Government
Office for Science

Foresight

# The future role of energy in manufacturing

## Future of Manufacturing Project: Evidence Paper 11

Foresight, Government Office for Science

# The future role of energy in manufacturing

**Professor Richard Green**
Imperial College Business School

**&**

**Professor Xiao-Ping Zhang**
University of Birmingham

October 2013

This review has been commissioned as part of the UK Government's Foresight Future of Manufacturing Project. The views expressed do not represent policy of any government or organisation.

# Contents

# Executive summary

This report considers the present and future role of energy in manufacturing, in the context of the need to deliver a low-carbon economy. That need presents two threats to UK-based manufacturers, and two opportunities. The first threat is that the price of energy in the UK will rise, compared to the cost faced by competitor firms abroad, placing UK manufacturers at a significant disadvantage. The second threat is that a low-carbon electricity supply will be unreliable, and that the cost of power cuts will rise. The first opportunity is related to this threat – manufacturing sites that can reduce their electricity imports at times when the power system is under stress are already paid for doing so. The need for such demand-side management, the options for providing it, and the price paid are all likely to increase over time. The second opportunity is that new low-carbon products will be needed – not least in the transport sector – and UK-based firms may be able to break into these new markets.

Manufacturing was directly responsible for 11.2% of the UK's Gross Domestic Product in 2010, and 16.5% of its final energy demand. Both shares have been declining over time, and electricity and natural gas have replaced coal, coke and oil. The energy intensity of most (but not all) industrial sectors fell between 1990 and 2010, with an overall effect of reducing energy per unit of output by 29%.

Energy costs ranged from under 2 per cent to just over 10 per cent of the value of output in 2010 (and more for some specific products). This makes some sectors that are exposed to international competition vulnerable if UK energy prices rise and those abroad (particularly outside the EU) do not, which is likely if the EU continues with more ambitious climate policies than the rest of the world.

There are few signs that companies move en masse to countries with weaker environmental controls (the so-called pollution haven hypothesis), but some recent evidence suggesting that this could be an issue in specific industries. Border tax adjustments that add carbon costs to imports and offset their impact on export prices are likely to be the most effective way of limiting the harm to UK industry while retaining incentives to decarbonise inside the country.

There is significant potential for decarbonising some industrial processes through carbon capture and storage, but this is very site-specific, although the North Sea gives the UK suitable storage options.

Energy efficiency could save more than one-fifth of projected manufacturing energy demand, and material efficiency techniques that reduce the weight of products or the amount of inputs wasted in production can further this. There are significant barriers such as lack of knowledge, limited investment budgets and split incentives (e.g. between landlords and tenants), which policy measures can sometimes overcome.

An increasing supply of intermittent renewable (particularly wind) energy and greater cross-border power flows could leave the UK vulnerable to more power cuts (which are currently at very low levels), particularly if too few conventional power stations are built over the next decade to replace those retiring. A four-hour blackout in the West Midlands on a working day would cost manufacturers there (with 275,000 employees) roughly £25 million in lost production and other impacts.

Timely demand response services (cutting consumption on instructions from the National Grid's controllers) can reduce the risk of blackouts and provide an income stream to offset electricity costs. Many manufacturers already sell these services, and the need for them, prices offered and the range of firms able to provide them are all likely to increase. UK manufacturers also have the opportunity to develop new low-carbon products, particularly in vehicle manufacturing and energy storage, provided that supportive policies for research and development and for knowledge transfer are put in place.

# 1. Introduction

This report considers the present and future role of energy in manufacturing, in the context of the need to deliver a low-carbon economy.  That need presents two threats to UK-based manufacturers, and two opportunities.  The first threat is that the price of energy in the UK will rise, compared to the cost faced by competitor firms abroad, placing UK manufacturers at a significant disadvantage.  The second threat is that a low-carbon electricity supply will be unreliable, and that the cost of power cuts will rise.  The first opportunity is related to this threat – manufacturing sites that can reduce their electricity imports at times when the power system is under stress are already paid for doing so.  The need for such demand-side management, the options for providing it, and the price paid are all likely to increase over time.  The second opportunity is that new low-carbon products will be needed – not least in the transport sector – and UK-based firms may be able to break into these new markets.

This paper starts with a review of the UK manufacturing sector, and how it currently uses energy, looking at the product mix, the processes involved and the amount currently spent.  Section 3 considers the future use of energy and how it can be decarbonised, through energy and material efficiency, carbon capture and storage (applied to some manufacturing processes as well as in the electricity industry) and the use of cleaner fuels.

The fourth section considers the vexed question of international competitiveness.  It is quite possible that the UK and Europe will incur the costs of decarbonising their energy supplies, but that other countries will not, at least in the medium term.  The evidence on energy costs, location and competitiveness is assessed, finding that there is little evidence that most sectors of the economy would be affected.  However, a few sectors are at significant risk of losing competitiveness.  The paper goes on to study another threat from a decarbonised electricity system, the potentially increased risk of power cuts.  While the risk cannot be quantified, the costs of a major outage can be – if the West Midlands lost power for four hours on a working day, the cost to manufacturers (alone) would be around £25 million.

Section 6 turns to the opportunities that a low-carbon economy may bring.  The electricity system will have a greater need for demand response services, and manufacturing firms will be able to provide these.  It should be pointed out, however; that many of the large manufacturers able to provide these services already do so, and the additional gains may be low, unless smaller companies are helped to access this opportunity.  Finally, the paper considers the opportunity to produce new low-carbon products, and in particular to build on the UK's strengths in vehicle manufacturing to contribute to the electrification of the world's cars.

# 2. Energy use in manufacturing

The availability of (relatively) cheap energy to drive machines in factories was one of the defining features of the first industrial revolution. The energy intensity of manufacturing is greater than that of the economy as a whole: while gross value added in manufacturing was 11.2% of GDP in 2010, it accounted for 16.5% of final energy demand. Table 1 gives data for output, employment and energy use in the manufacturing sector, based on the Standard Industrial Classification.

**Table 1: Manufacturing in the UK, 2010**

| SIC (2007) | Division | Number of enterprises | Total turnover, £ million | Approximate gross value added at basic prices, £ million | GVA as % of GDP | Employment (average during year), thousands | Energy use in MTOE | Energy intensity (TOE per £ of GVA) |
|---|---|---|---|---|---|---|---|---|
| 10 | Manufacture of food products | 6,380 | 72,862 | 19,343 | 1.5% | 381 | 2,550 | 0.13 |
| 11 | Manufacture of beverages | 977 | 18,685 | 5,870 | 0.4% | *55* | 611 | 0.10 |
| 12 | Manufacture of tobacco products | 10 | 10,553 | 1,864 | 0.1% | *5* | 20 | 0.01 |
| 13 | Manufacture of textiles | 3,935 | 5,307 | 1,931 | 0.1% | *35* | 553 | 0.29 |
| 14 | Manufacture of wearing apparel | 3,391 | 2,838 | 915 | 0.1% | 40 | 261 | 0.29 |
| 15 | Manufacture of leather and related products | 525 | 893 | 314 | 0.0% | *5* | 35 | 0.11 |
| 16 | Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials | 7,582 | 6,817 | 2,347 | 0.2% | 76 | 812 | 0.35 |
| 17 | Manufacture of paper and paper products | 1,770 | 11,308 | 3,203 | 0.2% | 53 | 1,812 | 0.57 |
| 18 | Printing and reproduction of recorded media | 14,464 | 10,761 | 4,889 | 0.4% | 139 | 539 | 0.11 |
| 19 | Manufacture of coke and refined petroleum products | 170 | 38,400 | 2,446 | 0.2% | *23* | 4,398 | 1.80 |
| 20 | Manufacture of chemicals and chemical products | 2,565 | 36,041 | 10,378 | 0.8% | 111 | 3,617 | 0.35 |
| 21 | Manufacture of basic pharmaceutical products and pharmaceutical preparations | 444 | 18,873 | 9,676 | 0.7% | 48 | 377 | 0.04 |

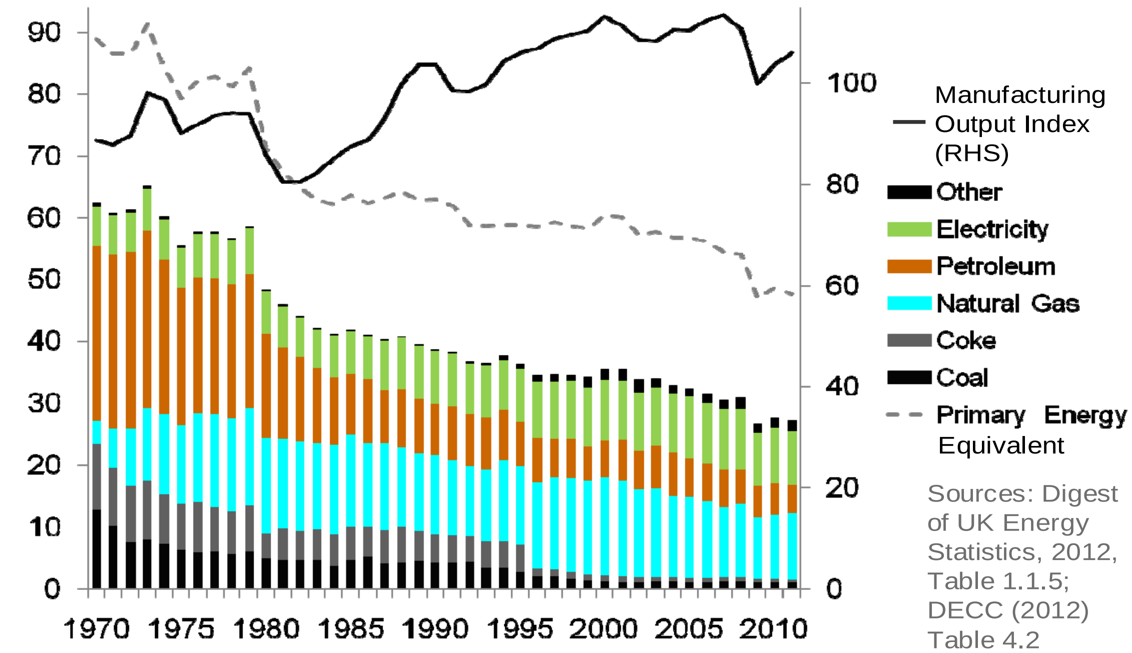
| SIC (2007) | Division | Number of enterprises | Total turnover, £ million | Approximate gross value added at basic prices, £ million | GVA as % of GDP | Employment (average during year), thousands | Energy use in MTOE | Energy intensity (TOE per £ of GVA) |
|---|---|---|---|---|---|---|---|---|
| 22 | Manufacture of rubber and plastic products | 5,994 | 19,794 | 7,049 | 0.5% | 149 | 1,826 | 0.26 |
| 23 | Manufacture of other non-metallic mineral products | 3,957 | 13,978 | 4,371 | 0.3% | 91 | 2,480 | 0.57 |
| 24 | Manufacture of basic metals | 1,452 | 18,612 | 4,101 | 0.3% | 76 | 2,217 | 0.54 |
| 25 | Manufacture of fabricated metal products, except machinery and equipment | 25,590 | 29,537 | 11,814 | 0.9% | 294 | 800 | 0.07 |
| 26 | Manufacture of computer, electronic and optical products | 6,387 | 20,522 | 9,092 | 0.7% | 133 | 506 | 0.06 |
| 27 | Manufacture of electrical equipment | 2,927 | 12,949 | 4,495 | 0.3% | 92 | 400 | 0.09 |
| 28 | Manufacture of machinery and equipment n.e.c | 8,642 | 33,180 | 12,132 | 0.9% | 191 | 527 | 0.04 |
| 29 | Manufacture of motor vehicles, trailers and semi-trailers | 2,794 | 46,321 | 9,957 | 0.8% | 136 | 835 | 0.08 |
| 30 | Manufacture of other transport equipment | 1,856 | 27,350 | 8,287 | 0.6% | 142 | 395 | 0.05 |
| 31 | Manufacture of furniture | 6,206 | 7,087 | 2,871 | 0.2% | 68 | 222 | 0.08 |
| 32 | Other manufacturing | 9,738 | 8,585 | 3,731 | 0.3% | 88 | 299 | 0.08 |
| 33 | Repair and installation of machinery and equipment | 6,235 | 12,640 | 5,505 | 0.4% | 103 | n/a | n/a |

Sources: ONS, Annual Business Survey 2011, Table C (Manufacturing) and DECC, Energy Consumption in the UK, Industrial Data Tables, 2012 Update, Table 4.6c(i). Employment figures in italics are inferred from employment costs

Figure 1 shows the longer-term trends for manufacturing output and energy use.[1] Manufacturing has been declining as a share of the UK economy, as in many other developed countries around the world. This partly reflects higher productivity growth which reduces the relative price of manufactured goods compared to services, but is also due to a worsening balance of trade.[2] The UK suffered from "Dutch disease" after the development of North Sea Oil led to an appreciation in the value of Sterling; the recent shift to being (again) a net importer of energy creates a need for an alternative source of foreign exchange.

