Can the UK afford (not) to produce chemicals in 2050?

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Contents (use the hyperlinks to navigate directly to the start of specific sections)

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Abbreviations and other terminology used in this report

* **BIS:** the Department for Business Innovation and Skills
* **CA:** Copenhagen Accord (2009)
* **CCA:** Climate Change Act (2008)
* **CCAs:** Climate Change Agreements
* **CCL:** Climate Change Levy
* **CCS:** Carbon capture and storage
* **CHP:** Combined heat and power
* **COGA:** Combined Off Gas Abatement
* **ETSAP:** Energy Technology System Analysis Programme
* **EU ETS:** EU Emissions Trading System
* **EU RED:** EU Renewable Energy Directive
* **GDP:** Gross Domestic Product
* **ICCA:** International Council of Chemical Associations
* **IRENA:** International Renewable Energy Agency
* **NEPIC:** Northeast of England Process Industry Cluster
* **OECD:** the Organisation for Economic Co-operation and Development
* **Ofgem:** Office of the Gas and Electricity Markets
* **RHI:** Renewable Heat Incentive
* **ROCs:** Renewable Obligations
* **SIC:** Standard Industrial Classification
* **UNFCCC:** United Nations Framework Convention on Climate Change

Foreword

The Chemical and Process industry in the UK is the leading manufacturing export sector and underpins the advanced manufacturing sector across the economy. It is an essential part of any attempt to move to a low-carbon advanced economy. But in playing this role in the UK and within the EU it is exposed to a number of challenges, which government and companies need to meet if its contribution to society is to be maintained.

Despite having made substantial improvements to its energy efficiency – some 35% between 1990 and 2006 – and its products contributing to reducing emissions elsewhere in the economy, the UK industry cannot tackle climate change alone. Neither can the EU. A global agreement is needed alongside other policy measures and approaches by industry and government here in the UK. Only by working in partnership can investment and innovations be secured which will retain a competitive industrial base in the UK in the face of a rapidly changing energy cost and supply situation.

This report highlights the role of the industry, the issue of carbon leakage and what are some of the responses to the goal of reducing carbon emissions. It sets out the challenges. What we need now is a long-term strategy to respond if we are to see both a rebalanced economy and a low-carbon one which has not just exported its emissions.

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Executive summary

The UK chemical industry contributes significantly to the economy, but faces increasing pressure from overseas competitiveness

The UK chemical industry is a substantial part of the economy in terms of turnover, employment and trade. Nonetheless, the industry is struggling competitively with the Middle East and the US due to the lower costs of energy and chemical feedstocks, and with the Far East due to rising demand and cheap labour. Shale gas is increasing the US's competitiveness. **→ See section 2**

There is insufficient evidence to confirm that UK climate policy and regulation is responsible for the loss of competitiveness

Parts of the chemical industry are shutting down in the UK and relocating to other regions due to demand, locality of raw materials and production costs. This is resulting in 'weak carbon leakage' and global greenhouse gas emissions may increase accordingly. Although these regions typically have less stringent rules, or an absence of regulation and policies to address greenhouse gas emissions, evidence suggests that the industry is not relocating due to climate policy. However, the UK's climate change targets are challenging for the industry and the wider economy. Such targets could impose further pressure on competitiveness in the UK in future and lead to 'strong carbon leakage' (where an industry relocates to a region where there is specifically less, or an absence of, regulation and policies to address greenhouse gas emissions). **→ See section 5.2**

The UK's carbon footprint associated with chemicals is increasing *(consumption basis)*

The UK chemical industry's greenhouse gas emissions (from direct energy use and processes) have reduced by 70% since 1990. However, this has not been solely the result of energy efficiency improvements. The reduction in the UK's chemical industry emissions has largely been a result of the closure of production sites and/or relocation to other nations with lower production costs and energy and feedstock costs. When examining the UK's carbon footprint from a consumption-based approach, where the UK would take account of emissions produced in other nations during the manufacturing of the goods it consumes, overall emissions associated with the consumption of chemical-derived goods and commodities are likely to be increasing. **→ See section 3.5**

Industry requires substantive reductions in emission intensities to satisfy UK climate targets

The UK chemical industry is anticipated to grow in the period to 2020. Growth rates of 1-3% could mean that, with no change to emission intensity or UK chemical production mix, the chemical industry could account for 11-25% of the total UK carbon budget in 2050. To ensure that the industry reduces its emissions by 80%, the absolute growth rates would require the emission intensity to reduce by ~2-4% p.a. Historically, technically mature industries reduce emission intensity levels by 1-1.2% p.a. It is extremely unlikely that the cumulative impact of incremental or efficiency improvements would deliver the radical reductions required by the UK's carbon budgets and target. **→ See section 3.4**

Industry requires an urgent, radical rethink of how it produces chemicals

If the industry is to step up to the challenge of meeting the UK's climate targets and maintain competitiveness it will need to move beyond incremental energy efficiency improvements towards more radical, step changes. This will require significant changes to the current processes operated, with commensurately high levels of capital investment. Promising options specific to the UK industry include biomass and waste CHP or gasification for direct energy production and/or feedstock substitution; carbon capture and storage technologies; and industrial symbiosis through for example, the reuse and recycling of heat, steam and gases. However, the major barrier to such changes is that there are few incentives to invest in new, low-carbon, chemical production facilities in the UK. → **See section 6**

Reducing the carbon intensity of high grade heat requirements is challenging

The chemical industry requires large quantities of high grade heat and steam; the low-carbon provision of which is a major challenge. There are substantial quantities of low-grade heat available in many processes, and technical options (such as condensing biomass boilers) could increase this. However, these require reconfiguration of existing infrastructure, the capital cost of which is difficult to justify in the current market. For example, the recovery of low-grade heat is not presently as financially viable as maximising more valuable electrical output from a biomass boiler. Often it is assumed that the heat demand can be substantially electrified, without considering the infrastructure required for this or the difficulty in generating high pressure process-grade heat from an electrical source. → **See section 7**

Waste must be seen as a commodity for the industry

The gasification of waste is a viable option for low-carbon energy production and/or chemical feedstock substitution. However, this is unlikely to be developed while it is more economically feasible to generate electricity from waste rather than hydrogen or syngas. → **See section 7.1.1**

Carbon capture and storage technology – attractive, but not timely

Cost, an ageing asset life and a multitude of small-scale organisations which collectively emit a large amount of CO_2 have arguably halted the development of CCS technology for the UK industry. If the industry were to pursue CCS it would have to combine it with new infrastructure and plants and the timeframes for this would not be commensurate with meeting 2020 carbon targets and would be unlikely to contribute substantially prior to 2030. → **See section 7.1.3**

Demand-side emission reduction potential must be acknowledged

The sector's contribution must be seen within the context of its overall contribution (via the use of its products within supply chains) to reducing emissions. It is important, therefore, to examine how society uses and values the goods and commodities produced by the industry. In some cases carbon-intensive chemical production may be instrumental in achieving reductions in energy demand and it is important that the contribution of the UK chemical industry to achieving wider spread reductions is recognised. There is also increased interest in industrial symbiosis and decentralised use of energy, heat and fuel as a practical way forward to increase energy efficiency and minimise waste. However, industry is unwilling to be dependent on one another, due to instabilities in the UK market. The industries and potential synergies exist to reuse, for example, surplus heat and steam, but there are limited incentives and no supporting infrastructure (e.g. heat networks). → **See section 7.1.2**

Industry perceives that UK investment is stalling and the low-carbon agenda is not helping

Industry argues that there is lot of uncertainty in the UK chemical industry surrounding the low-carbon agenda. Industrial stakeholders are concerned how a future carbon price could affect investment in the UK and how energy prices are going to be further impacted by the low-carbon agenda at an EU level. When comparing UK policy to the EU, industrial stakeholders are concerned at the UK's rate of progress and feel that the more stringent carbon-related policy is handicapping the industry. Industrialists want a level playing field for the UK (in Europe). → **See section 7.2**

Fossil fuels are too valuable to burn

Fossil fuel hydrocarbons are the primary feedstock for the chemical industry and it could be argued that their value as a fixed source of carbon is much greater than their energetic value, particularly when renewable wind, wave and solar energy could help decarbonise the energy sector. However, options for decarbonised chemical feedstocks are much more limited and costly. Decisions about whether our limited use of fossil fuel emissions associated with a carbon budget should be used for the chemical industry, the transport sector (particularly aviation) or other applications are determined by the complex interplay of legislative, policy and market conditions. To date there have been few policy initiatives which have recognised the unique challenges and potential contributions from this sector – some prioritisation seems likely to be required if the UK is to achieve its carbon reduction targets and retain its valuable and strategic chemical industry. Whilst industry can make compelling arguments why it should continue to use fossil fuel as a feedstock, if the UK were to pursue this strategy it would have to be viewed in the wider context of the UK's climate agenda and the ability of the UK to decarbonise by at least 80% by 2050. → **See section 7.2.2**

1. Introduction

Within the UK, the chemical industry plays an important role in the economy, as a major exporter and as a major employer. However, it also faces challenges associated with rising raw material and fossil fuel costs which, when combined with the changing demographics of global demand for chemicals, puts increasing pressure on the UK to remain competitive. Implementing climate change targets is likely to put further constraints on the industry's ability to respond to change. The UK Government plans to reduce the UK's global greenhouse gas emissions by 80% by 2050 from 1990 levels through the legally binding 2008 Climate Change Act. There is also an interim target of a 34% reduction by 2020. Therefore, the chemical industry is being asked to significantly mitigate its emissions, focusing on the more sustainable production of key and high-emitting commodities and continuing its drive for efficiency and emissions reduction. The industry has a unique role to play in that it can contribute to the emission reductions in other sectors through the properties of its products. The challenge, therefore, is how can the sector reduce its own emissions, yet still remain competitive in the global market and sustain its contribution to the UK economy?

Reducing greenhouse gas emissions from the chemical industry is challenging for a combination of reasons: its fundamental role in society, as a producer of intermediate and end-use consumer goods and commodities; its globalised nature and relationship with the global economy; the use of fossil fuels for feedstocks (i.e. as a source of carbon or hydrogen) in addition to energy generation; the emissions of considerable amounts of N_2O, as well as CO_2; and the need to control other environmental impacts. However, if governments are to take forward the scientific evidence underlining the global 2°C temperature target, as laid out in the 2009 Copenhagen Accord [1], then all greenhouse gas-emitting sectors will need to significantly reduce their emissions in the coming decades. Furthermore, the long-lived nature of CO_2 in the atmosphere (~100 years), means that it is the cumulative emissions released over time which are important. Therefore, if global emissions fail to peak in the short-term, then considerably higher emission reductions per annum will be required in the long-term [2].

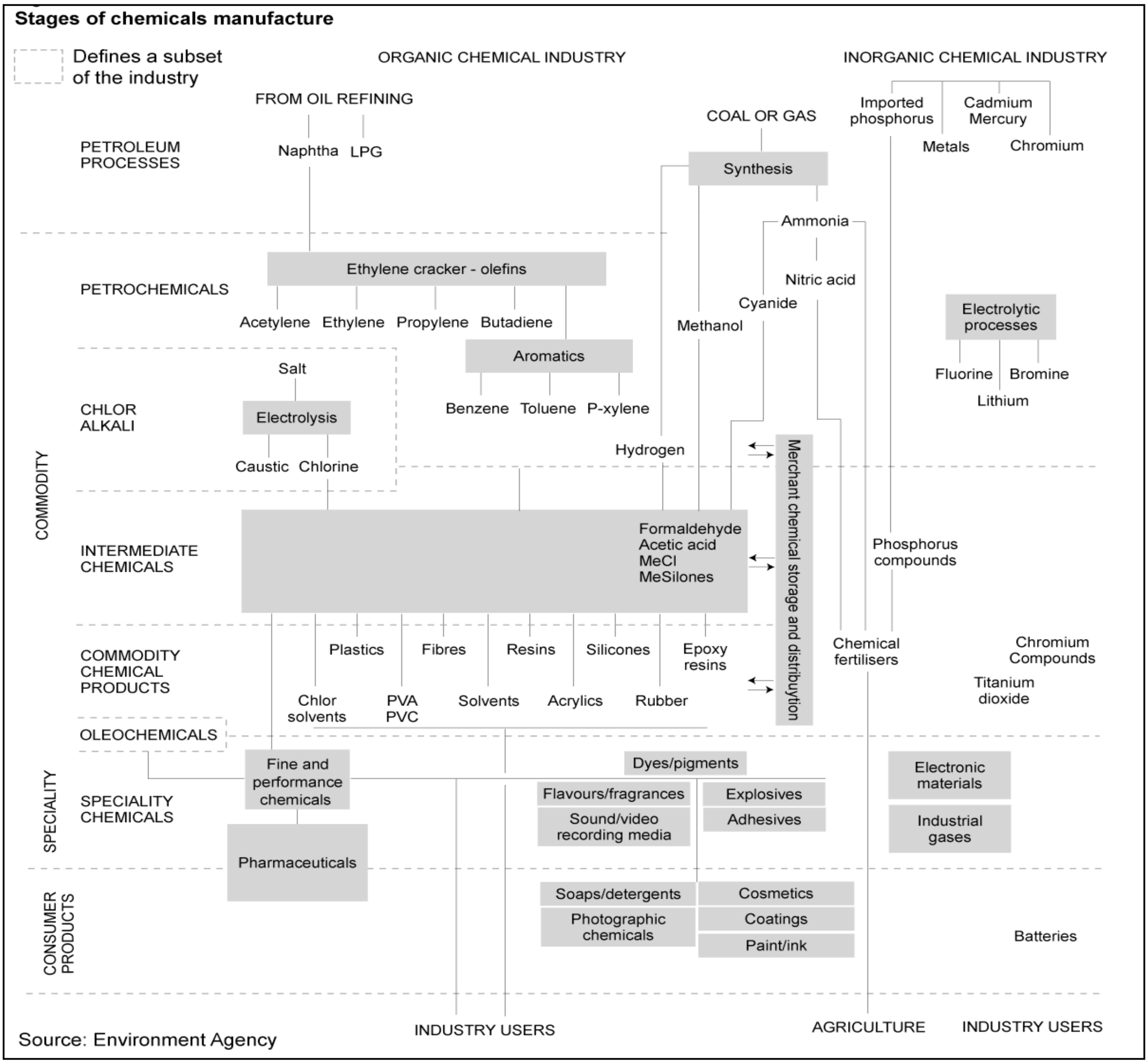
This report presents a market assessment of the UK's chemical industry to establish an improved understanding of the carbon intensity of chemical production processes, and to provide a climate change framing for the challenges which the sector faces. Practical measures to reduce overall greenhouse gas emissions are identified (including barriers and opportunities) and the report explores the global climate impacts of the relocation of the chemical industry from the UK to the US, Middle East and Far East, as a result of current and future climate policy. Finally, using input from a stakeholder workshop, the likely challenges and opportunities for the industry's competitiveness and subsequent ability to reduce its emissions are discussed.

