Six Thousand Feet Under

Burying the Carbon Problem

Stuart Haszeldine and Gil Yaron
edited by Tara Singh and Thomas Sweetman

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Executive Summary

The challenge of reducing emissions to tackle climate change is one of the toughest faced by modern economies. The political consensus is that we need to reduce our carbon emissions by 60-80% by 2050 and yet, instead of falling, they continue to rise. Worldwide emissions from fossil fuels are expected to rise 62% by 2030, with two thirds of that in India and China.

Carbon Capture and Storage (CCS) is a term for a set of technologies which could tackle part of this problem by capturing up to 95% of the carbon dioxide (CO_2) released by coal and gas fired power stations.

The CO_2 is captured from the station emissions, liquefied for transport by ship or pipeline before being finally stored underground in depleted oil and gas fields, coal seams or deep saline aquifers.

Our report finds that:

- Fitting CCS equipment to coal and gas power stations could slash global emissions by between 28-50% by 2050;
- Fitting CCS to UK plants could cut emissions by 20% by 2020;
- These emission reductions could be extremely affordable. If all large gas and coal fuelled electricity plants in the UK were fitted with commercially viable CCS, the additional cost of electricity would be around £60 per household per year. This is similar to the UK price currently paid for wind, the cheapest renewable technology currently available.

However, CCS is currently at demonstration stage. To develop and take full advantage of this technology requires the creation of a commercial CCS industry.

The UK is in an excellent position to do this, with world leading experts, an established engineering base and a selection of available and known storage sites.

In the UK, the cost of initial demonstration projects could also be partially offset by using CCS to extract extra oil from depleted reservoirs in the North Sea (Enhanced Oil Recovery, EOR).

Previously the UK government has successfully led domestic and international efforts on CCS legislation, but it is now failing to deliver real projects. In fact, recent government support has been woefully inadequate:

- Unlike for other low carbon technologies such as wind, there exist no commercial incentives to develop CCS in the UK. Investors originally asked the Government to allow CCS the same price support as that given to wind power. The Government refused;
- Instead, the Government has put all its eggs in one basket with a state sponsored competition. This will deliver just one small plant by 2014, a plant which according to our estimates will reduce carbon reductions at a cost of around £70/tCO_2;
- Moreover, the number of commercial CCS propositions in the UK has halved since 2007;
- In comparison, the proposals in this report would develop a full generation of new power stations at a cost of just £30/tCO_2 – saving 20% of UK emissions.

Our report concludes that the Competition is inadequate – instead, it is essential that Government gives investors a commercial incentive to back CCS. This can be done by giving carbon saved via CCS a carbon price of the same level given to other low carbon sources of energy, such as wind. We suggest that the Government either:

a. Creates a Decarbonised Renewable Obligation Certificate band to give CCS the same level of support as onshore wind or offshore wind; or
b Works towards introducing long-term purchase contracts for decarbomised fossil fuel electricty; or
c Allocates free EU Emission Trading Scheme allowances after 2012 to reward CO_2 stored. This would allow CCS stations to sell permits when they go up in value in the future, thereby recouping their costs.

These proposals will help create an industry for new build CCS plants. However, it is likely that fossil fuel plants will be given planning permission before this technology is fully developed.

The Government has claimed a new generation of fossil fuel power stations will be built ready to retrofit CCS when the technology becomes commercially viable. However, attempts to define how stations could be built ready to retrofit have been non existent or clumsy.

If the Government is serious about meeting this claim, we propose instead a series of stepped emissions standards dependent on worldwide progress on CCS:

- From 1 January 2009, all new fossil fuel power plants must have average annual emissions from the whole plant of 350 kg CO_2/MWh. This would eliminate new-build coal with no CCS, but would still enable unabated gas plant to avoid electricity shortages;
- By 2015, new build stations must meet an emissions standard of 170kg CO_2/MWh or better for coal, and 70 kg CO_2/MWh on gas. This would require CCS to be fitted for both coal and gas;
- By 2020, old build power stations should be retrofitted to meet this standard.