The declining share of manufacturing output also implies a declining share of the UK's energy use. Industry accounted for just under 20% of the UK's final energy consumption in 2011, down from 43% in 1970. The fuels used have also changed – in 1970, oil, coal and coke (made from coal) were dominant, but these have given way to electricity and natural gas. The dotted line shows the primary energy needed to meet the final demand, which has declined proportionally less than final demand. The rising share of electricity, which has a higher input of primary energy per unit of delivered energy, largely accounts for this, despite improvements in the conversion efficiency of the electricity sector.

**Figure 1:Energy used by industry in the UK**




Sources: Digest of UK Energy Statistics, 2012, Table 1.1.5; DECC (2012) Table 4.2

Table 1 showed that the energy-intensity of manufacturing varied significantly across sub-sectors, which immediately suggests the possibility that some of the changes in energy consumption are due to changes in the mix of industries. Table 2 shows that this has been a factor at the level of individual industries – the output of the iron & steel and basic metals industries has fallen by a fifth between 1990 and 2010, while their energy intensity fell by two-thirds. Other energy-intensive industries (in particular, chemicals) have grown, however, so that overall, changes in the composition of output have had

[1] The data for energy use are for a slightly broader grouping, "industry", which includes water supply.
[2] When a manufacturing firm outsources some of its activities to a services firm, this will also lead the sector to apparently shrink in terms of value added, even if the firm's output is unchanged.

almost no impact on aggregate energy consumption. Instead, a reduction of almost one-third in energy intensity has driven the reduction in energy use in manufacturing.

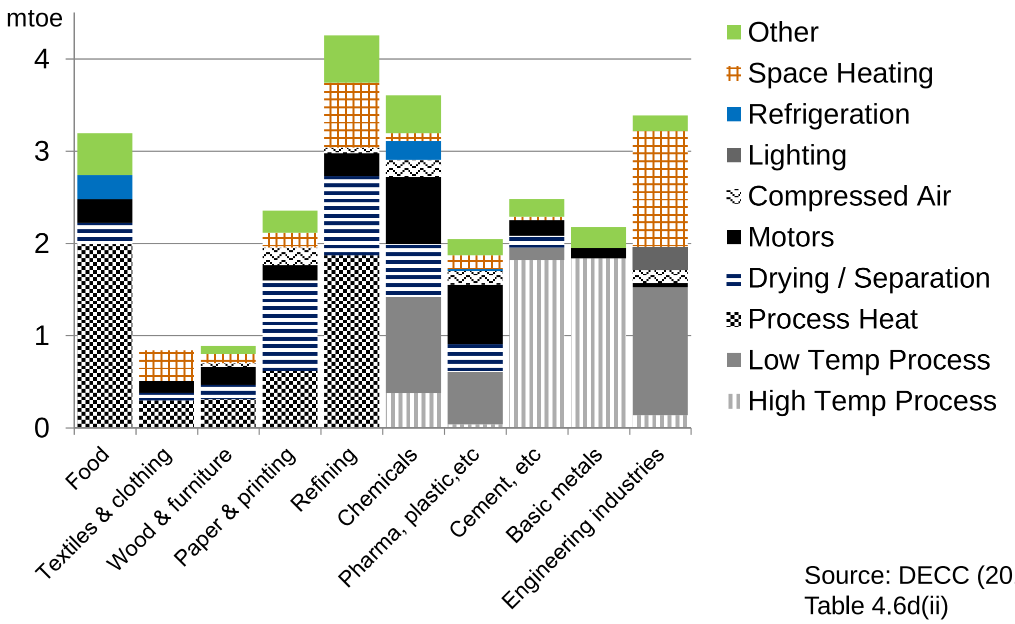
**Table 2: Energy Consumption and Changes between 1990 and 2010**

| Sector | Energy Consumption in 1990, mtoe | Change in energy consumption due to | | Energy Consumption in 2010, mtoe |
|---|---|---|---|---|
| | | Change in output, mtoe | Change in intensity, mtoe | |
| Iron & steel, Non-Ferrous Metals | 8.2 | -19% | -67% | 2.2 |
| Chemicals | 5.9 | 46% | -49% | 4.4 |
| Mechanical, Electrical and instrument engineering | 3.6 | -4% | -35% | 2.2 |
| Vehicles | 1.8 | 32% | -47% | 1.2 |
| Food, drink & tobacco | 4.2 | 7% | -29% | 3.2 |
| Textiles, leather, clothing | 1.2 | -54% | 50% | 0.8 |
| Paper, printing, publishing | 2.4 | -17% | 16% | 2.4 |
| Construction | 1.1 | 15% | -64% | 0.5 |
| Other industries | 8.7 | -5% | -7% | 7.7 |
| Unclassified | 1.5 | | | 3.1 |
| Total | 38.7 | 1% | -29% | 27.7 |

Source: DECC (2012, table 4.7)

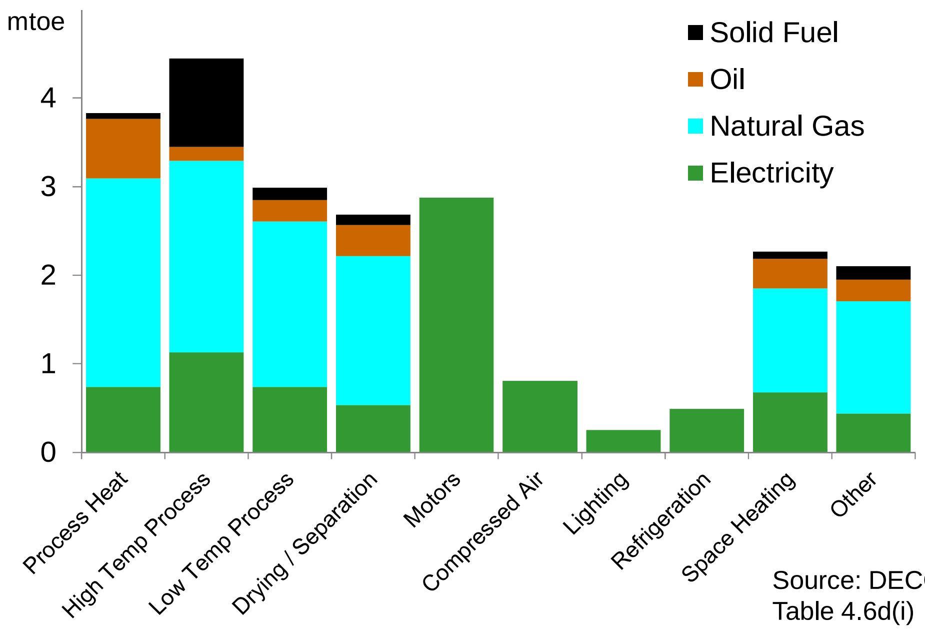
In industry, energy is needed for a wide range of processes, shown in Figures 2 and 3. It should be noted that the information is drawn from surveys using a variety of definitions; some industrial sectors do not differentiate between high- and low-temperature process heats.

**Figure 2: Energy used by process and industry, 2011**




Source: DECC (2012) Table 4.6d(ii)

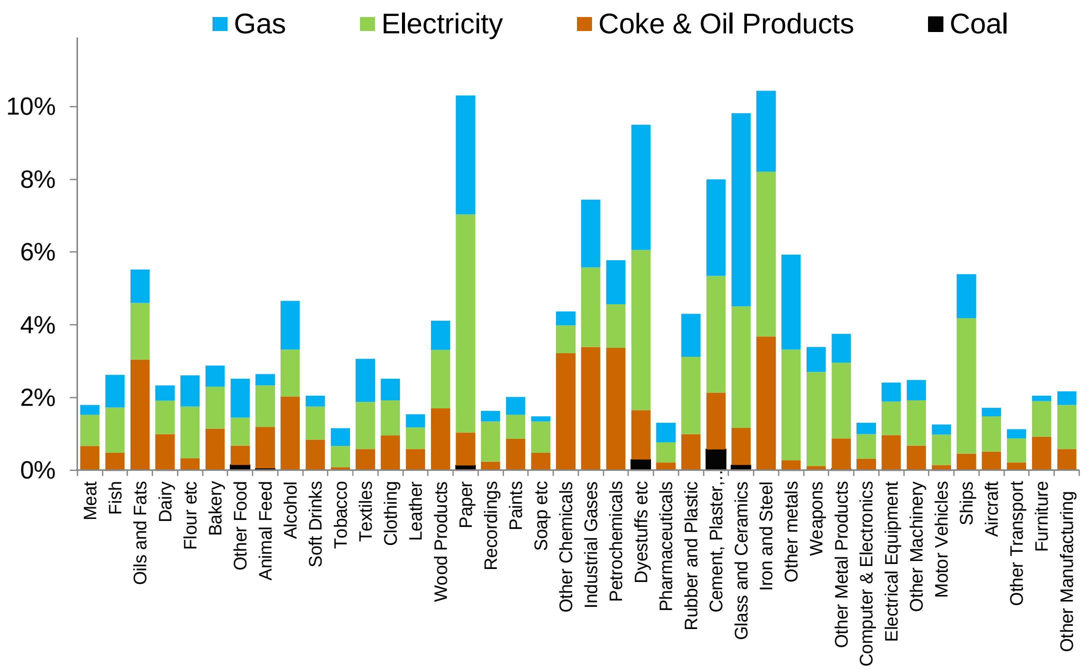
**Figure 3: Energy used by process and fuel, 2011**




Source: DECC (2012) Table 4.6d(i)

Figure 4 shows how the cost of energy varies across industrial sectors. Derived from the UK input-output tables for 2010, it gives the cost of energy as a proportion of the value of each industry's output. The share has varied from year to year with the level of energy prices; those were significantly higher in 2010 than five years earlier, when the previous tables were compiled. It does not measure the energy embodied in intermediate inputs bought by the sector (e.g. energy used in manufacturing the textiles bought by the clothing industry), although in most cases this will be very small.

**Figure 4: Energy costs as a percentage of output value**




Source: ONS Input-Output Tables for 2010

This figure shows how much the price of each sector's output would need to rise if a doubling of the cost of energy were passed through to its customers, but some sectors might not be able to raise their prices in this way.  Energy-intensive manufacturers exposed to international competition are particularly vulnerable, and the threat to them is considered in section 3 below.