2. Performance of the UK chemical industry

2.1 Segments of the chemical industry

The chemical industry is a very diverse sector, with a wide range of processes and products which are highly interlinked (see Figure 1). The products include basic organic (e.g. olefins, aromatics, plastic materials) and basic inorganic chemicals (e.g. hydrogen, chlorine, inorganic acids, gases) which are produced from raw materials (e.g. oil, gas, metals, minerals). These basic chemicals are then used as the building blocks for more refined or upgraded chemical products, such as commodity and speciality chemicals (e.g. plastics, rubbers, fibres, paints, solvents and fertilisers); or consumer products (e.g. pharmaceuticals, cosmetics and food ingredients) [3]. Moreover, the industry supplies basic chemicals to other industries for their processes and products. Given this role in society, the chemical industry becomes a complex and multi-tiered system, supplying many downstream processes and products and having a large variety of users and end-consumers.

Figure 1. Segments of the chemical industry [4]



Data availability and consistency

The chemical industry is a very diverse sector, which includes many different supply chains and the production of a large variety of products. Even though, in many cases, the chemical industry is grouped according to Standard Industrial Classification (SIC) systems, there exist many different statistics in the literature. Therefore, data is not always consistent.

Different organisations segregate the chemical industry differently, for example including and excluding segments and subgroups. As a result, there is inconsistent data and numerical variations between organisations.

Therefore, this report focuses on the analysis and evaluation of trends and not on single numbers.

In terms of the value of sales, basic organic chemicals (based on petroleum processes and coal or gas synthesis) account for the major share of chemicals produced. In 2010, UK producers had a market share of 39% in the UK. However, this has reduced significantly from about 50% [5, 6] before 2008, most likely due to the economic crisis and global competition. This reduction can be seen as one characteristic of the challenges for the chemical industry and will be discussed in the course of this report.

Another important segment is pharmaceuticals, which contribute significantly to the revenues of the chemical industry, in addition to playing an important role in UK trade [6]. The size of the different segments, and the segments deriving from basic chemicals, are illustrated in Figure 2 (below) and Table 1 (overleaf).

Figure 2. Chemical industry segments as share of production value in 2010, derived from [6]

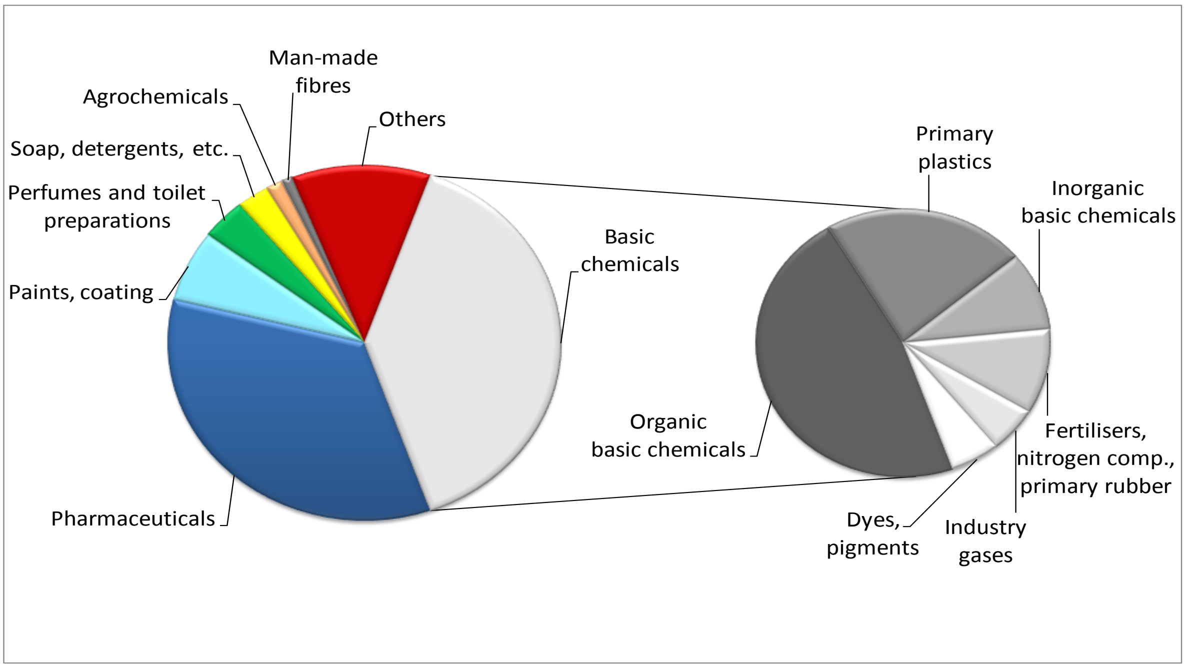


Table 1. Chemical sales by segments, derived from [6]

Sales chemical industry in 2010	£m
Basic chemicals	21,464
Pharmaceuticals	18,873
Paints, coating	3,537
Perfumes and toilet preparations	2,065
Soap, detergents, cleaning products	1,451
Agrochemicals	739
Man-made fibres	504
Others	6281
Chemical industry total	**54,914**

⇒

Sales *basic chemicals* 2010 by different product group	£m
Organic basic chemicals	10,082
Primary plastics	4,802
Inorganic basic chemicals	2,030
Fertilisers and nitrogen compounds	n/a
Industry gases	1,185
Dyes and pigments	1,161
Primary rubber	n/a

2.2 Performance of the chemical industry

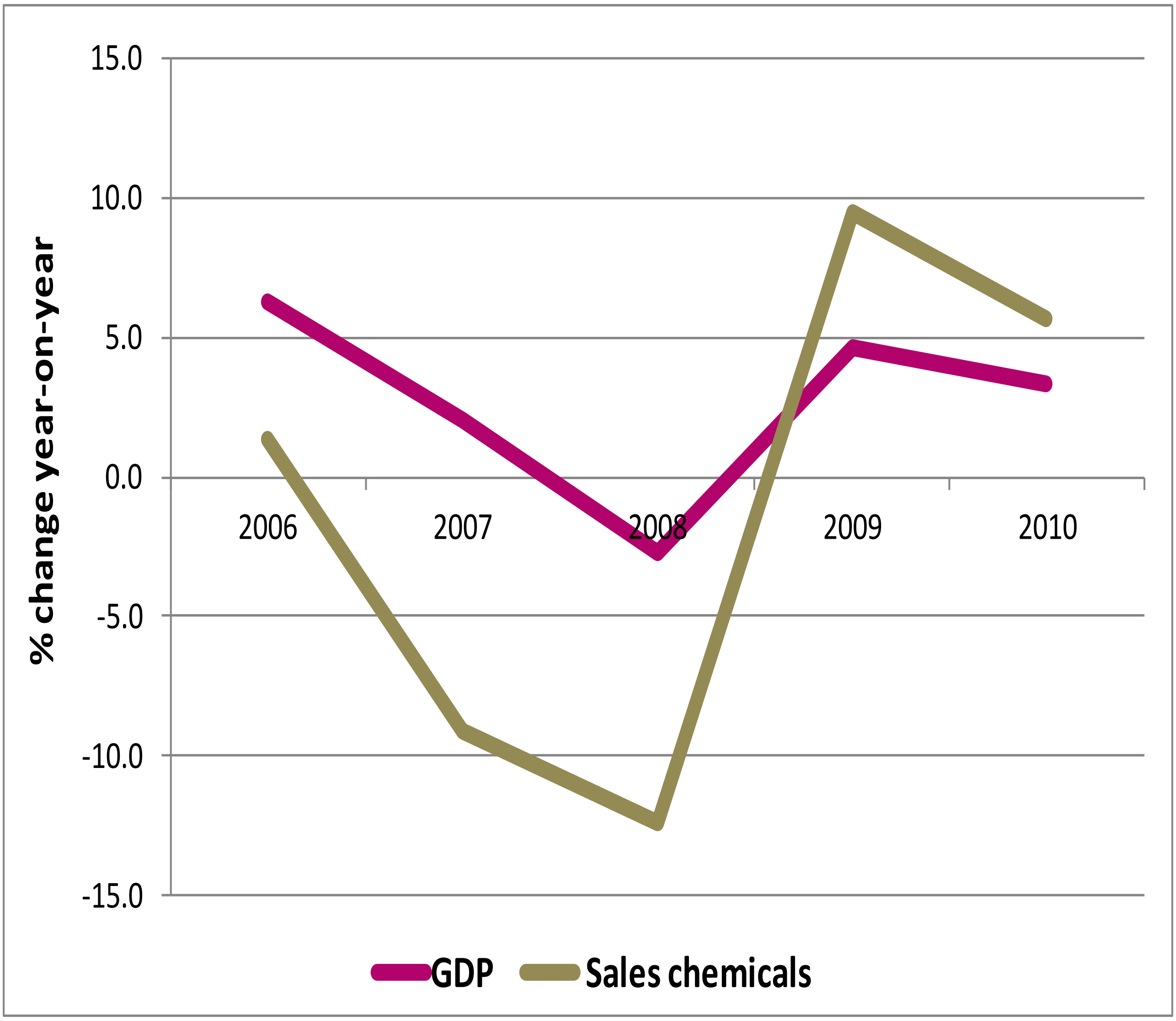
In 2010, chemical products had a global revenue of about £2,610 billion[1] [7, 8]. By region, Asia generates about 49% of global sales, followed by the EU with 25% (£407 billion) and North America with 20%. China and USA are by far the major producing countries with about 22.1% and 18.6% of global sales respectively, followed by Japan and Germany with approximately 6% each [5, 8, 9]. The share of the UK's chemical industry in 2010 was in the region of £55 billion. This is about 2% of global revenue (13% of EU), which makes the UK the fourth largest producer of chemicals within the EU after Germany, France and Italy [5-7, 9].

Within the UK, the chemical industry is one of the largest manufacturing industries[2] with approximately a 16% share of UK manufacturer sales [10, 11]. The contribution to the UK's GDP is about 1.4% [12]. National GDP and chemical industry revenues display significant correlation, but the amplitude of chemical sales is larger, as shown in Figure 3. This is partially explained by the tight integration of the chemical industry with other sectors of the economy and the dependence on their performance.

[1] Exchange rate on 16 June 2010: Euro to British Pound 0.8304.

[2] Other major manufacturing industries are: food production, motor vehicles, trailers and semi-trailers, machinery and equipment and fabricated metal products.

Figure 3. Change in GDP and chemical sales as percentages [6]



The chemical industry's downstream impact

Nearly every other industrial sector is somehow linked to the chemical industry, using its products at different scales and processing levels. More than 95% of all manufactured products in the UK contain inputs from the chemical industry [5, 6, 13].

From the industry's perspective, approximately 36% of its output is used as inputs in other manufacturing industries and 10% in non-manufacturing sectors [14]. According to a study by Oxford Economics [13], the upstream chemical industry and downstream chemistry-using sectors together contribute 21% of GDP and employ over six million people along the different supply chains.

