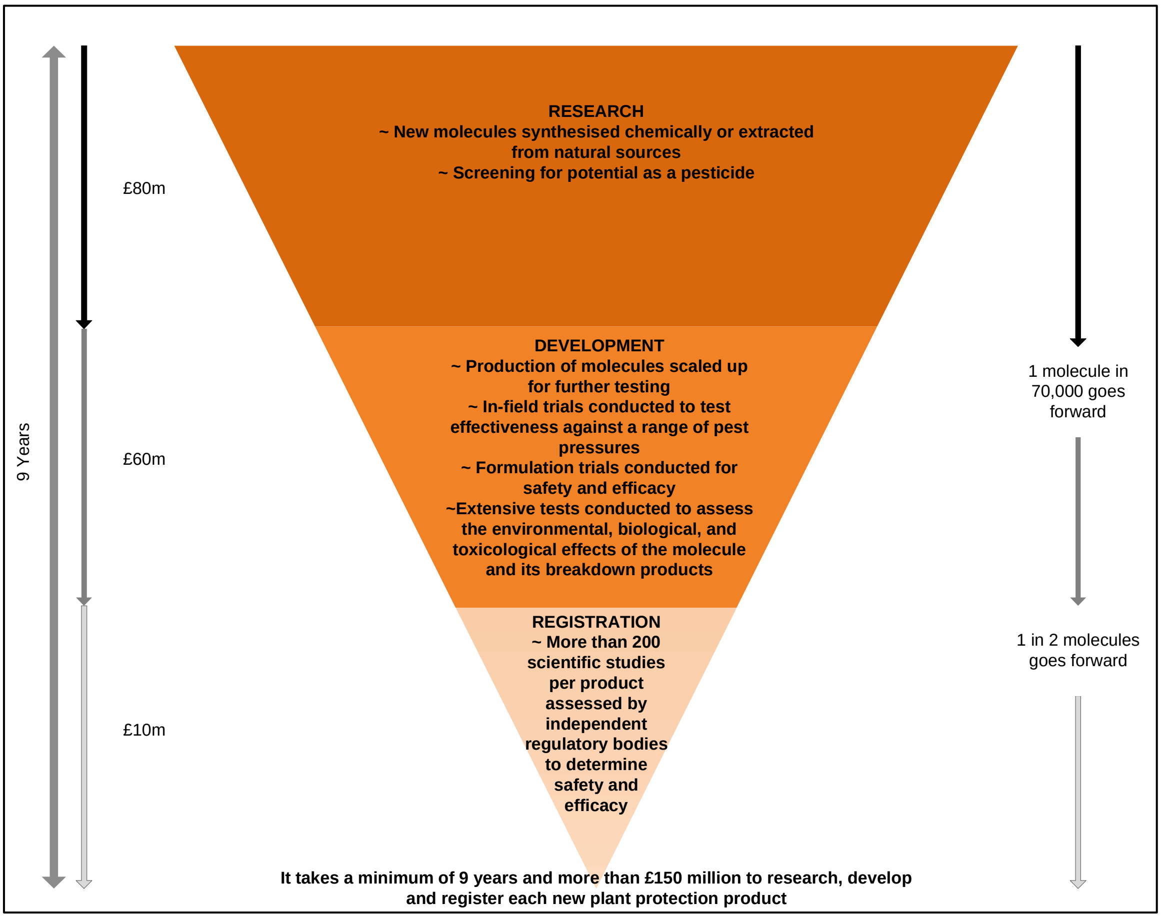
[100] Erisman, J.W., M.A. Sutton, J. Galloway, Z. Klimont and W. Winiwarter (2008) "How a century of ammonia synthesis changed the world." Nature Geoscience, Vol. 1 (Oct.): 636-639
[101] Fertilizers, Climate Change and Enhancing Agricultural Productivity Sustainably International Fertilizer Industry Association, July 2009

prone to bioaccumulate in organisms; and safer than their predecessors with very low mammalian toxicity. Pyrethroids, including *lambda*-Cyhalothrin, still account for up to 17% of global insecticide sales – a market worth more than $7 billion each year[102] – and have made a significant contribution to the UK economy.

As shown in Box 9 – Developing a new pesticide – the development of pesticides for crop protection is a chemistry intensive process. The search for new and better pesticides is driven by a number of forces, including:

- reducing the risks associated with usage, including the post-use residues to meet increasingly stringent regulation;
- reducing the costs and / or increasing the efficacy of products; and
- combating natural adaptation and immunity to products by pests.

Box 9: Developing a new pesticide



The impact of pesticides on yields is substantial (see case study on azoxystrobin). For it is estimated that without plant protection products up to 200% extra land would be required to produce the same

[102] DDT, pyrethrins, pyrethroids and insect sodium channels, T. G. E. Davies, L. M. Field, P. N. R. Usherwood, M. S. Williamson (2008) IUBMB Life, **59**, 3 , pp. 151 – 162.

amount of food in the UK[103]. The role played by different classes of pesticide is set out in Table 5-1.

Table 5-1 Pesticide benefits

Treatments	Benefits[104]
Seed treatments	Pre-sowing protection against disease and insects
Herbicides	Protect yield & quality against weed competition
Fungicides	Minimise yield loss and keep crops free of harmful fungi and their toxins
Insecticides	Prepare crops for insect attack and insect-borne disease infestation
Desiccants	Prepare crops for harvest to avoid yield loss
Plant growth regulators	Optimise productive yield, improve harvest efficiency and keep crops standing

On the basis of the above analysis, the literature review and stakeholder consultations, the farming (agriculture) industry is deemed to be ***highly dependent upon chemistry research***, and assigned a chemistry dependent weight of 93%.

5.7.2. Case study - Azoxystrobin

(i) Background

Azoxystrobin is a fungicide that provides broad-spectrum disease control and significant yield and quality improvements on a wide range of crops including potatoes, cotton, fruit, leafy vegetables, soybeans and wheat. The development of commercial products based on azoxystrobin provides a clear example of:

- how naturally occurring compounds can provide the inspiration for a new product;
- the transfer of knowledge from the academic literature to chemists working in a commercial environment; and,
- the process of chemical exploration that is required to synthesise a commercially viable product that meets strict health & environmental conditions.

UK based and trained chemists at Syngenta (formerly Zeneca and ICI) were alerted via a seminal academic paper published in 1981 to the properties of four related naturally occurring compounds that had been identified by Czech and German university-based scientists. For example, one of these

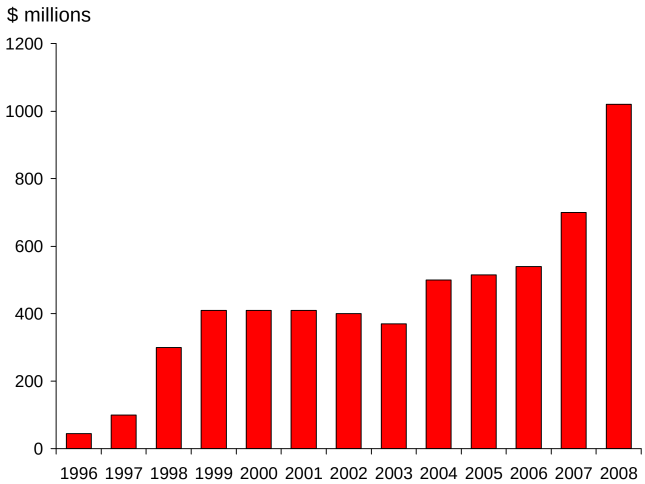
[103] Williams, AG, Audsley, E and Sandars, DL (2006) Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Main Report. Defra Research project IS0205. Bedford: Cranfield University and Defra
[104] Source: Crop Protection Association

compounds derives from a fungus found on beech trees. Where it was present no other fungi were found.

Research at Syngenta showed that the naturally occurring compounds needed modification to create a commercially viable product. In particular, the natural compounds broke down rapidly in sunlight. One of the first products from the synthesis, development, and regulatory process (azoxystrobin) was launched in 1996[105]. Azoxystrobin is now the world's biggest selling crop fungicide.

Azoxystrobin is widely used in farming, particularly in wheat farming, which accounts[106] for about 50% of UK arable farming by area and 50% of pesticide use in the UK. Applying agents containing azoxystrobin provides protection against many types of fungal diseases, and independent studies show an increase in yields for wheat in Northern European conditions of up to 9%[107]. Globally azoxystrobin is now used to treat more than 120 types of crop in around 100 countries – the fastest ever development track in the agrochemicals industry[108], and in some cases it gives even higher impacts on yields than in the case of wheat. For example, the commercial formulation Priori Xtra® raises sugar beet yields by 20% and in Brazil it is used to control leaf rust in the production of 4 million tonnes of soya. If this rust were not controlled, around an additional 2 million hectares of land committed to soya production would be required to make up the shortfall in yield. This is equivalent to the entire wheat area grown in the UK[109].

Figure 5-8, Azoxystrobin, the world's largest selling fungicide (annual sales)



Source : Syngenta/Oxford Economics

[105] At the same time BASF was following a different development path based on the same natural compounds with both companies only becoming aware of each other's interest from patent applications published in 1986.
[106] Evaluation of the impact on UK agriculture of the proposal for a regulation of the European Parliament and of the council concerning the placing of plant protection products on the market, ADAS 2008
[107] Impact of strobilurins on physiology and yield formation of wheat, Beck, Oerke, Dehne, Institute for Plant Diseases, University of Bonn
[108] Source: Syngenta
[109] Source: Syngenta

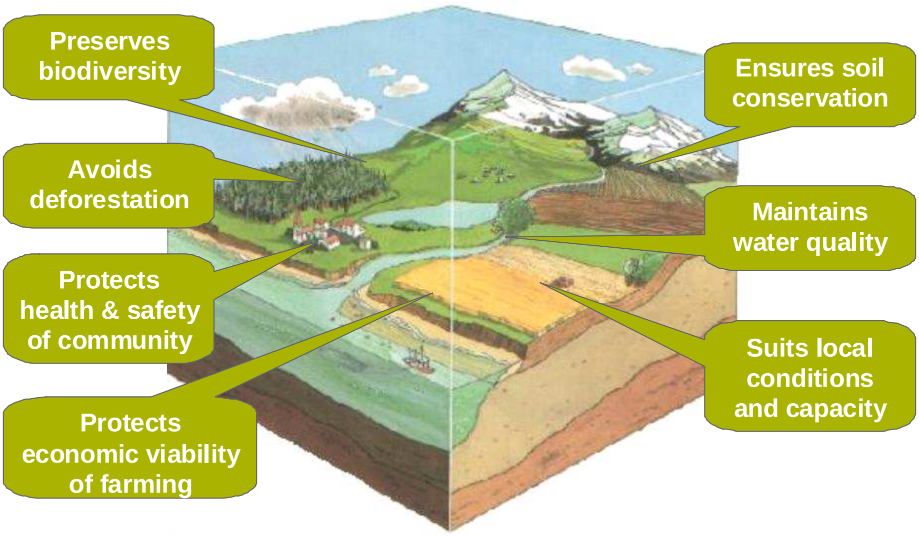
(ii) Economic impacts

The manufacture of the active ingredients for azoxystrobin, which is largely undertaken at Grangemouth, brings significant benefits to the UK economy. The product supports jobs and investment directly in the UK, through its supply chain and *via* the spending of employees involved in both its production and supply. For example, a £70m investment in the Grangemouth facility has recently been announced, as has the recruitment of an additional 50 staff, with the construction phase employing 200 workers.

However, the major economic impacts from azoxystrobin at a global and UK level come from its impact on crop yields. By increasing yields and enabling successful crop production across a wider range of land and climate combinations, products based on azoxystrobin are likely to have wide ranging impacts by[110]:

- lowering the global and UK prices of key agricultural products – including meat and dairy products which use cereals as feed;
- lowering the cost and increasing the availability of essential foodstuffs;
- reducing the amount of land that is required for crop production;
- increasing land available for other agricultural products, thus influencing their supply and price;
- increasing the supply of land for other non-agricultural uses, including recreation, housing and industry;
- reducing pressures to bring or keep wild land under cultivation, so increasing the diversity of habitats and related biodiversity;
- increasing UK "food security" and reducing the UK's food imports;
- increasing discretionary spending power for consumers, particularly for poorer households where food accounts for a bigger proportion of the overall shopping basket; and,
- improving nutrition standards in developing countries, so spurring growth and investment in education, which in turn boost world trade growth.

[110] Source: Syngenta



Source: Syngenta

(iii) Indicators of effects

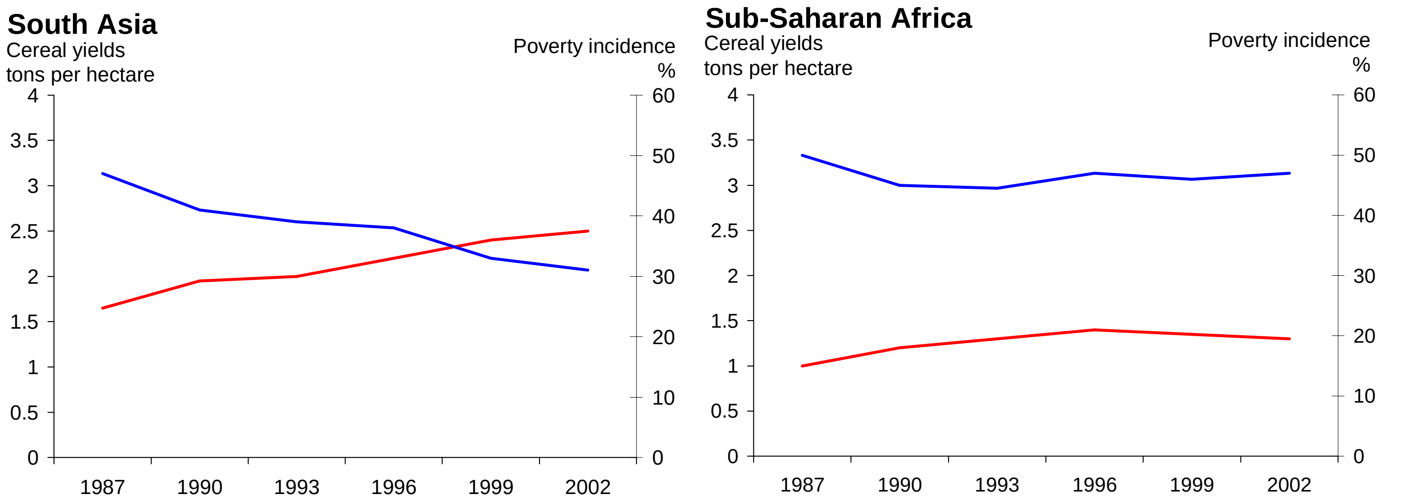
While a full economic impact analysis of azoxystrobin derived products is beyond the scope of this study, there are indicators available that help to put orders of magnitude on to the importance of crop protection products.

For example, studies[111] of the theoretical maximum yield for common crops, such as rice, wheat, maize, soyabean, cotton and potato, show that without current crop protection products between 22% (wheat) and 53% (cotton) of the maximum yield would be lost. Moreover, if the changes that the European Union is considering to the regulatory framework for pesticides and their use is implemented a substantial fall (25-53%)[112] in UK and EU crop yields is likely. While it is difficult to be precise about the impact that this would have on food prices, Cranfield University[113] suggest that the price of cereals, potatoes and vegetable brassicas would rise by up to 100%, if the most severe restrictions are imposed. This would increase the price of a loaf of bread by around 9p; a litre of milk by 3p; and a kilo of pork by 40p. This would put particular pressure on the budgets of low-income households and, among other things, work against initiatives to encourage healthy eating.

More generally there is evidence that higher crop yields are correlated with declines in the incidence of poverty in developing countries. Better nutrition boosts both the demand for and the ability to benefit from education, which help to deliver better lifetime opportunities to the population of low income countries and feeds back to increased demand for UK exports.

[111] Crop losses to pests, Oerke, Journal of Agricultural Science (2006)
[112] Evaluation of the impact on UK agriculture of the proposal for a regulation of the European Parliament and of the Council concerning the placing of plant protection products on the market, ADAS 2008
[113] What price protection? An economic assessment of the impact of proposed restrictions on crop protections substances, Rickard, Cranfield University School of Management

Figure 5-9: Crop yields and poverty



Source : Oxford Economics

Source : Oxford Economics

In a crowded country like the UK, increasing or maintaining the supply of wilderness and woodland through effective pesticide use, which minimises the amount of land dedicated to cultivation, also has substantial value, though pinning these values down is both complex and controversial. A recent study for DEFRA[114] identified contributions to total economic value from direct use – such as walking; indirect use including preservation of ecosystems; non-use values from the continued existence of landscape which include altruistic values related to a desire for others to be able to enjoy the resource and bequest values of leaving something for future generations to enjoy. A separate study in 2008 placed a value of at least £300m on the biodiversity benefits of a wide range of farmland birds[115].

[114] Scoping study on agricultural landscape valuation, DEFRA, 2007
[115] Environmental Accounts for Agriculture, DEFRA, 2008

5.8. Food and drink

This section presents a case study from the food industry to illustrate the role of UK chemistry research in facilitating success downstream of the chemical industry.

Dependence on chemistry research: highly dependent (95%)

- *Chemistry research directly enables the food and drinks industry to contribute **£20.8 billion** to the UK economy and directly supports **399,000 jobs** in the UK food and drink industry.*
- *Chemical science and chemical engineering are playing a critical role in the transformation needed to deliver a sustainable response to obesity in the UK – recent estimates put the costs of obesity on the NHS in England at £4.2 billion.*

Case study - Supporting the development of low fat foods

- *"Critical to the advances in food research will be effective interdisciplinary collaboration between academia, industry and government"[116]. The results of on-going research between the Chemical Engineering Department at the University of Birmingham and Unilever are explored in the attached case study.*
- *"Solutions to the problems in food production and sustainability will only be achieved by highly trained people working and leading in the food industry with the appropriate technical background[117]". One such example is the work of Professor Ian Norton, whose ground breaking research into the physical chemistry of polysaccharide transition (part funded by the EPSRC), led to the development of many new innovative products with a lower fat content while maintaining taste and texture performance.*

5.8.1. Chemistry research and the food and drink manufacturing sector

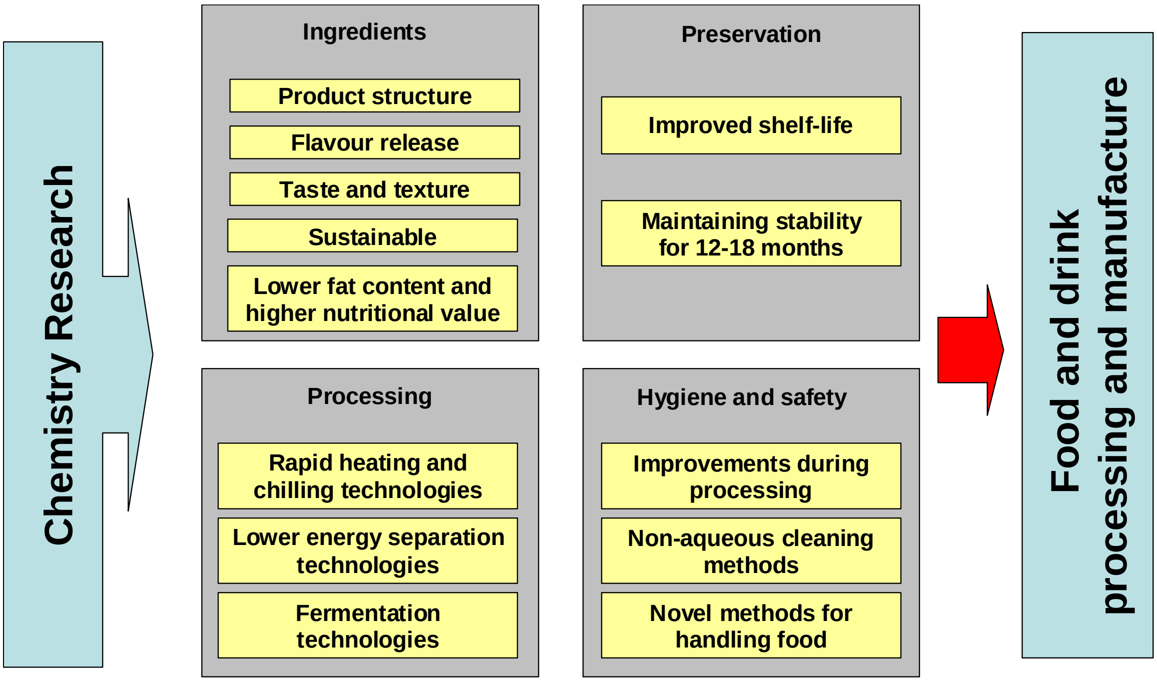
The UK's food and drink sector, encompassing the manufacturing and production of food, beverages and tobacco[118], generates almost £22 billion in GDP annually, accounting for 1.9% of the UK economy. The food and health industry supports 420,000 jobs, equivalent to 1.8% of total UK employment[119]. It should be noted that the sector does not include the wholesale or retail of food and drink produce, which in themselves are industries that contribute significantly to UK GDP and jobs.