Taken together, our proposals would encourage the development of a world-leading industry in a technology vital to the fight against climate change. Not only would we go a long way towards solving our own emission problems but we would also leave a lasting legacy to those in the developing world.

List of Terms

Annex 1 Countries – 38 industrialised countries given targets for reducing emissions under the Kyoto Protocol. It now also includes Belarus, Turkey and Kazakhstan.

Capture – The first stage in Carbon Capture and Storage. Before the CO_2 can be transported away for storage underground, it must first be separated from the power plant emissions. This can either be done before the fossil fuel is burnt (pre-combustion) or afterwards (post-combustion).

Capture Ready (CR) – The notion that plant built before Carbon Capture and Storage is ready can be constructed in such a way as to allow CCS equipment to be fitted to them once it is commercially viable.

Carbon Capture and Storage (CCS) – The process whereby carbon in the form of carbon dioxide is separated from plant emissions (captured), compressed and transported in pipes or containers and then, finally, stored underground.

Carbon Markets – A broad term that refers to the use of markets to create a price and therefore an economic incentive for reducing carbon. Also referred to as "cap and trade" or "emissions trading".

Clean Development Mechanism (CDM) – An arrangement under the Kyoto Protocol that allows Annex 1 countries to meet some of their emission reduction targets through investing in cheaper projects in developing countries, as opposed to more expensive ones at home.

Climate Change Levy (CCL) – The climate change levy is a tax on the use of energy in industry, commerce and the public sector.

Combined Heat and Power (CHP) – In conventional energy industries, electricity and heating are generated separately. This is very inefficient as electricity generation alone also produces a significant amount of heat which is then wasted. Combined Heat and Power seeks to address this by integrating both heating and electricity generation into one process, increasing efficiency to 75% or more as opposed to 50% in conventional generation.

Demonstration Plant – Although all the separate elements of Carbon Capture and Storage are already used in industry they have yet to be integrated into a single plant for electricity. Demonstration plants are the next step in the deployment of CCS. These will generate information on running expenses and technical issues that will allow the cost of CCS to be lowered to a commercially viable level and thus for full scale deployment to begin.

Enhanced Oil Recovery (EOR) – A term for techniques that increase the amount of oil that can be extracted from an oil field. In the case of Carbon Capture and Storage this would involve injecting the carbon dioxide from power plants into a depleted oil field. The carbon dioxide would then expand, pushing the oil out of the reservoir and allowing it to be extracted.

EU Allowances (EU-A) – These are allowances to emit carbon dioxide given out under the EU Emissions Trading Scheme which can then be bought or sold as needed.

The European Union Emissions Trading Scheme (EU ETS) – A carbon market based on the cap and trade principle whereby binding emission targets are set by the EU and allowances to emit up to these targets then sold. Companies that pollute more can buy surplus credits off those who pollute less provided the level of overall emissions does not exceed the cap limit.

Feed-in-Tariff (FIT) – Electricity generated from low carbon sources (be they renewables or plants with Carbon Capture and Storage) is often more expensive to produce than the market price. To encourage low carbon generation governments can opt to buy this electricity at higher rates (so called feed-in-tariffs). These tariffs decrease year on year as it becomes cheaper to generate from low carbon sources until they fall to a level competitive with conventional forms of generation and support is no longer required. Such tariffs have widely been credited with the successful expansion of renewables in other countries.

Kyoto – Refers to the 1997 Kyoto Protocol where ratifying countries agreed to engage in emissions monitoring, reduction and/or trading with an overall objective of reducing overall greenhouse gas inputs into the atmosphere, helping to prevent climate change. By the end of 2007 175 countries had ratified the protocol.

London Convention (1996 Protocol)/ OSPAR Treaty – These are treaties designed to protect the offshore marine environment from dumping waste at sea. Although legal under these agreements, care must be taken that implementation of CCS does not undermine these frameworks.