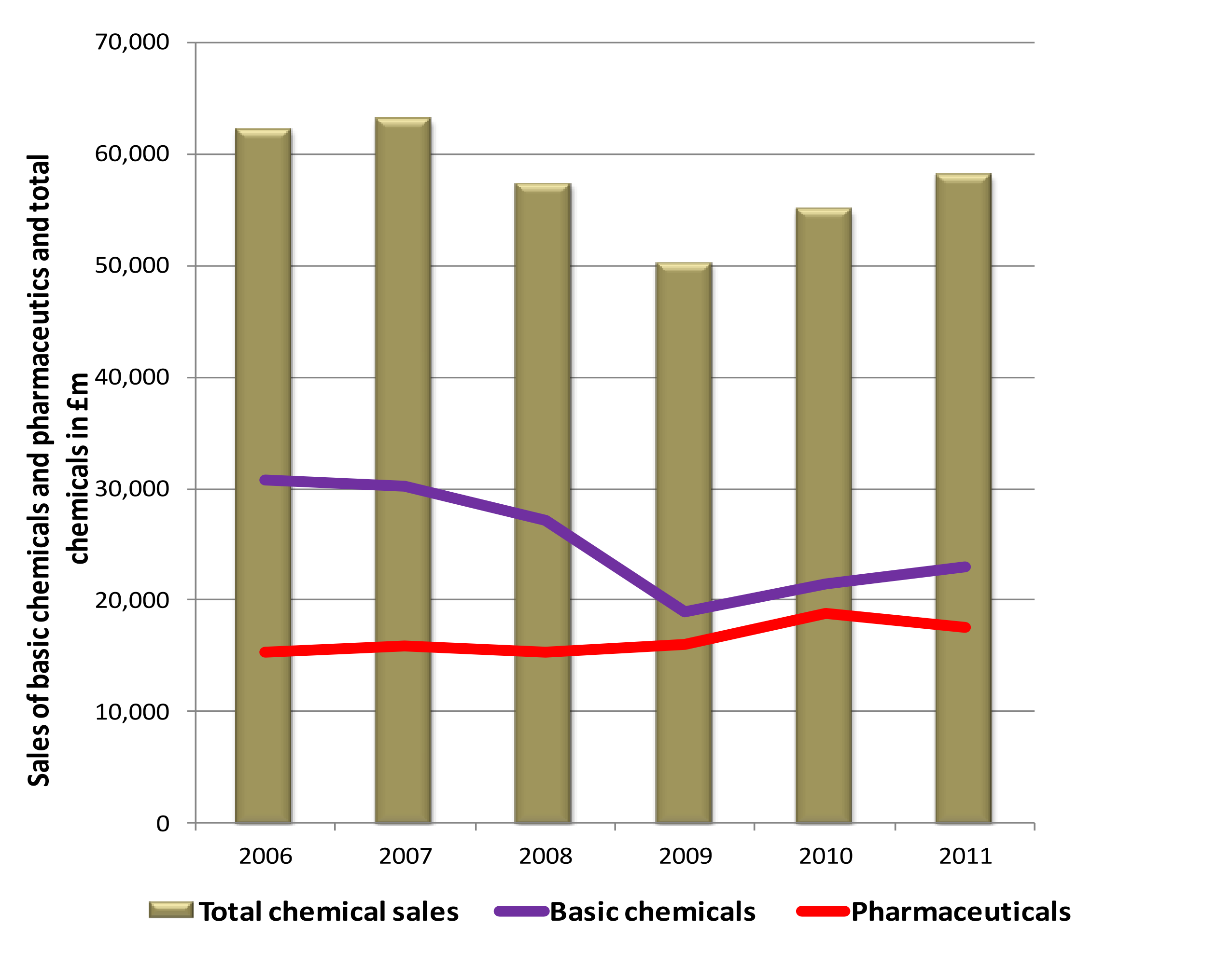
Figure 4. Direct contribution of chemistry to downstream industries, derived from [12]

2.3 Impact of the economic downturn

The interdependencies of the chemical industry with the other sectors resulted in it being strongly affected by the economic crisis. A downturn in demand led to a reduction in sales for the industry [6, 8, 13]. Up until 2008, the chemical sector was booming, but with the economic crisis in 2008 and 2009 the industry saw a significant reduction in sales of 9.1 and 12.4% respectively [6] (see Figure 3). In the course of 2010 and 2011 the sector saw growth to slightly above 2008 levels with a turnover of £58 billion [6]. However, this decreased again in 2012 by about 6% [10].

While the basic chemicals segment is still struggling to regain similar growth levels to those of 2006, the pharmaceuticals, perfume and toilet products, and agrochemicals have continued to grow (Figure 5). The pharmaceutical segment is the only segment which has shown almost continuous growth since 2006, and is the segment contributing most to UK trade surplus [6, 12, 13, 15].

Figure 5. UK chemical industry market – total sales trend and sales of basic chemicals and pharmaceutics in £m from 2006-2011 [6]



2.4 Exports of UK trade

The chemical industry is one of the largest exporting sectors in the UK and the largest manufacturing one, accounting for 18.7% of all UK exports [13, 16]. The chemical industry trade surplus was about £6,740 million in 2010 [5] larger than any other manufacture, with automotive having only moved into a small surplus in 2012. With an export value of £29,269 million for chemicals and £23,474 million for pharmaceuticals, the UK contributes 5.1% of global chemical exports and 7.4% to the global pharmaceutical exports [17].

The main share of exports comes from pharmaceutical products, which account for 47.3% of the UK's exports from the chemical industry. While the surplus of the total chemical industry did not change significantly between 2006 and 2010 (apart from 2009), the pharmaceutical segment showed a rapidly growing surplus over this period (see Table 2 and Figure 6). In terms of trade surplus, the pharmaceutical segment is ranked in third place in the UK industry behind finance and business services [12, 13].

Table 2. UK trade chemical industry 2006-2010 [5, 6, 18, 19]

	2006 (£m)	2007 (£m)	2008 (£m)	2009 (£m)	2010 (£m)	2011 (£m)
Export chemicals (excl. pharmaceuticals)	21,400	23,200	25,515	25,511	27,299	29,269
Imports chemicals (excl. pharmaceuticals)	19,932	21,364	24,510	23,082	26,484	29,283
Export pharmaceuticals	15,488	14,973	17,895	21,139	23,199	23,474
Import pharmaceuticals	10,374	11,266	11,742	13,917	16,231	17,442
Total UK exports	245,254	220,761	247,999	226,031	263,369	294,257
Total UK imports	326,296	314,306	343,656	310,428	363,929	395,430

The UK trade patterns for the chemical industry are outlined in Figure 6 and the overall trade balance of total UK trade is shown in Figure 7. Even though the export value of the chemical industry (excluding pharmaceuticals) is continuously growing (dark blue columns in Figure 6), the surplus from chemicals is fluctuating year by year (Figure 7). The value of pharmaceuticals is continuously growing (dark red columns in Figure 6) as well as the surplus (Figure 7). The trade surplus, mainly generated from pharmaceuticals, makes the chemical industry one of the few sectors with a positive trade balance in the UK.

Figure 6. UK trade (import and export) chemical industry

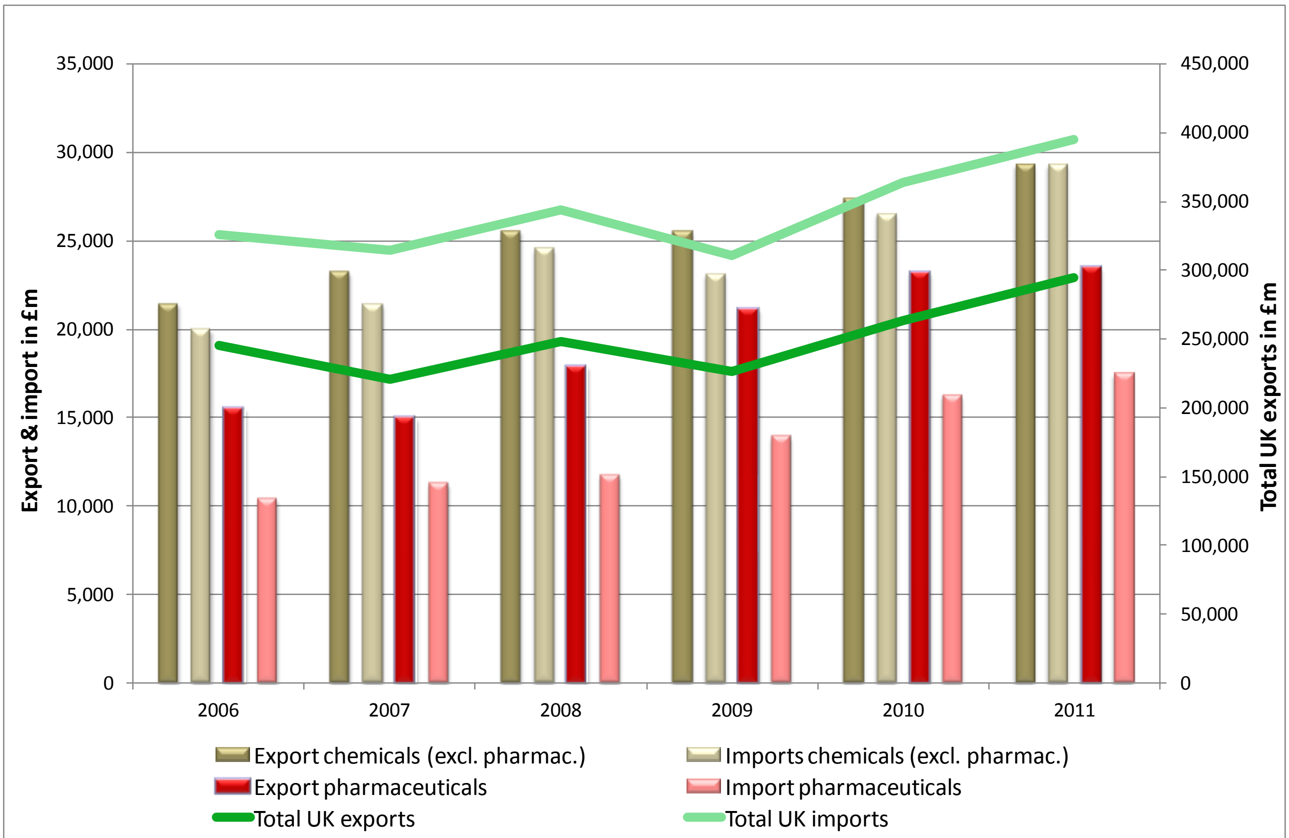
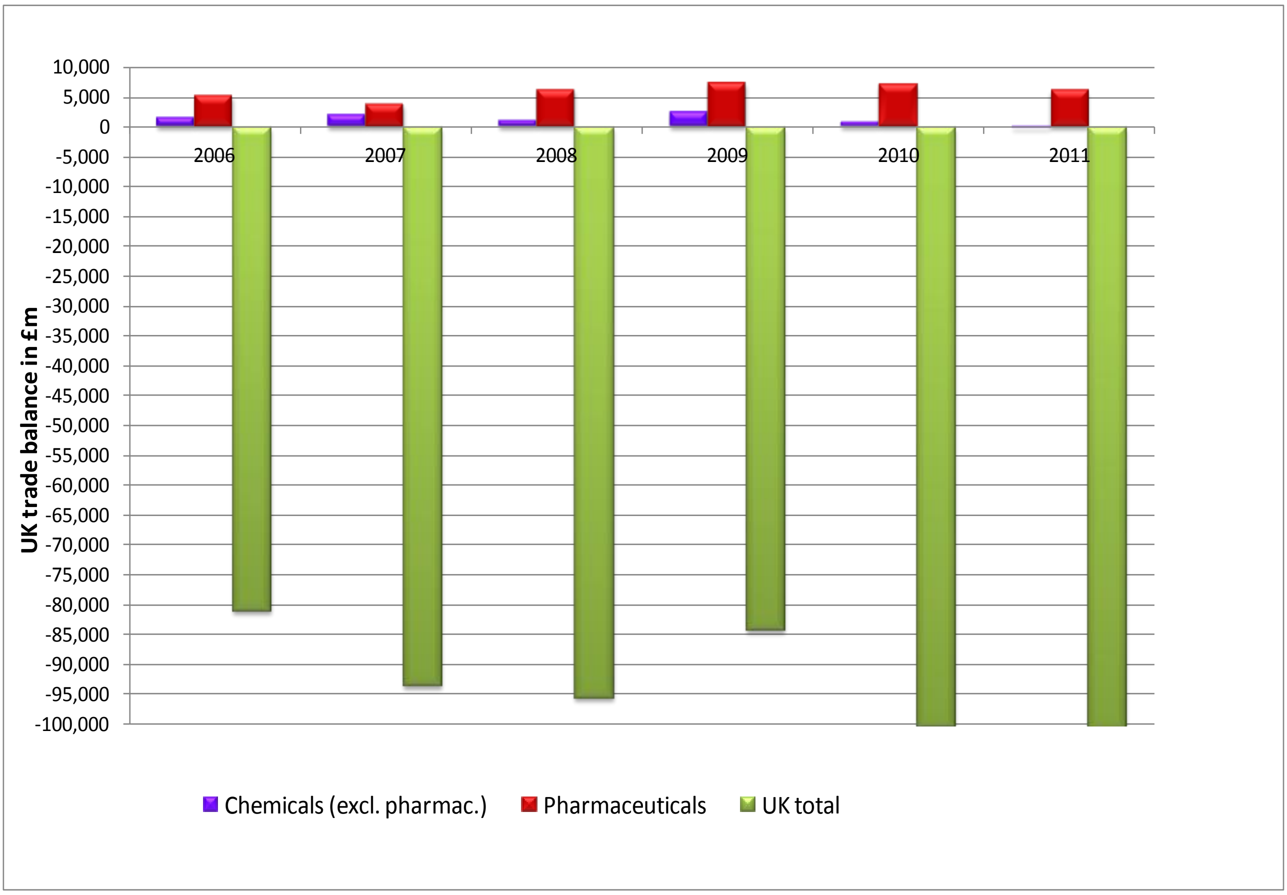


Figure 7. Trade balance of UK chemical industry and total trade



2.5 Labour force

In 2010, about 282,000 people were employed in the chemical industry (including rubber and plastic production and pharmaceuticals) [20]. This means that 4.8% of the 5.8 million UK's industrial sector employees[3] work in the chemical sector [19]. More than one-third of the employees are working in the basic chemical segment, which, as already shown, is also generating a major share of the revenues. Nonetheless, the biggest labour force is found in the plastic and rubber division with about 140,000 employees [20].

Indirectly, the chemical industry leads to further employment in the downstream sectors and supply chains which are supported by the sector in a ratio of 1:2 (1 employee in the chemical industry leads to 2 employees downstream) [13]. Other work suggests much higher factors up to 1:10 and the UK government accepts a ratio of 1:4 as being closest to the truth [21, 22]. Additionally, the average income in the chemical sector is about 30% above the national average [13] and GVA/head in the sector at £92kpa (source CIA) is amongst the highest in the UK [22].

[3] Total UK employment 31.72 million (2011 est.), UK industry: 18.2% = 5.8 million (19).