The impact of chemistry research on the food and drink sector manifests itself in several ways; firstly, through the industry's purchases of inputs from the 'upstream' chemistry reliant chemicals industry (e.g. organic and inorganic chemicals); secondly, the sector buys inputs from other 'downstream' industries that are dependent on chemistry research to varying degrees (e.g. paper, plastic and metal

[116] The Vital Ingredient: Chemical science and engineering for sustainable food, RSC/IChemE, page 73
[117] The Vital Ingredient: Chemical science and engineering for sustainable food, RSC/IChemE, page 8
[118] Tobacco is included alongside food and drink under the SIC system. Tobacco product manufacture represents approximately 5 % of the food and drink sector in the UK.
[119] Annual Business Inquiry (ABI) – Release date 16/06/2009. See www.statistics.gov.uk/abi/subsection_dg.asp, scaled to Blue Book 2009 constant 2005 prices.

products); and thirdly, the industry itself conducts chemistry research for a variety of reasons which are illustrated in figure 5.10.

Figure 5-10: The role chemistry research in the food and drink industry



The manufacture and processing of food and drink involves many different sub-disciplines of chemistry. Hygiene and food safety is being improved using the knowledge and skills of highly trained people in the fields of analytical chemistry, surface chemistry and chemical engineering. In addition, novel enzyme chemistry and technology is being applied to enhance the flavour release, taste and texture of different products. And having achieved the highest quality flavour and texture, chemistry research is essential in maintaining this through novel packaging solutions (e.g. modified atmosphere).

For example, a recent study by The Food Standards Agency[120] reported that recent developments in analytical chemistry have made it possible to detect smaller and smaller quantities of chemicals in food. Some of these may be potent toxins at high doses but may actually pose little risk for human health at the levels found in food. By using analytical chemistry to assess the toxicological risk of a contaminant at the levels present in food, it is possible to define a tolerable daily intake. Such research is particularly important for chemicals such as iodine that are vital for good thyroid function, which in turn is essential for health, but is toxic if we take too much of it[121].

Alternatively, there are many examples, where even very small quantities of a contaminant can have disastrous effects on human health e.g. the presence of mycotoxins in grain and nut products.

[120] Annual Report of the Chief Scientist 2008/09. Food Standards Agency.
[121] *Ibid* (page 19)

Mycotoxins are toxic chemicals that are produced by fungal infections of crops; they can be formed in a range of foodstuffs either in the field or in grain during storage. Mycotoxins are widely regarded as amongst the most serious of naturally occurring toxins that can contaminate our food supply. Meeting stringent legislation on permissible limits is crucial. With the potential to contaminate both primary and processed foodstuffs, chemistry research has been vital in providing approaches for risk assessment, detection, prevention and control, at all stages of the food chain. Chemistry research for the detection of mycotoxins was originally based around chromatographic methods. These however are generally time consuming and capital intensive, and hence a range of methods, mostly based on immunological principles, have been developed and commercialised for rapid analysis. These methods include, among others, enzyme-linked immunosorbent analysis (ELISA), direct fluorimetry, fluorescence polarization, and various biosensors and strip methods[122]. Innovative research at the University of Strathclyde using monoclonal antibodies led to the creation of Rhône Diagnostics Ltd, a successful company which has developed, manufactured and sold diagnostic test kits for use in food, feed and environmental control. Rhône Diagnostics Ltd was taken over by the German company R-Biopharm in 2002 but has maintained the technical and laboratory support service for diagnostic feed analysis in Glasgow. R-Biopharm is now the biggest supplier of test kits for food and feed analysis in Europe, selling test products in over 50 countries world-wide[123].

Closer to the consumer, on-going chemistry research involves the development of additives for insertion into foods and drinks. Additives can be used to enable food combinations to mix together, when naturally such an amalgamation would be impossible, or distinctly unappetising; an example of this is the gelling agent pectin, which is used in the manufacture of jams[124]. Furthermore additives can be used to increase the life of products, enabling food to be kept safely for longer, with the type of additive used dependent upon the food involved; meats are often preserved with nitrite and nitrate, and dried fruit with sulphur dioxide, all of which act to kill bacteria[125].

Chemistry research made possible the synthesis of nature identical flavourings resulting in cost-effective manufactured products having superior taste and smell. However, some consumers have begun to reject these synthetic flavours in favour of their natural counterparts. And this not only applies to flavours. As Gould (2000) notes, the desires of consumers, with regards to food products, have changed in recent years towards products that are of a higher quality, increased freshness, more natural, contain fewer additives and are nutritionally healthier[126].

Although synthetic flavours were traditionally much more cost effective than their natural counterparts, the sustainability and environmental cost of petrochemical derived flavours, along with changing consumer requirements has forced manufacturers to look for alternatives. Advances in distillation technology have allowed for less thermally damaging extractions of food and plants to produce more authentic natural flavours, to satisfy consumer demand in this direction. That said, the cost of natural flavours (such as vanilla) remains very high due to the large quantities of raw material and the

[122] Shephard G. Determination of mycotoxins in human foods Chem Soc Rev. 2008 37(11):2468-77
[123] http://www.r-biopharm.com/main.php?
[124] Food Standards Agency, http://www.food.gov.uk/safereating/chemsafe/additivesbranch/emulsifiers
[125] Food Standards Agency, http://www.food.gov.uk/safereating/chemsafe/additivesbranch/preservatives
[126] Gould G. (2000) “Preservation: past, present and future”, *British Medical Bulletin,* 56(1): 84-96

labour/time intensive processing required.

Chemistry research has enabled the intermediate-cost biotechnological production of natural flavours, offering manufacturers more scope with product development. Biotech routes for flavour synthesis are based on microbial fermentation processes or on bioconversions of natural precursors using tailored microbial cells or enzymes. In particular, microbial biocatalysis can be used for the production of many flavouring and fragrance aromatic compounds such as vanillin, the key component of vanilla flavour. Thus, while a reduced demand for goods including additives might suggest that the role of chemistry research in the food and drink sector would decline, this is not the case: such research is still being required to uncover natural alternatives to 'synthetic' additives.

Indeed, looking ahead, the Royal Society of Chemistry's (RSC) and the Institution of Chemical Engineers'' report *Food: The Vital Ingredient*[127] highlights the pivotal role that chemical science and chemical engineering will play in the future, in the transformations needed to achieve a sustainable food supply.

'Solutions to the problems of food production and sustainability are not simple, they will only be found by highly trained people working and leading in the food industry with the appropriate technical background. Only by understanding these problems in scientific and technological terms will the solutions be obvious to those with the power to initiate the required changes across the food chain'.

'Critical to advances in food research will be effective interdisciplinary collaboration between academia, industry and government to coordinate long-term strategic research.'

'Food innovation and particularly food safety is crucially dependent on the role and work of scientists and technologists in the food industries, in academia and research, in government departments and agencies, in food law enforcement, in local authorities, and in consultancies.'

Food: The Vital Ingredient: Chemical science and engineering for sustainable food (pp 8, 73 and 75)

It is clear that chemistry research has a vitally important role to play in the food and drink industry, and the industry is deemed to be ***highly dependent upon chemistry research.*** However, due to the production of organic food, which aims to produce food with a minimal chemical intervention, the food and drink industry is not wholly dependent upon chemistry research as reflected in the 95 % weighting.

5.8.2. Case Study – Supporting the development of low fat foods

For many years, the 'diet and health' spotlight has been on fats, with special emphasis on the message that not all fats are equal in terms of how they affect health'[128]. Chemistry research conducted across both industry and academia is playing a critical role in terms of making changes to

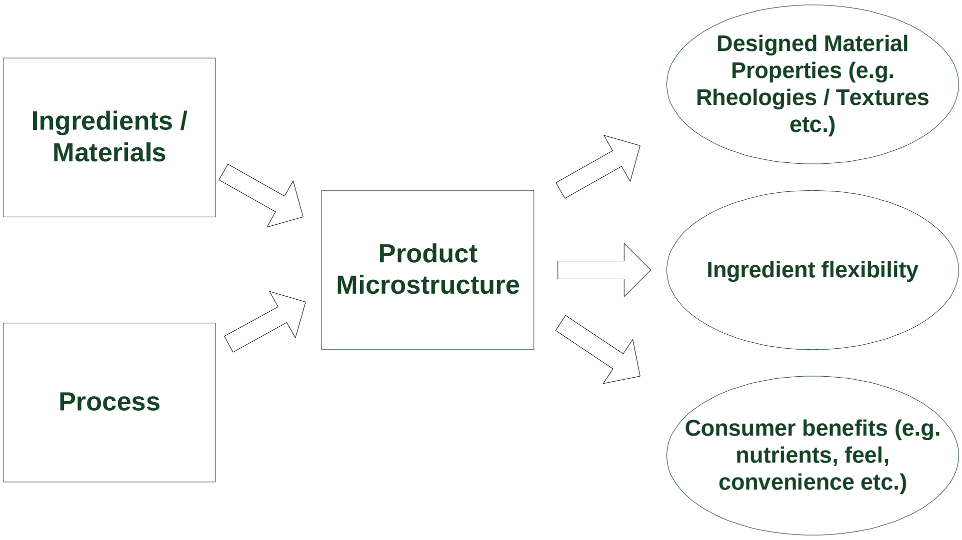
[127] http://www.rsc.org/images/foodreport_tcm18-142397.pdf
[128] Health, Diet and Cardiovascular Disease, Report of the Panel on Diet in relation to Cardiovascular Disease, Committee on Medical Aspects for Food Policy, London (1984)

the food supply to reduce the incidence of obesity[129]. Such research is a necessary condition to help deliver a sustainable response to obesity in the UK, which according to a study by the Department of Health[130] cost the NHS in England £4.2 billion in 2007 and could rise to £6.3 billion by 2015.

The on-going work of Professor Ian Norton, Professor of Soft Solid Microstructural Engineering, in the Department of Chemical Engineering at the University of Birmingham, and previously Chief Scientist at Unilever, provides a useful illustration of the beneficial impact of chemistry research on the food supply chain.

Professor Norton's doctorate was in the physical chemistry of polysaccharide conformational transition where he focused on fast reaction kinetics and thermodynamics. Having moved into industry, he focused in the area of colloids and interfaces and developed a microstructure approach. This approach is where the material properties are designed by choosing the ingredients and the way they physically interact and then designing the process to physically structure and trap the microstructure in the desired state, see figure 5-11.

Figure 5-11: Microstructure Approach



Professor Norton's research was part funded by the EPSRC on the basis of a CASE award between the University of York and Unilever and the results provided a clearer understanding of the material properties of polysaccharides. Professor Norton's PhD was followed by at least three others in this area all of whom received support by EPSRC grants and had fundamental input into the area of designing the microstructure of a product[131]. The approach can be used in many different areas including designing foods and home and personal care goods, as it informs some of the key issues when developing new products including:

[129] The Health Survey for England (HSE) data shows that in 2007, 60.8% of adults (aged 16 or over) in England were overweight or obese, out of these 24% were obese.
[130] Healthy Weight, Healthy lives: A Cross-Government strategy for England, published 2008. http://www.dh.gov.uk/en/Publichealth/Healthimprovement/Obesity/index.htm
[131] In addition, an EU project was funded in the area of material properties of polysaccharides and fundamental research was carried out in the UK, Sweden, Spain, and Italy.

- Emulsion design – how products spread (e.g. butter spreads, skin creams and lipsticks)
- Shelf-life – some foods must be stable for 12-18 months and then breakdown in seconds when put into the mouth to give taste

The same microstructure approach discussed above can also be applied to salt reduction in foods; it is possible to remove 80% of the salt content of a food product yet not impact on taste, texture or performance. Salt reduction in food has significant benefits for consumers in terms of their health; every day 26 million adults in the UK eat too much salt[132]. Cutting down on salt reduces blood pressure, reducing the risk of developing heart disease and stroke.

While at Unilever, Professor Norton was an inventor on more than 60 granted patents leading to many new and innovative products (e.g. Flora Light, Chicken Tonight) which are still sold today across the globe (e.g. 5 years after launch 'Latta' (Flora Light) had taken over from butter as the number one spread in Scandinavia, with a similar take-up in Germany and in the United States, where it is marketed as Promise Light). As with many other examples of using chemistry to improve or develop new products, it took at least 10 years to get the final refined product to market, but the returns for Unilever from the initial investment of just 20 people have been huge.

Now at Birmingham University, Professor Norton is leading on-going fundamental research into the design of food processes and microstructures. The theme of the research is to provide underpinning support to the food industry and to drive research forward in the new areas that are demanded by consumers and policy makers e.g. convenient, safe and healthy foods that still fit into a normal diet or are even seen as indulgent but healthy, and the design of food processes with zero waste, and thus lower environmental impact.

Alongside significant industrial funding, the EPSRC provides funding support for the work of the group at Birmingham, which is now the largest of its type in any UK academic engineering department (currently consisting of 4 members of staff, 4 post doctoral research fellows and 30 PhD and Engineering Doctoral students). ***The fundamental research that is supported by industry would not be possible without core funding from EPSRC and BBSRC.***

Recent examples of departmental work include:

- research in to a wider range of soft solids. Soft solids are used extensively in: foods, personal care products, cosmetics, paints, pharmaceuticals, home care / hard surface cleaning and laundry.
- research to indentify how food products can release their calorie content over longer periods of time, potentially resulting in a reduction in calorie intake by the consumer, by reducing the sensation of hunger over a longer period.

[132] Food Standards Agency, UK Source: http://www.eatwell.gov.uk/healthydiet/fss/salt/

5.9. Forestry and paper industry

This section presents a case study from the forestry and paper industry to illustrate the role of UK chemistry research in facilitating success downstream of the chemical industry.

Dependence on chemistry research: moderately dependent (53%)

- *Chemistry research directly enables the forestry and paper industry to contribute **£2.4 billion** to the UK economy and directly supports **40,000 jobs** in the UK forestry and paper industry.*
- *Chemistry plays an important part in the manufacture of paper, which relies on either mechanical or chemical pulping. Chemical pulping involves one of four processes – kraft, sulfite, semichemical, or soda – which dissolve lignin bindings within cellulose.*
- *Chemistry is also used in developing pigments utilised in every sheet of paper.*

5.9.1. Chemistry research and the forestry and paper industries

Forestry and paper production in the UK contributes £4.5 billion in value added to the UK economy, equivalent to 0.4% of total GDP. Of this value added, 88% is generated by the paper manufacturing industry. Total employment in the two industries before adjusting for their dependency on chemistry research is 78,000, with 12,000 employed in the forestry sector[133].

The chemical sector provides the forestry and paper industries with 15.9% of the total inputs required to generate the £12.9 billion output produced, amounting to £656 million[134]. Of this total £535 million of inputs are in the form of either organic and inorganic chemicals (£212 million), man-made fibres (£204 million), or paints and varnishes (£119 million). The forestry and paper industry also consumes the product of chemistry research indirectly, through industries which themselves utilise chemistry products. The principle form of this indirect chemistry consumption comes in the shape of inputs of plastic products, printing and publishing, and textiles, which together account for 7.9%, or £325 million, of the total inputs used by the industry. As this only considers the top three indirect chemical inputs the figure can be seen as an underestimate of indirect chemistry inputs into the industry (figure 5-12).

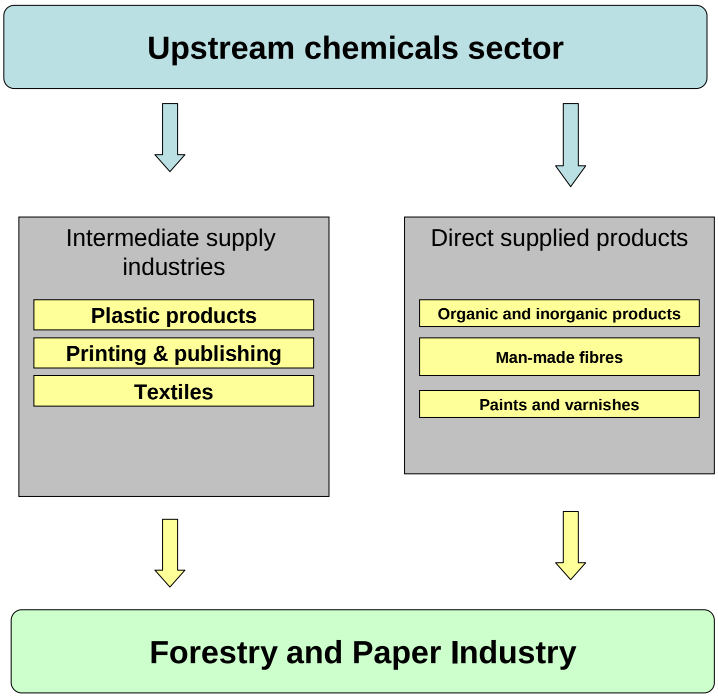
Stakeholders have deemed the forestry and paper industry to be ***moderately dependent*** (53%) upon the products of chemistry research to generate added value. The rationale for this is two-fold: the forestry industry does not consume chemical products to a high level (as opposed to wood product manufacturing, which is a separate industry), and the presence of alternative methods of paper production result in the possibility of non-chemical paper manufacture.

To produce paper it is necessary to create wood pulp, a dry fibrous material mainly composed of cellulose. Pulp is prepared by chemically or mechanically separating the cellulose fibres from wood.

[133] Annual Business Inquiry (ABI) – Release date 16/06/2009. See www.statistics.gov.uk/abi/subsection_dg.asp, scaled to Blue Book 2009 constant 2005 prices.
[134] ONS input-output tables 2007, www.statistics.gov.uk/about/methodology_by_theme/inputoutput/latestdata.asp

While mechanical pulping, physically grinds whole logs into fibres for pulp (without the use of chemicals), chemical pulping utilises one of four processes – Kraft, sulfite, semichemical, and soda – to extract cellulose from the wood by dissolving the cellulose's lignin bindings. Most chemical woodpulp is made by the Kraft process, where chips from de-barked logs are dissolved in caustic soda and sulphur by heat and pressure. The resulting strong brown pulp is then cleansed, bleached and dried, before being pressed into the final product[135,136]. The other chemical methods are based on similar processes, and involve variations in the chemicals used for the removal of the lignin and recovery of the pulp.