# 3. Future manufacturing energy use

The level of energy use in UK manufacturing over the next decades depends on the amount of output and the energy-intensity of its production. The scenarios in the Energy Technology Perspectives from the IEA (2010) are based on the European OECD countries producing similar levels of materials (aluminium, cement, chemical feedstocks, paper and steel) in 2050 as at present, with either modest growth or a slight decline. The UK government's Carbon Plan (DECC, 2011) assumes a 30% increase in industrial production in the period to 2050. Much of this will be in the less energy-intensive sectors. The 2050 Calculator from the UK Department of Energy and Climate Change contains an "extrapolation of current trends" giving a 30% reduction in metals output (compared to 2007), a 10% increase in minerals (including cement), and a 50% increase in other manufacturing output (while chemical production remains constant). The UK Energy Research Centre 2050 Project (UKERC, 2009) assumed a 2% growth rate of GDP, but did not report any sectoral breakdown. Industrial emissions in its Reference Scenario remain broadly constant, however; which would be compatible with current (or somewhat higher) levels of industrial output if there was little reduction in energy and emissions intensity.

The energy intensity of manufacturing can be reduced by a combination of material efficiency and energy efficiency. Material efficiency involves reducing the amount of a material (e.g. aluminium) required in a product (e.g. a car), reducing the amount wasted in making the car (e.g. in scrap from castings) or obtaining more of it through recycling, in order to reduce the amount of energy-intensive aluminium processing needed. Traditional "energy efficiency", in contrast, might be defined as using less energy per unit of output of (largely) unchanged products.

The IEA's Baseline scenario is based on a small improvement in energy efficiency over the next four decades; a similar reduction in energy inputs per unit of output of 0.2% per year is the least optimistic assumption within the DECC calculator. The IEA Blue Map scenario, based on finding the least-cost way to halve global energy-related $CO_2$ emissions by 2050 (compared to 2005), includes much greater improvements in energy efficiency. In the OECD European countries, industrial energy consumption would be 25% below the Baseline level, with industrial output unchanged. This is responsible for one-third of the reduction in direct emissions needed to move from the Baseline to the Blue Map trajectory. Recycling and energy recovery account for one-tenth of the reductions, while fuel and feedstock switching account for one-fifth. The largest contribution, at two-fifths of the emissions savings, comes from carbon capture and sequestration in industry.

The UK government (DECC, 2011) envisages energy demand by industry falling by "up to one quarter" from current levels. Given output growth, this would require a reduction in energy intensity of around 40%, from energy efficiency and fuel switching. Electricity (which would have very low emissions by 2050) and bio-energy would provide roughly half the sector's energy. Industrial CCS would capture around one-third of the sector's remaining emissions.

## 3.1 Carbon capture and storage

The IEA's Blue Map scenario suggests that carbon capture and storage could provide the biggest single contribution to reduced emissions from industry by 2050, although the UK government places a lesser emphasis on the technology. $CO_2$ from burning fuels or industrial processes would be captured and piped to a suitable underground storage site – if there is one within a reasonable distance. Fortunately for the UK, depleted North Sea oil and gas fields should provide suitable sites, with some existing infrastructure. The potential for installing CCS may depend critically on site-specific conditions, however; Johanssen *et al* (2012) show that emissions from oil refineries come from many different processes, and refineries may not have the space (or budget) for the pipework required to gather all of the flue gases to a central capture facility. If CCS can only be applied to the largest point sources within a refinery, the rate of capture will inevitably fall. In steel-making, the ULCOS consortium is developing three options that raise the purity (and reduce the volume) of CO2 emissions, allowing CCS to be fitted at lower cost (ULCOS, not dated). A fourth option, provided low-carbon electricity is available, is to use electrolysis.

Fennell *et al.* (2012) show that the costs of industrial CCS depend on the nature of the gas stream (in particular, on the purity of the $CO_2$ and its pressure). Estimated costs range from well below those of CCS at power stations (in natural gas processing and ammonia production) to well above them (in oil refining). Co-locating power stations and cement works could allow a calcium looping cycle that captures $CO_2$ emissions from both sources and also means that there is no need to calcine the Calcium Carbonate in the cement process. This is an example of industrial symbiosis, in which waste from one plant becomes a useful input to another nearby facility. A well-known case is at Kalundborg in Denmark, where a power plant exports steam to an oil refinery, gypsum (from its Flue Gas Desulphurisation unit) to a plasterboard manufacturer and heat to the local municipality (Jacobsen, 2006). Water is also extensively shared among the companies on this site.

## 3.2 Energy and material efficiency in manufacturing

While there are many strategies for saving energy (recently reviewed by Abdelaziz et al, 2011),[3] the barriers to energy efficiency are well-known. Energy efficiency often requires investment and must compete with revenue-generating projects for scarce funds; if the beneficiary of the investment is a tenant, a landlord who does not expect to capture the benefits through a higher rent will find investment financially unattractive. Many firms do not prioritise energy issues (perhaps because of bounded rationality) and may be unaware of their relative efficiency level – one feature of the original design of the UK's Carbon Reduction Commitment (a scheme aimed at organisations with large energy bills but low levels of energy intensity) was to give rebates to firms with above-average performance, hence bringing the issue to the attention of senior management. In practice, it proved too difficult to measure and rank the organisations, and the measure

[3] DECC (2011) have calculated that adopting only the most favourable options for saving electricity in the UK industrial sector would save 24 TWh per year – around one fifth of estimated 2030 demand. The measures were replacing over-sized motors with smaller ones, using variable speed drives (where suitable), running pumps at their most efficient speed, replacing large pumps with a cascade of smaller ones, only some of which are turned on at off-peak times and improving the insulation and operation of furnaces.

was changed to a straightforward tax. Firms with a specialist energy or environmental manager in charge of climate change issues out-perform those where the task is taken on by the CEO (Martin *et al*, 2012), while the adoption of a range of modern management good practices is associated with higher productivity and a 17% reduction in energy intensity (Bloom *et al*, 2010).

If managers are unaware of the measures that could be taken, demonstrator programmes or advice services may lead to savings. The UK ran an Energy Efficiency Demonstration Scheme that may have led to one quarter of the observed savings in energy demand during the 1980s (Griffin et al, 2012). German SMEs that received grant-funded energy audits typically discovered energy-saving investments with a positive net present value to the enterprise, saving carbon at a relatively low cost to the government (Fleiter *et al*, 2012). Even when energy-saving equipment has been installed, users must be trained to operate it correctly. Average practice often lags well behind best practice, even in energy-intensive sectors – several studies have suggested that savings of 15% to 20% in energy consumption would be possible if all firms adopted best practice (Saygin *et al*, 2011; Aranda-Uson *et al,* 2012; Laurijssen *et al*, 2013). UK firms in energy-intensive sectors were required to improve their efficiency through sector-specific agreements with the Treasury in return for rebates on the Climate Change Levy (a kind of carbon tax) which may have helped to spread best practice.

Energy saving is likely to get cheaper in future – Weiss et al (2010) find learning rates for demand side technologies averaging an 18% reduction for each doubling of cumulative output, a similar rate to those for supply-side technologies. Despite this, public policy tends to concentrate on supply-side measures (Wilson *et al,* 2012). As EU Energy Commissioner Andris Piebalgs has said, with demand-side measures, “there’s no red ribbon to cut” (quoted in Yergin, 2012, 631).

One perhaps less familiar approach to saving energy, particularly in those energy-intensive plants that have already achieved best practice in terms of energy per unit of output, will be to reduce the amount of output required per product sold. This material efficiency approach could involve reducing the weight of the products (although more complex (and expensive) shapes may be needed to achieve the same strength). Another aspect of the approach is to reduce the amount of product wasted within the production process – Milford *et al* (2011) show that only 84% of liquid steel and 59% of liquid aluminium reaches the final product; the remainder becomes process scrap at various stages of the production chain. Although this scrap is recycled, reducing the amount of metal heated unnecessarily could cut the sectors’ energy use by 17% (steel) and 6% (aluminium).

## 3.3 Lower-carbon fuels

Manufacturers could also reduce their carbon emissions by switching to lower-carbon fuels; the UK Committee on Climate Change recommends that electricity should be largely decarbonised by the 2030s. Figures 1 and 3 show that natural gas accounts for almost half the energy used in industry, and three-quarters of the fuel burned on-site. The use of coal, the highest-carbon fuel, is almost entirely limited to high-temperature processes where it may play a chemical role in the process, as with iron blast furnaces. Nearly a million tonnes of oil were used in low-temperature processes, and some for space heating and drying – gas would be a slightly lower-carbon alternative, although some parts of the UK are not actually connected to the gas grid.

Combined Heat and Power (CHP) is well-known for having a higher “headline” efficiency than producing electricity in large power stations, dividing the total useful energy by the heat input. This standard calculation mixes the amount of high-grade energy (electricity) and low-grade energy (heat) obtained from the fuel input, however; which is misleading. The correct calculation takes the two outputs separately. One MWh of natural gas could produce around 0.9 MWh of low-grade heat from a modern condensing boiler, or 0.55 MWh of electricity from a modern Combined Cycle Gas Turbine running on base load, which needs to be reduced by about 7% for transmission and distribution losses. A straight line running between these two points gives the different combinations of heat and electricity that could be obtained by splitting the same fuel input in different ways. As MacKay (2008) has pointed out, the output combinations from most CHP plants are not very far above this line. Re-using the waste heat from large-scale power generation (or other industrial processes) may offer greater efficiency savings, provided that suitable loads can be found within a reasonable distance, able to use heat at the outlet temperature (which will be too low for many applications). Some EU countries use this for district heating, although significant infrastructure is needed for this.

A more radical alternative is to use renewable energy directly in industry. Taibi et al (2012) suggest that up to 21% of the final energy (including feedstock) used by industry world-wide could be met by renewables by 2050. Three-quarters of this would come from biomass, with the rest from heat pumps and solar heating. It should be pointed out, however, that OECD countries (such as the UK) have a relatively high cost of biomass, reducing its economic potential there, and the UK’s northern latitude also reduces the effectiveness of solar heating. Producing biomass can also involve significant carbon emissions, and some types divert useful land from the human food chain.

# 4. Energy costs and competitiveness

While the government has a vision for industry in a low-carbon economy, this involves threats as well as opportunities. The first energy-related threat facing manufacturers is that of higher energy costs. In the short and medium term, a decarbonised energy system is likely to involve higher energy prices than business as usual (Stern, 2007). Renewable generation currently costs more than gas-fired power, and nuclear power is also likely to be more expensive in the short term, certainly involving a greater degree of construction risk for the first stations built in the UK for a generation. In the longer term, we should expect learning-by-doing (and Research and Development) to reduce the costs of renewable energy, while the prices of fossil fuels may rise – this depends on the balance between the need to extract oil from more difficult locations (technically or politically) and the development of improved techniques for accessing unconventional oil, such as from tar sands. "Fracking" in shale deposits has reduced the cost of gas in the United States (although current prices make investment in new wells unprofitable), and analysts are looking at applying similar techniques to oil production, and to reserves in other countries.[4] Whatever happens to the underlying cost of fossil fuels, however; applying carbon capture and sequestration to a power station (which most studies suggest will need to be part of any reasonably affordable low-carbon system) must increase its costs.[5]

Manufacturers facing higher energy costs will want to pass them on. In a competitive industry, all producers would normally pass through the full cost increase; one sign of a less competitive industry is that firms do not pass all of a cost increase on to their consumers, since they are balancing their profit margin against their sales. We have seen that the amount of energy embodied in manufactured products varies significantly across sectors, implying that a given rise in the price of energy would lead to different cost (and hence output price) impacts.