2.6 Outlook

The chemical industry is a steadily growing sector. Even though there have been reductions in output the global chemical industry is projected to keep growing until 2030. It has been estimated that the global turnover of the sector will double by 2030 compared to 2010 [8]. The global average growth rate is projected to be approximately 5% p.a. [8, 15, 23]; while the average growth in Europe and North America is expected to be lower at 2-3% p.a., in Asia it is 5-7% p.a. [8, 24]. Nonetheless, plastics and health products are projected to grow above the global average [8, 15, 23].

The production of basic chemicals in the Middle East is anticipated to grow at 6-9% p.a. until 2020 [24-26], due to the availability of low-cost feedstock. In China, a growth rate of 9-10% p.a. [24] is anticipated, linked with strong economic growth which would result in a high demand for basic chemicals, and primary rubber and plastics for downstream industries [27].

It is projected that by 2020 more than 50% of the global chemical production will take place outside developed countries [24]. This could mean a decrease in exports of basic chemicals from Europe. Nonetheless, the production of basic chemicals such as ethylene, propylene, butadiene, toluene and methanol is likely to increase up to 3% p.a. in Europe (compared to a global average of about 5% p.a.) over the coming years [26, 28, 29].

In the UK, population growth, an ageing population, GDP improvements, a growing export market, and demand increase from downstream industries [6] is projected to increase sales from the UK chemical industry by 3.5 to 4% p.a. until 2016 [6].

The significance of the chemical industry for the UK

The chemical industry is a significant contributor to the UK's economy, in particular the production of basic chemicals and pharmaceuticals. It supplies commodities and goods to many downstream sectors and industries and is a major employer; furthermore, it is one of the few industries which are a net exporter. However, the sector is very much dependent on the overall economic outlook and has therefore fluctuated with the global drop in demand. Despite positive growth forecasts, UK chemical production is having to compete with expanding production in the Middle East, Far East and the USA with its recent energy cost reductions, which is discussed in section 5.

3. Energy use and emissions from the chemical industry

3.1 Energy use

The chemical industry is one of the most energy-intensive sectors in the UK. It consumes about 22% of total UK industrial energy and accounts for 1-4% of total UK energy use [4, 30]. In addition to grid electricity, it directly uses fossil fuels for heating, cooling, pumping and other processes. Furthermore, fossil fuels are required as a chemical feedstock. Currently, it is highly dependent on natural gas and petroleum as the main energy sources [4]. With about £4 billion p.a. directly spent on energy it is, for many producers, the major cost factor and makes up approximately 30% of their total costs [4, 30, 31]. Nonetheless, about 8% of the energy is generated onsite by industry itself through combined heat and power (CHP) [4].

It has been estimated by the Chemical Industries Association that the UK chemical industry could improve its energy efficiency of processes by about 35% compared to 1990 levels [4, 9, 30, 31]. The main drivers to increase energy efficiency are fuel costs and international competition, but climate change targets also play a role. The latter are outlined in section 4. Nonetheless, the competitiveness of the chemical sector is very sensitive to volatile energy prices; consequently, the increasing dependence on gas imports is a major concern for the chemical industry in the UK [30].

Exploring global regions, the main feedstock used is strongly related to availability and location. While OECD nations mainly use petroleum and gas, China and other non-OECD regions use large shares of coal for energy use, whilst the Middle East relies on petroleum [32, 33]. One major change in energy and feedstock use in recent years is that shale gas is now playing an increasingly major role in the chemical industry, leading to a decoupling of gas and oil prices [33-35]. This is resulting in the provision of low-cost gas as an energy and feedstock source, especially in the USA [34, 36-38], which in turn is exporting unused coal to Asia and the EU [39]. China, which is estimated to have the world’s largest shale gas resources, could in the near future exploit this fuel source and increase its cost competitiveness significantly [34, 36-39]. Nonetheless, the chemical industry in China is still heavily based on coal [40].

Looking ahead, while high oil prices are likely to continue, this will be a major challenge for the chemical industry in Europe. Furthermore, the global energy market is entering a transition phase with the exploitation of relatively cheap shale gas. As a result, the USA, an early adopter of shale gas, could have a market advantage in producing basic chemicals derived from natural gas [29]. This is discussed more section 5.

3.2 Breakdown of feedstock and raw material use

Basic chemicals, which make up about 40-50% of the volume of produced chemicals, account for the largest use of raw materials such as oil, gases, metals, minerals and water; this is in addition to energy demand for the intensive steam cracking processes. For basic organic chemicals, condensates from crude oil and natural gas (e.g. naphtha) are used as feedstocks, while for inorganic basic chemicals metals, minerals and gases are the major raw materials. In terms of feedstocks globally, naphtha is the dominant raw material for basic chemicals and is projected to stay so. Currently, 51% of the global feedstock are naphtha, 14% methane, 11% coal [33].

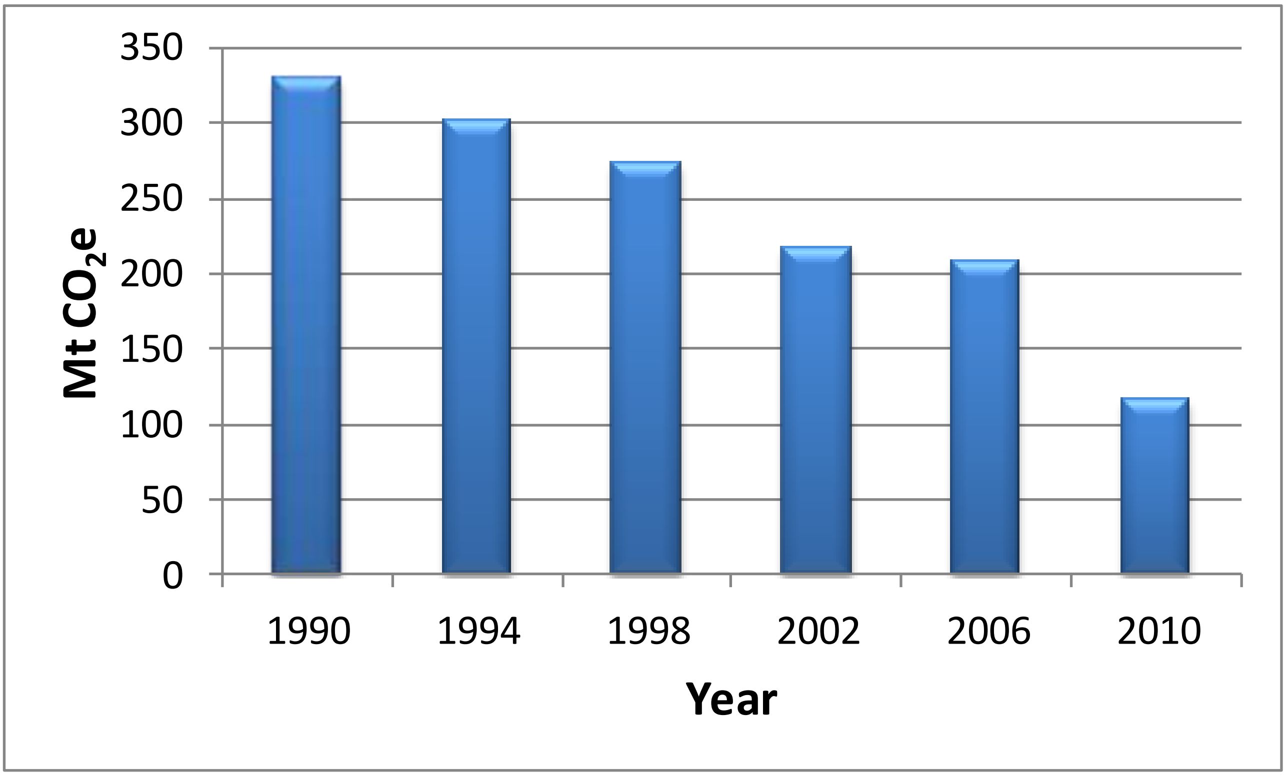
However, despite their high demand for raw materials and energy, basic chemicals are an integral part of the supply chains for most other chemicals and downstream sectors (see Figure 1). For example, ethylene is the basis for the production of many other chemicals and products and is the most significant chemical in terms of volume and value; yet, it is also one of the most energy-intensive products.

3.3 Emissions trends for the EU's chemical industry

Being a major user of raw materials and non-renewable resources for energy consumption and feedstock, the chemical industry releases significant amounts of greenhouse gases. The emissions can be split into three categories: direct emissions from energy use on-site, i.e. fossil fuel combustion and heat generation; indirect emissions from energy use, i.e. purchased electricity; and process emissions [4, 21, 31, 32].

Despite intensive energy use, between 1990 and 2010 the EU's chemical industry (including pharmaceuticals) emissions reduced from 330.4 Mt CO_2e to 165.8 Mt CO_2e [9], as shown in Figure 8. This is approximately a 50% reduction. At the same time, production increased by 70% [9]. This has been achieved mainly through efficiency improvements and recycling processes [9]. But it is perhaps also partially due to increasing production of less emission-intense and high-value products (e.g. pharmaceuticals), and reduced production (largely by a reduction in demand) of emission-intense chemicals (e.g. basic chemicals).

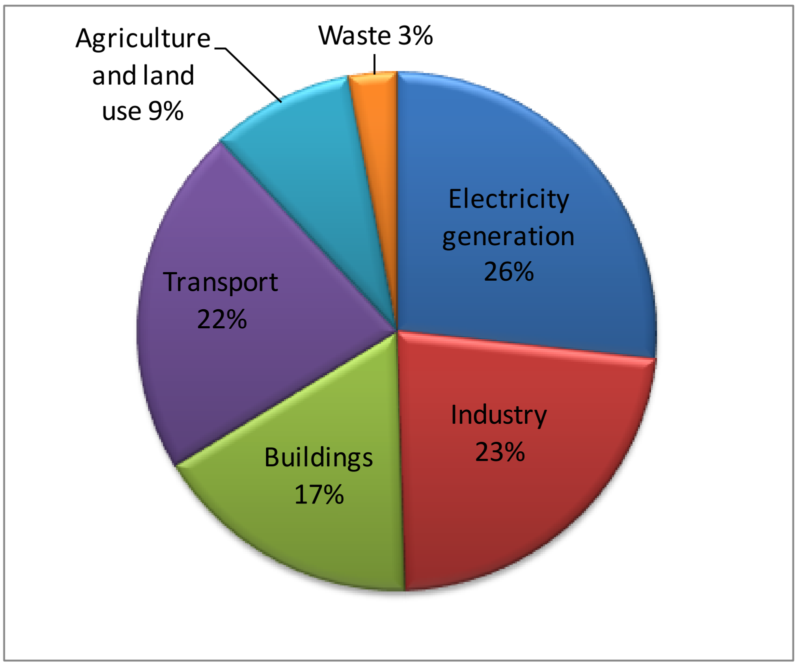
Figure 8. Greenhouse gas emissions released by the EU's chemical industry, derived from [9]



3.4 Emissions trends for the UK's chemical industry

In 2009, the UK emitted 560 Mt CO_2e in total for all sectors, of which 84% was in the form of CO_2, 7% as CH_4, 6% as N_2O and 2.6% as F-gases [41]. The industrial sector, including the chemical industry, contributed 131.6 MtCO_2e (~23%) of these total greenhouse gas emissions, as shown in Figure 9; of which over 80% occurred from generating heat [41]. Between 1990 and 2009, the UK's total emissions decreased by 24%. From a climate change perspective, note that this reduction is an important step towards meeting its legally binding interim target of a 34% reduction by 2020. Targets are discussed further in section 4.

Figure 9. Proportion of UK emissions from different sectors in 2009 by source, derived from [41]



The importance of indirect energy use

Emissions from the chemical industry occur from three different sources: direct and indirect energy use, and processes. While the direct energy use and process emissions are well documented, indirect emissions are more uncertain in databases and the wider literature. Nonetheless, in 2005, the UK's indirect energy use in the chemical industry was 12.04 MtCO2e from the use of 23.16 MWh electricity [36]. Emissions from direct energy use were 9.60 MtCO2e, and from processes 6.15 MtCO2e, in 2005 [3]. Under the United Nations Framework Convention on Climate Change (UNFCCC) producer-based reporting, indirect emissions are included under electricity production, and are reported as occurring outside the chemical sector.

Research by the International Council of Chemical Associations (ICCA) [36] showed that about one-third of the total production emissions of chemicals produced in the EU occur from indirect energy use. This should be taken into account when evaluating the chemical *industry's emissions. However, this share is likely to vary between EU nations and segments. Such emissions will also depend on the carbon intensity of the electricity source and the type of feedstock and energy source the production site is based on. Even though there may be more leverage for the chemical industry to decarbonise direct and process emissions, indirect emissions should not be overlooked.*

There are systems level implications surrounding current accounting frameworks and where responsibility lies to reduce emissions, which could result in unintended consequences. There is a range of future scenarios in the literature which assumes that energy-intensive industries could be powered to some degree by low-carbon electricity sources [39, 40], and in turn this would place a larger demand on the grid and its associated infrastructure.