Figure 5-12: The chemistry-using 'forestry and paper' industries



5.9.2. Case studies – Carbonless copy paper, stabilisation of pigment dispersion and dula polymer retention

UK chemistry research has had an impact, both domestically and globally, on the paper and pulp industry. Currently there are 52 mills in the UK producing an estimated 5 million tones of paper and board[137], part of the 500 million tones of paper produced around the world each year. The three very different case studies below demonstrate the great variety of ways in which UK chemistry research has found application in the paper making industry.

135 http://www.epa.gov/ttn/chief/ap42/ch10/final/c10s02.pdf
136 EPA (1983), *Review of New Source Performance Standards for Kraft Pulp Mills*, EPA-450/3-83-017
137 Source: Confederation of paper industries. http://www.paper.org.uk/information/pages/statistics.html

(i) Carbonless copy paper

Traditionally a sheet of carbon was required to transfer an image on one page onto another sheet of paper (as in receipt books). Research by Wiggins Teape in 1970s (then entirely UK based, now ArjoWiggins) led to the development of a copying process which did not rely on the presence of a carbon sheet. The new technique, which relied on micro-ink particles that burst on impact, was developed in collaboration with university based surface chemistry groups (including at Bristol University). Their work using basic chemistry principles solved the difficult problem of distributing the ink particles evenly in the paper sheet.

(ii) Stabilisation of Pigment Dispersion

Paper contains significant quantities of pigment, such as calcium carbonate. Pigments are normally transported in stabilised dispersions, resulting in companies essentially transporting water, both domestically and internationally. Therefore there is a commercial need to transport these pigments in the highest concentration possible, to reduce the amount of excess water transported.

In-house chemists at English China Clays' (now part of the international group Imerys), worked in collaboration with surface chemistry groups from the University of Bristol to find a methodology for high solid dispersion. Their research, based on the fundamentals of emulsion and stabilisation, relied heavily on basic chemistry and resulted in a process that has been extremely successful commercially.

(iii) Dual polymer retention

Making paper is a fast filtration process, in which a fibrous suspension is deposited on a moving wire web. Along with the large fibres, the suspension also contains a significant amount of very fine particles. A key part of the process of making paper is to retain as many of these fine particles as possible within the web. To assist with this chemical retention agents are added to the suspension.

Originally, polyelectrolytes were used. These are used widely in paper making in order to assist the retention of flocculation and aggregation of colloidal material, and also as additives for promoting wet and dry strength. Much of the early research it this area was developed by Allied Colloids in the UK during the 1960s and 1970s. The process is constantly being refined, with Allied Colloids (now part of the Ciba group) involved with developing the dual polyelectrolytes, dual polymer retention system, that was very successful commercially.

5.10. Health industry

This section presents a case study from the health industry to illustrate the role of UK chemistry research in facilitating success downstream of the chemical industry.

Dependence on chemistry research: Highly dependent (90%)

- *Chemistry research directly enables the health industry to contribute **£76 billion** to the UK economy and supports **2.93 million** jobs.*
- *Chemistry research is crucial for the health industry enabling significant improvements in treatment outcomes through the development of life enhancing pharmaceuticals, diagnostic devices and advanced materials.*
- *The process of bringing an innovative new medicine to market is expensive and time-consuming, with costs estimated to be over $1.2 billion. The medical impact appears in the downstream health sector some 5 – 20 years after discovery.*

Case study – Amlodipine

- *Led by Dr Simon Campbell at Pfizer, UK chemists discovered amlodipine, a drug that became an extremely successful treatment for hypertension and angina, with peak-year global sales of over $5 billion, and 2.2 million users in the UK.*
- *In comparison with some alternative treatments, amlodipine reduces the number of hospital visits and therefore costs to both patients and the health care system.*

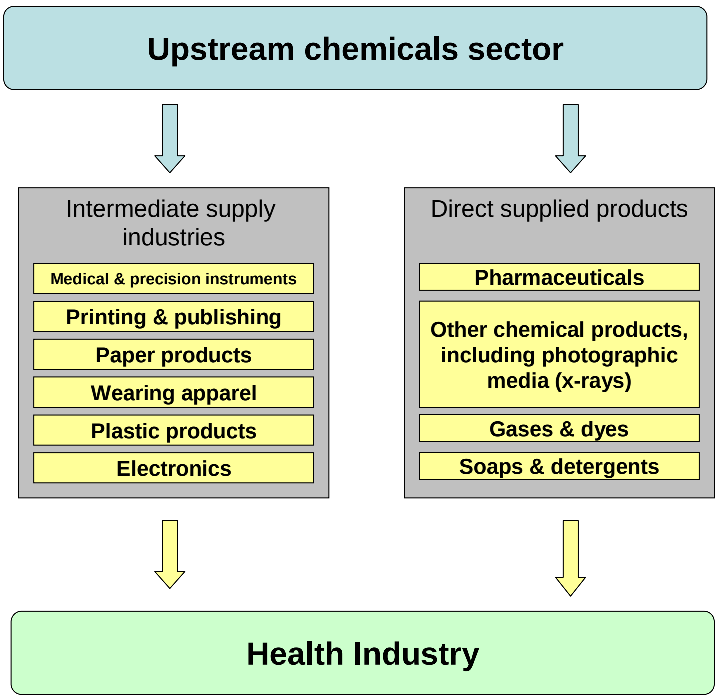
5.10.1. Chemistry research and the health industry

The health industry, including the National Health Service, is a central component of the UK economy, with a GVA of £84.4 billion contributing 7.1% of UK GDP. The health sector directly supports around 3 million jobs, which is equivalent to one in every seven jobs in the UK[138].

[138] Annual Business Inquiry (ABI) – Release date 16/06/2009. See www.statistics.gov.uk/abi/subsection_dg.asp, scaled to Blue Book 2009 constant 2005 prices

The UK health industry is ***highly dependent*** on the innovative chemistry research that is carried out across the spectrum in 'Not-for-Profit' organisations, charities, HEIs and the private sector. Outcomes of chemistry research – including pharmaceuticals, man-made fibres, gases, dyes and soap – form 24.5% of the direct inputs into the health industry and cost around £13.1 billion (Figure 5-13); pharmaceuticals alone account for £12 billion of health industry inputs (approximately 22.6% of total inputs)[139]. In addition to these direct inputs, the health industry also consumes a substantial level of inputs reliant on chemistry research, for example medical and precision instruments, which account for 10% of total inputs, and consume a high level of plastics in their production process. The health industry was deemed to be highly dependent (90%) upon chemistry research, with only 10% engaged in activities which are either only partially, or not at all, dependent on chemistry research. Examples here include social work and some forms of treatment such as speech therapy or occupational therapy.

Figure 5-13: The chemistry-using 'health' industries



Chemistry research and health benefits have gone hand in hand for many years; a manifest example is in the history of anaesthesia. Ether and chloroform were among the earliest examples of chemicals used in anaesthesia. Although these chemicals are no longer used due to the development of safer and more efficacious anaesthetics, the pioneering use of chloroform in obstetrics by Professor James Simpson in the 1840's, revolutionised surgical procedures at that time. Since then chemistry research has provided products such as halothane and propofol, both of which were commercialised in the UK. These two drugs in particular have enjoyed great successes globally and have made significant

[139] ONS input-output tables 2007, www.statistics.gov.uk/about/methodology_by_theme/inputoutput/latestdata.asp

contributions to both the upstream and downstream sectors. In terms of the upstream success, halothane is an inhalational general anaesthetic and is on the World Health Organisation's model list of essential medicines[140]. This core list presents a list of minimum medicine needs for a basic health care system, listing the most efficacious, safe and cost-effective medicines for priority conditions. Diprivan, the name by which AstraZeneca markets Propofol, is the world's best selling intravenous anaesthetic. From the perspective of the downstream sector, although general anaesthesia carries a certain amount of risk itself, the development of this class of drugs has undoubtedly enabled surgical intervention through minimising the pain and distress that a patient might otherwise suffer.

Many of the diagnostics within the medical industry are built upon components of chemistry research. These range from the devices such as MRI scanners and X-ray machines to diagnostic chemicals/probes such as monoclonal antibodies and radiotracers. Without the chemistry research, often at the fundamental level, doctors, nurses and hospitals would not have the technologies they need to assess or treat those that suffer from some of the world's most pervasive and chronic conditions.

Chemistry does not just result in the development of drugs or diagnostics either; significant gains have been made by the materials chemistry research communities in the development of novel biomaterials for numerous health-related applications (e.g. prosthetics, scaffolds for regenerative medicine). These tissue engineering and regenerative medicine approaches to modern healthcare require the use of chemicals and/or chemically-derived materials, e.g. porous bio-degradable scaffolds which are seeded with cells that grow within the scaffold to mimic naturally-occurring tissues. These materials can then be implanted into the patient and, within time, scaffolds will degrade, be reabsorbed and replaced by host tissues. These types of tissue engineered materials are currently used to engineer cartilage, skin and bone for implantation. In 2009, BBSRC awarded almost £4 million to scientists from the Universities of Keele, Southampton, Nottingham and Imperial College London to look at the development and repair of human skeletal tissue. Fractures, bone loss due to trauma or disease and other orthopaedic conditions pose a significant clinical and socioeconomic problem, especially with an ageing population, and treatment of these costs the NHS billions of pounds each year. This research program encompasses expertise in skeletal stem cells, scaffolds and novel biomaterials to identify the key growth factors, matrix proteins and physical conditions that will enhance tissue regeneration and ultimately lead to more effective skeletal repair strategies. The cost of bone health issues to the NHS is high and is rising, for example, the most common serious injury from a fall is hip fracture, which affects approximately 60,000 people per year in the UK, and costs the National Health Service (NHS) approximately £1.7 billion and results in up to 14,000 deaths[141]. These injuries are increasing and will continue to do so as we face an ageing population (the percentage of the population over 65 years will rise by 50% within the next 25 years and that over

[140] WHO Model Lists of Essential Medicines, 16th Edition March 2009. http://www.who.int/medicines/publications/essentialmedicines/en/index.html

[141] Older people's experiences of falls and bone health services report. 1st September 2008, Royal College of Physicians http://www.rcplondon.ac.uk/clinical-standards/ceeu/Current-work/Documents/Falls-PPI-report-Final-Version-08-09-01.pdf

80 years by around 80%[142].

Although not quantified, these examples clearly translate to substantially increased health and well-being in the population. While it is relatively easy to determine the upstream impacts of medical related chemical research, through pharmaceutical sales for example, without the continued funding of chemical research to underpin the outputs of the upstream chemical sectors, the economic costs associated with morbidity and mortality (e.g. hospitalisation, extended treatment costs and loss of employment revenue) would be significantly higher impacting both the downstream health sector and the UK economy as a whole.

In 2007/08 UK Universities reported income from research grants and contracts in Clinical Medicine and Pharmacy/Pharmacology amounting to over £1.2bn[143]. These funds were spent on world-class medical research to improve human health and enhance the economic competitiveness of the UK, including chemistry-based research. EPSRC itself has invested approximately £172 million in research and training in pharmaceutical chemistry over the last 5 years; this has attracted over £40 million in additional contributions[144], most of which comes from the pharmaceuticals industry (EPSRC). The improvements in healthcare as a result of this research, alongside that the internal research reinvestments that pharmaceutical companies make, have a considerable economic impact, when measured in terms of the additional quality of life gained by patients (Quality-Adjusted Life Years, QALYs), and the additional economic activity generated, directly and indirectly, by research.

In November 2008, the Wellcome Trust, along with the Medical Research Council and the Academy of Medical Sciences, published a report which estimated the economic benefits resulting from medical research in the UK. This study also comprised expenditure data from research conducted in cardiovascular disease and mental health in the UK between 1975 and 1992. The study estimated that investment of over £900m in cardiovascular research resulted in 138,000 QALYs being gained annually between 1986 and 2005[145]. Taking into account the additional health service costs associated with the QALYs gained, the study found a total economic benefit of 39% in perpetuity; a £1 investment in research led to a benefit stream of £0.39 per year thereafter. The findings for mental health research similarly demonstrated a total economic benefit stream of 37%.

The report specifically looked at the expenditure in previous years (1975-1992) to take into account the lag between basic research and any form of medical impact, which ranges from 5 to 20 years. This is a consequence of the necessary clinical trials and of the complex process of scaling production to a commercial level, and can cost over US$1.2 billion[146]. While these delays are significant, efforts are in place to shorten the period between discovery and the final product through the use of site-specific radio-labelling, which allows a candidate drug to be traced through the body to determine whether it will reach its intended target.

[142] http://www.bgsnet.org.uk/pdf/Sept2009.pdf British Geriatric Society Newsletter September 2009.
[143] HESA finance return 2007/08
[144] Based on research grant data collected by EPSRC
[145] Wellcome Trust 'Medical Research: What's it worth?' report http://www.wellcome.ac.uk/About-us/Publications/Reports/Biomedical-science/WTX052113.htm
[146] CMAJ. 2009 February 3; 180(3): 279–280. Drug development cost estimates hard to swallow.

5.10.2. Case study – Amlodipine

(i) Background

There can be no doubt of the importance of chemistry research to the health industry today. The discovery of the drug Amlodipine provides a useful insight into the way in which ground breaking chemistry research can generate benefits down stream, for both patients and the entire healthcare sector. The UK is a world leader in innovative medical research, with an emphasis on cutting-edge techniques to achieve ambitious goals.

Amlodipine was discovered by a team of chemists led by Dr Simon Campbell at Pfizer. The scientists involved in this discovery had previously trained at the Universities of Birmingham, Oxford and Manchester and were funded by the SRC (predecessor of the EPSRC). Amlodipine is used in the treatment of hypertension and angina pectoris. Amlodipine is a long-acting calcium channel blocker which decreases peripheral resistance by relaxing the smooth muscle of the arterial wall, and hence reduces elevated blood pressure. In the treatment of angina, amlodipine increases the flow of blood to the myocardium. In addition it offers the convenience of once-daily dosing with minimal side effects.

(ii) Economic Impact

Since its release, amlodipine has been commercially very successful. It is marketed by Pfizer in the UK as Istin and is available in 88 countries. Within the UK, it is estimated that there are 2.2 million patients using amlodipine, of whom approximately 53,000 use Istin[147]. The global peak year sales have reached over US$ 5 billion, clearly contributing significantly to the upstream pharmaceutical sector. As an example of downstream impact, a study performed by Menzin *et al.*[148] shows a cost analysis assessment of amlodipine versus enalapril. Like amlodipine, enalapril is used for treating hypertension; however it differs from amlodipine by being an angiotensin converting enzyme (ACE) inhibitor.

Through the use of stringent scientific procedures, the treatment effectiveness of amlodipine was compared with a placebo and enalapril for patients with coronary heart disease (also known as coronary artery disease) and normal blood pressure. Over a period of two years, the health of 2,000 US patients was observed, with hospital stays recorded by treatment and length. Industry standard financial data were applied to calculate the total cost of treatment from the associated costs of hospitalisation and the drug used.

The study found that the mean number of days in hospital per patient over the period was 1.1 for those using amlodipine, 1.3 for enalapril users, and 1.5 for those taking the placebo, with a statistically significant difference between amlodipine and placebo. The mean healthcare costs per patient over the two years were US$8,152 for amlodipine US$8,869 for enalapril and US$8,761 for

[147] Pfizer data.
[148] Menzin, J., Boulanger, L., Tang, S., Thakker, K., and Nissen, S. (2008), "Cost analysis of amlodipine versus enalapril in patients with coronary artery disease and normal blood pressure", *Applied Health Economics and Health Policy*, 6(2-3): 157-162.

those patients receiving the placebo. Separate studies in the US[149] and Europe[150] reports similar findings with per patient cost savings of $2,566[151] and 18.5%[152] against a placebo treatment. These results show that amlodipine usage not only reduces healthcare costs when compared to placebo, but also when compared to some alternative drug treatments.

A further study by Cathomas *et al.* corroborates these findings by concluding that amlodipine is a cost effective treatment for coronary atherosclerosis. Cathomas *et al.* found that amlodipine users benefited from an additional life expectancy of 0.083 years each compared to patients taking a placebo. Consequently the authors calculated that the cost-effectiveness of amlodipine treatment was approximately 14,650 Swiss Francs per life-year gained[153].

Coronary heart disease (CHD) is by itself the most common cause of death in the UK, with one in every five men and one in every seven women dying from the disease[154]. CHD is also the most common cause of premature death and although death rates from CHD have been falling in the UK since the late 1970s, the number of operations carried out to treat CHD has increased. Overall, there were around 428,000 inpatient cases treated for CHD in NHS hospitals in 2006/2007 in England and a further 49,000 in Scotland. CHD cost the healthcare system in the UK around £3.2 billion in 2006, where approximately 73% of this is the cost of hospital care with a further 19% spent on medications. This case study presents a single drug, the use of which can shorten the time that a patient requires hospitalisation and may offer more costs effective treatment when compared with placebos and other drugs. Although outside of the scope of this study, it is clear that there are many other chemical interventions for other indications which can offer significant reductions in hospitalisation time, reduce morbidity and mortality rates. Not only do the outputs of the health related chemistry research contribute to the UK economy through GDP gains (upstream), but the development of drugs such as amlodipine also generates healthcare cost savings. In doing so, the benefits from amlodipine use are extended beyond patients to the whole healthcare sector. These monetary savings made by the NHS can then be channelled into other health programmes or areas of general service provision.

Finally it is worth mentioning that improving the health of the population through the development of new drugs, therapies and other medical interventions also has the potential economic impact for the UK economy through a lowering of non-healthcare costs: in 2006, production losses due to mortality and morbidity associated with CHD cost the UK over £3.9 billion, with 65% of this cost due to the death and 35% due to illness in those of working age. The total cost to the UK of CHD is around £9 billion, comprising 36% direct health care costs, 27% production losses due to mortality, 16%

[149] Casciano R, Doyle JJ, Chen J, Arikian S, Casciano J, Kugel H, and Arocho R (2002) “Economic benefits of amlodipine treatment in patients with coronary artery disease”, *Pharmaeconomics*, 20(8):553-63.
[150] Rossetti F, De Portu S, Menditto E, Scalone L, Bustacchini S, Cricelli C, and Mantovani LG (2006) “Pharmacoeconomic consequences of amlodipine besylate therapy in patients undergoing PTCA”, *Pharmacological Research*, 53(3):197-201
[151] Casciano *et al.* conducted their study over a three-year period.
[152] Rossetti *et al.* studied amlodipine usage in Italy over a four-month period.
[153] Cathomas G, Erne P, Schwenkglenks M, and Szucs TD (2002) “The economic efficiency of amlodipine in the treatment of coronary atherosclerosis--an analysis based on the PREVENT study”, *Cardiovascular Drugs and Therapy.* 16(1):61-6
[154] Steven Allender, Viv Peto, Peter Scarborough, Asha Kaur and Mike Rayner (2008) Coronary heart disease statistics. BHF: London

production losses due to morbidity, and 21% due to informal care.

5.11. Home and personal goods industries

This section presents a case study from the home and personal goods industry to illustrate the role of UK chemistry research in facilitating success downstream of the chemical industry.

