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Low Carbon Technologies for Energy-Intensive Industries

Energy-intensive industries such as chemicals, paper, ceramics, cement, iron and steel are responsible for 45% of carbon emissions from businesses and the public sector in the UK. This briefing discusses carbon dioxide (CO_2) abatement technologies for these industries and policies to support their adoption.

Overview

- Government has to balance two competing goals: reducing CO_2 emissions and keeping industry in the UK. It does this by penalising emissions while incentivising investment in low carbon technologies.
- Over the next decade, existing technologies will be used to continue emissions reduction.
- Beyond 2020, transformative technologies, such as carbon capture and storage, will be needed to make significant improvements. Development and demonstration of such technologies requires considerable time and investment.
- Alongside this, where electricity use is essential to make a product, it will be important to use a low CO_2 electricity supply.

Background

Energy-intensive industries (EIIs, see Box 1) employ around 620,000 people in the UK, contributing over £49 billion in goods and services to the economy (2008). There is debate over how to ensure that production of these goods in the UK is compatible with achieving greenhouse gas emission targets. The Climate Change Act 2008 requires a 34% reduction by 2020 and an 80% reduction by 2050 compared with 1990 levels. Several policies are being used to penalise emissions and so encourage a shift to low carbon technologies. However, such technological change involves significant time and investment by EIIs, which could lead to "carbon leakage" (Box 2) – the movement of operations or investment outside the UK. To achieve a balance between reducing emissions and keeping industry in the UK, the government also provides commercial incentives to develop and implement abatement technologies.

Policy

The Climate Change Levy

The Climate Change Levy (CCL) came into effect in 2001 in the UK. It taxes the following commodities to try and encourage efficiency: electricity; coal; coke; natural gas; and other hydrocarbon gases in a liquid state. Electricity from renewable sources or electricity to be used in electrolysis (e.g. aluminium smelting) is not taxable under the levy. Also commodities that are used for non-fuel or for dual-use purposes, such as coal used in integrated steel plants, are exempt. Fuel used by "good quality" combined heat and power schemes is also not covered.

Box 1. Energy-Intensive Industries (EIIs)
EIIs use large amounts of electricity, fuel or heat and may also release CO_2 from raw materials (process emissions) e.g. in cement manufacture. The major EII sectors are iron and steel, aluminium, cement, ceramics, chemicals, food & drink, foundries, lime, glass, non-ferrous metals, paper and industrial gases.

EU Emissions Trading System (EU ETS)

The EU ETS is a "cap and trade" system for electricity generation and heavy industry implemented in 2005 to reduce greenhouse gas emissions (see POSTnote 354). EIIs covered by the system include iron and steel, cement, glass and ceramics and other industries involving combustion plants, for example oil refining. It is currently in Phase II, which runs from 2008-2012 and covers 45% of EU emissions. Each member state agrees with the European Commission the level of emissions allowable for the industries covered as a portion of an EU-wide cap. Allowances can then be traded between over-emitters and under-emitters. This creates a price for carbon dioxide (CO_2), and provides an incentive for low carbon manufacturing. In Phase III (2013-2020), aluminium, bulk organic chemicals, non-ferrous metals, and gypsum will be covered. The proportion of allowances that will be auctioned, rather than given out for free, will also rise from around 3% to at least 50%; with 100% auctioning in the UK power sector. Where carbon leakage is a significant risk, allowances will be free and allocated based on benchmarks from the most efficient operations. Article 10a of the revised EU ETS Directive outlines several criteria to determine a sector's risk of carbon leakage.

Box 2. Carbon Leakage
Carbon leakage is an increase in CO_2 emissions in one country as a result of emissions reduction policies in another. While electricity generators supplying the UK must be located here, EIIs sell products in global markets, and so must be internationally competitive. Leakage can occur in two ways: outward movement of existing operations; and multinationals shifting future investment elsewhere. If the leakage is to countries outside the EU ETS cap, worldwide CO_2 emissions could increase. However, finding examples of operations which have, or may, move primarily due to UK climate change policy is complex because many other factors are involved in these decisions, which are often not made public.

The Carbon Price Floor

The carbon price floor is a UK measure designed to increase certainty in the price of CO_2. It introduces a differential tax on fossil fuel if the CO_2 price falls below the UK government's planned figures of £30/tCO_2 by 2020 and £70t/CO_2 by 2030. It is hoped this will encourage investment in low carbon power generation when it comes into force in 2013. However, as it is a unilateral UK measure it could mean a higher UK price of CO_2 then elsewhere in the world.

Striking a Balance

Policies which penalise emissions create the risk of carbon leakage. After lobbying efforts by EIIs, particularly in response to the carbon price floor, the Treasury announced in 2011 that around £250m would be allocated over the spending review period to reduce the impact these policies have on electricity prices for EIIs. This included the provision of up to £110m to compensate EIIs for the indirect impacts that Phase III of the EU ETS will have on electricity costs from January 2013, and £100m to mitigate the impacts of the carbon price floor – subject to state aid rules.