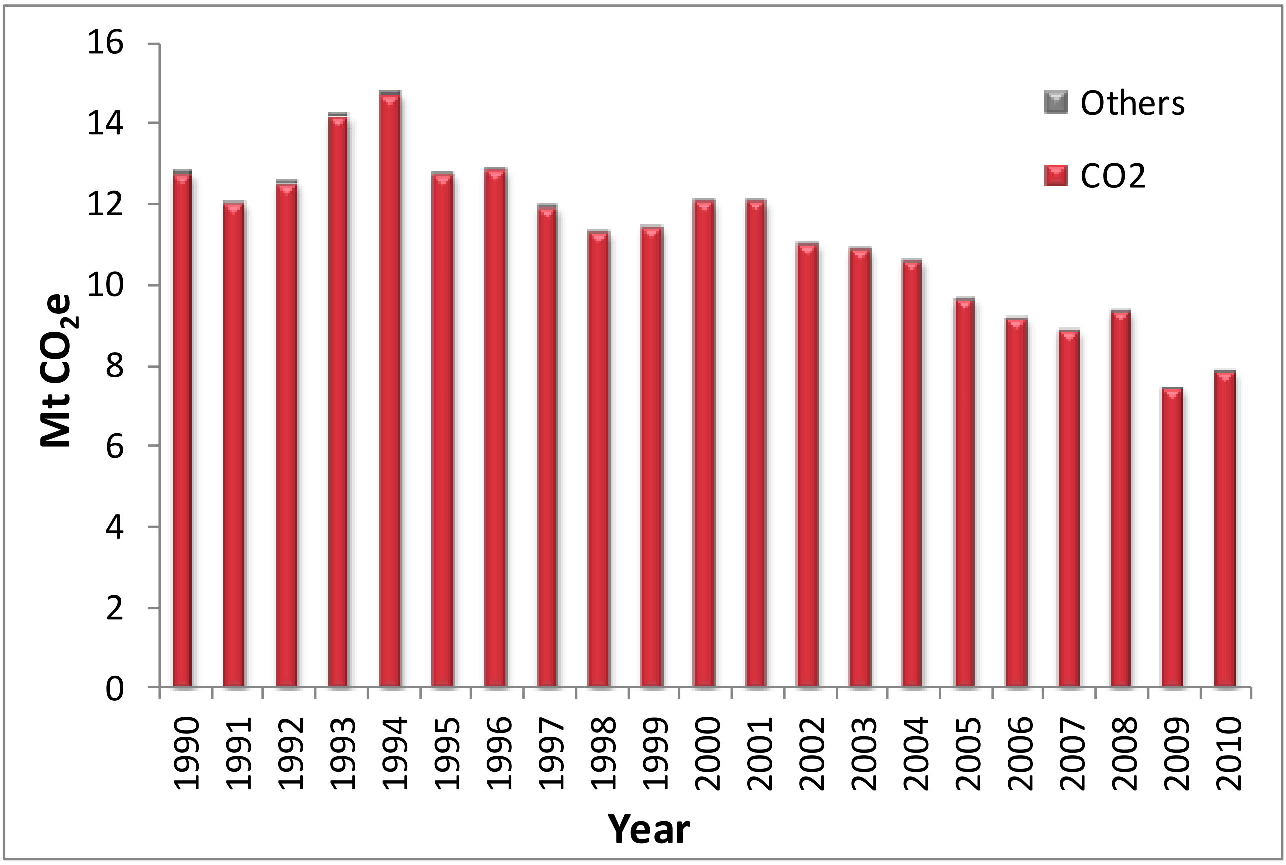
3.4.1 Direct energy use emissions

The main form of direct combustion of fuels for energy use in the UK chemical industry is gaseous fuels, with much smaller amounts of solid and liquid fuels (see Table 3). The major share of emissions is CO_2. The total greenhouse gas emissions from direct energy use in the UK chemical industry between 1990 and 2010 are shown in 0. It shows that the emissions have reduced by 38% - from 12.6 Mt CO_2e to 7.8 Mt CO_2e [42].

Table 3. Greenhouse gas emissions from direct energy use for the UK chemical industry, derived from [42]

		Implied Emission Factor			**Emission by GHG emissions**			**Total emissions**
Fuels for direct energy use	**Consumption (TJ)**	**CO_2 (t/TJ)**	**CH_4 (kg/TJ)**	**N_2O (kg/TJ)**	**CO_2 (Gg)**	**CH_4 (Gg)**	**N_2O (Gg)**	**CO_2e (Gg)**
Liquid fuels	2,632.28	78.08	2.11	0.63	205.53	0.01	0.00	206.16
Solid fuels	9,582.39	91.58	0.42	8.14	877.52	0.00	0.08	900.87
Gaseous fuels	117,603.50	56.84	5.56	0.11	6,684.62	0.65	0.01	6,704.84
Total fuel use	**129,818.18**				**7,767.67**	**0.66**	**0.09**	**7,811.88**

Figure 10. Trends for total greenhouse gas emissions from direct energy use (Mt CO_2e), derived from [42]



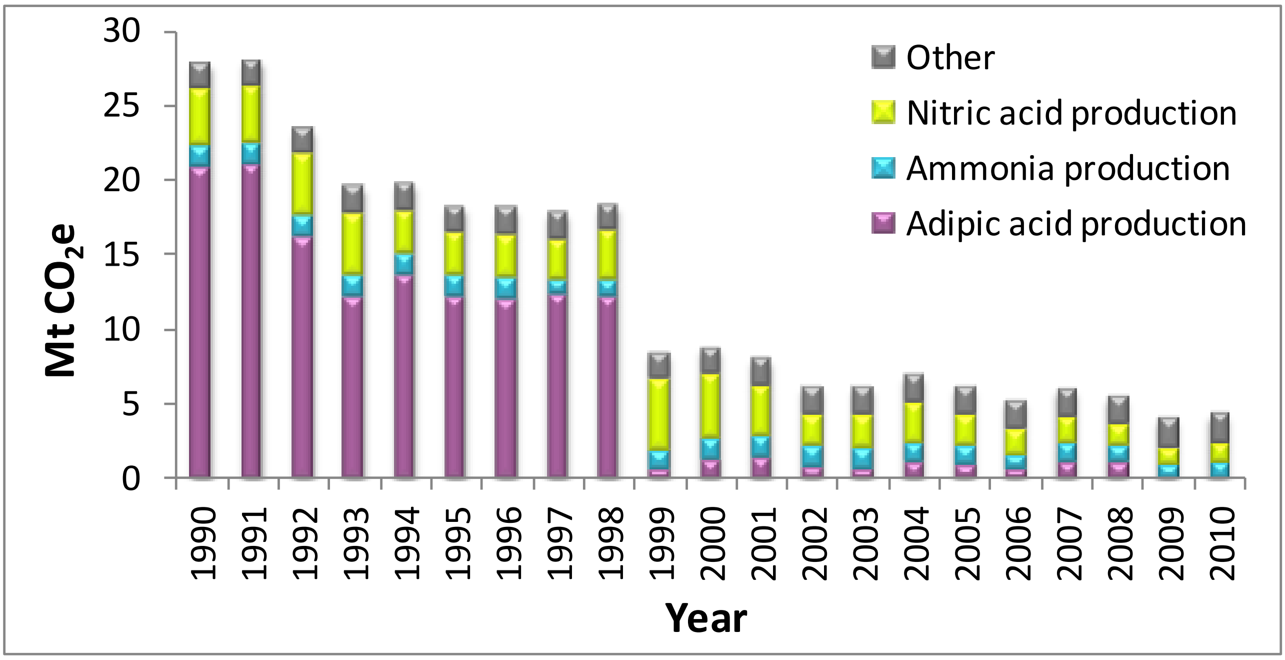
3.4.2 Process emissions

The process emissions, as shown in Figure 11, are much more diverse than emissions from direct energy use, as different production streams, supply chains and chemicals have different characteristics, emission factors and emit different greenhouse gases. CO_2 emissions from producing ethylene and ammonia [42] make up the vast majority. N_2O emissions are mainly a result of producing ammonia, nitric acid and adipic acid [42]. In 2010, in total, 4.3 Mt CO_2e were emitted, which is about 16.2% of the total process emissions of the UK manufacturing industry [42].

Figure 11 illustrates the trend of process emissions between 1990 and 2010. The figure illustrates several sharp emission reductions, notably a dip between 1998 and 1999 when the UK production of adipic acid was dramatically reduced through plant closure.

In total, the process emissions have reduced by 84% between 1990 and 2010 and are the main contributor to the overall emission reduction of the UK chemical industry [42]. To summarise, whilst CO_2 emissions have reduced by 1.5% during this time (from 2.99 Mt CO_2e to 2,95 Mt CO_2e), CH_4 has reduced by 56% (from 0.17 Mt CO_2e to 0.07 Mt CO_2e) and N_2O by 95% (from 24.64 Mt CO_2e to 1.32 Mt CO_2e) [42].

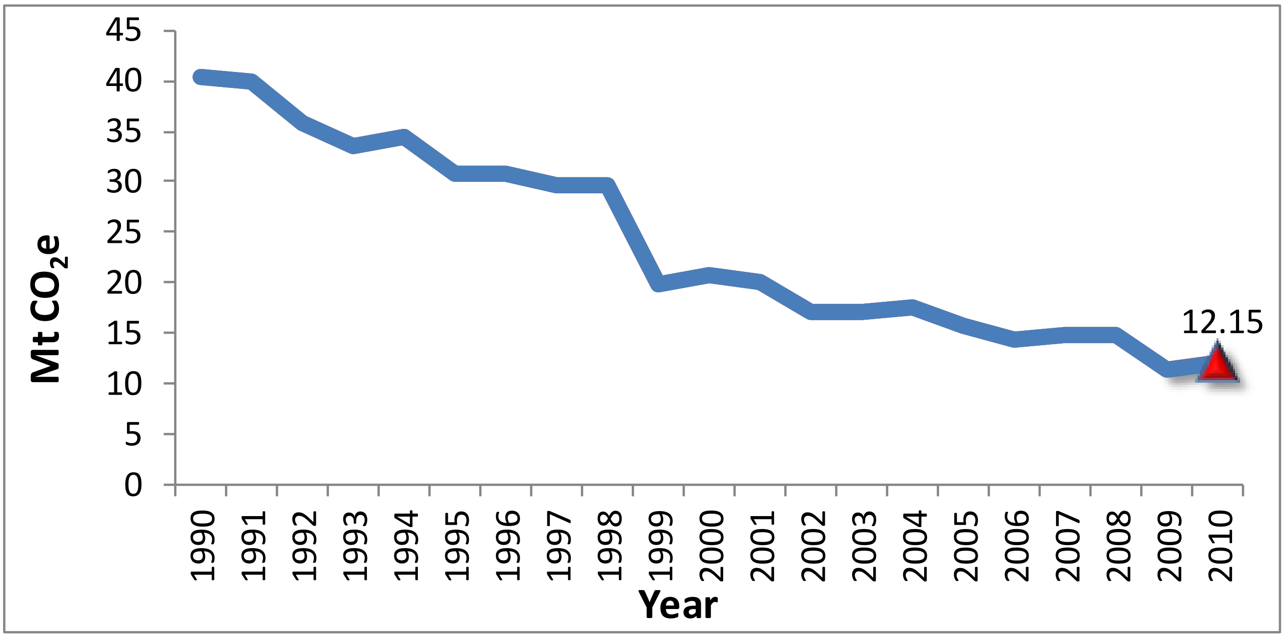
Figure 11. Total greenhouse gas emissions from processes (Mt CO_2e), derived from [42]



3.4.3 Total greenhouse gas emissions

Figure 12 collates the Figure 11's numbers to show the emission trends from direct energy use and processes of the UK's chemical industry from 1990 to 2010. In 2010, the UK chemical industry emitted 12.15 MtCO_2e, down from 40.48 MtCO_2e in 1990. 7.8 MtCO_2e was from direct energy use and 4.34 MtCO_2e from processes [42]. During this period, the sector's emissions have reduced by 70% [42]. Even though there are significant reductions, they are not based solely on efficiency improvements and the reduction of emission intensity, but are also due to significant production cuts or even shutdowns within the UK.

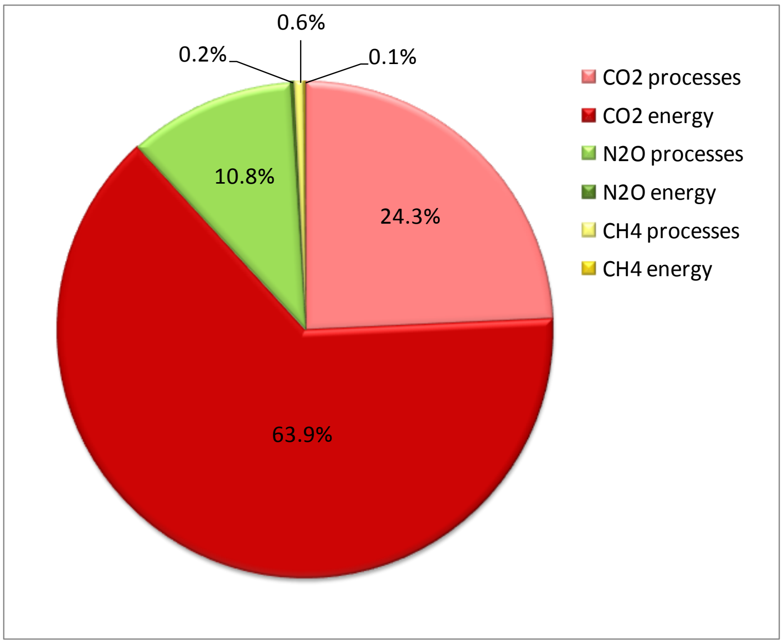
Figure 12. Total greenhouse gas emissions from the UK chemical industry (direct energy use and processes) (Mt CO_2e), derived from [42]



3.4.4 Greenhouse gas emissions by type and source

In terms of targeting mitigation potential within the sector, Figures 10-12 have so far outlined the split between, and trends for, the different types of emissions (energy use and processes) occurring in UK chemical plants. Figure 13 summarises the type and source (direct energy use or processes) of greenhouse gas. It underlines that the majority of emissions are CO_2 from direct energy use. The major share of N_2O emissions are from processes.

Figure 13. Total direct greenhouse gas emissions by type of greenhouse gas and source, derived from [42]



3.4.5 Relating global production to emissions

Table 4 shows the emission factor and volume of global production for different major chemicals, and their resultant total global emissions in 2005. Even though HCFC-22 and adipic acid have the highest emission factors, the majority of total process emissions are from basic chemicals, such as ammonia, ethylene and nitric acid. As these are used to produce other chemicals and products, they play an important role in mitigation. Lowering their emission intensity would provide significant emission reduction potential for overall global emissions.