Dependence on chemistry research: highly dependent (82%)

- *Chemistry research directly enables the home and personal goods industries to contribute **£4.9 billion** to the UK economy and support **148,000 jobs**.*
- *The sector is defined as the manufacture of household items (e.g. furniture and domestic appliances) and other personal goods (e.g. jewellery and sporting goods).*
- *Chemistry research feeds into the sector through its intermediate purchases, rather than being conducted within the sector. The requirement for research is driven as much by evolving safety regulations as the need for lower cost, higher quality inputs.*

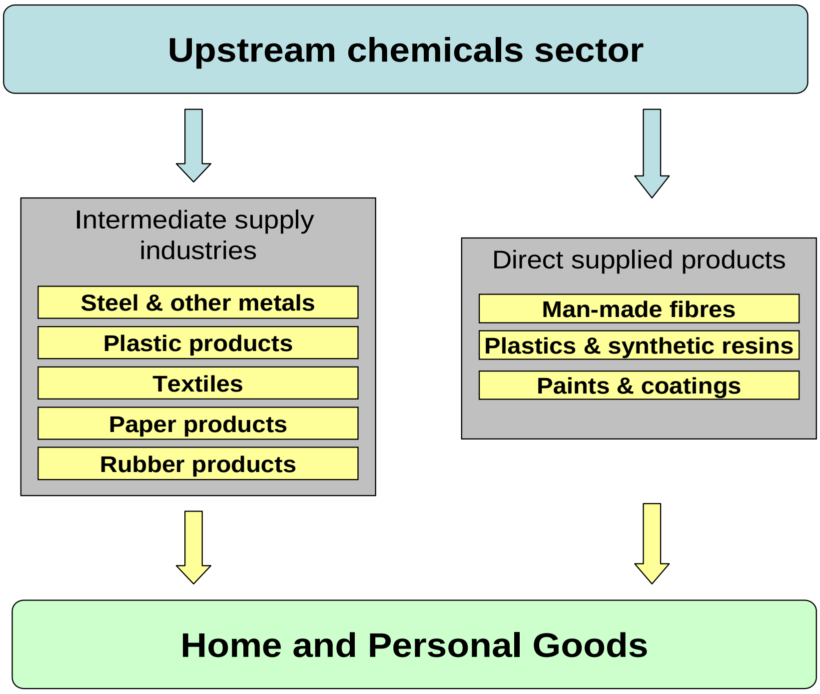
5.11.1. Chemistry research and the home and personal goods industries

The home and personal good sector encompasses the manufacture of household items (e.g. furniture, mattresses, carpets, washing machines, and hairdryers) and other personal goods (such as jewellery, sporting goods and toys). It is not a major sector in the UK economy, accounting for just 0.5% of total GDP[155], but the activity of the sector is **heavily dependent** upon chemistry research.

In 2007, the sector purchased £7.9 billion in external intermediate inputs, of which 6.6%, or £525 million, were sourced from the upstream chemistry-dependent chemicals sector, predominantly in the form of man-made fibres, plastics and synthetic resins, and paints, varnishes and printing inks. It also purchases a significant value of inputs from sectors in which chemistry plays a considerable role; inputs of metal and plastic products, textiles and paper into the sector alone amount to £1.9 billion, equivalent to 23% of the total inputs used (Figure 5-14)[156].

[155] Annual Business Inquiry (ABI) – Release date 16/06/2009. See www.statistics.gov.uk/abi/subsection_dg.asp, scaled to Blue Book 2009 constant 2005 prices.
[156] ONS input-output tables 2007, www.statistics.gov.uk/about/methodology_by_theme/inputoutput/latestdata.asp

Figure 5-14: The chemistry-using 'home and personal goods' industries



The sector can be split into three clearly defined sub-sectors, which utilise chemistry research in different ways.

- **The manufacture of furniture -** utilises significant amounts of textiles[157], which, as discussed in Section 5.14, rely considerably on chemistry research – for example the use of polyester and of fire-retarding materials
- **The manufacture of household appliances** - relies on plastics and electrical components – which themselves depend heavily on chemistry.
- **The manufacture of personal goods** - relies on chemistry to develop new materials (such as a polyurethane running track) and to combine materials to produce final goods with the desired properties (such as specific metal alloys in musical instruments).

The application of chemistry research in the home and personal goods industry is not static, as the demands of the industry and government regulations are constantly changing. This can be seen with the introduction of mandatory standards of flame retardation for furniture; UK government regulations require that all furniture is treated with a chemical retardant[158]. Therefore, chemical research is actively developing more effective mixtures to improve the level of retardation possible, with the lowest environmental impact.

[157] ONS input-output tables 2007, www.statistics.gov.uk/about/methodology_by_theme/inputoutput/latestdata.asp
[158] Office of Deputy Prime Minister (2000) *The Building Regulations 2000: Fire Safety*

5.12. Packaging

This section presents a case study from the packaging industry to illustrate the role of UK chemistry research in facilitating success downstream of the chemical industry.

Dependence on chemistry research: entirely dependent (100%)

- *Chemistry research directly enables the packaging industry to contribute **£970 million** to the UK economy and support **26,000 jobs**.*
- *Chemistry research, in the form of synthesised polymers, is crucial to the operation of this industry. Plastics of different forms are used for packaging (e.g. plastic bottles), depending on their properties and the requirements of the packaging.*

Case study – Self-reinforced polymer

- *UK-based academic interdisciplinary fundamental research led to the development of the Curv® self reinforced polymer composite, which has been applied commercially through industry collaboration.*
- *Curv® represents a technology which would never have happened without EPSRC funding, and the condition of only fundamental research that was attached – "discovery being given a free rein".*

5.12.1. Chemistry research and the packaging industry

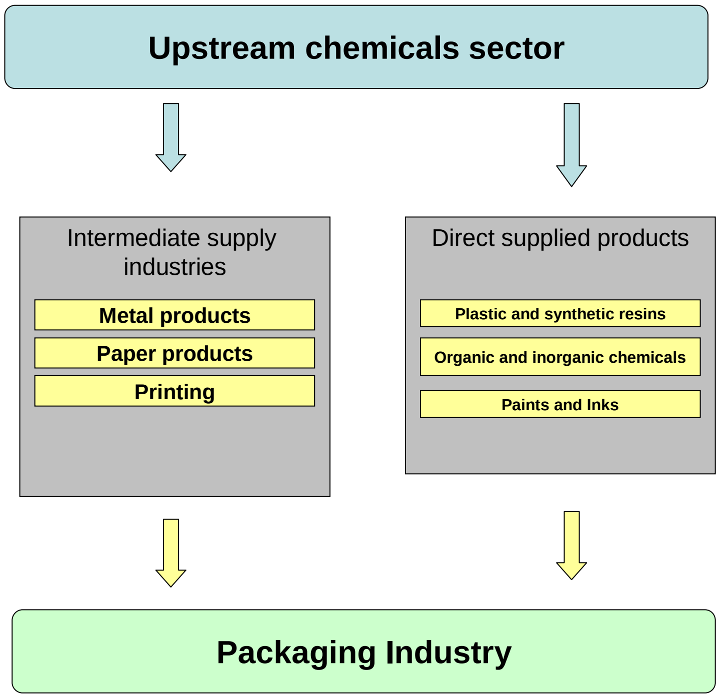
The manufacture of packaging products in the UK supports 26,000 jobs; this excludes paper packaging, which is classified under paper products. The industry generates £970million in value added, contributing 0.09% of UK GDP[159].

Under the Standard Industrial Classification system packaging is considered a part of the manufacture of plastic products. Unfortunately, the Supply and Use tables produced by the UK Office for National Statistics do not disaggregate the manufacture of plastics to enable a detailed examination of inputs into the manufacture of packaging, as seen in other case studies. Therefore, to provide a solution it can be assumed that the purchases required for the production of plastics is similar to that necessary for the production of packaging; the following analysis will therefore be restricted to relative terms.

[159] Annual Business Inquiry (ABI) – Release date 16/06/2009. See www.statistics.gov.uk/abi/subsection_dg.asp, scaled to Blue Book 2009 constant 2005 prices.

The packaging industry purchases approximately 41% of its inputs from the chemicals sector, with the vast majority of this consisting of plastic and synthetic resins, which account for 89% of chemical inputs[160]. In addition to inputs sourced directly from the chemicals sector, the packaging industry also relies on the purchase of inputs from chemistry-reliant industries, such as iron and steel, and paper products, which together represent 12.5% of inputs purchased (Figure 5-15).

Figure 5-15: The chemistry-using 'packaging' industries



Given the fact that this industry is solely concerned with non-paper packaging, Stakeholders have deemed the packaging industry to be ***entirely reliant*** on chemistry research. The plastic utilised by the packaging industry is dependent upon the properties required. If durable, strong packaging is required, for example for a 'living hinge', polypropylene (PP) is often utilised. Packaging for liquids often uses some form of polyethylene terephthalate (PET). PET has gained acceptance as a material of choice for beverage bottles, due to its rigid, transparent, and moisture barrier properties, coupled with its easy recyclability. It has been estimated that 67,000 tonnes of plastic bottles were recycled in the UK in 2005[161], and, since 1999, 17 million plastic bottles have been recycled as carpet in North America[162]. The packaging industry is also changing, as chemical advances have resulted in the development of renewable materials and components for packaging. Alternative starch based adhesives have been developed[163], along with renewable polymers for the packaging itself[164] helping

160 ONS input-output tables 2007, www.statistics.gov.uk/about/methodology_by_theme/inputoutput/latestdata.asp
161 WRAP (2006) *UK Plastic Bottle Recycling Survey 2006*
162 http://www.mohawkflooring.com/carpeting/everstrand/default.aspx
163 http://news.nationalstarch.com/NewsStory.asp?newsItemId=242

to make the sector environmentally sustainable. The development of plastic materials has journeyed through degradable, biodegradable and compostable plastics, with chemistry research efforts finding ways to produce commercially viable materials with the global environment factored in, e.g. sourcing starting materials from non-food crops and producing material in high yields through low energy, low water and low cost production processes165. These new materials that are being developed as environmentally conscious packaging also offer potential applications in the medical arena in terms of tissue regeneration, stitches and drug delivery.

5.12.2. Case Study – Self-reinforced polymers

As seen in Box 5 in Chapter 4, the Polymer IRC is one of the UK's leading polymer research centres, combining chemistry, engineering and physics research. With substantial funding from EPSRC the IRC began completely novel fundamental research in 1989 that led, among other things, to the development of self-reinforced polymers, particularly polypropylene and polyethylene.

From research to product

Using a process of hot compaction on high modulus polyethylene fibres, IRC researchers found that by applying the right temperature and pressure combination, the skin of the fibre can be melted. Once the assembly was cooled the skin recrystalises to form a matrix of the composite, with strong bonds to the un-melted core. Consequently, and as expected by the researchers, the resulting polymer possesses high stiffness and strength, while unexpectedly the polymer had very high impact strengths.

By 1994, these initial findings became known to Hoechst Celanese, a chemical products manufacturer. Hoechst Celanese held a license for the previous Leeds invention of high modulus polyethylene fibres which they marketed as Certran fibre. Consequently, a Leeds University spin-off company, Vantage Polymers, was established with seed funding from Hoechst Celanese, as a means to commercialise the research outcomes; the intellectual property was held by the British Technology Group (BTG).

On-going research by Vantage Polymers, in collaboration with the University of Reading, into the hot compacting of other materials led to the conclusion that polypropylene in the form of geotextile fabrics was a more cost-efficient material, and therefore commercially viable, for this market; importantly the material was fully recyclable. As a result, Vantage Polymers, with Hoechst now backed by the Ford Motor Company, focused on the development and marketing of these self-reinforced composites. This involved collaboration with a range of industries to explore a variety of applications:

- Support from Ford led to the prototype application of the composite as an automotive undertray, for which the combination of low density, excellent impact performance, abrasion

[164] http://www.metabolix.com/,
HGCA, Industrial uses for crops: markets for bioplastics
http://www.hgca.com/document.aspx?fn=load&media_id=5266&publicationId=5988
[165] A patent has been filed on Carbohydrate Lactone Polymers with applications in packaging by researchers from Imperial College, (WO/2009/118538).

resistance, thermoformability and recyclable properties were ideal.

- Collaboration with Westland Helicopters led to the development of cross-linked polyethylene fabrics in prototype helicopter radome covers. Polyethylene lends itself to radome covers due to its very low absorption of electromagnetic radiation, and any fears over high temperature creep were resolved by irradiation cross-linking the polyethylene.
- Inspired by a casual discussion with Wilson Benesch, Vantage Polymers worked with researchers at the University of Birmingham to measure and prove the suitability of their polypropylene for loudspeaker cones. This resulted in a further application of their technology.

Developing these products enabled Vantage Polymers to demonstrate that the product was commercially viable and led the company to have a small, but healthy, turnover. However at the same time it pushed the company to a point where it was necessary to make a large investment in order to grow further. In 2000 BP Chemicals obtained exclusive rights to the technology, invested £10 million, and marketed it as Curv®. BP pursued new applications, such as Nike shin-guards. Propex Fabrics has since purchased the license from BP, and is now operating a production plant in Gronau, Germany on a non-exclusive license.

Alongside this product development, the IRC was engaged in further research. With EPSRC funding the IRC examined the incorporation of carbon nanofibre into polypropylene, and with BTG funding researched the incorporation of a thin film of polypropylene. The latter research has resulted in significant commercial applications due to its easy post-forming properties, and has been applied to the packaging industry by Samsonite for the manufacture of high-end suitcases.

The importance of EPSRC

Prof Ian Ward, founder of the IRC, is adamant that the EPSRC played a crucial role in the development of Curv®. EPSRC funding enabled the IRC to undertake speculative research which would not have occurred without EPSRC - “discovery being given a free rein”. Prior to establishing Vantage Polymers the IRC demonstrated the technology to potential backers, many of whom dismissed the idea with a large amount of scepticism that any commercial application could result from the technology. Investors only became interested once Vantage Polymers, backed with seed funding from Hoechst Celanese, had shown the commercial potential of the material. EPSRC and BTG support in the patenting process also enabled the IRC to extract maximum value for the technology.

5.13. Printing and Publishing Industry

This section presents a case study from the printing and publishing industry to illustrate the role of UK chemistry research in facilitating success downstream of the chemical industry.

Dependence on chemistry research: moderately dependent (30%)

- *Chemistry research directly enables the printing and publishing industry to contribute **£4.9 billion** to the UK economy and support **98,000 jobs.***
- *Chemistry is essential to the printing industry, with modern inks relying on a wide variety of additives, ranging from pigments to humectants, to obtain the desired properties.*
- *Although the adoption of electronic publishing will decrease the reliance on inks, an exciting area of expansion – the flexible e-reader – is also dependent on chemistry research.*

Case study – Organic Light Emitting Diodes

- *UK multidisciplinary fundamental research led to the discovery of OLEDs and exploitation of this technology by a number of start-ups, with applications in mobile phone technologies.*
- *Future developments will enable OLEDs to be printed, allowing the potential disruption caused by disruptive technologies, such as e-readers, to be reduced.*

5.13.1. Chemistry research and the printing and publishing industries

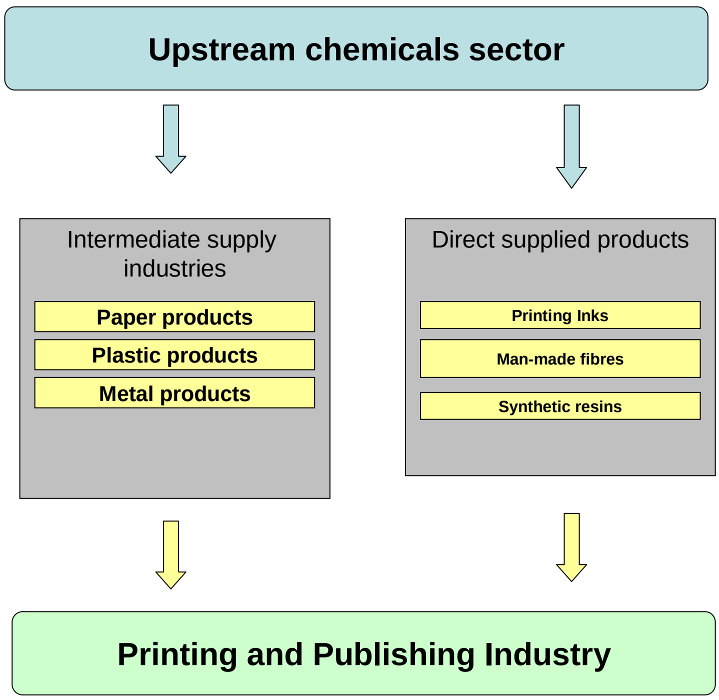
The UK's highly active printing and publishing industry generated £16.3 billion of value added in 2007, accounting for 1.45% of UK GDP. To generate this value added the industry employed 327,000 people[166].

The printing and publishing industry purchases a number of inputs from the chemistry industry, with printing inks, man-made fibres and other chemical products inputs costing the industry £581 million. Total direct purchases of inputs from the chemicals sector equalled £959 million in 2007, representing 7.6% of total inputs. Indirect chemistry-related inputs are even more significant, with the purchase of paper and plastic products costing the industry £3.8 billion in 2007, and representing 30% of total inputs[167] (figure 5-16).

Despite the relatively high value of chemistry-related inputs into the printing and publishing sector, Oxford Economics has classified the industry as being ***moderately dependent*** on chemistry research. The reason for this is that with the evolution of electronic forms of publishing, the paperless office and the internet, which reduce the need for any form of printing, the industry's dependency upon chemistry research is thus reduced.

[166] Annual Business Inquiry (ABI) – Release date 16/06/2009. See www.statistics.gov.uk/abi/subsection_dg.asp, scaled to Blue Book 2009 constant 2005 prices.
[167] ONS input-output tables 2007, www.statistics.gov.uk/about/methodology_by_theme/inputoutput/latestdata.asp

Figure 5-16: The chemistry-using 'printing and publishing' industries



Within the physical aspect of printing and publishing, ink plays an important role, and is heavily dependent on chemistry research. Modern inks differ tremendously from the first black inks, which were simple suspensions of carbon, used around 4,500 years ago. Today ink contains pigment, pH modifiers, humectants, polymeric resins, de-foamer, wetting agents, biocides, and rheology modifiers. The exact combination of components used is dependent upon the ink applicator, for example a high speed printer will have fewer humectants, as these retard the drying process. In addition to the physical properties of ink, chemists are required to create the various shades of ink desired by the market, such as copper phthalocyanine blue, a common blue pigment.

The properties required of ink change depending upon the application method. Therefore, as printing technology advances, the chemistry of ink will be required to advance simultaneously. One such advance is in the development of UV curable inks, which 'dry' as soon as they are cured. These versatile inks can be applied to a wide range of uncoated substrates, are suitable for high speed printing, and are free from the use of organic solvents. This means that 100% of the delivered volume is used to provide colouration, producing a more cost effective and environmentally acceptable product.

Chemistry research funded by EPSRC at the University of Strathclyde aims to deliver a range of 'intelligent' UV curable inks for use in food packaging. These can act as an indicator of food freshness by reacting to changes in the atmosphere caused, for example, by a broken seal. This not only has substantial implications for food safety, but will also help consumers avoid wasting food which is still acceptable for consumption.

Collaboration between ink developers and smart packaging researchers has led to increased use of conductive inks, which are currently used on some touch sensitive items such as keyboards and switches. Using the equipment and technical know-how of conventional printing techniques with conductive inks (e.g. silver based), has opened potential printed electronics applications in end-user industries such as consumer electronics, healthcare, power generation, military, logistics and the manufacturing sector. This development allows printing of RFID (radiofrequency identification) antennas and complex electronic circuitry; technologies which have been used in traceability of assets and inventory, cashless payments systems (e.g. road tolls, public transport) and tracking of humans (e.g. biometric passports) and animals.

As consumers and advertisers move towards electronic media, an exciting area of expansion is in the area of polymer Organic Light Emitting Diodes (P-OLEDs), the successful printing of which would revolutionise the flat display market[168].

5.13.2. Case Study – Polymer Organic Light Emitting Diodes

UK physicists and chemists have played a major part in developing newer, competing display technologies. Donal Bradley, Jeremy Burroughes and Richard Friend, working in the Cavendish Laboratory at the University of Cambridge pioneered the development of polymer organic light-emitting diodes (P-OLEDs) in the late 1980s, whilst undertaking basic research into the physics of semi-conducting polymers – thereby launching the field of so-called 'plastic electronics'[169]. This research built upon the fundamental chemistry research of their Cambridge chemistry colleagues Andrew Holmes, Paul Burn and Arno Kraft and so together they founded the university spin-out company, Cambridge Display Technology Ltd (CDT).