Higher relative prices are likely to reduce the demand for some products. As pointed out by the Carbon Trust (2010), this is part of how a system of carbon pricing *should* work – the higher product price signals the fact that it embodies more of the polluting by-product, and by discouraging purchase of the product, reduces output of the by-product. Alongside this demand-side impact, there is a supply-side effect: manufacturers may be able to reduce the impact on their costs and prices if they can cut down on their use of energy (or energy-intensive intermediate goods). Their prospects for doing so are discussed in section 4 below.

The biggest problem for manufacturers comes if their own country has put a price on carbon and its trading partners have not. In that case, the demand side effect may be muted because domestically produced goods are replaced by similar goods from abroad. Similarly, the supply side effect may be weakened if domestic producers find it less profitable to invest in a country with a carbon price, and if multi-national firms source more of their output from countries with cheap, but high-carbon, energy. The

[4] The price of coal may also respond to changes in the price of oil and gas; US coal exports have risen as more gas is used in the country's power stations, keeping down European prices.
[5] The cost could be partly offset if uses could be found for the captured $CO_2$. The amount of $CO_2$ used at present (chiefly for urea production) is an order of magnitude below total emissions, and while researchers are seeking other by-products (such as inorganic carbonates that might be used in construction), these are unlikely to reverse the need to sequester most of the captured gas.

combination of these effects is known as carbon leakage. A policy that reduced output and employment in the home country, while pushing up global carbon emissions due to the transfer of production to countries with higher-carbon energy systems, would be truly counter-productive.

It should be pointed out that the overall effects of carbon taxes or emissions trading depend on what is done with the revenues. If these are recycled by cutting other distorting taxes the economy may gain from a "double dividend" – not only is the environment improved, but the removal of the distortion leads to economic gains elsewhere. The natural counterpart to taxing energy is to reduce taxes on labour – the UK cut employers' National Insurance charges when it introduced the Climate Change Levy (a kind of carbon tax) in 2001. This is likely to lead to reductions in prices, and higher output, in labour-intensive sectors of the economy. Ekins *et al.* (2012) show that the carbon prices needed to achieve a 15% cut in the EU's carbon taxes by 2020 would, if recycled, lead to higher output in services and in some manufacturing activities (food, drink and tobacco and textiles both increase by about 0.5%), although engineering output falls by around 0.5%, and basic metals production by 1%. Because the sectors that are growing are by definition labour-intensive, employment rises across the EU as a whole, although some countries suffer reductions in both GDP and jobs. It should be noted that it can be much harder to create (or even expand) an industry than to destroy it, a fact that many equilibrium-based economic models fail to take account of. The large-scale econometric model used in this study, however; is based on observed behaviour in expanding and contracting industries.

Another possible benefit from tighter environmental regulation comes from the possibility that this will lead firms to become more innovative, a response known as the Porter Hypothesis (Porter, 1991). Commins *et al.* (2011) study firm-level data for the EU and find evidence that on average, higher energy taxes led both to increases in total factor productivity (the ratio of output to all of the inputs used by the firm; a broader measure than labour productivity variables of output per worker or per hour) and to reductions in employment. Their results were sector-specific, however; some sectors saw (small) reductions in total factor productivity and increases in employment, particularly textiles and clothing.

The rest of this section discusses the specific issue of carbon leakage. First, it assesses the evidence on whether energy costs, and environmental regulations more generally, affect the location of industry. The idea that they do so has become known as the pollution haven hypothesis, but the evidence for its existence is mixed. Subsection 4.2 discusses the risks of carbon leakage from the EU Emissions Trading Scheme, which have been studied extensively. Much of the economy faces little risk, but a few sub-sectors could be subject to significant carbon leakage.

## 4.1 Costs and location decisions

While it should be obvious that firms in an energy-intensive industry will take the price of energy into account when deciding whether and where to invest, it is not the only relevant factor. Blair and Premus (1987) review a number of studies of location decisions (across a range of industries) and suggest that access to markets, skilled labour and transport links are more important than proximity to resources and low energy costs, although they point out that "often industry-specific studies reach conclusions that differ from more broadly focused studies." Carlton (1983) studies new plant locations and sizes in three

US industries and finds a “surprisingly large” effect of energy prices – a one per cent change in electricity prices has a greater impact on the decision than a one per cent change in wage rates, even though none of his three industries is particularly energy-intensive.

High energy prices may reduce the attractiveness of investing in existing plants, even though Bae (2009) find that they do not lead to decisions to relocate (at least over the six-year period studied). Ratti *et al.* (2011) find that a 1 per cent increase in relative energy prices (that is, relative to other prices within the same country) reduced manufacturing investment by 1.9 per cent in a sample of European countries between 1990 and 2006. Uncertainty about future energy prices can also reduce the level of investment.

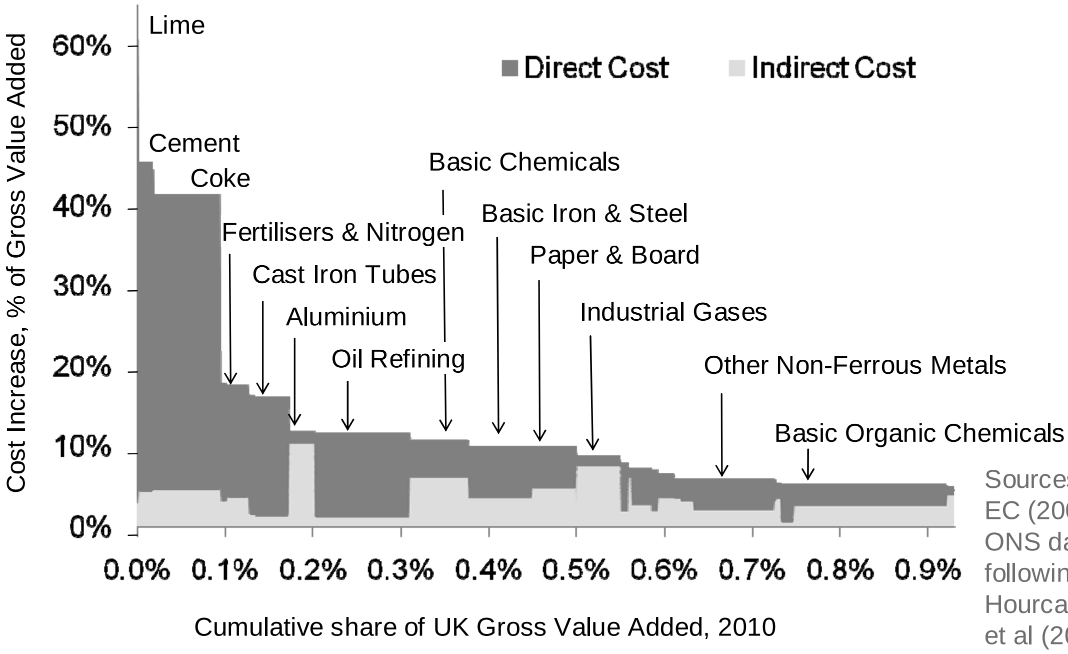
In a parallel to the possible effect of higher energy prices, environmental regulations have been accused of driving investment to jurisdictions with lower standards, the so-called pollution haven hypothesis. Although this accusation seems plausible, many empirical studies have failed to find evidence to support it. More recent work, however, takes the nature of the industry into account. Cole *et al.* (2010) find that Japanese environmental regulations (and other industrial regulations) tended to raise the country’s net imports, particularly from developing countries (likely to have less stringent regulations) and for industries with high environmental costs. Sectors that were marked by high transport costs or by agglomeration economies (measured by the degree to which the firms in Japan were clustered in particular prefectures) are likely to be geographically immobile; the impact of regulation on these sectors was much smaller. The implication for measures to internalise the environmental costs of energy is that while many sectors may not be much affected, there is a danger that imports could rise for some energy-intensive sectors.

## 4.2 Studies of carbon leakage

The potential for Carbon Leakage has been an issue for the EU Emissions Trading Scheme (ETS) since its inception. The ETS requires all affected installations – power stations and larger industrial plants in a range of sectors (principally cement, chemicals, metals (aluminium, iron and steel), oil refining and paper) – to surrender one permit for each tonne of carbon dioxide that they emit. The number of permits available caps the emissions from the affected sectors, and should be set so that total emissions – from the ETS sectors and the predicted amount from the rest of the economy – follow the desired path. If the cap is set below Business As Usual (BAU) emissions from the ETS sectors, then some companies will have to take costly actions to reduce their emissions. Buying a permit is an alternative to doing so, and the avoided cost therefore gives the permit a value. Even if the current cap is above BAU emissions (which is the case at present, given the effects of Europe’s economic difficulties), if permits can be banked for future use at a time when the cap would be tighter, they retain some value.

Industry is affected in two ways by the ETS. Firms in the sectors covered by the ETS will need permits for their own emissions, whether caused by burning fossil fuels or by the industrial process itself. (An example is the case of cement, where around half the $CO_2$ emitted during the production process is given off as limestone is converted into clinker, a precursor for cement). Alongside these direct costs, firms that buy electricity face an indirect cost if that sector’s permit costs are passed through into the price of power (as has been the case). Figure 5, which uses a European Commission (2009) study of sectors at risk of carbon leakage to update work by Hourcade et al (2007) gives estimates of the direct and indirect cost impacts for the worst-affected industrial sectors, together with the size of those sectors in the UK. The light bars show the impact of a €30/tonne permit price that leads to a €13.95/MWh increase in the price of electricity – the impact that would be expected if power prices are sometimes set by coal plants and sometimes by gas. The darker bars show the direct permit costs at the same price (€30/tonne).

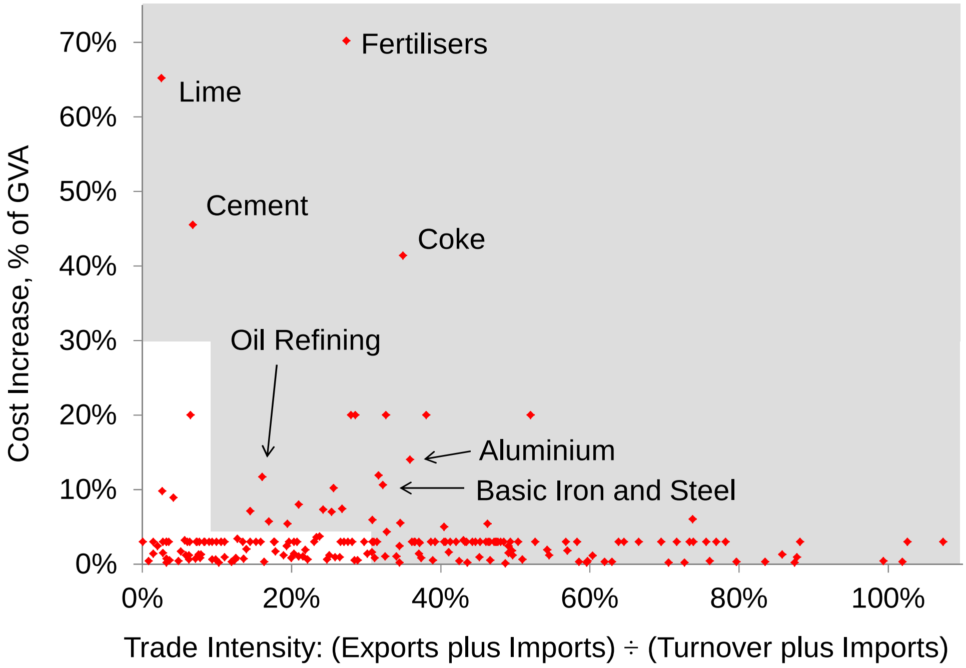
**Figure 5: Cost increases under the EU ETS**




Sources: EC (2009); ONS data; following Hourcade et al (2007)

It is clear that the worst affected sectors could see cost increases equal to a significant portion of their value added. The proportion of the UK's GDP at stake may be small, but that would be little consolation to the companies and employees affected, especially if a plant is in an area with few alternative employers. However, a cost increase on its own is not enough to guarantee a problem: the main question is whether the sector faces (or could face) competition from imports that are not subject to a similar increase. The European Commission has defined sectors facing a significant risk of carbon leakage as those facing a cost increase of more than 5% of their gross value added when trade intensity (exports plus imports divided by domestic turnover plus imports) is 10% or greater; those facing a cost increase of more than 30% of gross value added, whatever their trade intensity; and those with a trade intensity of more than 30%, whatever the predicted cost increase. Figure 6 gives the results of the Commission's assessment. Many sectors are so open that they are deemed to be at risk of carbon leakage, despite having very small cost increases; however, it should be noted that most of these will not be direct participants in the ETS.