Natural Gasification Combined Cycle (NGCC/CCGT), Integrated Gasification Combined Cycle (IGCC) and Pulverised Coal (PC) – All are types of fossil fuel power plant. NGCC is an advanced form of Combined Cycle Gas Turbine (CCGT) power plant. It runs on gas and emits less CO_2 than the other two while both PC and IGCC run on coal.

Near Zero Emissions Coal Programme (NZEC) – A joint venture initiative between the UK and China. It consists of an 18-month work programme designed to help build capacity for carbon capture and storage technology in China.

Parts per million (ppm) – Since global warming is largely driven by the concentration of greenhouse gases in the atmosphere targets for avoiding such warming are usually put in those terms. The concentration of carbon dioxide (the major component of greenhouse gases) in the atmosphere currently stands at 387ppm. If we continue to emit carbon dioxide at our current rate this is expected to reach around 700ppm by 2100 with potential rises in global temperatures of 6C. At such temperatures the extinction of life on earth as we know it becomes a distinct possibility. In order to avoid more than a 2C rise, which will still have adverse impacts, we need to stabilise at 550ppm, or better yet at 450ppm, by 2050.

Renewables Obligation (RO) – This is the primary support scheme for renewable electricity projects in the UK. Under the scheme UK suppliers of electricity have an obligation to source an increasing proportion of their electricity from renewable sources.

Stern Review – Conducted by Sir Nicolas Stern, Head of the UK Government's Economic Service, and his team of researchers this was published in 2006. The review provides the definitive account of the economics of climate change as well as an in-depth examination of its consequences.

Storage – The final stage of Carbon Capture and Storage. At this point the CO_2 being transported is pumped underground where it is kept away from the atmosphere. Options for storage include: at the bottom of oceans or in deep saline aquifers. However the most favoured at the moment is in depleted oil fields. This is largely due to the fact that the geology of such fields is already well known and the process of storing the CO_2 can be used in Enhanced Oil Recovery which offsets the cost of CCS.

Transport – After the CO_2 is separated from the rest of the power station emissions it needs to be transported to a suitable storage site. This can be done either through pipelines or by container over road, rail or sea.

United Nations Framework Convention on Climate Change (UNFCCC) – Signed at the 1992 Earth Summit in Rio de Janeiro. The treaty is aimed at stabilizing greenhouse gas concentrations in the atmosphere at a level that would avert climate change.

1

The Background

Electricity has to be delivered abundantly, securely, and cheaply in industrialised countries. Now an additional objective is to deliver electricity with minimum greenhouse gases. Carbon Capture and Storage has emerged rapidly from obscurity to become seen as the saviour of many national energy policies which have low CO_2 objectives, including policy in the UK. CCS can greatly reduce CO_2 emissions at coal and gas fired power plant. In Germany, which has an economy similar to the UK, it is calculated that after easy and profitable energy-saving gains are made, commercially viable CCS will be required after 2020 for emissions reductions in excess of 30%[1]. Consequently, expectations of CCS are very high, but will not be met unless much greater effort and acceleration is put into development and deployment by national governments.

The need for CCS arises from the position the industrialized world finds itself in, with over 90% of its energy supplied from fossil fuel, increasing rates of carbon emissions. The UK has no proven route to enable rapid building of renewable electricity projects, and only onshore wind power as a proven renewable technology for routine use. Worse still, all the options for future near-term clean electricity have big disadvantages. Offshore wind, tides, waves and solar PV are all developing rapidly, but are not yet able to supply national or regional grids with industrial-sized flows of electricity. Nuclear power will provide only ten percent of UK electricity by 2020, a small percentage of total energy supply, and takes decades and billions of pounds to build. To develop a set of choices for future electricity production, the UK government has to support the development of several new technologies. CCS is one of these, which can provide resilient diversity of fuel, and help to bridge the clean power gap until 2020, then 2050 and beyond, whilst renewables continue to develop. This view has been endorsed by the Government not least in May 2008 when David Miliband said, "*We need to shift to low carbon, investing not only in renewables and nuclear, but also moving forward with Carbon Capture and Storage to limit the damage of our continued dependence on coal.*"