P-OLEDs are now being developed by Cambridge Display Technology (CDT), their collaborators and licensees, and major display manufacturers such as Matsushita (Panasonic) and Seiko Epson. They are currently manufactured for use in small displays such as mobile phone screens, but large TVs are on the horizon, and more unconventional products, such as e-readers, gift cards, labels and active packaging, with a major engineering effort currently focused on enhancing yields and lifetimes.

Off the back of the initial fundamental physics and chemistry research there have been several other P-OLED related start-ups in the UK addressing display and other market sectors including MicroEmissive Displays (founded by Ian Underwood (University of Edinburgh) and Jeff Wright (University of Paisley)) that developed P-OLED/Silicon microdisplays; Opsys (Victor Christou (University of Oxford)) that developed 'dendrimer' OLED materials.

For use in healthcare diagnostics, Molecular Vision (Donal Bradley, John and Andrew de Mello (Imperial College London)) is developing quantitative point-of-care devices combining P-OLED light sources with semi-conducting polymer photodiodes as detectors for microfluidic-chip-based medical analysis. Lumicure (Ifor Samuel (University of St Andrews)) is developing P-OLED 'active plasters'

[168] http://www.inkworldmagazine.com/articles/2009/10/the-specialty-inks-market.php
[169] For a further discussion of the economic impact of plastic electronics refer to www.parliament.the-stationery-office.com/pa/cm200809/cmselect/cmdius/50/50i.pdf, or www.berr.gov.uk/files/file45988.pdf

for photodynamic therapy treatments of skin cancers.

Semi-conducting polymers have the major advantage that they are soluble and therefore can be readily deposited onto a display substrate, for example, by spin-coating or printing (e.g. ink-jet, gravure, screen), without the need for a controlled vacuum-environment. Further fundamental research in this area by Richard Friend and Henning Sirringhaus in the late 1990s led to the discovery that active electronic circuits could be printed using semi-conducting polymers. In 2000, Plastic Logic was spun out of the Cavendish Laboratory to develop a broad range of products, using this technology to manufacture light, flexible, paper thin electronic display devices such as the recently launched QUE[170]. Nano e-Print (Aimin Song ex Manchester University) is a more recent start-up developing high-speed, printed nano-transistors.

The proven economic impact from this research includes:

- So far, CDT Ltd has raised over £250 million through investments and sale of stock, including its acquisition by Sumitomo, a Japanese company, in September 2007. It currently employs around 150 people in the UK, including a team of over 80 scientists with PhDs or other higher degrees based at their technology development centre in Godmanchester, UK.
- Plastic Logic currently employs a staff of 90 in the UK, predominantly at PhD level and so far has raised over $150m from VC funding in Europe, Asia and the US.[171]
- Recent developments have seen the emergence of technologies that could replace the printed word, such as e-readers. The ability to print P-OLEDS would enable the printing industry to evolve with these technological changes, ensuring that the disruptive nature of these changes is kept to a minimum.

[170] http://www.plasticlogic.com/ereader/index.php
[171] Interestingly, most of the venture capital investment in both CDT and Plastic Logic was from non-UK investors. One interviewee suggested that UK investors are more risk averse because very few have a science background and are unlikely to have any understanding of what they are actually investing in. On the other hand investors from abroad, and the US in particular, often have a science background and that knowledge can help inform their investment decision. The following anecdote was used to stress this point: 'When buying a second hand car, people who have a little understanding of what is under the bonnet can make a more informed decision about whether to purchase the car or not compared to people with zero knowledge of how an engine works, or even what it looks like!'

5.14. Textiles industry

This section presents a case study from the textiles industry to illustrate the role of UK chemistry research in facilitating success downstream of the chemical industry.

Dependence on chemistry research: entirely dependent (100%)

- *Chemistry research directly enables the textile industry to contribute **£3.8 billion** to the UK economy and support **69,000 jobs**.*
- *UK-based research plays a prominent role in the chemistry research that is vital for the textiles industry.*

Case study – Polyester

- *Although developed in the UK during the 1940s, polyester is still one of the most widely-used synthetic materials within the textiles industry, used to make products from bed sheets to high performance sportswear.*
- *Its wide application owes to its desirable properties, which include durability, wrinkle-resistance, easily washable and quick drying.*
- *Polyester is also widely utilised outside of the textiles industry, with widespread use in the automotive industry, the packaging of drinks, and photographic and video film.*

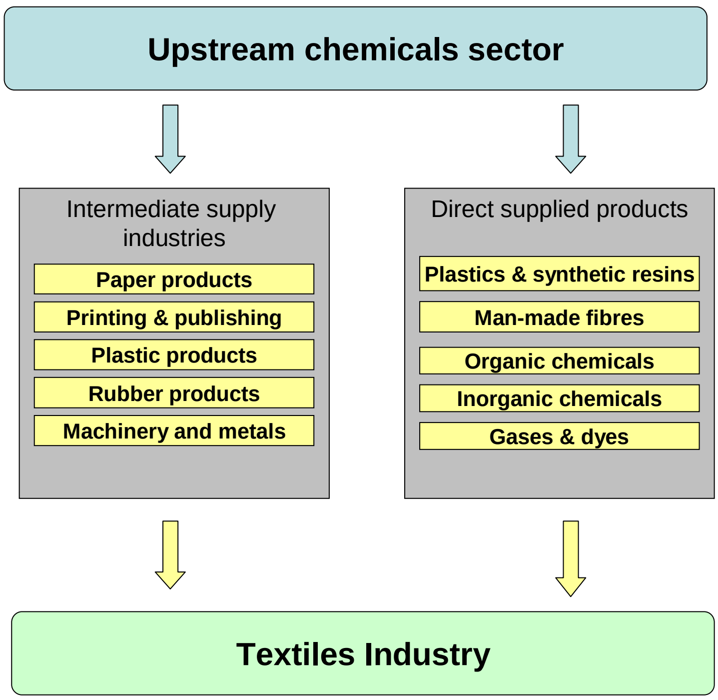
5.14.1. Chemistry research and the textiles industry

The UK textile industry touches the lives of all people in one way or another. From clothing, footwear and home textiles (e.g. bed linen, carpets and curtains) through medical and safety textiles to composites and ballistics; the industry is used by consumers, athletes, manufacturers and engineers.

The textiles industry in the UK is ***entirely dependent*** on inputs that either would not exist or would be less effective without the results of chemistry research. Today direct inputs to the textiles industry in which chemistry plays a crucial role – synthetic fibres, dyes, plastic and synthetic resins and organic chemicals – cost the industry £500 million, over 14 %[172] of its total inputs (figure 5-17). This linkage has a long tradition with landmark developments such as the creation of the first polyester fibre called Terylene in 1941 by a group of UK chemists and which was first manufactured by ICI (See the case study in section 5.14.2).

[172] ONS input-output tables 2007, www.statistics.gov.uk/about/methodology_by_theme/inputoutput/latestdata.asp

Figure 5-17: The chemistry-using 'textiles' industries



There are many examples of how chemical products are used in the textiles industry. During the manufacturing process, textiles have to pass through different chemical and non-chemical treatments. Chemical products are used in yarn formation, fabric pre-treatment and finishing, textile laminating and in coatings. The chemicals used include colorants and dyeing auxiliaries, polymers, finish-effect chemicals, and printing inks and additives among others. Textile chemical products include, for example, highly specialised chemicals like biocides (chemicals that kill living organisms in a selective way), flame retardants, fragrances, microcapsules with phase change materials for microclimate control and super-hydrophobic water repellents as well as simple commodity chemicals or mixtures like emulsified oils and greases, starch, waxes, softeners and some surfactants[173].

Though the production of textile chemicals has played a vital role in the success of the textiles industry, there are continuing pressures on the industry for further innovation and development in order to do things quicker, more cost-effectively, and with lower adverse environmental impacts than offered by conventional technology. Examples include the search for lower impact chemical formulations used in the manufacturing process to reduce VOC emissions, improved efficiency dyeing procedures [174] and improving the water repellency and laundering properties of textiles to lower the energy and water use associated with the washing and drying of clothes[175].

[173] http://www.teonline.com/textile-chemicals/
[174] http://www1.dystar.com/products/featureddyes08.cfm?CFID=582952&CFTOKEN=54549190
[175] http://www.chemistryinnovation.co.uk/roadmap/sustainable/roadmap.asp?previd=250&id=261

The material from which textiles are made is even now changing with the production of clothing from recycled materials[176]. The textile industry is being continually influenced by advances in the chemical sciences with the aim to lower environmental impact and increase sustainability.

In terms of the future, an example of current research in textiles chemistry is the work on embedding being carried out at the University of Liverpool. When Nylon is embedded with nanoparticles the resulting nanocomposite exhibits significant improvement in tensile strength as compared to the pristine material. Such nanocomposite materials are an ideal replacement for metals and rubber in a wide variety of applications ranging from e.g. flexible high-strength, light-weight body armour to construction materials.

Other examples include the products of Exilica Limited, a University of Coventry spin-out company that has been established to exploit the production and use of spherical polymer micro-beads and hollow silica nano-shells with use as novel transport and delivery agents. Both types of particles can discharge their contents through varying release mechanisms, depending upon their environment and/or final formulation. Embedded into materials, they can be used to create smart textiles[177].

5.14.2. Case study - Polyester[178,179]

(i) Background

The development of Polyester – a category of polymer which contains the ester functional group in their main chain - provides an example of how a particular chemistry research project can lead to extensive benefits in the textiles industry and beyond.

- Two British chemists, John Rex Whinfield and James Tennant Dickson, employees of the Calico Printer's Association of Manchester, patented "polyethylene terephthalate" in 1941, after advancing the early research of Wallace Carothers. Polyethylene terephthalate is the basis of synthetic fibres such as Terylene, the first polyester fibre created by Whinfield and Dickson along with inventors W.K. Birtwhistle and C.G. Ritchiethey and first manufactured by ICI in 1941.

- The applications of the polymer vary from making products like bottles for soft drinks or a substrate for magnetic recording media such as floppy discs to being used as a fibre to make clothes.

(ii) Use in the textiles industry

- Despite its discovery some seventy years ago, polyester has retained wide usage within the textiles industry, due to the many forms it can take and the desirable properties these forms hold. Polyester fibre is used in all types of clothing, either alone or blended with fibres such as

176 https://plana.marksandspencer.com/we-are-doing/sustainable-raw-materials/stories/57/
177 http://www.exilica.co.uk/index.html
178 http://www.swicofil.com/pes.html
179 http://www.polyesterconverters.com/pcl_apps/stage1/stage2/applications_and_enduses/historyofpet.htm

cotton, giving a material that is durable, wrinkle-resistant, easily washable and quick drying[180]. In addition to being inter-woven with other materials, the base polyester filament fibre can be extruded in such a way as to engineer improved appearance, quick drying or possess high levels of heat retention. These extruded fibres (either hollow tubes or crimped) are used as insulating padding in cold-weather clothing, offering an advantage over traditional insulation materials as they retain their shape over time. According to DuPont Teijin Films, "Plain polyethylene terephthalate (PET) or polyester is most commonly associated with a material from which cloth and high-performance clothing are produced (e.g. DuPont Dacron® polyester fibre).

- In addition to traditional apparel, polyester's properties make it an attractive choice of material in the manufacture of sportswear, personal protective wear, tyre cord, safety/conveyor belts and filter media.

(iii) Use in other industries

Use of polyester is not restricted to the textiles sector. The properties which have made its use so widespread in the textiles industry have not been ignored by other sectors, and its use has spread to almost every aspect of daily life.

- Increasingly over the last ten years PET has gained acceptance as a material of choice for beverage bottles, due to its rigid, transparent, and moisture barrier properties, coupled with its easy recyclability. It has been estimated that 67,000 tonnes of plastic bottles were recycled in the UK in 2005[181], and, since 1999, 17 million plastic bottles have been recycled as carpet in North America[182].

- The ability to fully recycle polyester has led to the development of the Eco Circle closed-loop recycling scheme. Based in Matsuyama, Japan, Eco Circle is a closed-loop recycling scheme, in which participants send their used polyester products to Eco Circle where it is recycled into polyester of the same quality as the original product, wasting nothing[183].

- The automotive industry draws heavily on polyester in the production of vehicles. On top of the use of polyester in all of the fabrics used in a car, polyester is used in the manufacture of fan belts, seat belts, airbags and tyres – Teijin Fibers Limited recently announced an agreement with Eco Circle to produce tyres containing recycled polyester fibres[184].

- Polyester film (PETF) is a semi-crystalline film used in many applications such as videotape, high quality packaging, professional photographic printing, X-ray film, floppy disks, etc. The production of PETF through roll quenching and biaxial orientation gives the film a tensile

[180] www.selectcomfort.com/eng/newsSection/redirect.cfm?sectionID=news/extranetNewsDetail.cfm&categoryId=7&newsItemID=59&lefNavId=6#polyester
[181] WRAP (2006) *UK Plastic Bottle Recycling Survey 2006*
[182] http://www.mohawkflooring.com/carpeting/everstrand/default.aspx
[183] Eco Circle, www.ecocircle.jp/en/index
[184] http://www.innovationintextiles.com/articles/110.php

strength a third of that of steel[185].

- Used for decades as a substrate in magnetic recording media (e.g. tape back-up for data storage for computers, DVDs), the economic impact on the UK (and global) economy of polyester applied in this way is so hugely significant that it is almost immeasurable.

[185] www.vct.com

5.15. Water

This section presents a case study from the water industry to illustrate the role of UK chemistry research in facilitating success downstream of the chemical industry.

Dependence on chemistry research: entirely dependent (100%)

- *Chemistry research directly enables the water industry to contribute* ***£7.6 billion*** *to the UK economy and supports* ***52,000 jobs*** *in the UK.*
- *Chemistry plays a crucial role in both the before and after consumption sections of the water cycle.*
- *Further research into both technology and analytical methodology is essential in order to meet and overcome future global challenges relating to water.*

Two case studies show how recent chemistry research and technology development has enabled new and effective application of fundamental discoveries made several decades earlier.

- *These provide an example of how Royal Society supported chemistry research, led to a spin-out company with international presence, followed by the outcomes of impact and on-going collaboration between a water company and Bangor University.*

5.15.1. Chemistry research and the water distribution industry

Defined as the collection, purification and distribution of water, the UK's water distribution sector generated £7.6 billion in value added in 2007, contributing 0.8% of the UK's GDP. Activity in the water industry directly supported 52,000 jobs[186].

Despite, the chemistry-reliant chemical sector supplying just 3% of the value of inputs used by the water sector (predominantly organic and inorganic chemicals), stakeholders consulted judged the water industry to be ***entirely dependent upon chemistry research***. Chemistry plays a major role in the treatment and distribution of drinking water and also in the treatment of wastewater, as illustrated in Box 9.

Box 9 – The role of chemistry in the household water cycle

Treatment of water **before household consumption** ensures that water supplied to homes is safe to drink. The level of treatment can vary from simple disinfection to multi-stage advanced treatment, depending on the quality of the source water. This pre-consumption treatment involves several key steps:

1. Clarification, where chemical coagulants are added to remove colour and particulate material.

[186] Annual Business Inquiry (ABI) – Release date 16/06/2009. See www.statistics.gov.uk/abi/subsection_dg.asp, scaled to Blue Book 2009 (in constant 2005 prices).

2. Filtration to remove any residual particles, including micro-organisms.

3. Final disinfection, typically using chlorine, to inactivate any remaining bacteria and micro-organisms and to keep the water safe as it passes through the distribution system.

Some waters may also require advanced oxidation processes to remove organic contaminants, such as pesticides, and others may require specific treatments such as ion exchange, to reduce nitrate levels, or desalination for brackish or salty water.[187]

Treatment **after household consumption** involves returning water to a state that will not pollute the environment when released; therefore treatment seeks to remove pollutants from the water. During a multi-stage process, solid pollutants are removed by a series of filters followed by biological treatment and filtration. The final effluent may then receive some form of chemistry-based disinfection before it is discharged. Chemical science is playing an increasing role in nutrient removal and the removal of specific organic compounds such as endocrine disrupting chemicals[188,189].

Chemical science also plays a significant role in the remediation of the aquatic environment following pollution incidents.

Chemistry research within the water sector is therefore playing a vital role in the transformations that are needed to achieve a sustainable fresh water supply, both domestically and on a global scale.

By way of example, agriculture consumes 70% of global water resources and with the expansion of food production necessary to meet demand from the growing population will have serious implications for the world's fresh water resources[190]. Water shortages are already evident in many parts of the world, particularly in parts of Australia, Asia and North Africa; indeed it is estimated that almost 1 billion people around the world have no access to clean drinking water and 1 in 4 people in developing economies live without sanitation facilities. Fundamental chemistry research is a necessary condition to support strategies that will provide the technological solutions needed to deliver new and improved methods of optimising water use, treating contaminated water, recycling water, desalinating water and preserving water in soil and harvesting water for irrigation. Even if the UN Millennium Development Goals for water and sanitation are achieved, there will still be more than 800 million people without water and 1.8 billion without sanitation in 2015[191]. This highlights ***the need for further chemical research within the water sector.***

5.15.2. Case study 1 – manipulated osmosis desalinisation

(i) Background

Global water scarcity is a pressing concern, with the Food and Agriculture Organisation of the United Nations (FAO) predicting that by 2025 1.8 billion people will be living in areas of absolute water

[187] RSC (2009) http://www.rsc.org/Chemsoc/Chembytes/HotTopics/DrinkingWater/howtreated.asp
[188] Sustainable Water: Chemical Science Priorities RSC (2007)
[189] Water Environment Federation (2009) *Following the Flow: an inside look at wastewater treatment*
[190] The Vital Ingredient: Chemical science and engineering for sustainable food, January 2009
[191] UN Millennium Development Goals, www.un.org/millenniumgoals/index.shtml

scarcity, and two-thirds of the world's population will live in water stressed areas[192]. However, given that 97.5% of the earth's water is salt water, the potential supply of freshwater that can be obtained through the process of desalination is infinite.

One of the primary methods of desalination is the use of ***Reverse Osmosis, the process of separating water from a solute***. Normal osmosis occurs when water passes from an area of low solute concentration to an area of high concentration, through a semi-permeable membrane, equalising the level of concentration between the two areas. By applying high levels of pressure to the process, it is possible to force this water movement to run in the opposite direction (reverse osmosis), creating an area of high solute concentration and an area of low solute concentration; when applied to seawater, reverse osmosis results in concentrated brine and drinking water. However, due to the large number of different chemical components in seawater, the instruments used during the desalination process suffers from significant corrosion, fouling and scaling problems, all of which increase the cost of operation by increasing energy and chemical consumption.

Previously, research into reducing the corrosive, fouling and scaling properties of seawater has focused on mechanical solutions, for example the addition of extra filters. The Centre for Osmosis Research & Applications (CORA) at Surrey University, benefiting from a £250,000 award by the Royal Society in 2005[193], adopted a different approach by researching the chemistry of seawater. By building on previous research supported by EPSRC they found that by adding manipulative chemical agents to the seawater created single ionic solutions, which did not possess any of the undesirable corrosive, fouling and scaling properties of seawater. By avoiding the problem, rather than just providing a remedy, chemistry research has provided a much more sustainable solution.

The Manipulated Osmosis Technology process developed by CORA also has a further benefit of being highly efficient. The process begins with manipulation of the osmotic pressure by adding an osmotic agent to a draw solution, thus allowing water to move from the source, seawater, leaving the salt behind. The resulting diluted solution then undergoes a separation stage to produce potable water, while the osmotic agent is recycled for reuse again.