**Figure 6: Sectors at risk of losing competitiveness under the EU Emissions Trading Scheme**




Source: EC (2009) following Carbon Trust (2010)

These calculations show the sectors that might be at risk; the next question is whether the impacts would be large enough to create significant carbon leakage. This depends on the size of the cost increase and the extent to which competition is price-based; some companies may be able to retain market share despite charging high prices because of the quality of their products. High transport costs can also protect European firms (but existing high levels of trade imply that transport costs are not an important barrier). The Non-metallic Minerals sector is characterised by relatively high transport costs, and Fitzgerald *et al.* (2009) show that prices for this sector in several EU countries followed domestic (wage) costs rather than foreign prices, implying that ETS-imposed cost increases could successfully be passed on. In contrast, prices in the Basic Metals sector closely followed foreign (US or German) prices, implying that EU firms were in a world market with little scope to pass on cost increases.

This result was echoed in an ex-ante study by Smale et al (2006), which predicted that aluminium smelting might become unprofitable in the EU. Output reductions in the other sectors they looked at (cement, newsprint, petroleum and steel) were small, and the affected firms were mostly able to increase their profits, given that they had received many permits free of charge. Demailly and Quirion (2007) also found that impacts on the iron and steel sector would be small, and profits would rise as long as a sufficient proportion of the permits needed were given away without charge.

More recent studies consider the impact of charging industrial firms for their permits, as is already the case for most electricity generators under Phase III of the ETS. Monjon and Quirion (2011) find that European production of cement could fall by 25%, with a 14% reduction in aluminium output. They calculate that the increase in emissions from aluminium production outside the EU would equal 26% of the fall in intra-EU emissions, while cement would have a leakage-to-reduction ratio of 20%. Over the ETS as a whole, the predicted ratio was much lower, in part because there is little leakage from the

electricity sector, where extra-EU trade is very small. This does not stop the scale of leakage in particular sectors from being a problem, however.
Two main approaches can be used to combat leakage, discussed by the Carbon Trust (2010). One is a border tax adjustment, already well-established for Value Added Tax and the like – a company exporting a product is able to reclaim the VAT that it paid on inputs, while importers have to pay VAT on their purchases. This ensures a “level playing field”, both inside and outside the UK. In principle, companies in the ETS could get a rebate on their carbon costs for exported output, and importers could be taxed. In practice, the calculations could be very complex, particularly when a number of different methods could be used to produce the imported product. An alternative method is to continue giving free permits to firms that are vulnerable to imports or might be tempted to transfer investment and production overseas. If the number of permits is linked to actual output, the impact on the firm’s marginal costs should be limited, giving it the incentive to continue production; if the ratio of permits to output is based on the best available technology, the firm has an incentive to improve its production techniques. It should be obvious, however, that the overall incentive to reduce emissions is lower than if permits were auctioned. Nonetheless, free allocation is the approach taken within the ETS.

Monjon and Quirion (2011) find that overall emissions are lower with a border tax adjustment than with output-based permit allocation, not least because this reduces the EU’s imports of carbon-intensive goods, so that “leakage” could even be negative. The Carbon Trust (2010) has suggested that the optimal policy is sector-specific, and that border taxes would be appropriate for cement and clinker, based on the emissions from best available technology. Border tax adjustments in the case of steel from blast furnaces would be more complex to negotiate, and free allocations of permits would provide time to establish these. In the case of aluminium, however, it may prove impossible to verify the carbon content of the electricity used (since direct emissions are only a small part of the cost increase), making border tax adjustments impractical; in this case, direct support for investments in the industry might be preferable.

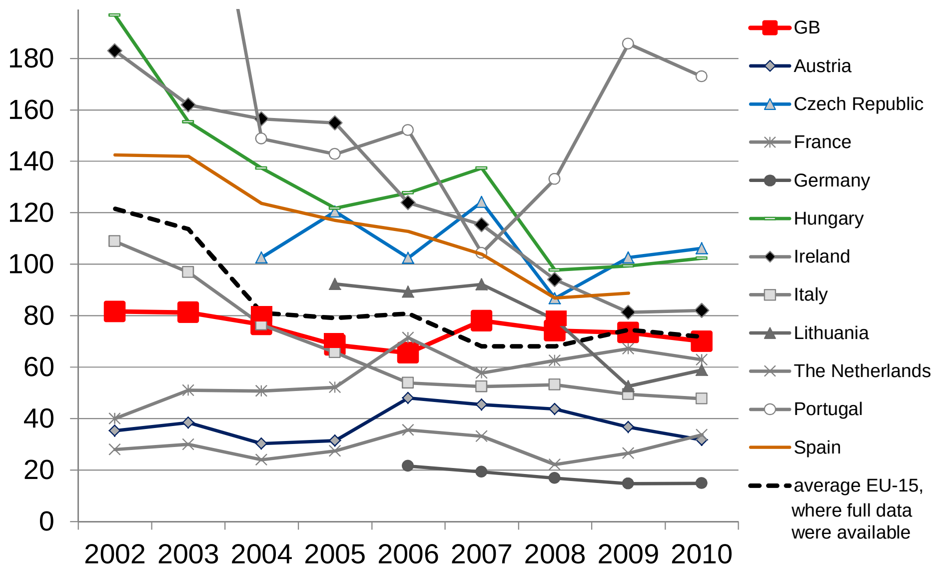
# 5. Risks to the security of electricity supply

The second threat facing manufacturers is that electricity supplies could become less reliable. A low-carbon electricity system in the UK is likely to involve a significant proportion of wind generation, which is entirely dependent on the weather. To make the most efficient use of the various renewable resources around Europe, it is likely that much more electricity will be transmitted over long distances. Wind power will come from around the Atlantic seaboard (including the British Isles) and the North Sea, while solar power will most economically come from the south of Europe and from North Africa. Hydro-electric stations in Scandinavia and the Alps will be able to balance the inevitably intermittent output from other sources. While thermal generators and energy storage in the UK will also provide back-up, intermittent generators and long transmission links both involve an increased risk of system failure.

Even in the short term, the risk of power cuts in the UK appears to be rising. Ofgem (2012) highlights the imminent closure of a large number of coal- and oil-fired power stations, and a shortfall in the investment required to replace them. In part, this may be the unique result of a hiatus in investment caused by uncertainty over the government's Electricity Market Reforms, to be resolved by the implementation of those reforms. A system dominated by renewable power will still require many thermal power stations that do not run very often, and building these may be fundamentally unattractive to investors. The Electricity Market Reforms include a capacity market intended to deal with this problem, but it will not be ready in time to deal with the short-term issue, and may prove inadequate over the longer term.

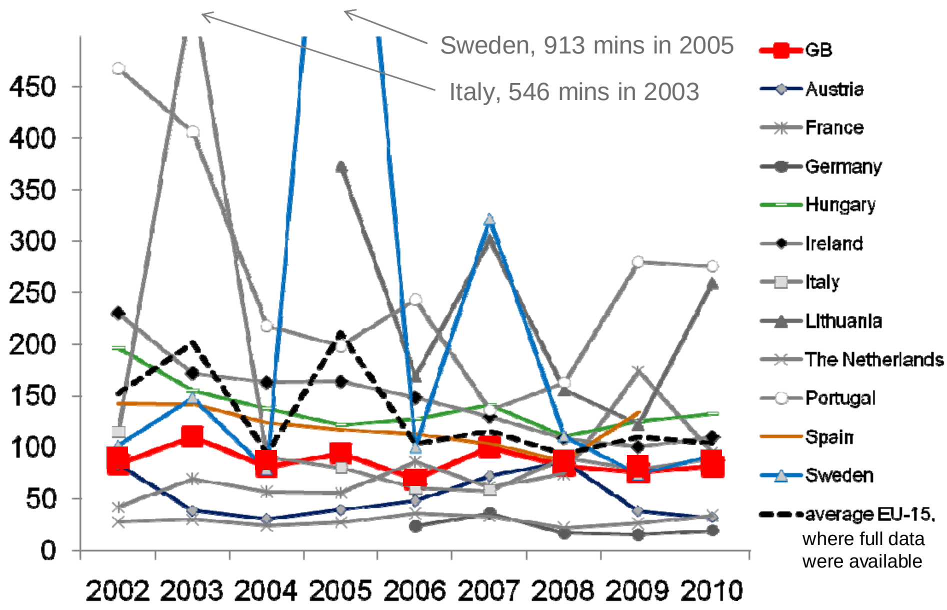
Electricity consumers do not enjoy perfect reliability today, of course. Figures 7 and 8 show that the average UK consumer loses supply for around 80 minutes a year; ten minutes of this are the (averaged) impact of exceptional events such as severe winter storms. For both measures, the UK is currently close to the average of those EU-15 countries ("Old" Member States) for which five or more years of data was available in CEER (2012), but ten years ago, its performance was better than average. Most of these outages are due to problems on the local distribution systems, but the greatest disruption comes when millions of people are simultaneously affected by a problem in the transmission system or a shortage of generation.

**Figure 7: Electricity supply interruptions in EU countries: minutes per customer per year, excluding exceptional events**




Source: CEER (2012), Table A2.1.1

**Figure 8: Electricity supply interruptions in EU countries: minutes per customer per year**




Source: CEER (2012), Table A2.1.1

Power system outages and other disturbances have significant impacts on electricity users. LaCommare and Eto (2006) estimated the annual cost for power interruptions to U.S. electricity consumers at $79 billion. Table 3, drawn from a meta-analysis of US outage studies by Lawton et al (2003), shows the relationship between outage duration and costs, for residential and for small and large industrial and commercial customers. Costs increase with the duration of an outage, but less than proportionally, and the larger industrial and commercial customers also faced costs that were lower in proportion to their annual consumption than smaller firms. Within the two broad groups of firms, manufacturers had higher costs for a one-hour outage than any other type of firm (with the exception of large financial services companies). This was in large part driven by their relatively high demands; the costs per kWh of annual demand mostly varied less between types of firm than the absolute numbers.

**Table 3: Outage Duration and Cost: Meta-analysis of US studies**

| Timing and Duration | Residential Customer | Small Industrial / Commercial Customer (118 MWh/year) | Large Industrial / Commercial Customer (17.5 GWh/year) |
|---|---|---|---|
| Summer -- 1 Hour | \$2.90 | \$1,200 | \$8,200 |
| Summer - 8 Hour | \$7.20 | \$4,400 | \$41,000 |
| Winter - 1 Hour | \$3.30 | \$1,800 | \$20,000 |
| Winter - 8 Hour | \$8.32 | \$6,300 | \$105,000 |

Source: Lawton et al (2003). All values given in 2002 US Dollars.