> "Developing CCS is not a single magic remedy, but it can provide carbon dioxide reduction at a large scale, rapidly, directly, and with minimal behaviour change by voters, and at low or no extra cost to consumers in the EU who are already paying through the EU-ETS"

None the less CCS has significant disadvantages: it relies on imported fuels (although the UK could extract indigenous coal resources); it uses more fuel in a power plant to strip the CO_2 from waste gases (currently 30%, though expected to be 10% or less by 2020); it continues to damage landscapes by mining and it will increase the price of electricity (but by much less than recent fluctuations).

Nobody would undertake CCS if there was an established alternative which could

1 McKinsey, "Cutting carbon, not economic growth: Germany's path", 9 April 2008, see http://www.mckinsey quarterly.com/Energy_Resources_Materials/Strategy_Analysis/Cutting_carbon_not_economic_growth_Germanys_path_2104

have the same impact on the same timescale. Developing CCS is not a single magic remedy, but it can provide carbon dioxide reduction at a large scale, rapidly, directly, and with minimal behaviour change by voters, and at low or no extra cost to consumers in the EU who are already paying through the EU-ETS. The climate message is clear: the UK and the world cannot continue to burn fossil fuels and release CO_2. Either fossil fuel burning must cease completely, or CCS must be installed rapidly. Neither of these is happening.

So what are we doing about it?

The UK Government has stated that it wishes to be a leader in CCS, and will build an operational CCS power plant by 2014. The UK has had many successes in preparing for CCS nationally and internationally. But a project has not yet been built. Past efforts are not encouraging. The UK Government failed to recognise the significance of one of the world's first large CCS possibilities at Forties oilfield in 2003 which would have put the UK over ten years ahead of the rest of the world on CCS, and later chose not to support early development of CCS at Peterhead gas plant operating from 2009. The UK also rejected a diversity of industry CCS propositions in 2007 which, if built, could decarbonise the supply of 20% of all UK electricity starting from 2012.

In 2008 the UK is showing indecision and lack of forethought on how to make new and existing power plants "capture ready" and how to ensure those plants transfer to CCS operation. Meanwhile the rules for the UK's flagship CCS power plant competition enable the single winner to delay full CCS operation until 2020.

Making sure that CCS happens and is funded is obviously very difficult. However, the longer that CCS takes to arrive, the worse climate change effects for the long term will become, and the more expensive adaptation will be. The Stern Review of climate change economics in 2006 stated that CCS support needed at least a five-fold increase worldwide. Now is the time to do that.

The Wider Picture: Policy and Climate Change

The current political consensus in the developed world is that atmospheric concentrations of Carbon Dioxide must not rise above 550 parts per million, or 450 parts per million CO_2e, at the lower end of the scale.

The atmosphere in 2007 contained 383 parts per million CO_2e. It is clear that all these limits to CO_2e will be surpassed unless emissions decrease within ten years, or shortly after.

UK climate policy

The questions now are around 'what to do?' It is well understood that lifestyle changes can play a part – yet changing behaviour is very difficult. Many people reduce, re-use, or recycle – yet still choose or are forced to use private road transport, and allow themselves aviation travel for vacations. The barriers to individuals and small businesses changing energy use, or investing in efficient equipment include the lack of short term financial payoff. More substantial changes such as altering our houses and buildings are an even longer term activity, taking many decades. The Stern Review of 2006[2] found a way to express the scientific knowledge in economic terms. It is clear those actions taken now to reduce the causes of climate change will be much cheaper than in the future.