To incentivise investment in energy efficiency and low carbon technologies, 65% discounts on the CCL are available under Climate Change Agreements (CCAs) for EIIs, in return for meeting negotiated CO_2 reduction targets. These will rise to 90% in 2013 for electricity as part of the mitigation package for the carbon price floor. To qualify for CCAs the sector's energy costs per unit of production value must be more than 3%. This rises to greater than 10% if a threshold 'import penetration ratio', which assesses the risk of carbon leakage, is not met (2006 Energy Products Directive). Also, under a non-legally binding commitment, at least half of the revenues from the auctioning of EU ETS allowances could be spent to tackle climate change both in the EU and in developing countries.

The availability and cost of capital for low carbon technology is an important consideration and so the government's Green Investment Bank,[1] which is designed to accelerate private sector investment in the UK's transition to a "green economy" over the coming years, may play a role.

Existing Low Carbon Technologies

Energy costs are considerable for EIIs and so have driven improvements in energy efficiency. These improvements resulted in an average yearly reduction of 1.1% in energy related carbon emissions between 1990 and 2007.[2] The prevailing message from EIIs is that they will spend the next decade implementing best available technologies (BAT) to further increase energy efficiency, without changing how their core processes operate. There are several potential energy efficiency measures that have short payback periods. These range from good practices, such as maintenance and adding lagging to pipes, to more advanced technologies including better monitoring and process control. However, the consensus is that many of the easy abatement options have already been implemented.

Achieving further efficiency savings will require major investments, such as replacing steam boilers or updating onsite power plants. With these assets lasting several decades, replacement or retrofitting with energy efficient alternatives will make financial sense only if the existing equipment is at the end of its natural life. Thus it can take time for the most energy efficient technology and practices to become standard through an industry, and feasibility might also be limited as a result of the original design of the plant. Investments in low carbon technology for the UK also need to compete with other international opportunities within multinational companies, such as building a brand new plant outside the UK. The following are some examples from a range of industries describing continuing energy efficiency measures.

Iron and Steel
The UK's three integrated iron and steel plants make up the bulk of this industry's 20.4 Mt of CO_2 emissions - the largest outside the power sector. Most emissions come from coke use in the blast furnace reaction. Modern furnaces operate close to the theoretical minimum amount of coke needed, meaning continued use of BAT in peripheral activities is required to realise industry expectations of a 20% CO_2 reduction by 2020 compared with 1990 levels. Improving on-site electricity generation can yield major reductions. For example, at the Tata steelworks in Port Talbot, a £60m investment enabled the recycling of exhaust gases to produce 10% of the plant's electricity needs. This also led to a 60% reduction in the amount of natural gas needed, and a reduction in CO_2 emissions of 0.3 MtCO_2/year

Brick
The UK brick industry emits ~1 MtCO_2/year. Ibstock, the largest manufacturer in the UK, has implemented a number of energy efficiency measures to date through investments totalling £50m in new kiln and dryer technology. For example, a new £12m kiln has yielded fuel savings of around 25%.

Cement

The UK's 14 cement plants accounted for 5.7 $MtCO_2$ emissions in 2010 (9.6 $MtCO_2$ in 2007). In cement production, 40% of the emissions come from heating the kiln and 60% from the chemical reaction that produces the clinker, which is the main component of cement used in concrete. Advancements in energy efficiencies in the UK and the impact of the recession saw CO_2 emissions fall 57% between 1990 and 2010. A common abatement measure uses surplus heat from the kiln to dry the input material. Alternatives to fossil fuels, such as tyres and waste packaging, are also increasingly used. The UK cement industry replaces 38% of the kiln energy with waste-derived alternatives (nearly 17% from biomass), less than some EU countries with better waste recovery and greater public acceptance. However, such measures do not address the 60% of emissions coming from the chemical reaction itself, which requires new technologies (Box 3).

Transformative Technologies

The government's Carbon Plan predicts that total industrial emissions may have to be reduced by 70% by 2050 to meet its national targets. However, an energy consultancy firm has estimated that, assuming no significant carbon leakage occurs and best available technology is implemented, UK emissions will fall just 13% by 2050.[3] This suggests that new technologies will be needed.

Some potential transformative technologies are specific to a given industry; Box 3 outlines the potential of novel cements. Others may have applications across a range of sectors. For example, as an alternative to fossil fuels, biomass can be used to create syngas, a mix of carbon monoxide and hydrogen, which as a fuel has the potential to reduce emissions in the brick and other kiln-based sectors (Box 4). This syngas, along with other industrial biotechnologies, can also form the basis for the manufacture of a wide range of low carbon chemicals (Box 5). Future biomass availability is critical to the success of these technologies. For instance, it is vital that the source of biomass does not compete with food production. An example source is municipal solid waste, from which a company called Graphite Resources can recover up to 55% as useful biomass. Finally, carbon capture and storage could be applied to plants with very large CO_2 emissions.