It should be noted that these are average costs: a one-hour power interruption could cost a semi-conductor manufacturer \$2 million. Very short outages are sufficient to crash computers and data servers, with significant consequences for intensive care systems and life support machines (Sullivan, 2009). Reichl et al (2012) have calculated the Value of Lost Load (per kWh lost, rather than per outage) in Austria, again dependent on the timing and duration of an outage. Table 4 shows their calculations for outages at different times on a working day; Table 5 shows how the costs vary across sectors of the economy.

**Table 4: Value of Lost Load for different power outages on a working day**

| **Duration** | **Summer 10 a.m.** | **Summer 10 p.m.** | **Winter 10 a.m.** | **Winter 10 p.m.** |
|---|---|---|---|---|
| **1 h** | 17.1 €/kWh | 3.2 €/kWh | 21.2 €/kWh | 7.1 €/kWh |
| **12 h** | 4.7 €/kWh | 3.9 €/kWh | 5.3 €/kWh | 4.5 €/kWh |

Source: Reichl et al (2012)

**Table 5: Economic assessment of a 12-hour summer power outage in Austria**

| **Sector (with NACE 2008 Code)** | **Number of severely/very severely affected units (1,000s)** | **No. of persons affected (1000s)** | **Power not supplied (GWh)** | **Total loss (million €)** | **VOLL (€/kWh)** |
|---|---|---|---|---|---|
| A: Agriculture, hunting and forestry | 179.6 | 474.1 | 1.7 | 5.9 | 3.47 |
| B: Mining and quarrying | 0.3 | 6.1 | 1.0 | 1.2 | 1.20 |
| C: Manufacturing | 25.0 | 605.7 | 34.4 | 114.0 | 3.31 |
| D: Electricity, gas, steam and air conditioning supply | 1.5 | 27.0 | 13.9 | 14.1 | 1.01 |
| E: Water supply; sewerage; waste management and remediation activities | 1.9 | 16.8 | 3.3 | 2.2 | 0.67 |
| F: Construction | 28.5 | 263.3 | 0.7 | 29.4 | 42.00 |

| | | | | | |
|---|---|---|---|---|---|
| G: Wholesale and retail trade; repair of motor vehicles and motorcycles | 69.3 | 576.0 | 3.6 | 125.2 | 34.78 |
| H: Transportation and storage | 13.0 | 200.4 | 4.7 | 27.7 | 5.89 |
| I: Accommodation and food service activities | 41.3 | 237.8 | 0.9 | 11.0 | 12.22 |
| J: Information and communication | 14.3 | 84.1 | 0.8 | 12.3 | 15.38 |
| K: Financial and insurance activities | 6.3 | 117.3 | 2.1 | 20.6 | 9.81 |
| L: Real-estate activities | 14.4 | 38.5 | 0.8 | 8.1 | 10.13 |
| M: Professional, scientific and technical activities | 50.7 | 182.8 | 1.4 | 17.9 | 12.79 |
| N: Administrative and support service activities | 11,0 | 179,0 | 1,1 | 14.3 | 13.00 |
| OPQRSTU: Public sector | N/A | 996.5 | 8,5 | 45.6 | 5.36 |
| **Non-Household consumers** | **457.1** | **4,005.6**** | **78.9** | **449.7** | **5.7** |
| **Household consumers***** | **3,598.3** | **8,262.1**** | **23.4** | **28.1** | **1.2** |

Source: Reichl et al, 2012

The authors have also published a Spreadsheet model, Apostel, which allows users to calculate the cost of various outage scenarios. All are based on Austrian data; however; the cost of outages affecting manufacturers is closely linked to the value added of the production that would be lost in an outage. Eurostat data show that Austrian manufacturers had an average Gross Value Added of €1.81 million per GWh of electricity consumption, while those in the UK had a figure of €1.58 million per GWh. Multiplying the outputs from Apostel by the ratio of UK to Austrian GVA per GWh (0.87), and then by the £/€ exchange rate (£0.86 = €1) allows us to apply them to scenarios of UK power outages.

Ofgem (2012) reports on the risk of power outages in over the next five years, showing that small capacity shortfalls can be met by reductions in voltage that many customers would not notice. As the size or duration of an outage increases, however, blackouts become first possible and then certain, as shown in Figure 9. The source diagram is in terms of household disconnections; however, Ofgem point out that National Grid would first attempt to disconnect industrial customers, and so Figure 9 shows the amount of industrial load that would be lost. In practice, for large outages, a mix of industrial and household customers would be affected.

**Figure 9: Impact of Electricity Outages**

| Duration: | | | | |
|---|---|---|---|---|
| 6+ hours | Possible black-outs < 1.5 GW | Black-outs < 1.5 GW | Black-outs < 2.3 GW | Black-outs > 2.3 GW |
| 4 – 6 hours | Possible black-outs < 1.5 GW | Possible black-outs < 1.5 GW | Black-outs < 2.3 GW | Black-outs > 2.3 GW |
| 2 – 4 hours | Dimming Lights | Possible black-outs < 1.5 GW | Black-outs < 5 GW | Black-outs > 5 GW |
| 0 – 2 hours | Dimming Lights | Dimming Lights | Black-outs < 5 GW | Black-outs > 5 GW |
| | 0 – 1.5 GW | 1.5 – 2.8 GW | 2.8 – 5 GW | 5+ GW |

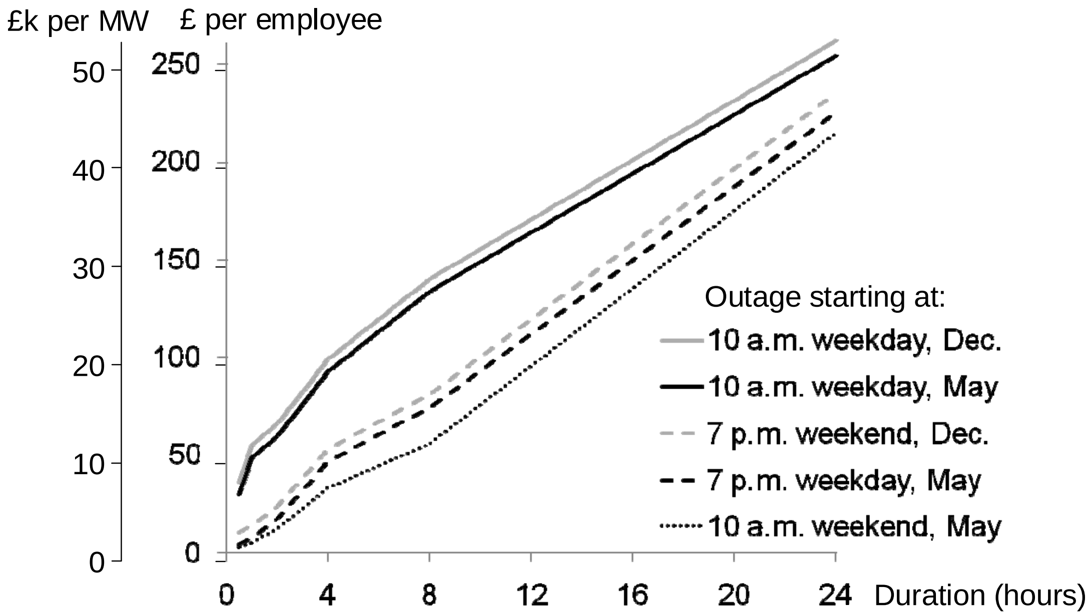
Size of generation shortfall

Source: Adapted from Ofgem (2012)

Ofgem consider a number of scenarios, each with its own risk of a capacity shortfall, depending (for example) on whether Great Britain was exporting or importing power to France at the point when a problem occurred. The common theme is that the risk of shortfall is very low in the next year or so, when substantial spare capacity exists, but it rises sharply by 2016-17 as older plants retire. The UK government has an Electricity Market Reform programme intended to make investment in reserve capacity more attractive; at the time of writing its impact on investment and capacity margins is unknown. The Ofgem work does not study the risk of power cuts caused by disturbances to the transmission system or sudden changes in generation away from the peak hours – it is likely that these risks will rise (from very low levels) as the level of wind generation increases.

Figure 10, below, shows the estimated costs, per manufacturing employee and per MW of demand shed, of outages of different lengths between half an hour and 24 hours. The costs are slightly higher in December than in May; they are significantly lower if the outage starts after the end of the working day, and a lower still if the outage starts at the weekend. Many manufacturing plants work throughout the week, however, and would therefore incur significant costs, as shown in the diagram.

**Figure 10: Impact of Outages on UK Manufacturing**




Source: Authors' calculations adapting the APOSTEL model (Reichl et al, 2012)
*http://www.energyefficiency.at/en/web/projects/blacko.html*

To put these numbers in perspective, if an outage blacked out the West Midlands region, where there are 275,000 employees in manufacturing, for one hour on a non-working day, the cost to the sector would be approximately £1 million.  A four-hour outage on a working day, in contrast, would cost manufacturers roughly £25 million in lost production and other impacts.  Costs to other sectors would also be significant.

# 6. Opportunities for manufacturers

The previous sections have highlighted two threats to the manufacturing sector from a decarbonised energy system: the risk of losing competitiveness and the danger of power cuts. The future energy system also offers opportunities, however, and we deal with two of them in this section: selling demand response services to the electricity industry, and manufacturing low-carbon vehicles.

## 6.1 Selling demand response services

To ensure the stable operation of the power grid, electricity supply and demand needs to balance on a moment-by-moment basis. Traditionally, most balancing has been done by adjusting the output of power stations, and some generating capacity has always been kept in reserve to respond at short notice to changes in demand or failures at other power stations. Some customers are able to respond to the grid operator's request to change their demand, however; and this Demand Side Management, or Demand Response, offers an opportunity to manufacturing firms in the low-carbon future. Many countries are developing smart energy network controls to help balance the supply and demand of electricity efficiently and cost-effectively.

National Grid already buys a variety of demand response services from industrial (and other) customers. Frequency response is triggered automatically if the system frequency falls below pre-set levels, whereas Fast Response (within 2 minutes) and Short-Term Operating Reserve (within up to four hours) are requested via electronic messages. Given the scale of the transmission system, only large customers are able to contribute a meaningful amount of response. Some companies, such as Flexitricity, act as aggregators, grouping smaller customers together in order to provide National Grid's minimum volume. In future, flows on the distribution network are likely to become more variable as the level of distributed generation increases. If this leads distribution companies to buy demand response services to manage potential congestion on their networks, well-located manufacturers may find a profitable market for smaller volumes of response. However, just as with measures to promote energy efficiency, small and medium enterprises may not be able to devote the managerial time required to take part in demand response services; since energy costs are low for most SMEs, reducing them further is not a priority. Many of the large industrial customers capable of providing these services already do so.

## 6.2 Manufacturing for low-carbon energy

A low-carbon energy system will need many new products. Manufacturers in the UK may be able to develop an early-mover advantage in some of these. In particular, the UK still has great expertise in the vehicle industry, although there is no longer a UK-owned mass market manufacturer. Electric or possibly hydrogen vehicles offer a plausible low-carbon alternative to conventional cars, with prospects studied in the King Review of 2007-8, amongst others.

The uncontrolled charging of electric vehicles would pose a significant challenge to the power system, but their controlled charging offers a flexible resource that should help smooth out the overall fluctuations in load and intermittent generation, making power interruptions less likely. Hydrogen fuel cell vehicles potentially offer greater efficiency (at least within the vehicle itself) and a longer range than battery-constrained electric vehicles, but also require a completely new infrastructure for fuelling. At this time, the government should be facilitating research and demonstration projects in both technologies in order not to close off options for the future.

Energy storage is another industry in its infancy, with a number of UK manufacturers involved, many spun out from universities. The Engineering and Physical Sciences Research Council is investing heavily in energy storage research; this could help create a significant UK industry, if there is sufficient support for later stages in the development chain. Other components of the future electricity system will also have to be manufactured, but this industry already has many well-established companies, some in the UK, and hence less scope for early action to secure a first-mover advantage. Nonetheless, transmitting low-carbon power across Europe will require significant investment in High Voltage DC and Flexible AC Transmission Systems, and this creates a manufacturing opportunity.