Yet abundant contradictions exist in UK policies and approaches: on roads, airports and economic growth by increased consumption. Plans are made for leisurely CO_2 reductions to meet a 60% cut by 2050. This does not match with the evidence of climate change. If the UK is committed to evidence based

2 Stern, "The economics of climate change", Cambridge Press, 2006.

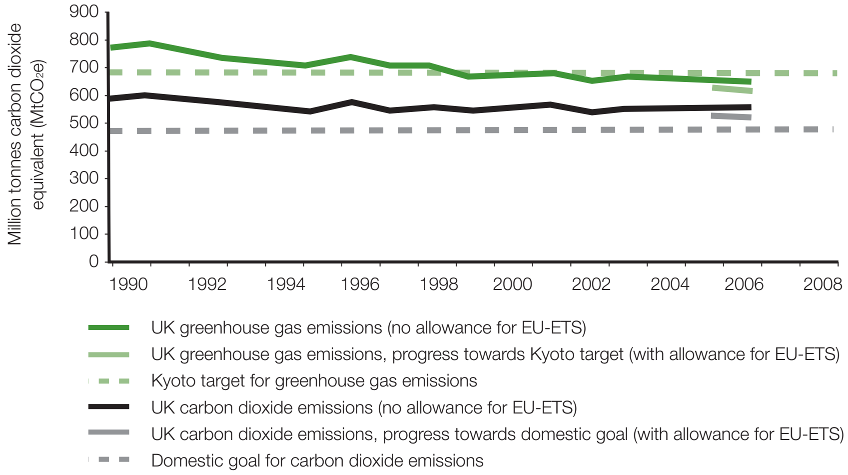
policy, then much more rapid emissions reductions are needed. If the UK is committed to being a leader in global change, then unilateral actions may be required. If new businesses, technologies, machines and methods of operating are needed – then these can be turned into opportunities for the UK, not costs.

Is the UK doing well?

The UK Government argues it is "leading the world on climate change." (Fig. 1) However, the real reason that CO_2 emissions appear to have declined is not due to successful green policies, but to three other factors:

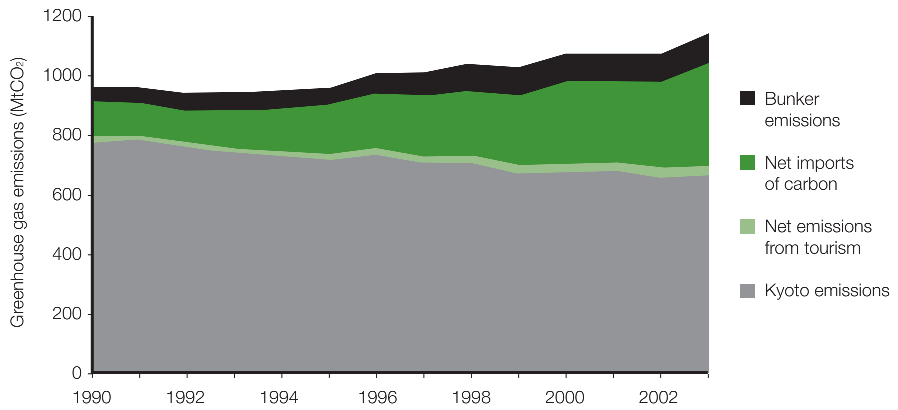
- Switching fuel – The dash-for-gas from 1990 meant electricity production switched from coal to cleaner gas fuel. This one-off benefit cannot be repeated, and UK Energy policy now wishes to reduce dependence on imported gas[3]. If the price of gas remains high, then coal will recover as a cheap fuel of choice;

Fig 1 DEFRA CO_2 emissions since 1990 and progress towards targets



Source: Budget 2008, Chapter 6

Fig 2 UK CO_2 emissions consumption basis



Note: Bunker emissions include radiative forcing factor of 3 for international aviation.