Carbon Capture and Storage (CCS)

Carbon Capture and Storage (CCS, see POSTnote 335), captures CO_2 released by a process and then stores it permanently underground to stop it entering the environment. Alternatively this CO_2 could be used as a raw material (Box 6). So far CCS development in the UK has focused on power generation, but sectors it could be applied to include iron and steel, ammonia production and cement manufacture. It has being reported that if CCS was implemented outside power generation that it would be feasible to abate ~38 Mt of CO_2, increasing the previously quoted 13% reduction between 2008 and 2050 to a 42% reduction.[3] There are three main points to consider when applying CCS to industry as opposed to power generation:

- sector-specific capture technologies are needed;
- the costs of CCS across sectors is different;
- cost effective CCS needs CO_2 transport clusters.

Sector-Specific Capture Technologies

The CCS technologies needed to capture industrial emissions differ from those needed to capture power sector emissions because the processes and the way in which the CO_2 is generated are different. They will also vary between industries meaning CCS will be available on varying timescales. For example, each novel steelmaking technology may require a unique CCS technology (Box 7).

Box 3. Clinker Replacement and Novel Cements

As 60% of cement emissions come directly from the chemical reaction there are three reduction options: make less clinker, use a different reaction or capture and store the CO_2 (see section on CCS). Waste materials from other processes, such as power station fly ash, are widely used to reduce the amount of clinker needed, depending on the required specification.

There is also scope for increasing adoption of novel cements that make use of non-standard chemical reactions and raw materials to reduce emissions. However, their use may be limited due to:

- global location and availability of the alternative raw materials;
- the ability to demonstrate equivalence to traditional cement and to have this recognised in various building regulations;
- acceptance by the construction industry of what is likely to be a more expensive product.

The Mineral Products Association sees it as unlikely that traditional cements will ever be completely replaced, in a cost-effective manner, in load bearing construction.

Box 4. Syngas in Brick Manufacture

Ibstock, Europe's largest brick manufacturer, predicts that if all plants were retrofitted, syngas could replace half of the natural gas burnt in kilns, currently responsible for 1 $MtCO_2$/year. It could also be used in other kiln-based processes such as ceramics. However, changing fuels requires the development of new kiln technology and large capital investments to determine its feasibility; Ibstock estimate a commercial scale trial would cost €8-9m.

Box 5. Renewable/Low Carbon Chemicals

Syngas from renewable sources might also be used to create low carbon transport fuels and chemicals. For example it could be used to replace or supplement fossil fuel derived syngas in nitrate fertiliser production. Furthermore, companies such as INEOS Bio are producing syngas from waste and feeding this to bacteria, converting it to carbon neutral bioethanol. Bioethanol can be used as a renewable transport fuel, or as a chemical intermediate for the production of various plastics and chemical products.

Instead of converting biomass to syngas, companies such as Solvert are planning to ferment green waste from kitchens and gardens to create chemicals including n-butanol, used to create plastics and other products. This would produce 90% fewer emissions then deriving n-butanol from crude oil. In the future, further use of biotechnology could replace not just the production of the raw materials but also the processes used to make the end-products. Energy intensity is reduced as biologically-based reactions can take place at atmospheric pressure and physiological temperatures, unlike existing methods.

Box 6. CO_2 Utilisation
CO_2 can be reacted with materials such as mining residues, in a process termed mineralisation, 'fixing' it in value-added products used for construction. In principle, similar reactions could also be used to reclaim metals from industrial wastes such as steel slag, so improving the economics. Alcoa currently operates a 70,000 tCO_2/year mineral waste carbonation plant in Australia, equivalent to taking 17,000 cars off the road. Alcoa mix CO_2 into the bauxite residue from aluminium production, forming stable inorganic minerals. Their long-term plan is to apply this to all their refineries, which could permanently store 300,000 tCO_2/year from Australian refineries alone.

In the future, converting captured CO_2 into other products might be viable. CO2Chem, a Grand Challenge Network funded by the Engineering and Physical Sciences Research Council to help realise the potential of science which is 20-40 years away, is aiming to reduce our dependency on petrochemicals by developing a diverse range of CO_2 based alternatives. For example CO_2 could be directly used in chemical reactions to produce compounds such as cyclic polymers. Methanol is another potential product from captured CO_2 - a 5million litre/year plant was built in Iceland in 2011 and others are planned. Costs competitive with conventional methanol production are claimed.

While using CO_2 may be economically viable in specific applications, depending on the value of the commodity produced, it is unlikely to be as widely applicable as indefinite storage.