(ii) Economic impact

The technology developed by CORA has clear commercial potential, however when initially introduced into the market in 2003 CORA believed it to be 'slightly ahead of its time'; by 2009 it is now regarded as a promising/emerging technology. Despite the initial hesitation, a spin-off company (Modern Water) was founded and was floated on the London AIM stock market 6 months later, valued at £70 million. Since listing in June 2007, the company has constructed a proving desalination plant which has been feeding directly into the potable water supply in Gibraltar since March 2009, and a second commercial plant in Oman has been operational since November 2009[194]

[192] FAO (2009) http://www.fao.org/nr/water/issues/scarcity.html
[193] http://royalsociety.org/publication.asp?id=5631
[194] http://www.modernwater.co.uk/mw/news/releases/2008/2008_12_11/

5.15.3. Case study 2 – Electrochemistry: A route to efficient coagulation in water treatment - Aguacure Ltd

(i) Background

Electro-coagulation is a process of using low levels of electricity rather than chemicals to remove dissolved and suspended contaminants from water. Although the fundamental concepts of electrochemistry date back to Michael Faraday and are well over 100 years old, it is only in more recent years that a clearer fundamental understanding of the complex chemical and physical processes involved, along with improvements in power conversion technologies and modern electronics, have seen the technology move from the laboratory to a commercial environment. With increasing scarcity of chemicals and escalating costs, there is a strong drive towards chemical-free water treatment methods such as AguaCure's electro-coagulation.

Aguacure Ltd is a spin-in company based at Bangor University. The company relocated to Bangor University due to the University's expertise in electro-chemistry research. Several years have been spent testing the technology, utilizing the close links with Bangor University. The research has been funded by a combination of research grants from The Welsh Assembly and self-funding by the company owners. After 2 to 3 years of fundamental chemistry research in electro-coagulation, the company successfully demonstrated the applicability and commercial benefits of electro-coagulation to remove nickel and phosphate from paint in the automotive industry and phosphate and suspended solids in the water industry.[195]

(ii) Economic impact

The chemistry research conducted by Aguacure Ltd can be seen to give a number of benefits. First, there are proven costs advantages for companies that purchase their technologies due to low power consumption, simple and robust technology; second, there is no/reduced chemical handling, meaning that the process is more environmentally friendly than a wholly chemical-based alternative; third, the approach generates less sludge, or residue, than chemical treatment, offering major cost savings to any company generating sludge as part of their wastewater treatment (e.g. sewage treatment by water companies).

The company has also gone international with their technology. The system is in use in Portugal, to improve drinking water quality, following tests at public health laboratories in Lisbon. Aguacure Ltd is now part of the Modern Water Group, following an investment of £400,000 in December 2008[196].

[195] Advances: The journal; for Science, Engineering and Technology in Wales; Issue 154, Winter 2007
[196] http://www.modernwater.co.uk/mw/news/releases/2008/2008_12_11/

6. Annex

Annex 1: Study methodology

The methodological approach utilised in this study seeks to identify and quantify the ways in which chemistry research contributes to the prosperity of the UK economy. There are many channels through which chemistry research makes a contribution to the UK economy, including, but not exclusively:

- underpinning the output of the 'upstream' chemicals and chemical products industries;
- providing key inputs to much of the rest of the 'downstream' economy to sustain their products;
- facilitating productivity growth and investment in the economy;
- creating the basis for competitive advantage and international trade.

But measuring the economic benefits of chemistry research to the UK economy is a challenging task. Some of the benefits are directly measurable and readily quantifiable (e.g. the contribution to employment, GDP, trade and investment), but others less so (e.g. health benefits and lives saved from pharmaceutical drugs, improvements to quality of life from new or improved products, and environmental savings from more energy efficient fuels and lubricants). Moreover, the economic benefits of commercialised chemistry research can occur many years after the basic (or 'blue-sky') research took place, and those benefits can spillover to many other diverse and un-related areas of the economy.

To overcome these challenges, the methodological approach sought to identify and quantify the ways in which chemistry research contributes to the prosperity of the UK economy using a twin-tracked process, which is summarised as follows:

1. Quantify the importance of chemistry research to the 'upstream' chemistry dependent sector by:

- Defining the upstream sector using the standard government industrial classification (SIC 2003[197]) code 24: manufacture of chemical and chemical products that includes businesses that manufacture dyes, fertilisers, rubber, plastics, pesticides and pharmaceutical products among others;
- Quantifying the economic importance of the upstream sector using publicly available statistics from the Office for National Statistics (ONS);
- Supplementing the desk-based research with stakeholder consultations – 17 interviews were conducted with businesses operating in the upstream sector. This served three key

[197] This study utilises the 2003 Standard Industrial Classifications, the more recent 2007 classifications were not used as data were not available at this level at the beginning of the study. More information on the 2003 classification of individual activities can be found at: http://www.statistics.gov.uk/methods_quality/sic/downloads/UK_SIC_Vol2(2003).pdf

purposes: firstly to explore the importance of chemistry research within the upstream sector, secondly to identify how the outputs of the upstream sector are used as inputs into other industries that in turn produce products and services, and thirdly to identify specific beneficial outcomes of basic chemistry research which could perhaps be used as case studies.

2. Quantify the importance of chemistry research to the 'downstream' chemistry-using sector by:

- Identifying the key chemistry-using industries, based on the outcome of consultations with businesses operating in the upstream sector, the project steering group, and the Chemistry Innovation Knowledge Transfer Network (CI-KTN);
- Scoring each key downstream chemistry-using sector according to their dependence on chemistry research, which in turn was based on consultations with over 20 businesses operating in the downstream industries and validated with further desk-based research;
- For each downstream sector, estimating the contribution to jobs and GDP that is chemistry research dependant by using the scores to 'weight' publicly available statistics available from the ONS.

Within our approach it is important to note that:

- While the study focused at UK level benefits, it was clear from our analysis that UK-based chemistry research has significant international benefits;
- The study exclusively addresses the question of what are the economic returns to the UK population and the UK economy from UK based chemistry research. We recognise that UK chemistry research benefits other countries, just as our analysis recognises that the UK benefits from research from the rest of the world. Indeed, some chemistry research is undertaken in the UK with the expectation that it will predominantly or exclusively benefit health care in other countries (for example research on tropical diseases/technologies for developing nations). However, benefits to countries other than the UK are outside the scope of this study.
- The economic impacts for the UK economy have been disaggregated as follows:
    - *direct impacts* that arise from new or improved products and from efficiency and competitiveness gains for private and public sector establishments (metrics used include turnover, employment, GDP, exports and inward investment);
    - *multiplier effects* that arise from further economic activity associated with additional income and supplier purchases by applying a methodology consistent with the HMT 'Green Book'[198] and English Partnerships guide to additionality[199];
    - *'wider' benefits* that are a result of research that delivers positive benefits to society as a whole and so improves quality of life (e.g. a health enhancing or environment

[198] HMT Treasury (2003), 'Appraisal and Evaluation in Central Government'.
[199] English Partnerships (October 2008), 'Additionality Guide (Third Edition): A standard approach to assessing the additional impact of interventions'

damage limiting discovery).

The study's approach also sought to identify and quantify the channels through which chemistry research make a contribution to the UK economy, including:

- *sustaining and improving the UK's research base* – cutting edge chemistry research helps maintain the UK science base and the ability of university departments, research establishments and domestically located businesses to compete for staff, (international) students and research contracts. In this way it positively contributes to the UK's reputation in many areas of science and helps to foster the UK's reputation and attractiveness to inward investment.

- *technical knowledge transfer and expertise* that flows from research establishments to industry (and often back again) allowing businesses to identify, develop and market new products and services, all supported by national Knowledge Transfer Networks such as Chemistry Innovation.

It is important to note that this study is not a cost-benefit analysis but an economic assessment. The study focused on robustly demonstrating achieved gross economic benefits to the UK based on empirical evidence and stakeholder consultations, without consideration to the costs of providing that benefit.

Annex 2: Examples of current collaborative projects

The Chemistry Innovation KTN works with academia and industry to form effective collaborative partnerships. It is currently involved in 67 'live' collaborative projects – with a value of £38 million. Some examples are listed below:

Project	Academic Centre	Company
Integration of mineral separation and metal production for total environment cost minimisation	Imperial College	Rio Tinto
Fast production, detection and use of green oxygen-enriched air	Surrey	Data stripe
Towards sustainable polysulfone plastics	York	Clariant UK Ltd
Discovery and Large-Scale Production of Novel Oxidase Biocatalysts from Marine Microorganisms for Industrial use in Deracemisation Reactions.	Herriot Watt	Ingenza Limited
Asymmetric hydroformylation: a powerful tool for the clean synthesis of pharmaceutical intermediates	St Andrews	Chirotech Technology
Development of new techniques for highly sensitive trace gas analysis	Oxford	Oxford Medical Diagnostics
Microfluidic sorting, processing and analysis of viable cells	Glasgow & Hull	GSK,LGC, Syrris (Dolomite), Epigem
On-line analysis of structured dispersions	Leeds	Malvern instruments
A biochemical engineered high throughput screen using stem cells	UCL	SCS
Development of novel emulsifiers and foaming agents based on anisotropic particles	Hull	Unilever
Aqueous particle gels: linking structure, rheology and sedimentation	Bristol	Bayer Cropscience
Soft lubrication of multiphased complex fluids	Imperial	Unilever
High throughput Studies of Liquid Crystalline and Polymeric Electrolytes	Southampton	Ilika Technologies
Design of barite nanoparticles and nanocomposites	Surrey	Viaton, BP
Froth Coalescence and Bursting Models: from two bubbles to 30 million tons per annum	Imperial College	Anglo American plc
Catalytic Chromophores for combined synthesis and coloration of Poly(lactic acid): The DyeCat Process	Leeds	DyeCat Ltd
Novel catalysts for methanol synthesis prepared by a nitrate-free route	Cardiff	Johnson Matthey
A New Organocatalytic System for Asymmetric Epoxidation	Loughborough	Charnwood Molecular
Exploring the scope of the partial reduction of pyridines	Oxford	Lilly UK
Electrochemical Synthesis in Flow Chemistry	Cardiff	Prosidion Ltd
Smart Surfaces for HTT Nanodevices	Imperial	Air Products
Evaluating downstream processing options at the bioprocess-business interface	University College London	AstraZeneca, Cambridge Antibody Technology

Source: Chemistry Innovation Knowledge Transfer Network

Annex 3: Highly ranked chemistry institutions

The Research Assessment Exercise 2008 (RAE) of the quality of research conducted in UK higher education institutions provides more direct insights to the international standing of chemistry and chemistry related departments in the UK. As shown in the figure the RAE identifies a ranking of research quality which differentiates according to the international standing of the research being undertaken within university departments. Quality levels 4* and 3* are awarded to research that is either world-leading or internationally excellent. The panels making these judgements included non-academic users of research – including those from industry, the healthcare and voluntary sectors, the professions and Government – alongside academics.

The figure shows the 12 UK institutions which received 4* or 3* rankings for 70% or more of their research activities. These institutions employ over 600 top-level research staff, slightly over half such staff spread across all UK university chemistry departments.

Highly ranked chemistry institutions

RAE Chemistry 4*+3* rankings	4*	3*	4*+3*	Full-time equivalent category A staff
University of Nottingham	30	55	85	35
University of Cambridge	40	40	80	62.95
University of Bristol	25	50	75	67
Imperial College	20	55	75	53.1
University of Oxford	30	45	75	73.9
University of Warwick	15	60	75	32.8
University of York	15	60	75	46.71
University of Leeds	20	50	70	37.2
University of Liverpool	20	50	70	37.1
University of Sheffield	15	55	70	33.7
Universities of Edinburgh & St Andrews	30	40	70	76.89
Universities of Glasgow & Strathclyde	10	60	70	51.4

Source: RAE 2008

Annex 4: Examples of key research centres

Institution	**Focus**
The National Industrial Biotechnology Facility, Manchester	Demonstration and scale-up facility for bringing developments in biotechnology to the chemical sector
OMIC, Manchester	Government supported University Innovation Centre for the speciality organic materials and polymer industries.
Institute of Process Research & Development, Leeds	Combines chemists and engineers who work with the fine chemical and pharmaceuticals industries to improve manufacturing processes
Centre of Excellence for Biocatalysis, Biotransformations & Biocatalytic Manufacture, Manchester	R&D to create new biocatalyst-based processes for industry
Department of Chemistry, University of Oxford, Oxford	The largest and most productive university research laboratory in the UK, publishing around 200 original research papers and books each year and contributing over £80 million to the university as a result of its spin-out activities.
The Centre for Materials Discovery, Liverpool	Material synthesis and characterisation, with strengths in molecular modelling capabilities
The Knowledge Centre in Materials Chemistry, virtual network via Chemistry Innovation KTN	Aims to facilitate a step change in the performance of the chemicals sector through combining research capabilities in the North-West
The Polymer Interdisciplinary Research Centre, Leeds	Research in polymers and complex fluids
The Centre for Bioactive Chemistry, Durham	Bio-imaging, redoxybiochemistry, biocatalysis and protein engineering
Centre for Process Innovation, Redcar, Newcastle and Durham	Developing products, processes, services and businesses in the process and manufacturing sectors
Green Chemistry Centre of Excellence, York	Development and implementation of green and sustainable chemistry and related technologies.
Dundee Drug Discovery Unit, Dundee	Translation of basic science into drug targets, for use as tools to investigate disease pathways and for potential pre-clinical drug candidates.

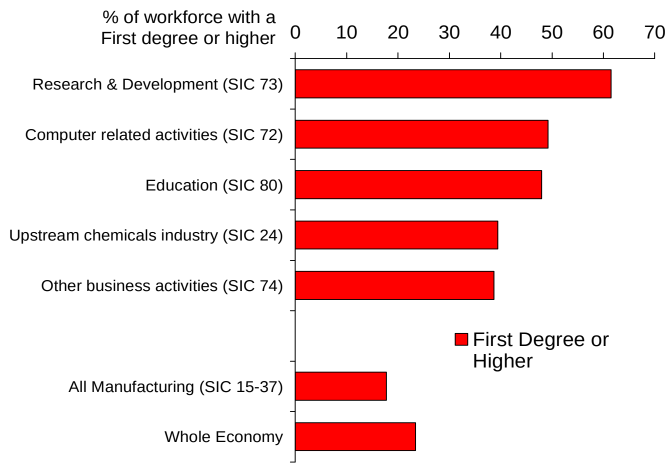
Source: Chemicals – The UK Advantage, UKTI

Annex 5: Labour skills and productivity in the upstream chemistry sector

An industry employing a highly qualified workforce is typically placed among the most highly productive industries. Highly productive industries and productivity growth are crucial to the UK economy. The upstream chemistry industry meets both criteria, as demonstrated below.

The upstream chemistry industry now employs just over 200,000 workers, many of whom are highly qualified scientists and engineers. Within the UK economy, the upstream industry is the 4th largest industrial sector in terms of the proportion of the workforce who are educated to at least degree level (see figure below), with almost 40 % of employees holding a first degree or higher. This is almost 50% higher than the equivalent figure for employees across the UK economy as a whole[200].

Qualifications in the upstream chemicals industry, 2008

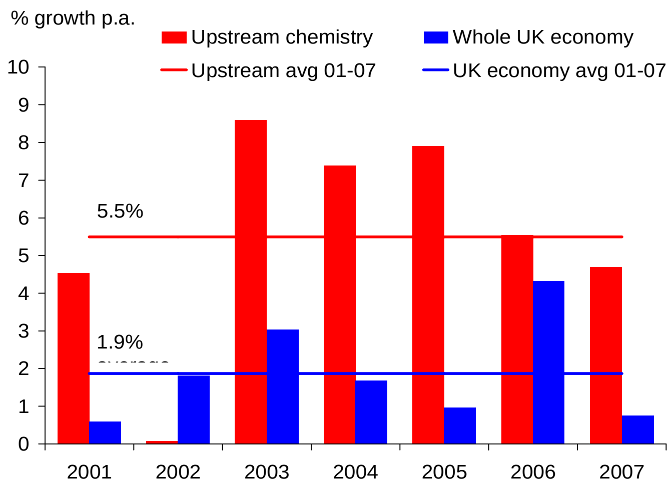


Source : Oxford Economics based on Labour Force Survey (2008q1)

Labour productivity in the upstream chemistry industry in 2007 was around £83,500 per worker, which is more than double the UK average (£37,500). Furthermore, productivity growth in the upstream industry, averaging around 5.5% a year in real terms, has been almost treble the rate of productivity growth for the UK economy as a whole.

[200] Labour Force Survey (LFS April-June 2008)

Labour productivity growth, 2005 prices



Source : Oxford Economics, Annual Business Inquiry, Blue Book 2009

By way of comparison, the upstream chemicals industry is more productive than the UK motor industry and produces more than 80 % more output per worker than across manufacturing as a whole.

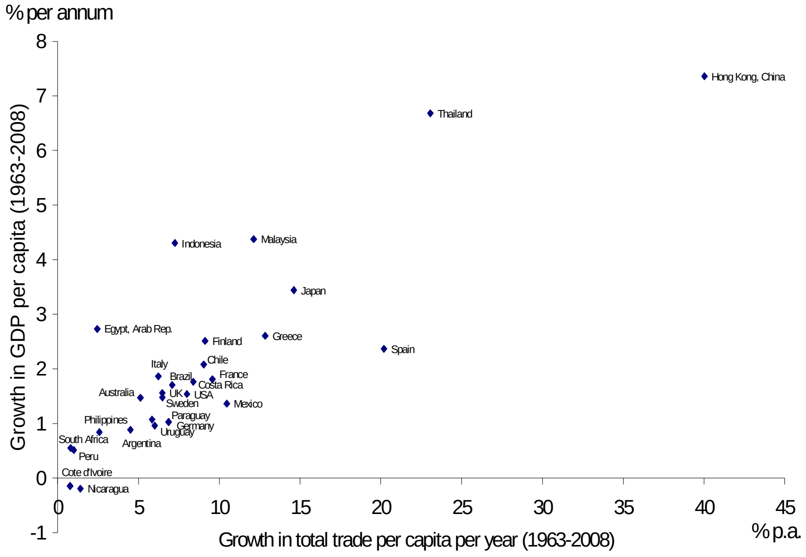
Labour productivity in the upstream chemicals industry, 2007

Sector comparison	**Value added per worker (£) 2005 prices**	**Upstream sector in detail**	**Value added per worker (£) 2005 prices**
Extraction	624,100	Pharmaceuticals	106,800
Telecommunications	119,700	Man-made fibres	90,700
Financial intermediation	84,600	Rest of upstream sector	84,900
Upstream	**83,500**	Pesticides	80,200
Air transport	66,600	Paints, varnishes and mastics	59,300
Aerospace	63,100	Plastics	58,700
Computers & related activities	59,700	Fertilizers	53,400
Adverting	58,700	Rubber	46,900
R&D activities	49,700	Dyes and pigments	42,600
Motor Vehicles	49,400	Soap and detergents	37,800
Legal activities	48,100		
Public admin and defence	39,900		
Distribution	28,500		
Education	25,400		
Health	24,300		
Post	23,700		
Manufacturing (total)	45,800	Upstream (total)	83,500
Whole economy	37,500		
Source: ONS Blue Book, 2009, and Annual Business Inquiry			

Annex 6: Trade and the upstream chemistry industry

Trade performance is a key determinant of economic growth and prosperity. Over the last 40 years, the countries that have grown fastest have typically been those that have also seen the fastest growth in international trade.