Source: ONS (2007) and CAIT Database and Vivid Economics

3 DTI, "The energy challenge: a report", 2006, see www.dti.gov.uk/energy/review/CM6887

4 Helm, Too good to be true? The UK's climate change record, 2007, see http://www.dieterhelm.co.uk/publications/Carbon_record_2007.pdf

- De-industrialisation – A growing economy whilst manufacturing less and;
- Exporting emissions to developing countries.

The UK manufactures fewer goods now than in 1990. This has driven a decline in power related emissions. Because so many goods are imported the UK is effectively reducing its CO_2 emissions through the import of products, mainly from China. However because of the way the United Nations Framework Convention on Climate Change (UNFCCC) calculates emissions (attributed only to those arising directly in the UK), these emissions are attributed to China, even though the products are made for, and consumed within, the UK.

If these emissions are repatriated, outline calculations indicate that imports add around 20% to the UK annual emissions figures. Net imports in 2006 from China (calculating both China imports and UK exports) were around 125 Mt CO_2e in 2006, adding to a declared UK total[4]. When all countries are considered, the UK trade deficit of greenhouse gases rises from 110 Mt CO_2e in 1990 to as much as 620 Mt CO_2e in 2006. In light of such figures it is clear we must consider all our options for reducing emissions. Exactly what place CCS has in reducing these is discussed further in the following chapter.

2

The Role of Carbon Capture and Storage

Additional methods of reducing the environmental impact of our lifestyles are needed, and needed quickly. The only method currently proposed, to directly reduce CO_2 emissions from fossil fuel use, is carbon capture and storage.

It is clear from Business as Usual projections by the International Energy Agency (IEA) that, if nothing changes, the use of fossil fuels will continue to increase up to 2030 and beyond[5]. The growth of renewable energies (biomass, hydro, wind, wave and tide) will only equate to 14% of world supply. Nuclear will grow slowly, forming only 5% of world energy supply. This while fossil fuel use (oil,gas and coal) will be double that of 2005 in 2030, with CO_2 emissions increasing by 55%. The biggest growth (73%) is in coal use – which is the fuel that emits the most CO_2 per unit of energy – and most of this increase is in China and India. Even on scenarios of 'Alternative Policy', where world governments take some action on energy security and climate change, the use of fossil fuels increases by 1.5% per year. Only in the 2006 Beyond Alternative Policy Scenario (BAPS), do emissions actually decline. The use of CCS around the world is essential to make 11 of that 29 $GtCO_2$ per year emissions reduction happen.

Carbon capture and storage can be built rapidly, fitted within the existing industrial system, and operated to make a profit, if fit-for-purpose pricing of electricity is introduced. Essentially a suite of equipment, it can be fitted to new and retro-fitted to existing coal and gas fuelled power stations. This equipment then captures 85% to 95% of the CO_2 which is currently discharged into the atmosphere. Once captured the CO_2 is liquefied by pressure, transported through pipes like natural gas networks, and finally injected by a borehole into the microscopic pores of deeply buried rocks, where it will remain isolated from the atmosphere.

Potential Impact

Stabilising global CO_2 emissions at the levels of 2008, or even 1990 is not enough, emissions must fall in order to reduce CO_2 concentration in the atmosphere.

According to a special report by the IPCC[6], CCS is capable of reducing worldwide CO_2 emissions by 50% by 2050. A similar requirement for CCS is indicated by the IEA WEO[7] BAPS – forming 11 Gt of that 29 Gt CO_2 per year emissions reduction. The Stern Review[8] also highlighted CCS prominently, with potential to contribute up to 28% of global carbon dioxide mitigation by 2050. In 2007 the respected USA Battelle institute analysis[9] of global energy technologies stated that the technical challenge involved in reducing CO_2 emissions towards zero is "unprecedented". A portfolio of technology solutions are needed, ranging from demand reduction to nuclear. Of these, up to 40 Gt CO_2/yr could be stored by CCS (compared to 25 Gt CO_2/yr emitted from humans in 2005).