It is worth noting that the chemical commodities in Table 4 (overleaf) require a range of fossil fuels and raw materials to produce them, which also have varying emission factors and subsequent impacts on the climate and wider environment. In terms of emissions reduction, there are avenues to explore regarding fuel switching, from a more carbon-intensive to a less carbon-intensive fuel. However, this is likely to be most relevant for nations which are heavily dependent on more carbon intensive coal, such as China.

Table 4. Global aggregated greenhouse gas emissions from production of different chemicals [21]

Chemical	Global production (kt)	Emission factor ($kgCO_2e/kg$)	Emissions ($MtCO_2e$)
Ammonia	142,239	1.40	199
Ethylene	92,949	1.65	154
Nitric Acid	49,716	2.31	115
HCFC-22	515	147.56	76
Adipic Acid	2,549	10.97	28
Carbon Black	8,788	2.62	23
Methanol	30,598	0.72	22
Calcium Carbide	10,003	1.09	11
Soda Ash	41,844	0.14	6

Have UK emissions reduced to date?

Under the producer-based reporting mechanism, within which the UK reports its emission inventories to the UNFCCC, emissions are reducing. The main reasons cited in the literature for the fall in producer-based emissions are a switch from coal to gas power during the 1990s [41, 43], the relocation of manufacturing industries overseas [41, 42] and the reduction in non-CO_2 gases [43].

Despite UK chemical industry emissions reducing by 70% from direct energy use and processes since 1990, further examination is therefore needed to establish how this was achieved. Efficiency improvements have unquestionably contributed to these reductions. Nonetheless, the economic crisis coupled with high and rising energy/feedstock costs have arguably led to the closure of production sites and/or relocation to other nations with lower production costs, resulting in territorial emission reductions.

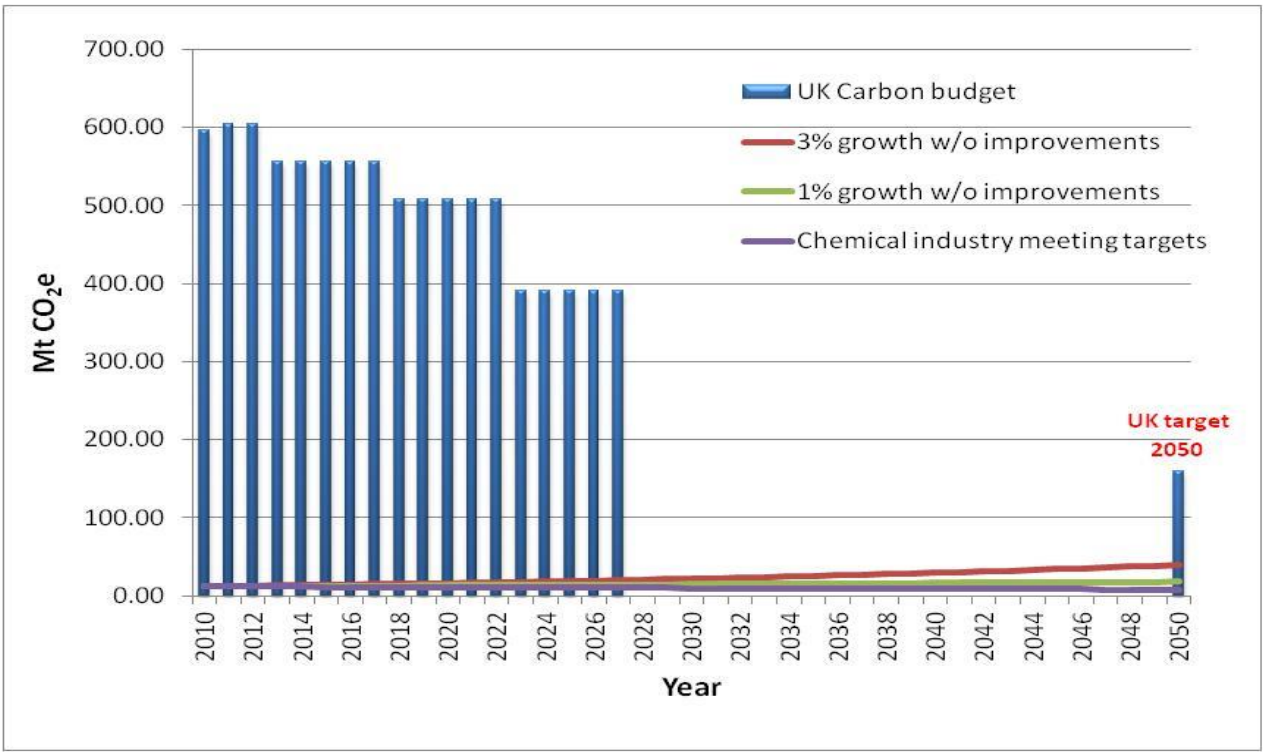
When examined under a consumption-based reporting mechanism, where the UK would take account of emissions produced in other nations during the manufacturing of the goods it consumes, the UK's share of global emissions is increasing [41, 43]. The rate at which consumption-based emissions are increasing is also related to the rate of growth in consumption. Therefore, despite territorial emissions reducing since 1990, when examined under a consumption-based approach, UK emissions associated with the consumption of chemical-derived goods and commodities are likely to be increasing.

3.5 Future projections of CO_2 emissions from chemical production – outlining the challenge

The global demand for chemicals is continuously growing. As subsequent emissions from the sector also increase, any relative efficiency improvements would need to offset absolute sectoral growth if emissions are to reduce on average. From a climate change perspective the important quantity is the total cumulative emissions released over time, not the emission levels at a set point in the future and so, urgent and meaningful emission reductions will be required in the coming decades and, therefore, the absolute growth in the sector is of significant importance here [44].

While the UK chemical industry's direct and process emissions have reduced by 70% since 1990, the sector is projected to grow and, therefore, absolute emissions from the sector are likely to grow too. Whilst embracing growth, the sector still has to adhere to the Climate Change Act (80% reduction on 1990 levels) and – even more demanding – the UK pledge to the Copenhagen Accord [1] (holding global temperatures below 2°C). If the UK chemical industry grows at 3% p.a. between 2010 and 2020 [8, 15, 23, 24] without reducing its emission intensity or changing the current chemical production mix, its direct and process emissions would increase by 34% by 2020 and (if extrapolated) 226% by 2050. Even a slower growth rate of 1% p.a. [8, 15, 23, 24] would increase the emissions by 10.5% by 2020 and 49% by 2050. These projections are at odds with current and future climate policy and also with holding global mean average temperatures below 2°C. They do not account for indirect emissions, although wider efforts to decarbonise the energy system and electricity sector could constrain future increases from electricity use. Mapping these projections against the UK's carbon budgets [41, 45, 46], as in Figure 14, demonstrates how the industry would progress in relation to the aspirations of the 2050 target.

Figure 14. Projected emissions from the chemical industry until 2050 under different growth options projected against the UK's carbon budget



If the chemical industry is to reduce its emissions by 80% from 1990 levels, scaling emission reduction out to 2050 would result in an emissions budget of ~8Mt; this would relate to ~5% of the total carbon budget. Referring to Figure 14 (above), if the chemical industry is to grow at 3% p.a., without any decrease in carbon intensity of production below today's figures, it will account for approximately 25% of the UK's carbon budget in 2050; similarly, if it grows at 1% p.a. it will account for approximately 11%.

Assuming no growth in the industry, emissions intensity would need to reduce by 1% p.a. However, relating anticipated absolute growth against the UK's carbon budgets lays bare the challenging emission cuts which are required for the chemical industry.

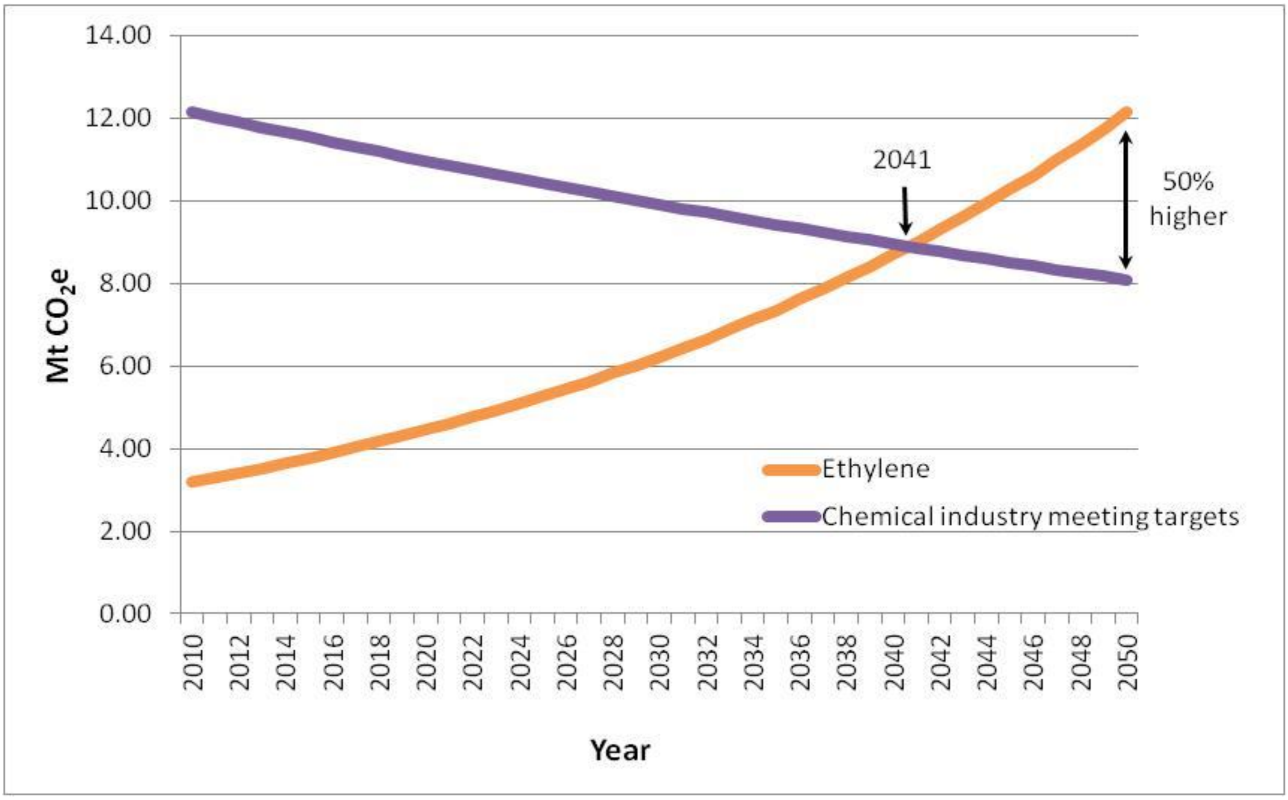
Assuming the 3% p.a. growth rate, again, the emissions intensity will need to reduce by ~4% p.a. to meet climate targets. Even with a lower growth rate of 1% p.a. emission intensity would need to reduce by ~2% p.a. Putting this into context historically (since ~1970), mature industries have reduced emissions intensity by 1-1.2% p.a. [47, 48]; the rate of reduction has reduced below this since 1995 [47].

Therefore, even for the lower growth rate, extremely demanding sustained reductions rates are required which are more than double that which has historically been achieved. Furthermore, as nations such as the UK are committed to avoiding global mean average temperatures rising above 2°C (see Copenhagen Accord [1]), equating this target to the growth of the UK chemical industry highlights further the extremely challenging task of adhering to this goal with any sound degree of probability (>50%) [49-51].

To illustrate these findings further, the example of ethylene production is used. In 2012, the UK had 2,855,000 t/year installed capacity of ethylene steam cracking capability [52] and produced 1,933,500 t in 2010 [53]. UK ethylene production is projected to grow by 3.4% p.a. [54] and in 2010 approximately 26% of the emissions from the chemical industry were attributed to ethylene production.

Given the above assumptions, the emissions from ethylene would increase by 40% by 2020 and 280% by 2050, compared with 2010 levels. These levels of growth would result in ethylene production accounting for 40% of the chemical industry's carbon budget in 2020. By 2041, the emissions would account for all of the industry's budget; in 2050, it would be 50% higher, as shown in Figure 15 (overleaf).

Figure 15. Emissions from UK ethylene production at a projected growth rate of 3.4% compared with the future carbon budget for the UK chemical industry



This analysis shows that the UK chemical industry will need to move beyond incremental energy efficiency improvements towards more radical, step changes. This will require difficult decisions regarding investment, technologies, feedstock and products, as well as a significant role for demand-side reduction and behavioural change. Further still, if the industry struggles to significantly decarbonise in the years up to 2050, there will be a demand on other sectors of the economy to take their own steps to ensure that UK climate policy is delivered and wider global commitments met.

The need for demand-side measures

The above analysis indicates that, as with all sectors of the economy, urgent and significant decarbonisation of the chemical industry is going to be very challenging. The responsibility for such levels of emissions reduction cannot sit with the chemical industry alone, nor within the UK territory. It will require collaboration with the international chemical producers and downstream users and consumers to re-examine how they use and value the goods and commodities produced by the industry. This includes the use of concepts such as:

- *Material efficiency – the provision of material services with less material production [55].*
- *Waste hierarchy – reducing demand, reusing, recycling, recovery [56].*
- *Circular economy – rebuilding capital by enhancing the flows of commodities from the*

chemical industry within the technosphere, ensuring that materials remain at a high grade instead of being downcycled [57].