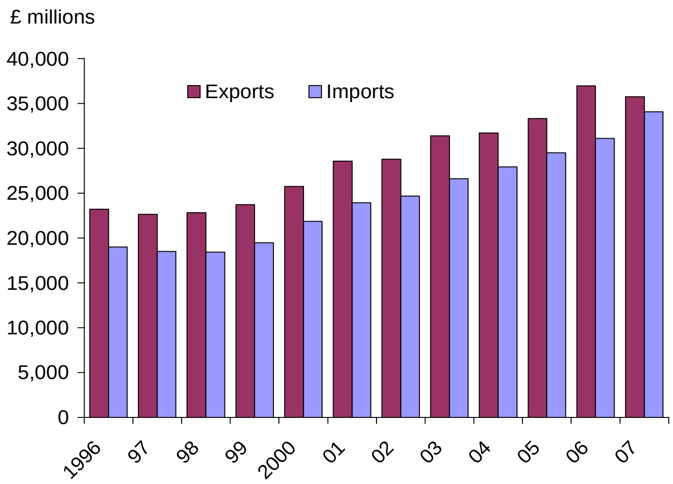
Economic growth and trade



Source: WDI, Oxford Economics calculations

The UK upstream chemicals industry has made a positive contribution to the UK's trade performance over many years. This is shown by a positive balance of trade, or trade surplus. This means the UK's exports of upstream chemicals exceed UK imports of chemicals (see Figure A-1).

Figure A-1 Trade performance of the upstream chemicals industry, 1996-2007



Source: Oxford Economics, uktradeinfo.com

Over the past decade, the upstream industry has been one of the UK's highest exporting industries, ranking just behind the electrical and optical equipment industry[201], and accounting for around 15% of UK export of goods each year, and around 11% of UK imported goods. In terms of the size of exports, the upstream industry is comparable with that of the UK's transport equipment sector (defined as SIC codes 34 and 35 and comprising motor vehicles, water transport and aircraft).

Within the UK, the pharmaceuticals industry is consistently in the top three industrial sectors in terms of trade surplus[202], while over the past two years it has ranked at number 1 (see Figure 4-8). The chemical materials and products industry, another component of the upstream chemicals industry, also features highly. Industries that are internationally competitive are more likely to show a trade surplus and be affected by the general macroeconomic environment such as exchange rates and international demand. Importantly, an industry with a trade surplus will also make a positive contribution to the UK's balance of trade and hence UK GDP.

Trade surplus rankings by detailed industry sectors, 2007 and 2008

	2007				2008			
	Value of exports £m	Value of imports £m	Trade surplus £m	Rank 2007	Value of exports £m	Value of imports £m	Trade surplus £m	Rank 2008
Medicinal & pharmaceutical products	14,632	10,245	4,388	1	17,266	11,266	6,000	1
Power generating machinery & equipment	13,581	9,944	3,637	2	15,009	11,937	3,072	2
Machinery specialized for particular industries	7,242	5,831	1,411	3	7,798	5,925	1,873	3
Chemical materials & products not elsewhere specified)	3,835	2,738	1,098	4	4,310	3,517	794	4
Non-ferrous metals	5,792	6,407	-615	5	6,844	6,561	283	5
Source: https://www.uktradeinfo.com/index.cfm?task=annualTrade								

[201] As defined as SIC codes 30 to 33, a group that includes the manufacture of office machinery, radio, television and communication equipment, and medical and optical equipment.
[202] http://www.abpi.org.uk/statistics/section.asp?sect=2#29

Annex 7: The economic significance of R&D

The UK Department for Business, Innovation and Skills identifies five different methods by which R&D activity enhances the productivity of the firm or sector that invests in it:

- R&D plays an important role in the innovation process. It results in the technology that brings new products and services to the marketplace or underpins better and more efficient processes, thereby facilitating improved productivity.
- International research has repeatedly demonstrated the positive links between levels of R&D investment, productivity and economic performance.
- Accordingly, the long-term prosperity of the UK economy depends critically on the level of productivity that it achieves: how many goods and services it can produce per person employed. The higher its productivity, the greater are the resources available to society as a whole and the higher are living standards.
- International research has consistently demonstrated the positive correlation between R&D investment intensity and company performance measures such as sales growth and share price in the sectors where R&D is important.
- Businesses are in a better position to achieve and maintain competitive advantage in the increasingly global marketplace with sustained R&D and other related investment at the right levels.

Enhanced firm and sector productivity means businesses are able to pay their workforce higher salaries and shareholders higher dividends, whilst generating higher profits. But not all of the benefits of that R&D spending are *'private'* - i.e. captured by the innovator. Instead some of the technological advances and innovations *spill-over* to other businesses and sectors, improving their competitiveness, reducing their costs, and subsequently boosting the performance of the wider economy. *Social returns* are the benefits from R&D captured by the whole economy from both the private return and the spill-over return.

Academic studies show that the 'spill-over' benefits from R&D can be very large, with R&D investment generating a social return of around 50-100 %. They show that for every £100 million invested in R&D one can expect – over the long term - an increase in GDP of £50-100 million each and every year. (Figure 2-1).

Figure 2-1: Estimates of private and social returns to R&D

Author (year)	Estimated private rate of return (%)	Estimated social rate of return (%)
Terleckyj (1974)	29	48-78
Mansfield (1977)	25	56
Sveikauskas (1981)	10-25	50
Scherer (1984)	29-43	64-147
Berstein & Nadiri (1988)	9-27	10-160
Goto-Suzuki (1989)	26	80
Berstein & Nadiri (1991)	14-28	20-110
Nadiri (1993)	20-30	50
Average	**25**	**70**
Source: DTI Economics Paper 5: DTI Strategy - The Analysis, November 2003, page 17[203]		

A previous study by Oxford Economics conducted an econometric analysis of the spillovers from R&D expenditure by sector[204]. This study examined the private and social returns to R&D spending created by R&D activity in seven sectors, including the upstream chemicals sector, all selected due to their high level of R&D activity (see Figure).

Overall long-run impact from an increase in UK R&D by sector

Sector	Private return %	Spillover return (%)	Social return %
Chemicals (including pharma.)	25	40	65
Aerospace	10	59	69
Machinery and equipment	6	0	6
Motor Vehicles	12	0	12
Radio and television equipment	20	34	54
Precision equipment	8	64	72
Manufacturing	18	29	47
Econometric analysis of R&D spillovers by sector. Oxford Economics, (2006).			

The results show that the upstream chemicals sector generated the highest private rate of return of the seven sectors analysed reflecting the strong patenting system operating within the sector that helps businesses capture the benefits from their own R&D expenditure. **The upstream chemicals**

[203] http://www.berr.gov.uk/files/file14768.pdf
[204] Econometric analysis of R&D spillovers by sector. Oxford Economics, (2006).

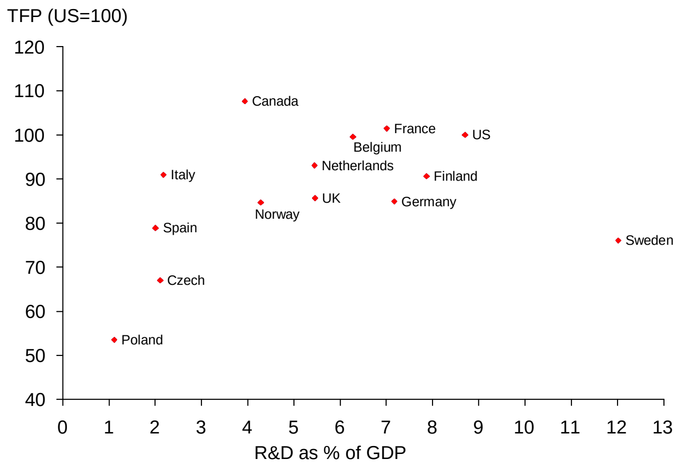
sector creates a high level of spillover returns of 40 % to generate a social rate of return of 65 %, just behind the precision equipment and aerospace sectors.

The academic literature highlights several channels through which R&D benefits flow between companies and to other sectors, with supply chain relationships thought to be particularly important. Examples include:

- Sale of products embodying new technology;
- migration of staff from one firm to another;
- access to intellectual capital (for example collaborative research or university links);
- supplier development activities by larger businesses; and,
- other transfers of know-how through interlocking supply chains, knowledge sharing or imitation.

Figure 2-2 illustrates the spillover benefits that result from R&D investment. It shows the general relationship between R&D investment and underlying productivity performance in the manufacturing sector, as measured by Total Factor Productivity (TFP). Countries that are close to the top of the league in terms of high manufacturing productivity (e.g. the US, France and Belgium) tend also to be close to the top of the league in terms of total R&D spending as a proportion of GDP; countries near the bottom of the productivity league (e.g. Czech Republic, Poland and Spain) tend to be near the bottom of the R&D league tables as well.

Figure 2-2: R&D spending and total factor productivity



Source: Oxford Economics/Haver Analytics

Annex 8: Sector calculation tables

All sectors comparison with constant price GDP 2007

	GDP Weighting	GDP 2007 (current prices, £m)	GDP 2007 (2005 prices, £m)	Total employment (000s)	Weighted		
					GDP 2007 (current prices, £m)	GDP 2007 (2005 prices, £m)	Employment (000s)
Aerospace	100%	7,644	6,780	107	7,644	6,780	107
Automotive	100%	9,271	8,223	166	9,271	8,223	166
Construction	41%	90,976	84,665	1,711	37,461	34,862	741
Electronics	88%	15,792	16,361	322	13,932	14,434	279
Energy	44%	18,038	13,565	82	8,004	6,019	32
Extraction	100%	25,196	24,605	22	25,196	24,605	22
Farming	93%	7,894	6,116	79	7,316	5,669	69
Food & Drink	95%	22,206	21,887	420	21,096	20,793	399
Forestry & Paper	53%	3,355	4,513	78	1,787	2,404	40
Health[1]	90%		84,363	3,256		76,008	2,933
Home & Personal Care	82%	6,657	6,044	181	5,435	4,935	148
Packaging	100%	1,021	970	26	1,021	970	26
Printing	30%	15,418	16,277	327	4,625	4,883	98
Textiles	100%	3,043	3,783	69	3,043	3,783	69
Water	100%	8,695	7,561	52	8,695	7,561	52
Total Downstream		**235,206**	**305,714**	**6,898**	**154,525**	**221,927**	**5,181**
Total Upstream impact			**36,500**	**824**		**36,500**	**824**
Total Impact						**258,427**	**6,005**

Notes:

1. Where available, the 2007 current/nominal price GDP data are taken from the Annual Business Inquiry (Release date 16/06/2009). The exceptions to this are the healthcare industry (where we have utilised Government figures, which are reported in constant prices, therefore no applicable current price value is presented in the table) and farming (where we have used HMT Blue Book data as the ABI severely underestimates the size of the sector). Data in this column corresponds to the tables below.
2. The 2007 GDP in constant 2005 prices values are the result of both adjustments made for changes of prices in each sector, and scaling to ensure all values are consistent with the 2009 Blue Book. 2005 has been chosen as the base year as this is the current base for ONS GDP values.
3. The constant price weighted GDP and weighted employment values are those presented in Figure 3-5 and in each case study.

Aerospace

SIC code	Description	Examples	Score	GDP 2007 (current prices, £m)	GDP 2007 (2005 prices, £m)	Total employment (000s)	Weighted GDP (2007 current prices, £m)	Weighted GDP 2007 (2005 prices, £m)	Weighted Employment (000s)
34.1	Manufacture of aircraft and spacecraft	Composite materials, use of chemical additives, insulating materials	1.00	7,644	6,780	107	7,644	6,780	107
34	**Total aerospace**		**1.00**	**7,644**	**6,780**	**107**	**7,644**	**6,780**	**107**

Note: *= data withheld by ONS to protect company confidentiality , - = zero

Automotive

SIC code	Description	Examples	Score	GDP 2007 (current prices, £m)	GDP 2007 (2005 prices, £m)	Total employment (000s)	Weighted GDP (2007 current prices, £m)	Weighted GDP 2007 (2005 prices, £m)	Weighted Employment (000s)
34.1	Manufacture of motor vehicles	Use of PET in tyres, polyester in seats, seat belts, airbags, fan belts, chemicals in paints, oils and lubricants	1.00	5,471	4,853	74	5,471	4,853	74
34.2	Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers	Use of PET in tyres, polyester in seats, seat belts, airbags, fan belts, chemicals in paints, oils and lubricants	1.00	824	731	24	824	731	24
34.3	Manufacture of parts and accessories for motor vehicles and their engines	Use of PET in tyres, polyester in seats, seat belts, airbags, fan belts, chemicals in paints, oils and lubricants	1.00	2,976	2,640	68	2,976	2,640	68
34	**Total automotive**		**1.00**	**9,271**	**8,223**	**166**	**9,271**	**8,223**	**166**

Note: *= data withheld by ONS to protect company confidentiality , - = zero

Construction

SIC code	Description	Examples	Score	GDP 2007 (current prices, £m)	GDP 2007 (2005 prices, £m)	Total employment (000s)	Weighted GDP (2007 current prices, £m)	Weighted GDP 2007 (2005 prices, £m)	Weighted Employment (000s)
45.11	Demolition and wrecking of buildings; earth moving		0	1,104	1,027	23	0	0	0
45.12	Test drilling and boring	Lubricants	0.3	87	81	1	26	24	0
45.21	General construction of buildings and civil engineering work	Use of chemical additives/plastics	0.3	36,608	34,068	561	10,982	10,221	168
45.22	Erection of roof covering and frames	Use of chemical additives/plastics	0.3	2,091	1,946	39	627	584	12
45.23	Construction of highways, roads, airfields & sports facilities	Use of chemical additives/plastics	0.3	2,061	1,918	44	618	575	13
45.24	Construction of water projects	Use of chemical additives/plastics	0.3	256	238	3	77	71	1
45.25	Other construction work involving special trades	Use of chemical additives/plastics	0.3	6,209	5,778	112	1,863	1,733	34
45.31	Installation of electrical wiring and fittings	Insulation in wiring	1.00	9,677	9,006	203	9,677	9,006	203
45.32	Insulation work activities	Use of chemical additives/plastics	0.3	822	765	21	247	229	6
45.33	Plumbing	Lubricants and plastics	0.3	5,277	4,911	120	1,583	1,473	36
45.34	Other building installation	Use of chemical additives/plastics	0.3	1,518	1,413	39	455	424	12
45.41	Plastering	Use of chemical additives	0.3	1,036	964	18	311	289	5
45.42	Joinery installation	Use of chemical additives/plastics	0.3	3,658	3,404	75	1,097	1,021	23
45.43	Floor or wall covering	Use of chemical additives/plastics	0.3	1,260	1,173	25	378	352	8
45.44	Painting and glazing	Use of chemical additives/plastics	0.3	2,683	2,497	67	805	749	20
45.45	Other building completion	Use of chemical additives/plastics	0.3	2,517	2,342	61	755	703	18
45.5	Renting of construction or demolition equipment with operator		0	1,042	970	18	0	0	0
25.11	Manufacture of rubber tyres and tubes	Use of chemical additives/plastics	0.3	504	469	6	151	141	2

25.12	Retreading and rebuilding of rubber tyres	Use of chemical additives/plastics	0.3	30	28	1	9	8	0
25.13	Manufacture of other rubber products	Use of chemical additives/plastics	0.3	722	672	18	217	202	5
25.21	Manufacture of plastic plates, sheets, tubes & profiles	Use of chemical additives/plastics	1.00	1,545	1,438	33	1,545	1,438	33
25.23	Manufacture of builders' ware of plastic	Use of chemical additives/plastics	1.00	2,278	2,120	56	2,278	2,120	56
25.24	Manufacture of other plastic products	Use of chemical additives/plastics	1.00	1,945	1,810	51	1,945	1,810	51
26.11	Manufacture of flat glass	Use of chemical additives/plastics	0.3	133	124	1	40	37	0
26.12	Shaping and processing of flat glass	Use of chemical additives/plastics	0.3	656	610	15	197	183	5
26.13	Manufacture of hollow glass	Use of chemical additives/plastics	0.3	214	199	5	64	60	2
26.14	manufacture of glass fibres	Use of chemical additives/plastics	0.3	234	218	3	70	65	1
26.15	Manufacture and processing of other glass including technical glassware	Use of chemical additives/plastics	0.3	110	102	3	33	31	1
26.21	Manufacture of ceramic household and ornamental articles	Use of chemical additives	0.3	185	172	7	56	52	2
26.22	Manufacture of ceramic sanitary fixtures	Use of chemical additives	0.3	165	154	3	50	46	1
26.23	Manufacture of ceramic insulators and insulating fittings	Use of chemical additives	0.3	*	0	*	0	0	0
26.24	Manufacture of other technical ceramic products	Use of chemical additives	0.3	*	0	*	0	0	0
26.25	Manufacture of other ceramic products	Use of chemical additives	0.3	15	14	1	5	4	0
26.26	Manufacture of refractory ceramic products	Use of chemical additives	0.3	141	131	4	42	39	1
26.3	Manufacture of ceramic tiles and flags	Use of chemical additives	0.3	70	65	2	21	20	1
26.4	Manufacture of bricks, tiles and construction products, in baked clay	Use of chemical additives	0.3	425	396	9	128	119	3
26.5	Manufacture of cement, lime and plaster	Use of chemical additives	0.3	488	454	6	146	136	2

26.61	Manufacture of concrete products for construction purposes	Use of chemical additives	0.3	1,241	1,155	25		372	346	8
26.62	Manufacture of plaster products for construction purposes	Use of chemical additives	0.3	504	469	2		151	141	1
26.63	Manufacture of ready-mixed concrete	Use of chemical additives	0.3	739	688	12		222	206	4
26.64	Manufacture of mortars	Use of chemical additives	0.3	*	0	*		0	0	0
26.65	Manufacture of fibre cement	Use of chemical additives	0.3	*	0	*		0	0	0
26.66	Manufacture of other articles of concrete, plaster & cement	Use of chemical additives	0.3	67	62	2		20	19	1
26.7	Cutting, shaping and finishing of stone	Use of chemical additives	0.3	292	272	9		88	82	3
26.81	Production of abrasive products	Use of chemical additives	0.3	58	54	2		17	16	1
26.82	Manufacture of other non-metallic mineral products	Use of chemical additives	0.3	309	288	5		93	86	2
25 / 26 / 45	**Total Construction**		**0.41**	**90,976**	**84,665**	**1,711**		**37,461**	**34,862**	**741**

Note: *= data withheld by ONS to protect company confidentiality , - = zero

Electronics

SIC code	Description	Examples	Score	GDP 2007 (current prices, £m)	GDP 2007 (2005 prices, £m)	Total employment (000s)	Weighted		
							GDP (2007 current prices, £m)	GDP 2007 (2005 prices, £m)	Employment (000s)
30.01	Manufacture of office machinery	Semiconductor manufacture	1.00	397	411	8	397	411	8
30.02	Manufacture of computers and other information processing equipment	Semiconductor manufacture	1.00	880	912	17	880	912	17
31.1	Manufacture of electric motors, generators and transformers	New materials + insulating materials	0.6	1,105	1,145	22	663	687	13
31.2	Manufacture of electricity distribution & control apparatus	New materials + insulating materials	0.6	1,366	1,415	35	820	849	21
31.3	Manufacture of insulated wire and cables	New materials + insulating materials	1.00	414	429	9	414	429	9
31.4	Manufacture of accumulators, primary cells and primary batteries	Insulating materials	1.00	153	159	3	153	159	3
31.5	Manufacture of lighting equipment and electric lamps	New lighting technologies	0.6	643	666	18	386	400	11
31.61	Manufacture of electrical equipment for engines and vehicles nec	New lighting technologies	0.6	378	392	8	227	235	5
31.62	Manufacture of electrical equipment nec	New lighting technologies	0.6	1,158	1,200	25	695	720	15
32.1	Manufacture of electronic valves and tubes and other electronic components	Semiconductor manufacture	1.00	1,229	1,273	26	1,229	1,273	26
32.2	Manufacture of television and radio transmitters and apparatus for line telephony and line telegraphy	Semiconductor manufacture+new materials and insulation	1.00	1,547	1,603	21	1,547	1,603	21
32.3	Manufacture of television and radio receivers, sound or video recording or reproducing apparatus and associated goods	Semiconductor manufacture+new materials and insulation	1.00	676	700	14	676	700	14