5 IEA, World Energy Outlook, p76, 2007, see www.iea.org

6 IPCC, "Special report on carbon capture and storage", 2005, see www.ipcc.ch

7 IEA, World Energy Outlook, 2007 see www.iea.org

8 Stern, "The economics of climate change". Cambridge Press, 2006

9 Batelle, "Global Energy Technology Strategy: addressing climate change". Phase 2, 2007, see http://www.pnl.gov/gtsp/docs/gtsp_2007_final.pdf

Thus, rapid growth is required from CCS. To stabilize the atmosphere at 500ppm CO_2e CCS must grow rapidly from around 4.4 Mt CO_2/yr in 2008 to store 2,160 Mt CO_2/yr in 2050, and 22,330 Mt CO_2/yr in 2090 (27% of possible CO_2 emissions). Our calculations suggest that for CCS alone to achieve the safer 450ppm CO_2e limit, these storage figures would have to be doubled.

For the large USA economy, which is dependent on coal for electricity, CCS is fundamental. Likewise in the developing economies of China and India, the application of CCS is critical for its domestic benefits of air quality and world benefits of reduced CO_2. In China coal met over 60% of all energy needs during 2007. Coal use in electricity generation is expected to grow, as is the manufacture of liquid fuels from coal, so that CO_2 emissions, 5,200 Mt CO_2/yr in 2005, reach 11,400 Mt CO_2/yr in 2030[10]. India has a less certain path, but is very reliant on domestic and imported coal, so that emissions could grow from 1,100 Mt CO_2/yr in 2003 to 3,900 Mt CO_2/yr in 2030. In both countries, the homeland priority is to provide more electricity reliably with efficient power plant, without reducing output and expenditure through CCS. To develop both within and without China and India CCS needs start-up help from outside. Building demonstration CCS plants eligible for EU-ETS allowances in these countries is one method.

These trends are not just confined to the largest economies. Worldwide we are witnessing a "dash for coal", for cheap electricity generation and as a secure means to avoid imports of liquid vehicle fuels. Burning coal for electricity, or making diesel from coal, produces twice to three times as much CO_2 as using crude oil. This is in direct conflict with climate imperatives to reduce CO_2 emissions.

All recent major reports show that CCS has a fundamental role in tackling worldwide emissions causing climate change. CCS could provide from 27% to 50% of the solution, that in combination with a wide range of energy conservation and technology change measures, will provide the answer to our emissions problem.

10 IEA, World Energy Outlook, 2007, see www.iea.org

What is involved?

Simply put carbon capture and storage is a method which could enable fossil fuels to form the backbone of worldwide electricity production, but with greatly reduced emissions of CO_2 from combustion. In the UK, CCS will consist of three activities:

- Combustion of fuel in a power plant. This can be coal, gas, petroleum coke, or biomass. The CO_2 is separated from the plant emissions before or after combustion (see *Methods for CO_2 Capture*);
- Transport of CO_2 away from the power plant. This is undertaken by pressurising the CO_2 to form a liquid, drying the liquid, and transporting it in a dedicated pipeline for distances of hundreds of kilometres;
- Injection of liquid CO_2 into the microscopic pore space of sandstone rocks buried deeper than 800m beneath the bed of the North Sea. Here the CO_2 will remain trapped, or dissolve in surrounding saline water for tens of thousands of years.

Long term safety

Secure retention in engineered storage sites is sometimes considered to be a safety problem by members of the public. However there are many natural occurrences where CO_2 has been retained as pure gas or fluid for many millions of years (in Italy, Arizona, Utah), or as a large component of the crude oil mixture (North Sea). Therefore there are extremely good reasons to believe that engineered storage to make artificial CO_2 accumulations should be successful – provided that good quality site surveys enable resilient sites to be chosen.