The benefits of applying these technologies are two-fold (a) enabling low carbon energy supply systems; (b) facilitating flexible control and efficiency to ensure security of power supply while dealing with uncertainties of power flows resulting from uncertainties of generation, demand and energy market transactions.

In these areas, there are significant manufacturing opportunities. However, policies including suitable investment incentives will need to be developed to ensure a leading position in these areas for the UK. This includes support for R&D activities and for knowledge transfer. Special measures would need to be taken to educate skilled graduates to face the exciting opportunities to come.

# 7. Conclusions: manufacturing in a low-carbon energy system

The UK is planning to largely decarbonise its energy system over the next four decades. This is likely to increase the cost of energy, and place pressure on companies, such as many manufacturers, that use a lot of it. The pressures should not be exaggerated; many firms use little energy, or are not vulnerable to price-based competition from firms in countries that are not raising their energy costs. For the worst affected companies, however; there will be a significant loss of competitiveness. This might be offset by border tax adjustments, although the political obstacles to these should not be under-estimated.

At the same time, many energy-saving technologies are already available, giving scope for improvements of 20% or more in energy efficiency, even before considering the gains from materials efficiency techniques such as re-use and re-cycling. The obstacles to investments in energy efficiency sometimes stem from awareness, and government policies to increase companies' knowledge of what is possible should be promoted.

A second threat to UK manufacturing comes from the risk of interruptions to energy supplies, and particularly electricity supplies. These risks are unquantifiable, but stem from the increase in intermittent generation sources and long-distance transmission, together with the possible consequences of dependence on gas imports.

Decarbonisation also offers opportunities. Improvements in communication between the electricity industry and its customers (part of the smart grid) may allow more manufacturers to provide demand response services, gaining an income to set against their rising power bills. New products will also be required, particularly in low-carbon vehicles. The UK's continuing capabilities in this sector should allow it to gain significant manufacturing opportunities, as long as policy is appropriate and supportive.

# References


Abdelaziz, E. A., R. Saidur and S. Mekhilef (2011) A review on energy saving strategies in industrial sector, *Renewable and Sustainable Energy Reviews*, 15, 150-168

Aranda-Uson, A., G. Ferreira, M. D. Mainar-Toledo, S. Scarpellini, and E.L. Sastresa (2012) Energy consumption analysis of Spanish food and drink, textile, chemical and non-metallic mineral products sectors, *Energy*, 42, 477-485

Bae, S. (2009) The responses of manufacturing businesses to geographical differences in electricity prices, *Annals of Regional Science*, 43, 453-472

Blair, J.P. and R. Premus (1987) Major Factors in Industrial Location: A Review, *Economic Development Quarterly* 1, 72-85

Bloom, N., C. Genakos, R. Martin and R. Sadun (2010) Modern Management: Good for the Environment or Just Hot Air?, *Economic Journal*, 120, 551-572

Carlton, D.W. (1983) The Location and Employment Choices of New Firms: An Econometric Model with Discrete and Continuous Endogenous Variables, *The Review of Economics and Statistics*, 65, 440-449

Cole, M.A., R.J.R. Elliott and T. Okubo (2010) Trade, environmental regulations and industrial mobility: an industry-level study of Japan, *Ecological Economics*, 69, 1995-2002

LaCommare, K.H. and J. H. Eto, “Cost of Power Interruptions to Electricity Consumers in the United States (U.S.)”, Ernest Orlando Lawrence Berkeley National Laboratory, February 2006

Commins, N., S. Lyons, M. Schiffbauer and R.S.J. Tol (2011) Climate Policy & Corporate Behavior, *Energy Journal*, 32, 51-68

CEER (2012) 5th CEER Benchmarking Report on the Quality of Electricity Supply, April 2012, Brussels, Council of European Energy Regulators

David, P.A. (1990) The dynamo and the computer: a historical perspective on the modern productivity paradox” American Economic Review, 80, 355-361

Delarue, E.D., A.D. Ellerman and W.D. D’haeseleer (2010) “*Short-term CO2 abatement in the European power sector: 2005-2006*,” Climate Change Economics, I, 1-21.

Demailly, D. and P. Quirion (2007) European Emission Trading Scheme and competitiveness: A case study on the iron and steel industry, *Energy Economics*, 30, 2009-27

DECC (2011) Capturing the full electricity efficiency potential of the UK, November 2011, available from http://webarchive.nationalarchives.gov.uk/20121217150421/http://decc.gov.uk/assets/decc/11/consultation/electricity-demand-reduction/7035-capturing-full-elec-eff-potential-edr.pdf (accessed 23 May 2013)

European Commission (2009) Draft Commission Staff Working Document: Impact Assessment. Accompanying document to the Commission Decision determining a list of sectors and subsectors which are deemed to be exposed to a significant risk of carbon leakage pursuant to Article 10a (13) of Directive 2003/87/EC. SEC(2009) 1710 final. Brussels, Commission of the European Communities

Ekins, P., H. Pollitt, P. Summerton and U. Chewpreecha (2012) Increasing carbon and material productivity through environmental tax reform, *Energy Policy*, 42, 365-376

Fennell P.S., N. Florin, T. Napp and T. Hills (2012) CCS from industrial sources, *Sustainable Technologies, Systems and Policies* Carbon Capture and Storage Workshop:17 http://dx.doi.org/10.5339/stsp.2012.ccs.17

FitzGerald, J., M. Keeney and S. Scott (2009): Assessing vulnerability of selected sectors under environmental tax reform: the issue of pricing power, *Journal of Environmental Planning and Management*, 52:3, 413-433

Fleiter, T., E. Gruber, W. Eichhammer and E. Worrell (2012), The German energy audit program for firms-a cost-effective way to improve energy efficiency?, *Energy Efficiency*, 5, 447-469

Griffin, P. W., G.P. Hammond, K.R. Ng and J.B. Norman (2012), Impact review of past UK public industrial energy efficiency RD&D programmes, *Energy Conversion and Management*, 60, 243-250

Hourcade, J.-C., D. Demailly, K. Neuhoff and M. Sato (2007) Climate Strategies Report: Differentiation and Dynamics of EU ETS Industrial Competitiveness Impacts, Cambridge, Climate Strategies

Jacobsen, N.B. (2006) Industrial Symbiosis in Kalundborg, Denmark: A Quantitative Assessment of Economic and Environmental Aspects, *Journal of Industrial Ecology*, 10, 239-255

Johansson, D., J. Rootzen, T. Berntsson and F. Johnsson (2012) Assessment of strategies for CO2 abatement in the European petroleum refining industry, *Energy*, 42, 375-386

Laurijssen, J., A. Faaij and E. Worrell (2013) Benchmarking energy use in the paper industry: a benchmarking study on process unit level, *Energy Efficiency*, 6, 49-63

Lawton, M. Sullivan, K. Van Liere, A. Katz, and J.H. Eto (2003) A Framework and Review of Customer Outage Costs: Integration and Analysis of Electric Utility Outage Cost Surveys, Ernest Orlando Lawrence Berkeley National Laboratory

Mackay, D.J.C. (2008) Sustainable Energy – Without the Hot Air, Cambridge, UIT

Martin, R., M. Muuls, L.B. de Preux and U.J. Wagner (2012) Anatomy of a paradox: Management practices, organizational structure and energy efficiency, *Journal of Environmental Economics and Management*, 63, 208-223

Milford, R. L., J.M. Allwood and J.M. Cullen (2011) Assessing the potential of yield improvements, through process scrap reduction, for energy and CO2 abatement in the steel and aluminium sectors *Resources Conservation and Recycling*, 55, 1185-1195

Ofgem (2012) Electricity Capacity Assessment: Report to Government, Reference 126/12, London, Office of Gas and Electricity Markets

Porter, M.E. (1991) America's Green Strategy, *Scientific American,* 264, 96

Ratti, R.A., Y. Seol and K.H. Yoon (2011) Relative energy price and investment by European firms, *Energy Economics*, 33, 721-731

Reichl, J., M. Schmidthaler and F. Schneider (2012) The Value of Supply Security: the Costs of Power Outages to Austrian Households, Firms and the Public Sector, Energy Institute, Johannes Kepler Universität Linz

Saygin, D., M.K. Patel, E. Worrell, C. Tam and D. Gielen, (2011) Potential of best practice technology to improve energy efficiency in the global chemical and petrochemical sector, *Energy*, 36, 5779-5790

Smale, R., M. Hartley, C. Hepburn, J. Ward and M. Grubb (2006) The impact of CO2 emissions trading on firm profits and market prices, *Climate Policy*, 6, 31-48

Sullivan, M.J., M. Mercurio, and J. Schellenberg (2009) Estimated Value of Service Reliability for Electric Utility Customers in the United States, Ernest Orlando Lawrence Berkeley National Laboratory

Taibi, E., D. Gielen and M. Bazilian (2012) The potential for renewable energy in industrial applications, *Renewable and Sustainable Energy Reviews*, 16, 735-744

ULCOS (not dated) Ultra-Low Carbon dioxide ($CO_2$) Steelmaking web site, http://www.ulcos.org/en/about_ulcos/home.php (accessed 17 May 2013)

Weiss, M., M. Junginger, M.K. Patel and K. Blok (2010) A review of experience curve analyses for energy demand technologies *Technological Forecasting and Social Change*, 77m 411-428

Wilson, C, A. Grubler, K.S. Gallagher and G.F. Nemet (2012) Marginalization of end-use technologies in energy innovation for climate protection, *Nature Climate Change*, 2, 780-788

# Appendix

## Appendix 1: Operating a Low-Carbon Electricity System

A low-carbon energy system, with a large number of intermittent and small-scale generators, poses special challenges for system operators, which we review in this appendix.

### Energy storage

Storage has the technical ability to provide a number of benefits to the electricity system – for example, by smoothing supply profiles from variable generation and potentially reducing constraint costs by allowing generation to run during periods of low demand. It can also potentially save or defer network upgrade costs that may be required in the future to meet peak demand.

There are two main ways to deploy storage. Bulk storage connected at transmission level offering significant balancing services for example to respond to the variable output from some renewables and to capture the benefit of extreme variations in prices. Distributed storage is built onto the distribution network, and, in addition to the balancing services provided by bulk storage, may avoid the need for upgrades to the distribution network. A number of storage technologies can provide very fast response rates to support the electricity system. For example battery storage and pumped hydro storage are able to respond almost instantaneously.

### Electric vehicles

A major new source of storage is likely to come from electric vehicles. Global growing societal concerns about the detrimental effects of fossil fuel-based road transport on climate, air quality, environmental heritage and energy security bring interest in the development of electric vehicles (EVs). The King Review of low-carbon cars (King, 2007) concluded that in addition to other low-carbon technologies and behaviour change, road transport based on EVs would be necessary to implement an 80% reduction in transport emissions. This certainly will need fundamental paradigm shifts to decarbonise transport by developing new concepts, methods and technologies ranging from the energy generation, energy storage and distribution of energy, to the overall efficient use of energy in the car, new vehicle concepts and architectures, novel ICT solutions and services, to the management of mobility and logistics in order to implement the intelligent integration of electric vehicles (EVs) into power grids.

The massive integration of electric vehicles would bring big challenges to the future energy supply systems in terms of significant demand increase, fast changing power flows, and uncertainty of power demand distribution around the energy supply system. It would make the situations even worse if this were coupled with the intermittency of renewable generation, in particular wind and solar. National Grid has already anticipated the big challenge of dealing with the intermittency of wind generation.