These measures contribute to reducing the embodied emissions associated with the end goods and services. In addition it is necessary to reduce the demand for chemical-based commodities and goods, including changing behaviour and practices towards them. This is, of course, very difficult to achieve in practice and the barriers and opportunities are discussed in section 7.

4. Emission targets and policy framework

4.1 European targets

The EU commitment is to reduce greenhouse gas emissions to 8% below 1990 levels in the period of 2008-2012, and 20% below by 2020. This target is implemented with the 'Europe 2020' growth strategy, including binding legislations to achieve the reduction [58]. By 2050, the EU recommends that emissions are cut to 80-95% below 1990 levels [59]. Due to the characteristics, technological potential and socio-economic importance of different sectors, there are specific roadmaps for each sector; the targets from which are listed in Table 5. From the industrial sectors it is expected that energy-intensive industries (including the chemical industry) achieve a higher than 80% emission cut by 2050 through cleaner technologies, efficiency improvements and carbon capture and storage (CCS) technology.

Table 5. The EU roadmap for a low-carbon economy [59]

GHG reductions compared to 1990	**2005**	**2030**	**2050**
Total	-7%	-40 to -44%	-79 to-82%
Sectors			
Power	-7%	-54 to -68%	-93 to -99%
Industry	-20%	-34 to -40%	-83 to -87%
Transport	+30%	+20 to -9%	-54 to -67%
Residential and service	-12%	-37 to -53%	-88 to -91%
Agriculture	-20%	-36 to -37%	-42 to -49%
Other Non-CO_2 emissions	-30%	-72 to -73%	-70 to -78%

4.2 UK policy landscape

In the UK, the Climate Change Act [46] sets a legislative framework to reduce the nation's emissions by 2050 by at least 80% below the 1990 emission level [41]. The Act includes various actions of which one is to provide a system of carbon budgets and targets. Compared to the EU commitments, the UK's emission target is more ambitious and legally binding in the years up to 2050. As with the EU, recommendations of how to remain inside these emission budgets are to increase efficiencies of energy, materials and processes; to replace fossil fuels with low-carbon alternatives (e.g. bioenergy, electrification); to improve technologies; and through CCS technologies [41]. As already mentioned, the industry has high indirect carbon emissions associated with electricity imports, so any switch to the grid would have to ensure that the carbon intensity of the electricity mix is lower than the fuel being substituted.

The first four budgets in their successive five-year periods, starting in 2008, are shown in Figure 14 [41]. The fourth budget (2023-27) is 1,950 $MtCO_2e$ and is a 50% reduction below baseline levels. This budget is seen as very challenging by the chemical industry and has subsequently received criticism [30, 60, 61]. It is argued that with such sharp and rapid reductions in emissions since the third budget (2,544 $MtCO_2e$, years 2018-22), measures to assist and support the industry are essential to ensure the industry is not devastated [5] and emissions potentially moved elsewhere.

Climate change policies relevant to the chemical industry

There are several policies and acts in place at the EU and UK level which have an impact on the chemical industry. The most significant of these are outlined below:

EU Emissions Trading System (EU ETS) *http://ec.europa.eu/clima/policies/ets/index_en.htm and https://www.gov.uk/eu-ets-carbon-markets Measure to reduce industrial greenhouse gas emissions cost-effectively; implemented in 2005. It follows the cap and trade principle. The amount of greenhouse gas released by industries is limited and will be reduced over time. Within this emissions cap companies will receive allowances, which they can trade with one another as needed. If a company's greenhouse gas is outside its allowances it will be fined. Unused allowances can be used for the following years or be traded with other companies. Approximately two-thirds of industry emissions are covered by the EU ETS, of which around half are also covered by CCAs. In 2013, Phase III of the scheme will start, with fewer free permits available; auctioning will be the main method of allocating allowances.*

EU Renewable Energy Directive *http://ec.europa.eu/energy/renewables/targets_en.htm requires that by 2020 the share of energy from renewable sources (wind, solar, hydro-electric, tidal power, geothermal energy, biomass) in the EU will be 20% (15% for UK). The aim of the Directive is to enable the EU to cut greenhouse gas emissions and reduce dependence on imported energy and to encourage technological innovation and employment in Europe. Member states are largely free to set their own policy frameworks for meeting the directive targets, which, for the UK, comprise the other policy measures mentioned here.*

Climate Change Levy (CCL) *https://www.gov.uk/green-taxes-and-reliefs/climate-change-levy* *Tax on non-domestic energy products to encourage industry and businesses to reduce their energy consumption or switch to less carbon-intensive sources. It taxes: electricity, gas and solid fuels.*

Climate Change Agreements (CCAs) *https://www.gov.uk/climate-change-agreements* *High-carbon energy is taxed according to CCL. Businesses improving energy efficiency or reducing emissions to reach emission reduction targets obtain a 65% discount from the CCL.*

Renewable Heat Incentive (RHI) *https://www.gov.uk/government/policies/increasing-the-use-of-low-carbon-technologies/supporting-pages/renewable-heat-incentive-rhi* *Incentivises renewable heat use in industry. It is a financial support programme which provides payments to industry, businesses and public sector organisations which generate and use renewable energy to heat their buildings. The aim is to reduce greenhouse gas emissions from heating to meet climate change targets.*

5. Global competition, relocation and impact on the climate

5.1 Global competition and relocation

In recent years there has been increasing chemical production in China and the Middle East and, subsequently, reduced growth in European countries [33, 40]. Between 2001 and 2011, China's sales increased from about 8% to 27% of global chemical transactions, and for the rest of Asia from about 14% to 19% [9]. During the same period, the EU's global market share decreased from about 30% to 20%, North America's from about 28% to 17% and Japan's from about 11% to 6% [9].

5.1.1 Classical reasons for relocation

In the face of globalisation, especially since the fall of the Iron Curtain and the opening up of Asian nations such as China, markets have become more open and logistically more efficient [62]. This has provided organisations with new opportunities to relocate to other regions where production is lower cost. Usually, there is a whole suite of drivers which influences the decision to relocate, but low production and labour costs, as well as incentives for foreign investment, are typical drivers [62, 63]. Nonetheless, they are often closely linked to policy and legislation frameworks, such as taxes or the regulation of working conditions through employment legislation, which in the end are reflected in cost [62]. Drivers vary from industry to industry, but efficiency and productivity improvement; labour force qualifications; price and wage trends; development levels; and infrastructure and legislation frameworks are important indicators for most decisions to relocate [62-64].

5.1.2 Shifting patterns of supply and demand

The economic downturn, resulting in a decreased demand for chemicals in Europe, coupled with high oil prices, has led to a negative impact on the European chemical industry [58]. The costs of energy and feedstock are important drivers, especially for basic chemical production, as feedstock expenditure represents 70-90% of the total production cost [29, 40]. Furthermore, the EU as a whole is dependent on Extra-EU nations for these feedstocks and fuels.

However, there is an abundant supply of low-cost raw materials in the Middle East [5, 25]; in the Far East, China has a plentiful supply of coal [15, 27, 34, 65]; and, furthermore, the USA is a rapidly growing new market power since shale gas has increased its indigenous gas supply [29, 34, 37, 40, 66].

In addition to relocating the industry closer to sources of fossil fuels and raw materials, the role of demand and consumption are worth noting. Asia is providing the largest growing market for chemicals [58] – in China, for example, there are major demand increases for chemicals. As multinational companies tend to increase production in the regions with the growing demand (e.g. China) or where they have a clear cost advantage (e.g. Middle East) [29, 40] this is also reducing the competitiveness of chemical production in the EU. The carbon reduction strategies for such nations are explored in section 5.2.

Many assessments and consultancy reports see a need for the European chemical industry to specialise in order to remain competitive in the face of change, for example by providing high-tech and high-quality products [8, 15, 26, 29, 40, 60, 67-70]. Furthermore, they argue that the industry needs to move into niche markets which cannot be delivered by China or the Middle East, as they currently lack the knowledge and technology to go beyond producing basic chemicals [8, 15, 26].

Nonetheless, European nations, such as the UK, have an existing basic chemical segment which contributes significantly to the sector's turnover and employs a large share of labour. The challenge here, as with other established industrial sectors, is what to do with an ageing infrastructure and asset base. New projects require high capital investment and, coupled with conservative rates of innovation, responding to such advice is likely to require support and incentives at a government level. Moreover, asset conversion is often not an option as processes are unique and optimised for a single purpose.

5.2 The impact of relocation on the climate

The relocation of energy- and emissions-intensive basic chemical production to regions with lower production costs than the UK is not a short-term economic consideration. The capital intensity of the industry leads to asset lives of 30-50 years; decisions on relocation are not easily made nor reversed. Government policies can also have considerable impact on investments, so deliberation is needed as to what role climate change policies could play on decisions to invest in the energy-intense and highly regulated chemical industry in Europe and the UK, or rather, elsewhere in growing markets [6, 9, 15, 40].

If an industry relocates to a region where there is less, or an absence of, regulation and policies to address greenhouse gas emissions, it is known as 'strong carbon leakage' [71-73]. However, evidence suggests that a growth in global greenhouse gas emissions is more likely to result from the relocation of the industry to nations in the Far East and the Middle East [71, 72, 74, 75]. The main drivers become changes in demand, locality of raw materials and production costs. The relocation is not related to any climate policy and is known as 'weak carbon leakage'. On the production side, the level of global greenhouse gas emissions would then be related to the production efficiency and the fuel and feedstock choice. There are three points to note here:

1. As China, for example, is heavily dependent on coal and the EU more so on gas, it is likely that global greenhouse gas emissions would increase in the short-term because of 'weak carbon leakage'.
2. Even though the relocation might place production outside the remit of control for a nation such as the UK, thus reducing its share of global greenhouse gas emissions, there would still be a level of demand for the commodities and goods produced, and therefore a sustained source of emissions.
3. Energy efficiency does not necessarily equate to carbon efficiency. Even though developing markets in the Far East may be able to exploit more energy-efficient technology compared to ageing plants in the EU, the choice of fuel and feedstock will also dictate the overall carbon efficiency of a production process, as will indirect emissions.

If stronger climate policy is to be exercised within the EU, either directly (via a carbon price) or indirectly (via regulation), the impact of 'strong carbon leakage' is likely to become more apparent [71]. To some degree, this observation can be evidenced by exploring climate policy in the expanding regions. China, as with the EU and UK, does have a binding emission reduction target. However, it is not with regard to an absolute emissions reduction, but a reduction in greenhouse gas emissions per unit of GDP (i.e. emissions intensity). This effectively means that the target could be met with an increase in national GHG emissions if economic productivity also increased during the same period. The target is to reduce emissions during the twelfth Five Year Plan (2011-2015) by 17% and by 2020 by 40-45%, compared to 2005 levels [58]. In comparison, the USA has an emission reduction target of 17% below 2005 levels by 2020; however, this is not binding [76]. As an example for Middle East states, Saudi Arabia has no binding targets to reduce emissions implemented, but has taken various steps to achieve sustainable development. Emission reduction activities focus on developing and implementing CCS; disclosing and assessing methane gas emission sources; the assessment and prevention of underground fuel storage tank pollution; assessing the environmental impacts of mining activities; and the recycling of waste plastics [77]. Looking ahead, without a global agreement to address climate change and with considerably weaker policies currently serving in regions where relocation is apparent, global greenhouse gas emissions from the sector are likely to increase.

Criticism of UK climate policy

The objective of the UK's (and the EU's) emission reduction targets is not ostensibly to encourage the relocation of the industry overseas, potentially increasing net global greenhouse gas emissions. Yet parts of the UK's chemical industry have criticised its national climate change policies and emission targets [5, 54]. For example, they argue that existing and future climate policies are pricing the UK out of the market [54]. The main drivers are, for example, but not limited to, excessively steep emission reductions in the short- to medium-term; and the adoption of a unilateral policy approach by the UK, not in keeping with the rest of the EU. Looking ahead, even though the UK's carbon budgets and targets are economically very challenging for the industry, evidence suggests that climate policy alone is not driving relocation, it is the combination with cost competitiveness. However the potential for future 'strong' carbon leakage means the industry should act strategically with the government in the short-term to seek opportunities to rethink supply chains and incentivise the development and demonstration of new low-carbon technologies. There are, of course, several technical and non-technical barriers to achieving this, as discussed in sections 6 and 7.

6. Mitigation

Being an energy-intensive industry with crude oil, natural gas and coal as main sources for energy use and feedstock, the chemical industry has significant greenhouse gas emissions [4, 13, 31, 32, 41]. The literature is awash with high-level reviews as to how the chemical industry can reduce its emissions [3, 21, 31, 32, 78-81]. What most of these reviews have in common is that they are sufficiently broad in scope and are too far removed as to not actually address the complex nature of the industry and the challenges which mitigation presents. They instead provide an outline of the type of technologies which could deliver savings in the future. These main technology measures include improvements to emission intensity through more efficient use of energy, materials and processes; the use of renewables as fuel (e.g. bioenergy and low-carbon electricity) and alternative feedstocks (e.g. biomass and waste); and carbon capture and storage technology [82].

This section includes input from a stakeholder workshop held at NEPIC as part of this project. Its purpose is not to provide an exhaustive list of the potential energy efficiency improvements for each production route for UK chemicals. It instead discusses the main technologies which could be feasible for the UK; from the analysis for this report, these are mainly seen as being low-carbon/renewable fuel and feedstock substitution.

The analysis also incorporates the perspectives of key process industries. Although pharmaceutical producers are a net exporter for the UK and an important part of the chemical industry, the carbon emissions associated with their production are low in comparison to producing basic and intermediate chemicals and are not discussed further. The barriers to uptake are analysed in section 7.