33.1	Manufacture of medical and surgical equipment and orthopaedic appliances	Semiconductor manufacture+new materials and insulation	1.00	1,596	1,654	35	1,596	1,654	35
33.2	Manufacture of instruments and appliances for measuring, checking, testing, navigating and other purposes except industrial process control equipment	Semiconductor manufacture+new materials and insulation	1.00	3,012	3,121	56	3,012	3,121	56
33.3	Manufacture of industrial process control equipment	Semiconductor manufacture+new materials and insulation	1.00	476	493	10	476	493	10
33.4	Manufacture of optical instruments and photographic equipment	Semiconductor manufacture+new materials and insulation	1.00	712	738	14	712	738	14
33.5	Manufacture of watches and clocks	Semiconductor manufacture+new materials and insulation	1.00	50	52	1	50	52	1
30 / 31 / 33	**Total Electronics**		**0.88**	**15,792**	**16,361**	**322**	**13,932**	**14,434**	**279**

Note: *= data withheld by ONS to protect company confidentiality , - = zero

Energy

SIC code	Description	Examples	Score	GDP 2007 (current prices, £m)	GDP 2007 (2005 prices, £m)	Total employment (000s)	Weighted		
							GDP (2007 current prices, £m)	GDP 2007 (2005 prices, £m)	Employment (000s)
40.11	Production of electricity	Nuclear processes - dependent on uranium purified using chemical processes?	0.3	7,261	5,461	32	2,178	1,638	10
40.12	Transmission of electricity	chemistry in wires	1.00	3,703	2,785	11	3,703	2,785	11
40.13	Distribution and trade in electricity	chemistry in wires	0.3	7,074	5,320	39	2,122	1,596	12
40.2	Manufacture of gas; distribution of gaseous fuels through mains	Use of chemical processes and additives	0.3	*		*	0		0
40	**Total Energy**		**0.44**	**18,038**	**13,565**	**82**	**8,004**	**6,019**	**32**

Note: *= data withheld by ONS to protect company confidentiality , - = zero

Extraction and Production of Petrol

SIC code	Description	Examples	Score	GDP 2007 (current prices, £m)	GDP 2007 (2005 prices, £m)	Total employment (000s)	Weighted		
							GDP (2007 current prices, £m)	GDP 2007 (2005 prices, £m)	Employment (000s)
11.1	Extraction of crude petroleum and natural gas	Lubricants for drilling, polymers for enhanced extraction	1.00	22,719	22,186	13	22,719	22,186	13
23.2	Manufacture of refined petroleum products	entire refining process relies on chemistry	1.00	2,477	2,419	9	2,477	2,419	9
11 / 23	**Total Extraction and Production of Petrol**		**1.00**	**25,196**	**24,605**	**22**	**9,293**	**9,075**	**13**

Note: *= data withheld by ONS to protect company confidentiality , - = zero

Farming

SIC code	Description	Examples	Score	GDP 2007 (current prices, £m)	GDP 2007 (2005 prices, £m)	Total employment (000s)	Weighted GDP (2007 current prices, £m)	Weighted GDP 2007 (2005 prices, £m)	Weighted Employment (000s)
01 (Part)	Agriculture, hunting and related service activities	Dependence on fertilisers, fungicides, herbicides and insecticides. Not 100% as removed aspect of (i) organic farming (3.9%) and (ii) hunting, trapping and game propagation	0.95	7,553	5,852	68	7,175	5,559	65
05.01	Fishing		0.3	212	164	8	64	49	2
05.02	Operation of fish hatcheries and fish farms		0.6	129	100	3	77	60	2
01	**Total Farming**		**0.93**	**7,894**	**6,116**	**79**	**7,316**	**5,669**	**69**

Note: *= data withheld by ONS to protect company confidentiality , - = zero
A 0.95 weighting is given to agriculture to account for the 5% share which is organic farming (Source: Defra).

Food & Drink

SIC code	Description	Examples	Score	GDP 2007 (current prices, £m)	GDP 2007 (2005 prices, £m)	Total employment (000s)	Weighted		
							GDP (2007 current prices, £m)	GDP 2007 (2005 prices, £m)	Employment (000s)
15.1	Production, processing and preserving of meat and meat products	Additives and preservatives	0.95	3,143	3,098	99	2,986	2,943	94
15.2	Processing and preserving of fish and fish products	Additives and preservatives	0.95	579	571	17	550	542	16
15.31	Processing and preserving of potatoes	Additives and preservatives	0.95	625	616	10	594	585	10
15.32	Manufacture of fruit and vegetable juice	Additives and preservatives	0.95	58	57	2	55	54	2
15.33	Processing and preserving of fruit and vegetables nec	Additives and preservatives	0.95	972	958	25	923	910	24
15.4	Manufacture of vegetable and animal oils and fats	Additives and preservatives	0.95	130	128	1	124	122	1
15.51	Operation of dairies and cheese making	Additives and preservatives	0.95	1,171	1,154	23	1,112	1,096	22
15.52	Manufacture of ice cream	Additives and preservatives	0.95	156	154	3	148	146	3
15.61	Manufacture of grain mill products	Additives and preservatives	0.95	1,045	1,030	*	993	978	0
15.62	Manufacture of starches and starch products	Additives and preservatives	0.95	83	82	*	79	78	0
15.71	Manufacture of prepared feeds for farm animals	Additives and preservatives	0.95	374	369	8	355	350	8
15.72	Manufacture of prepared pet foods	Additives and preservatives	0.95	473	466	4	449	443	4
15.81	Manufacture of bread; fresh pasty goods & cakes	Additives and preservatives	0.95	2,112	2,082	76	2,006	1,978	72
15.82	Manufacture of rusks and biscuits; preserved pastry goods and cakes	Additives and preservatives	0.95	1,424	1,404	32	1,353	1,333	30
15.83	Manufacture of sugar	Additives and preservatives	0.95	*	0	*	0	0	0
15.84	Manufacture of cocoa, chocolate and sugar confectionery	Additives and preservatives	0.95	2,459	2,424	24	2,336	2,302	23

15.85	Manufacture of macaroni, noodles, couscous etc	Additives and preservatives	0.95	*	0	*	0	0	0
15.86	Processing of tea and coffee	Additives and preservatives	0.95	705	695	7	670	660	7
15.87	Manufacture of condiments and seasonings	Additives and preservatives	0.95	320	315	7	304	300	7
15.88	Manufacture of homogenised food and dietetic food	Additives and preservatives	0.95	-	0	-	0	0	0
15.89	Manufacture of other food products nec	Additives and preservatives	0.95	1,436	1,415	32	1,364	1,345	30
15.91	Manufacture of distilled potable alcoholic beverages	Additives and preservatives	0.95	2,100	2,070	11	1,995	1,966	10
15.92	Production of ethyl alcohol from fermented materials	Additives and preservatives	0.95	*	0	*	0	0	0
15.96	Manufacture of beer	Additives and preservatives	0.95	495	488	16	470	463	15
15.97	Manufacture of malt	Additives and preservatives	0.95	87	86	1	83	81	1
15.98	Manufacture of mineral waters and soft drinks	Additives and preservatives	0.95	1,016	1,001	17	965	951	16
16	Manufacture of tobacco products	Additives and preservatives	0.95	1,243	1,225	5	1,181	1,164	5
15 / 16	**Total Food & Drink**		**0.95**	**22,206**	**21,887**	**420**	**21,096**	**20,793**	**399**

Note: *= data withheld by ONS to protect company confidentiality , - = zero
A 0.95 weighting is given to food and drink to allow for food and drink products prepared organically and without chemicals (Source: Defra).

Forestry and Paper

SIC code	Description	Examples	Score	GDP 2007 (current prices, £m)	GDP 2007 (2005 prices, £m)	Total employment (000s)	Weighted GDP (2007 current prices, £m)	Weighted GDP 2007 (2005 prices, £m)	Weighted Employment (000s)
02.01	Forestry & logging	N/A	0	313	421	11	0	0	0
02.02	Forestry and logging related service activities	N/A	0	64	86	1	0	0	0
21.1	Manufacture of pulp, paper and paperboard	Pigments, particle retention systems, carbonless copy paper	0.6	824	1,108	12	494	665	7
21.21	Manufacture of corrugated paper and paperboard and of containers of paper and paperboard	Pigments, particle retention systems, carbonless copy paper	0.6	1,151	1,548	31	691	929	19
21.22	Manufacture of household and sanitary goods and of toilet requisites	Pigments, particle retention systems, carbonless copy paper	0.6	450	605	8	270	363	5
21.23	Manufacture of paper stationery	Pigments, particle retention systems, carbonless copy paper	0.6	153	206	5	92	123	3
21.24	Manufacture of wallpaper	Pigments, particle retention systems, carbonless copy paper	0.6	46	62	1	28	37	1
21.25	Manufacture of other articles of paper and paperboard nec	Pigments, particle retention systems, carbonless copy paper	0.6	354	476	9	212	286	5
2 / 21	**Total Forestry and Paper**		**0.53**	**3,355**	**4,513**	**78**	**1,787**	**2,404**	**40**

Note: *= data withheld by ONS to protect company confidentiality , - = zero

Health

SIC code	Description	Examples	Score	GDP 2007 (current prices, £m)	GDP 2007 (2005 prices, £m)	Total employment (000s)	Weighted		
							GDP (2007 current prices, £m)	GDP 2007 (2005 prices, £m)	Employment (000s)
85.11	Hospital activities	medical and surgical technical care activities such as diagnosis, treatment, operations, analyses, emergency activities, etc	1.00	6,375	0	301	6,375	0	301
85.14	Other human health activities	activities of nurses, midwives, physiotherapists or others in the field of optometry, hydrotherapy, medical massage, occupational therapy, speech therapy, chiropody, homeopathy, chiropractic, acupuncture and the like	0.6	2,333	0	266	1,400	0	160
85.2	Veterinary activities	activities are carried out by qualified veterinarians in veterinary hospitals as well as when visiting farms, kennels or homes, in own consulting and surgery rooms or elsewhere.	1.00	1,273	0	41	1,273	0	41
85.3	Social work activities	activities provided on a round-the-clock basis directed to provide social assistance to children, the aged and special categories of persons with some limits on ability for self-care, but where medical treatment or education are not important elements	0	7,422	0	575	0	0	0
5	**Total Health**		**0.24**	**11,028**	**0**	**1,183**	**2,673**	**0**	**502**
	Health sector	**Blue Book Estimate**	**0.90**		**84,363**	**3,256**	**76,008**	**0**	**2,933**

NB: Health sector GDP from the ABI, above, does not include government spending and employment in the NHS – which represents the majority of the health sector in the UK Therefore to fully capture the health sector we use GVA estimates from the Blue Book (source: ONS 2009 Blue Book) (capturing both the private and public health sector), and employment data from both the ABI and the ONS Public Sector employment statistics

Home and personal care

SIC code	Description	Examples	Score	GDP 2007 (current prices, £m)	GDP 2007 (2005 prices, £m)	Total employment (000s)	Weighted GDP (2007 current prices, £m)	Weighted GDP 2007 (2005 prices, £m)	Weighted Employment (000s)
36.11	Manufacture of chairs and seats	polymers/foams/flame retardants - Polyurethane - Foams, seals, tires, adhesives and sealants, textiles (e.g. spandex)	1.00	959	871	27	959	871	27
36.12	Manufacture of other office and shop furniture	polymers/foams/flame retardants - Polyurethane - Foams, seals, tires, adhesives and sealants, textiles (e.g. spandex)	1.00	866	786	19	866	786	19
36.13	Manufacture of other kitchen furniture	polymers/foams/flame retardants - Polyurethane - Foams, seals, tires, adhesives and sealants, textiles (e.g. spandex)	1.00	648	588	18	648	588	18
36.14	Manufacture of other furniture	polymers/foams/flame retardants - Polyurethane - Foams, seals, tires, adhesives and sealants, textiles (e.g. spandex)	1.00	1,587	1,441	44	1,587	1,441	44
36.15	Manufacture of mattresses	polymers/foams/flame retardants - Polyurethane - Foams, seals, tires, adhesives and sealants, textiles (e.g. spandex)	1.00	232	211	8	232	211	8
36.21	Striking of coins and medals	New materials	0.3	*	0	*	0	0	0
36.22	Manufacture of jewellery and related articles nec	New materials	0.3	*	0	*	0	0	0
36.3	Manufacture of musical instruments	New materials	0.3	37	34	1	11	10	0
36.4	Manufacture of sports goods	New materials	0.6	167	152	6	100	91	4
36.5	Manufacture of games and toys	New materials	0.3	161	146	5	48	44	2
36.6	Miscellaneous manufacturing nec	New materials	0.3	1,296	1,177	32	389	353	10

29.71	Manufacture of electric domestic appliances	Insulating materials	1.00	548	498	15	548	498	15
29.72	Manufacture of non-electric domestic appliances	New materials	0.3	156	142	6	47	42	2
29 / 36	**Total home and personal care**		**0.82**	**6,657**	**6,044**	**181**	**5,435**	**4,935**	**148**

Note: *= data withheld by ONS to protect company confidentiality , - = zero

Packaging

SIC code	Description	Examples	Score	GDP 2007 (current prices, £m)	GDP 2007 (2005 prices, £m)	Total employment (000s)	Weighted		
							GDP (2007 current prices, £m)	GDP 2007 (2005 prices, £m)	Employment (000s)
25.22	Manufacture of plastic packing goods	Use of chemistry in plastics	1.00	1,021	970	26	1,021	970	26
25	**Total packaging**		**1.00**	**1,021**	**970**	**26**	**1,021**	**970**	**26**

Note: *= data withheld by ONS to protect company confidentiality , - = zero

Printing and publishing

SIC code	Description	Examples	Score	GDP 2007 (current prices, £m)	GDP 2007 (2005 prices, £m)	Total employment (000s)	Weighted GDP (2007 current prices, £m)	Weighted GDP 2007 (2005 prices, £m)	Weighted Employment (000s)
22.11	Publishing of books	Use of chemical additives	0.3	1,354	1,429	30	406	429	9
22.12	Publishing of newspapers	Use of chemical additives	0.3	2,894	3,055	52	868	917	16
22.13	Publishing of journals and periodicals	Use of chemical additives	0.3	3,950	4,170	64	1,185	1,251	19
22.14	Publishing of sound recordings	Use of chemical additives	0.3	179	189	3	54	57	1
22.15	Other publishing	Use of chemical additives	0.3	659	696	21	198	209	6
22.21	Printing of newspapers	Inks etc	0.3	78	82	2	23	25	1
22.22	Printing not elsewhere classified	Inks etc	0.3	5,117	5,402	127	1,535	1,621	38
22.23	Bookbinding and finishing	Use of chemical additives	0.3	212	224	6	64	67	2
22.24	Composition and plate-making	Etching chemicals	0.3	205	216	4	62	65	1
22.25	Other activities related to printing	Use of chemical additives	0.3	507	535	12	152	161	4
22.31	Reproduction of sound recording	Chemistry role in electronics and ICT	0.3	173	183	3	52	55	1
22.32	Reproduction of video recording	Chemistry role in electronics and ICT	0.3	72	76	2	22	23	1
22.33	Reproduction of computer media	Chemistry role in electronics and ICT	0.3	18	19	1	5	6	0
22	**Total Printing and publishing**		**0.3**	**15,418**	**16,277**	**327**	**4,625**	**4,883**	**98**

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Textiles

SIC code	Description	Examples	Score	GDP 2007 (current prices, £m)	GDP 2007 (2005 prices, £m)	Total employment (000s)	Weighted		
							GDP (2007 current prices, £m)	GDP 2007 (2005 prices, £m)	Employment (000s)
17.11	Preparation and spinning of cotton-type fibres	Artificial fibres/dyes	1.00	6	7	-	6	7	0
17.12	Preparation and spinning of woollen-type fibres	Artificial fibres/dyes	1.00	87	108	2	87	108	2
17.13	Preparation and spinning of worsted-type fibres	Artificial fibres/dyes	1.00	15	19	1	15	19	1
17.14	Preparation and spinning of flax-type fibres	Artificial fibres/dyes	1.00	-	0	-	0	0	0
17.15	Throwing and preparation of silk and throwing of synthetic or artificial filament yarns	Artificial fibres/dyes	1.00	*	0	*	0	0	0
17.16	Manufacture of sewing threads	Artificial fibres/dyes	1.00	10	12	-	10	12	0
17.17	Preparation and spinning of other textile fibres	Artificial fibres/dyes	1.00	*	0	*	0	0	0
17.21	Cotton-type weaving	Artificial fibres/dyes	1.00	33	41	2	33	41	2
17.22	Woollen-type weaving	Artificial fibres/dyes	1.00	39	48	2	39	48	2
17.23	Worsted-type weaving	Artificial fibres/dyes	1.00	44	55	1	44	55	1
17.24	Silk-type weaving	Artificial fibres/dyes	1.00	126	157	3	126	157	3
17.25	Other-type weaving	Artificial fibres/dyes	1.00	23	29	-	23	29	0
17.4	Manufacture of made-up textile articles except apparel	Artificial fibres/dyes	1.00	587	730	..	587	730	0
17.51	Manufacture of carpets and rugs	Artificial fibres/dyes	1.00	337	419	8	337	419	8
17.52	Manufacture of cordage, rope, twine and netting	Artificial fibres/dyes	1.00	44	55	1	44	55	1
17.53	Manufacture of non-wovens and articles made from non-wovens except apparel	Artificial fibres/dyes	1.00	40	50	1	40	50	1
17.54	Manufacture of other textiles nec	Artificial fibres/dyes	1.00	332	413	8	332	413	8

17.6	Manufacture of knitted and crocheted fabrics	Artificial fibres/dyes	1.00	51	63	1	51	63	1
17.7	Manufacture of knitted and crocheted articles	Artificial fibres/dyes	1.00	144	179	7	144	179	7
18.1	Manufacture of leather clothes	Artificial fibres/dyes	1.00	*	0	*	0	0	0
18.21	Manufacture of work wear	Artificial fibres/dyes	1.00	169	210	5	169	210	5
18.22	Manufacture of other outerwear	Artificial fibres/dyes	1.00	498	619	11	498	619	11
18.23	Manufacture of underwear	Artificial fibres/dyes	1.00	143	178	5	143	178	5
18.24	Manufacture of other wearing apparel and accessories nec	Artificial fibres/dyes	1.00	315	392	11	315	392	11
18.3	Dressing and dyeing of fur; manufacture of articles of fur	Artificial fibres/dyes	1.00	*	0	*	0	0	0
17-18	**Total textiles**		**1.00**	**3,043**	**3,783**	**69**	**3,043**	**3,783**	**69**

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Water

SIC code	Description	Examples	Score	GDP 2007 (current prices, £m)	GDP 2007 (2005 prices, £m)	Total employment (000s)	Weighted		
							GDP (2007 current prices, £m)	GDP 2007 (2005 prices, £m)	Employment (000s)
41	Collection, purification and distribution of water	Purification chemicals, osmosis	1.00	4,082	3,220	29	4,082	3,220	29
90.01	Collection and treatment of sewage	Purification chemicals, osmosis	1.00	4,613	4,341	23	4,613	4,341	23
41	**Total Water**		**1.00**	**8,695**	**7,561**	**52**	**4,082**	**7,561**	**52**

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