UK plans to integrate a large number of electric vehicles into power grids. WWF (2011) predicts that some 1.7 million electric vehicles will be on the road by 2020 and 6.4 million by 2030 in order to implement the UK's climate change measures. This would mean means that 6% of all UK cars in 2020 are electric vehicles, rising to 18% in 2030. With 1.7 million electric vehicles, the additional charging capacity needed is 5 GW (assuming the charging power for electric vehicles is 3kW). The additional electricity demand will be increased from 5 GW to19 GW in 2023. However, through smart charging control along with a real-time tariff mechanism, the additional charging demand could be shifted away from the peak system demand. In comparison, the German Government has put forward the so-called "National Platform for Electric Mobility" to have 1 million electric vehicles on roads by 2020, while this becomes 6 million in 2030. By 2050, Germany shall be able to make automobile transport carbon free. The Chinese government is going to make annual production of electric vehicles reach 2 million by 2020 and 5 million by 2030.

The UK is facing the challenges of how to efficiently and effectively develop and manage the EV infrastructure for charging and discharging and hence reduce the peak demand, power flows and improve the reliability, security, resilience and efficiency of power grids. On the other hand, if we can manage the charging and discharging of EVs intelligently, the massive Electric Vehicles will become a dynamic mobile energy system, which has the great potential to be integrated with the non-mobile existing energy supply system to make it resilient and help deal with the uncertainties of distributed and renewable energy sources of the future energy systems.

Hydrogen Fuel Cell Vehicles (FCEV) are a special type of electric vehicle, in which power is generated on board from a hydrogen fuel cell. One recent UK government-industry study (DECC, 2013) involves eleven industry participants and three UK government departments. The study shows that with the mass production of FCEV, costs will be brought down; there will be the potential for 1.6 million FCEVs on UK roads by 2030, with annual sales of more than 300,000. It has been suggested that a coordinated network of hydrogen refuelling stations will need to be constructed with an initial roll-out of 65 stations, to be increased to 1,150 sites by 2030. The motor industry sector has recognised that it is vital to develop and deliver new low carbon solutions for vehicles. Hydrogen fuel cell technology is considered to be one of the major low carbon technologies in ensuring sustainable transport. In order to bring the first FCEVs to market, the close collaborations between industry partners and government agencies become important to implement their benefits with necessary policies, national fuelling station infrastructure.

Demand-management and grid-balancing are key technologies to facilitate a steady increase in renewable energy sources and mitigate intermittency of generation. Demand management is a key enabler to mitigate the cost of energy infrastructure and the need for spinning reserves. In this context, distributed energy storage whether embedded in the transport system as large scale plug-in hybrid / EV fleets or stationary embedded in the building fabric of the UK housing stock will be instrumental in amplifying the impact demand management can have on grid-balancing. Ofgem (2010) has calculated that if 5% of peak demand were shifted by a few hours each day (moving around 7 GWh on each occasion), annual savings would be £150 million or more.

## Distributed generation and storage

The connected home including micro-generation, distributed storage and E-mobility will give rise to a wide range of connected devices that will enable large scale deployment of managed energy services in the UK and elsewhere. Managed devices will include white goods, heating controls, energy storage devices, micro-generation e.g. PV and transport e.g. plug-in hybrid and pure electric vehicles. This will coincide with large scale availability of broadband and mobile communication services in the UK. In the context of big data, cyber security and ICT will become key drivers for a decentralised and distributed energy world.

## Intelligent distribution

The transformation towards a decentralised energy world is turning the energy system upside-down: energy produced by the increasing penetration of decentralised generation (DG) now leads to net flows of power in the opposite direction to which the system has been developed over decades, this is especially pronounced in the UK with the trajectory for economy wide decarbonisation by 2050 set out in the 2008 Climate Change Act. This fundamental change requires a new technologies and new approaches in all aspects of the distribution grid business: from network design through to operations. Nowadays the network and the customers connected must all be considered together as an interactive end-to-end system: this is the essence of the Smart Grid. Decentralised control has a key role to play in underpinning and maintaining this transition. Therefore, in successfully making this transition in the UK, it is essential that a system wide perspective is taken rather than simply focusing on individual solutions, as not taking a systems approach can lead to suboptimal outcomes.

One such innovative solution which can aid Distribution Network Operators (DNOs) in taking a ‘smart approach’ to managing this new system dynamic brought about by the growth in decentralised energy resources, is adding a voltage control transformer between the medium and low voltage systems. This type of transformer offsets the voltage in the network which allows enough space for the voltage swing while still keeping it within statutory limits and in many cases replaces the need for grid reinforcement. The voltage control transformer is an innovative solution and is enabled by adding additional components and intelligence to a standard transformer, e.g. sensors, computation, and controls, thus enabling the extra voltage control capability. In designing the optimal system development approach (the most effective and economic), the DNO must consider many variables such as the current network, the projected load/generation growth, energy prices, and commodity prices.

In order to look into ‘smarter approaches’, over a number of years the E.ON Group has invested significant sums into research programs to develop environmental and cost efficient alternatives to deal classical grid reinforcement. A very promising new asset from this research program is the aforementioned voltage control transformer, which is a conventional transformer with added control units to regulate the conversion ratio, between the medium and low voltage systems.

This unit is a cost efficient solution in the majority of cases thus having the potential of replacing large amounts of potential grid reinforcement. The integration of this unit is as simple as replacing an existing conventional transformer as a result of the fact that industrial partners have achieved the integration of these additional components within the size specifications of a conventional transformer to make it possible to integrate the new transformer type into existing substation thus reducing a lot of the installation and integration cost.

However, it is worth noting that if the draft regulation proposed under the Eco Design Regulation (Directive 2009/125/EC Eco Design Regulation) with regard to small, medium and large power transformers is implemented, it will prevent this technology from being used. Although it is possible to make a voltage control to confirm with the proposed regulation by using a much larger and more expensive transformer as the basis this will defeat the purpose of finding a cost effective alternative to grid reinforcement. This much larger transformer suffers all of the same installation and integration costs and environmental impacts as the Eco Design Transformer. As a result, the regulated DNO will choose the most cost efficient solution and the amount of avoided grid extension will drop to near zero. As stated above, this comes with a large $CO_2$ impact. The effects of the $CO_2$ footprint for grid extensions show that although the voltage control transformer itself has higher losses than the conventional or the Eco Design Transformer, the avoided amount of embedded $CO_2$ of the cables by far outweighs all other scenarios as can easily be seen below. Therefore, we would urge UK Government to be mindful of the negative implications posed by these draft regulatory proposals for British based innovation and manufacturing in a solution. Indeed the proposals as currently framed would otherwise preclude the application of what is highly relevant solution in the context of the UK's own smart energy system transformation. Therefore, we again reiterate the need for a system wide perspective to be taken when developing policy to support the deployment of innovative alternative energy technologies.

## Social benefit and potential government support

A wide range of social benefits can be expected from large scale introduction of decentralised VPP (Virtual Power Plants) technologies combined with demand-management and grid-balancing. This will contribute significantly towards achieving $CO_2$ emission reduction through decarbonisation of the grid with renewable energy sources and declining dependencies on fossil fuels. New concepts such as intelligent energy communities will create a new awareness in the general population of the changing energy system, new breed of consumer products and the contribution each individual can make towards energy efficiency. New business models and market competition in a less regulated energy market will provide the tools to address aspects of fuel poverty, long-term investment in the energy system and better control over rising energy bills.

Government support is needed to create the necessary policy and regulatory frameworks to facilitate new technologies to market and interworking between consumers, gird operators, generators and energy trading. The building blocks established in the contexts of demand management and grid balancing will be fundamentals for the development of future energy supply systems for smart cities.

## Worldwide power blackouts

Power blackouts are referred to as very large scale long duration interruptions. Blackouts are considered to be rare events however the impacts of these events are quite often very significant. Table A1 shows the major worldwide power blackouts as well as the economic losses when data are available. Since the early 1990s, according to data gathered by Professor Massoud Amin at the University of Minnesota, the number of power outages affected more than 50,000 people a year, and the annual cost of blackouts is between \$80 billion and \$188 billion in the U.S. This was because of the ageing system infrastructure and less investment on research and development.

**Table A1: Major Worldwide Power Blackouts**

**February 8-9, 2013:** some 650,000 homes and businesses in the north eastern US lost power as the result of a powerful nor'easter that brought hurricane-force wind gusts and more than two feet of snow to New England.

**October 29–30, 2012:** Hurricane Sandy with high winds and coastal flooding affected a large part of the eastern United States. It was estimated 8 million customers were without power. It is virtually impossible to protect the system from a storm like Sandy.

**July 31, 2012:** Three power grids across half of India went down. The blackouts, which were considered to be the largest power outage in history, occurred on 30 and 31 July 2012, respectively. The blackout affected more than 620 million people. The estimated outage generating capacity was 32 GW.

**Feb 4, 2011: In** Brazil, a blackout was caused by a failure in an electronic component of protection system of the concerned substation. The blackout lasted about 16h while 53m people were affected.

**Nov. 10, 2009:** Brazil (most states) + Paraguay**.** Storms near the Itaipu hydroelectric dam on the Paraguay-Brazil border caused power cuts where 87 million people were affected in Brazil for 25min to 7h. The entire nation of Paraguay, with a population of 7 million, experienced briefly the blackout.

**January-February 2008**: Winter storms resulted in a nearly two-week blackout where some4 million people around the central Chinese city of Chenzhou were affected.

**November 4, 2006**: The blackout affected South West Europe including some parts of Germany, France, Italy, Belgium, Spain and Portugal. The blackout was initiated by switching off a high voltage line over a river to let a cruise ship pass. Some 15 million people in Germany, France, Italy and Spain were affected..

The blackout resulted in the splitting of the Electricity Power Grid into three zones: West, East and South-East. The blackout lasted for 2h.

**August 18, 2005:** Blackout occurred in Indonesia (Java Island) due to the technical failure, and a subsequent cascading failure. The blackout lasted 7h while 100m people were affected.

**Nov 29, 2004:** In Spain, due to human error/technical failure, a transmission line was overloaded where 5 blackouts took place within 10 days and 2 million people were affected.

**Sept. 28, 2003**: Italy (all Italy, except Sardinia). A short in a power line in Switzerland initiated the blackouts which affected 95% of Italy. Some 55 million people were affected by the 18 hour blackout.

**Aug. 14, 2003**: The worst US blackout was triggered by a cascade of breakdowns. 50 million people in eight states and Canada, some for more than a day, were affected.

The total economic loss was estimated about USD 6 bn

**January 2, 2001**: India. The blackout was due to the technical failure of substation in Uttar Pradesh.

The12h blackout affected some 226 million people while the economic loss was estimated to be US$ 110m

**Feb 20, 1998: The blackout in** New Zealand was due to the technical failure that was a cascading failure caused by a line failure. It lasted for 4 weeks while 70,000 people were affected.

**July 13, 1977**: Lightning caused an outage of electricity where around 8 million people in New York City were affected. Power was restored 25 hours later.

**Nov. 9, 1965**: The Great Blackout occurred and 25 million people in New York were affected.

## References to the appendix

DECC (2013) UK H2 Mobility – Phase 1 Results, April 2013; London, Department of Energy and Climate Change

King, J. (2007) The King Review of low-carbon cars: Part I, Part II, London, HM Treasury

Ofgem (2010) Demand Side Response: A Discussion Paper, Ref: 82/10, London, Office of Gas and Electricity Markets

WWF (2011) Electric Avenues - Driving Home the Case for Electric Vehicles in the UK, London, WWF

Foresight
1 Victoria Street
London SW1H 0ET
**www.bis.gov.uk/foresight**
**URN 13/821**