6.1 Increased energy efficiency

It is likely that absolute growth within the sector will require more than just incremental gains to ensure that the UK industry remains committed to reducing its greenhouse gas emissions. At the same time, with significant improvements in energy efficiency already made in the last few decades (see section 3), further substantial step changes in efficiency within existing UK plants and infrastructure are likely to be increasingly limited. Nonetheless, as one of the most energy-intense sectors in the UK there is still potential to improve energy efficiency through, for example, one-off relative savings via new plant, combined heat and power (CHP) and waste heat recovery.

An example of a major saving made to emissions can be observed in Figure 11 in section 3.4.2. N_2O emissions from UK adipic acid production decreased by >90% between 1998 and 1999. During this time, the adipic acid plant at Wilton (used during the nylon production process) was owned by Dupont [83]. The Combined Off Gas Abatement (COGA) plant removed N_2O by reacting it with methane to produce nitrogen, CO_2 and water. Installing this technology measure meant a reduction of the equivalent of 2% of total UK greenhouse gas emissions in 1990, and excess heat was used to produce steam which was subsequently used elsewhere during nylon production. The plant closed in 2009.

6.2 Biomass as an energy source and feedstock

As with nearly every other sector of the economy, there are hopes in achieving high levels of mitigation from using biomass. In the case of the chemical industry, savings of over 5 $MtCO_2eq$ per year are estimated from using biomass as fuel and feedstock [14]. There are some projections which show that by 2030, 35% of global chemical production could, to some extent, be based on biomass [65]. The feasibility of using biomass – whether for energy, feedstocks or alternative chemicals – will largely depend on the net greenhouse gas emission savings, when compared to the fuel being replaced, yet there are a wider set of sustainability impacts which are also worth balancing [84]. The simplest option to harness the energy content in biomass is through combustion. It could also be upgraded to a fuel or feedstock (e.g. hydrogen or methane) via other thermal conversion technologies such as gasification and pyrolysis, or via biological conversion technologies such as anaerobic digestion. In terms of product substitution, i.e. producing bio-derived chemicals, the Department for Business Innovation and Skills (BIS) identifies that the application of biotechnology (e.g. fermentation technology, biotransformation, enzyme technology, structural biology) could not only benefit environmental and energy efficiency, but could lead to significant savings and cost reductions [14, 17]. Nonetheless, under current emission accounting protocols there is insufficient economic incentive to justify substantial investment in the new assets which would be required to implement bio-derived product substitution. However, such mitigation measures are likely to progress in global regions where it is economically attractive, such as Brazil, which benefits from large quantities of biomass feedstock and has a substantial existing biotechnology industry [85].

Exploring what is viable for the UK, biomass is likely to be utilised through CHP and feedstock production. As a substantial amount of energy is generated directly on site, there is the option to convert power generation to combined heat and power, to produce both electricity and heat. However, given the need to decarbonise substantially, there is a move towards renewable CHP plants – using biomass and/or municipal solid waste (MSW). There are UK Government incentives to achieve this too [86], under the RO and RHI incentives. As the main direct power and steam provider to the Wilton site, Sembcorp introduced their 'Wilton 10' 35 MW_{el} biomass power station in 2007 [87]. The biomass is supplied locally and it saves approximately 0.2 Mt CO_2 p.a. More recently, the ability to capture and distribute heat from the process has further increased the site's efficiency.

Biomass and waste gasification provide viable options in the UK to supply low-carbon electricity, methane feedstock (replacing natural gas) and hydrogen feedstock (replacing natural gas steam reforming). Air Products and Chemicals are building an advanced gasification energy-from-waste plant on Teesside [88]; additional sites are also planned. It will process up to 350,000 tonnes of industrial, commercial and municipal waste p.a. to provide up to 50MW power; investing in UK industry and providing significant employment. This site is of significance to the chemical industry, as Air Products state that the production of hydrogen will be considered in the future – providing a low-carbon source for feedstock substitution. The environmental and techno-economic viability to produce hydrogen from biomass gasification for ammonia production has been explored at a research level [89, 90] and could be considered viable, again if policy and incentives support commercial scale demonstration plants.

6.3 Carbon capture and storage technology (CCS)

CCS technology is an important mitigation option in almost all emission scenarios for all carbon emitting sectors [47]. It would require capturing and separation of CO_2 during chemical production and this could occur at point sources (e.g. during ammonia production), prior to combustion or feedstock use (e.g. some biomass arrangements) and in post combustion flue gas (e.g. coal gasification). Additionally, and often overlooked, significant amounts of energy would be needed for the process than without; up to one-third more energy depending on, for example, the capture point and age of technology. However, as yet, the technology is unproven. Given its applicability for a range of sectors, it is worth noting the important opportunities and barriers to consider for the UK chemical industry, to be discussed in section 7.

6.4 Demand-side measures and the circular economy

Embodied carbon emissions can be reduced through demand-side mitigation, by increasing material and resource efficiency and reusing and recycling chemical products. However, what these measures entail is a reduced demand for the production of new chemicals, which is a challenge the industry has to meet. In the analysis in section 3.5 a range of growth levels were assumed (1-3%) and of course, the smaller growth levels would go some way to minimise this. However, referring back to the rates of reductions required by the industry under the higher levels of growth, such levels arguably lie beyond supply-side mitigation and require demand-side reduction also. Despite this, application of concepts such as industrial ecology and the circular economy seek to reduce emissions through reusing resources and materials in the technosphere. Kalundborg Symbiosis is the world's first well-functioning example of achieving this [91]. Waste products, including steam, gases, heat, slurry and dust are traded between public and private organisations at the same site, in a closed-cycle system. Partners include DONG Energy; industries producing (e.g.) fertiliser, cement and nickel; waste water treatment facilities; and end-users such as farms. This reduces carbon emissions compared to these organisations functioning stand-alone; for example, waste heat from one organisation is used as heat input for another organisation, requiring less overall heat production.

Furthermore, when exploring the downstream users of commodities and products produced by the chemical industry, there are wider savings to be made other than decarbonising just the production process. Chemical products themselves are an important contribution to mitigation in other sectors as they allow emission reduction due to, for example, fuel and energy saving in the transport sector, energy savings in housing, and improved yields in agriculture [21]. It has been estimated that globally in 2005, chemical products saved about twice as many emissions in other sectors than were generated by the chemical industry itself [17, 21].

7. Barriers and opportunities for the UK's chemical industry

The preceding sections for this report have illustrated the substantial challenges faced by the chemical industry and the potential impact of decarbonisation targets on the industry if those challenges are not positively addressed. However, there are substantial barriers to those changes, which were discussed with stakeholders at a workshop and which are discussed below.

7.1 Mitigation

In section 6 key mitigation measures were outlined; these were subsequently discussed at the stakeholder workshop.

7.1.1 Fuel and feedstock substitution with biomass and MSW

Stakeholders agreed that given the issues of relocation, competitiveness and carbon targets, there were few incentives to develop and use bio-derived chemicals such as biopolymers in the UK. Nonetheless, they said that customers are expressing interest in such products. Feedstock price would have to become more competitive if there was to be substantial uptake. Stakeholders saw the conversion of biomass and waste to electricity or renewable feedstocks (e.g. hydrogen) via gasification and the use of CHP as the most viable options for the UK.

Biomass prices were seen as being too high when compared to fossil fuels. As one stakeholder put it:

"Oil is cheaper than milk, it is too cheap."

Furthermore, as demand for biomass is increasing in national and global markets, the industry present at the workshop noted that contracts between biomass suppliers must be renewed within shorter timescales (much less than the previously typical ten year period). The price for the biomass feedstock is also increasing each time, as biomass becomes a more desirable commodity.

When assessing the practicalities of using biomass for CHP or steam production, several technical barriers were identified. The chemical industry requires large volumes of steam and this was seen as being very difficult to generate using biomass. Biomass can produce low pressure steam but the proportion of existing fossil fuel capacity which could be replaced was perceived to be small.

"The process barriers for steam are not the temperature but the pressure."

It is, in principle, possible to increase heat recovery by operating a biomass-fired boiler in condensing mode. This takes advantage of the high moisture content of biomass feedstocks and recovers the latent heat of vaporisation of the water in the feedstock. However, recovery of this low-grade heat is not presently as financially viable as maximising the more valuable electrical output.

Some stakeholders were mindful of the competing end-uses for biomass in terms of transport, power etc.

"If biomass could be used for heat and as a syngas for feedstock substitution, how much biomass would this actually require? There is probably not enough biomass for the process industry."

When considering the production of syngas from waste gasification, it is currently more economically feasible to generate energy rather than low-carbon hydrogen. However, if there were market incentives which favoured the production of hydrogen in the future, stakeholders felt that existing process routes could be adapted to facilitate this e.g. ammonia not requiring methane reforming. It was added that there would be enough hydrogen to do this for existing assets. When asked whether this would increase the investment potential in the North-east for renewable hydrogen, one stakeholder responded by saying:

"Would people come here for renewable hydrogen?
Probably not, but there is the potential for direct displacement."

7.1.2 Industrial symbiosis

From a resource and material efficiency perspective, the use of energy from waste raises questions regarding the integration and exchange of heat and steam – for example, between multiple organisations. This was discussed at the workshop with the stakeholders, in particular the recycling and reuse of chemicals and chemical-derived products. Recycling and reuse at the end of product life was seen as very challenging and to achieve this, one stakeholder bluntly put it:

"Ban landfill within five years."

Nonetheless, it was reported that customers are also asking for recycled products in order to say that they are low-carbon. So there is a level of demand from the consumers. The reuse of waste chemicals and products raised further economic barriers.

"Waste needs to become a commodity. But this results in a price hike in waste – people want to make money, and this prices the feedstock out of the market."

When pressed on aspects of the circular economy and the example of industrial symbiosis in Kalundborg [91], stakeholders agreed that this was a practical way forward to increase energy efficiency and minimise waste. However, one stakeholder stated that:

"People are loath to be dependent on someone else. If they rely on someone else to take heat, what if they go under?"

This remark was particularly poignant with regard to the uncertainty in the UK chemicals market and issues of relocation. Even though the stakeholders stated that *"decentralised needs to work"*, the synergies and willpower are limited. The industries and potential synergies exist but, again, the consumers of heat and power were also seen as being as cautious as the suppliers.

A final barrier outlined for recycling was that the end products produced by the chemical industry are often combined with other products and therefore do not necessarily feed back into the chemical industry's supply chain. Despite this, stakeholders agreed that it would be more strategic for the UK to explore the recycling of products, such as polymers, instead of using biopolymers.

7.1.3 Carbon capture and storage technology

CCS technology was seen as being attractive for new plants and where there are point sources, for example ammonia. But it was regarded as not being cost-effective when capturing CO_2 from existing assets – or at a smaller scale.

"It is just too costly for older plants."

This was seen as a large barrier for the UK chemical industry, which has an ageing asset life and a multitude of small-scale organisations which collectively emit a large amount of CO_2. Coupled with the decision for the UK Government not to select the proposal at Teesside as a preferred bidder in the £1 billion Capture and Storage Commercialisation Programme competition, this does not paint a promising picture for the development of CCS for the UK chemical industry. If the industry were to pursue CCS it would arguably have to combine it with new infrastructure and plants and the timeframes for this would not contribute to meeting carbon targets.

7.1.4 Electrification of industrial heat

Stakeholders showed frustration with the UK Government on the topic of electrification of heat.

"How do you get the heat? The UK Government does not understand industrial heat."

Government proposals were criticised for not fully taking into account the infrastructure required, for the grid and the industry, as well as the grade of heat which the industry requires.

7.2 Climate policy and relocation

7.2.1 Uncertainty in the UK chemical industry

Stakeholders were in agreement that people are worrying how a future carbon price could affect investment in the UK. Likewise, at an EU level it is perceived that energy prices are going to be further impacted by the low-carbon agenda.

"The perception is that there is a lot of uncertainty."

Furthermore, the ageing asset base in the UK was also regarded as delaying investment. An ammonia plant was stated as closing down due to a combination of economics and carbon uncertainty – leaving only two ammonia plants in the UK. But despite this, one stakeholder pointed out that investment is still ongoing in the UK, where Lotte Chemical UK Ltd is investing heavily in Teesside, as are Air Products.

Finally, at a more specific level, there was discussion surrounding a reduction in pharmaceutical investment in the UK. With many patents expiring, reducing research and development productivity, and increased competition from lower cost overseas production in nations such as China and India, the sector's competitive position is under pressure.

Looking ahead, the stakeholders were keen to promote the use of shale gas in the UK, whether imported or indigenous. However, when questioned on the ability of shale gas to meet UK carbon targets, stakeholders agreed that the two were not currently commensurate.

7.2.2 UK climate policy

When discussing UK policy in comparison to the EU, the stakeholders expressed concern as to how the UK is progressing.

"The UK is not helping itself in the EU by having a higher carbon price…
we want at least a level playing field with Europe – we are handicapping ourselves."

Concerns were also raised with regard to policy clashes when producing heat from biomass. One stakeholder stated that the UK Government may be able to achieve the Renewable Heat Incentive using biomass, but this does not necessarily mean it will meet its carbon targets. Further criticism was provided regarding greenhouse gas reporting to Ofgem. It was felt harsh that the full life cycle for the biomass system had to be reported, whereas only the combustion of the fossil-based system was reported.

Towards the end of the workshop a rather fitting point was raised by one stakeholder, which captured the viewpoints and thoughts of other stakeholders present:

"Fossil fuels are too valuable to burn…we should reserve fossil fuels to make valuable products and focus on renewables for primary energy… this may not get to the target, but it is a step in the right direction."

On the face of it, with options to decarbonise power through means such as wind, tidal and solar there is, arguably, a rationale for such a case. However, it would have to be viewed in the wider context of the UK's climate agenda and the ability of the UK to decarbonise by 80% if a strategy were pursued. Furthermore, there are fewer supply options for the decarbonisation of heat and, in particular, such a strategy would be of significant issue for the transport sector (including aviation).

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