Cost of CCS in Different Sectors

The cost of capturing emissions will depend on the size of the operation, its location (relative to pipelines or storage sites), the technology needed, and impurities in the waste CO_2. Costs of between £30 and £150 per tonne of CO_2 are predicted for industry as a whole, lowering to around or below £50/tCO_2 for steelmaking and ammonia plants.[3] This is below the government's target carbon price floor of £70t/CO_2 by 2030, which would make using CCS cheaper than paying the tax. However, it could still be more expensive than producing elsewhere (Box 2). Costs may also be prohibitive for smaller, geographically dispersed emitters such as cement plants, which are not near cost-effective transport and storage infrastructure. In this case, CO_2 utilisation may prove economically viable (Box 6).

Box 7. Combining Coke-Free Steelmaking with CCS
The ultra-low carbon dioxide steelmaking consortium of EU steel companies and research institutions identifies these four steelmaking technologies as part of their goal to more than halve emissions.

- **Top Gas Recycling with CCS (post-2020).** This emits CO_2 in a way that is compatible with subsequent CCS and could be retrofitted to existing UK plants, reducing total CO_2 emissions by up to 60%.[4] A full scale demonstration project is expected in France by 2015.

Further reductions would require new designs to replace coke.

- **Hisarna Smelting**, a total redesign yielding a 20% CO_2 reduction (80% if combined with CCS).[4] The first pilot plant is in the Netherlands.
- **the ULCORED process.** This uses gas (instead of coke) and electricity to create steel and could also be used with CCS.
- **ULCOWIN (Alkaline Electrolysis).** This uses electricity to create steel. It is unlikely to be commercialised before 2040 and requires cheap, decarbonised, electricity.

CO_2 Transport Clusters.

Pipeline infrastructure to transfer captured CO_2 to storage facilities will require significant capital investment. There are real economies of scale in this infrastructure: doubling investment in a pipeline provides 10 times the capacity.[5] Thus, cost effective industrial CCS will require cooperation with the very large CO_2 emitters of the power sector to create CO_2 transport clusters. For example creating pipework suitable for a future cluster would add 10% to the first power station project but could reduce future CO_2 transport costs by 40%.[5] The location of EIIs in the UK lends itself to transport clusters, as much heavy industry is geographically compact within short distances to oil fields and saline formations, which have massive storage potential. A proposed cluster which involves a project applying for European funding through DECC is described in Box 7. The forthcoming DECC CCS delivery programme will consider industrial CCS and the importance of clustering to achieve cost-effective CCS for the mid-2020s.

Box 8. Transport Cluster - the Process Industry CCS Initiative (PICCSI, Tees Valley)
This initiative involves Progressive Energy, Lucite International, GrowHow, BOC and Px and is supported by the Northeast of England Process Industry Cluster (NEPIC). Infrastructure to connect these emitters situated within a few km of each other, and close to potential storage sites in the North Sea, could provide ~8% of the UK's required reduction by 2030. The cluster is anchored by a project developed by Progressive Energy and its partners for a pre-combustion capture technology coal gasification power plant. The power plant with the industrial units could potentially capture up to 14-22 MtCO_2 a year.

Decarbonised Electricity

Some processes, such as the chloralkali process, which uses electrolysis to split brine, cannot avoid the use of electricity. This process produces a range of chemicals used throughout other industries, for example water treatment and the plastic in cars. 75% of CO_2 emissions from INEOS' plant in Runcorn come from its electricity supply. Thus significant emissions reductions can come from using a low carbon or decarbonised electricity supply (Box 9). The government's Electricity Market Reform (EMR) intends to establish investment in low-carbon energy production. However, renewable sources such as wind come at a price premium and so the 2011 Autumn Statement made reference to exploring options to reduce the impact of the EMR on electricity-intensive industries.

Box 9. An Example of Combined Heat and Power
To reduce emissions, INEOS and its partners have commissioned an "energy from waste" combined heat and power (CHP) station adjacent to their plant. Here the power station's fuel comes from burning refuse as a low CO_2 alternative to fossil fuels to produce electricity. This provides 25% of the electricity INEOS needs. Due to the high efficiency of the CHP method of energy generation, its electricity is not taxed under the climate change levy.

Endnotes

1 Green Investment Bank, http://www.bis.gov.uk/greeninvestmentbank
2 Hammond GP, Norman JB, *Decomposition analysis of energy-related carbon emissions from UK manufacturing*, Energy, 2011
3 Element Energy, *Potential for the application of CCS to UK industry and natural gas power generation*, 2011
4 Centre for Low Carbon Futures, *Technology Innovation for Energy Intensive Industry in the United Kingdom*, 2011
5 Carbon Capture and Storage Association, *A Strategy for CCS in the UK and Beyond*, 2011

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