Methods for CO_2 capture

There are three main methods proposed for CO_2 capture at a full-size power plant:

a Post-combustion capture – where the fuel is burned and the CO_2 is separated from flue gas by an amine or ammonia solvent. This can be applied to coal or gas combustion.

b Pre-combustion capture – where the fuel is gasified (if coal or petroleum coke), and the syngas (if an IGCC coal fired plant) or natural gas (in a normal combined cycle gas turbine plant) is chemically split to form CO_2 and hydrogen.

The high concentration of CO_2 enables easier solvent separation, and the hydrogen can be burned to produce heat for electricity, or can be sold as hydrogen energy carrier, or can be used in the chemical industry to upgrade oily or tarry hydrocarbons to liquid fuels.

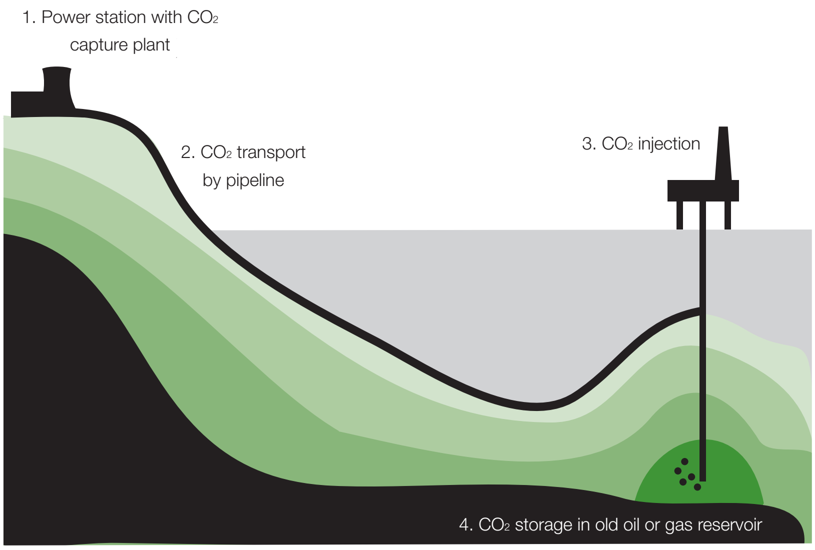
c Oxy-fuel combustion – where pure oxygen is separated from air, and then used to combust the gas or coal fuel. This produces heat for electricity generation and the waste CO_2 is easily separated from water.

"Learning by Doing"

In 2008, a limited number of experimental small prototypes of CCS have been built onto full-size operating power plant in the EU, Canada, Australia and USA. From these experiences, there are many reasons to be confident that CCS will work quickly, and at large-size scale. All the component technologies are built and deployed at significant scale, for other purposes. CO_2 capture works daily in oil refineries, in natural gas separation and in large ammonia plants. Pipeline transport of CO_2 has operated for thirty years in the USA. Injection of CO_2 deep underground has been undertaken for Enhanced Oil Recovery since the 1970s.

The main doubts for CCS lie in the building and operating costs of a large and integrated system. In such situations the organisations who build the first plants will learn rapidly, and so gain 'first mover advantage', but this will come at a financial cost which has not been quantified. Deep pockets are needed.

Fig 3 CCS system diagram



Affordable Abatement

There have been a number of detailed studies of the costs of CCS but it can be difficult to compare results as they are sensitive to (amongst other things) different assumptions on the CCS technology, coal and gas prices and whether the alternative is an existing coal or gas plant. The costs reported below all compare CCS with an existing coal plant and have been converted into pounds in 2007 prices.

As the graph below shows, the estimated additional cost of adding CCS to pulverised coal (PC) plant – the government's preferred option – is most likely to be around 1.9p/kWh for plant built between now and 2015. In comparison the wholesale price of electricity is currently around 6p/kWh.

We arrive at this estimate by drawing on four major studies (these are based on mature CCS costs rather than demonstration, for more details see Study Estimates Appendix). Fitting CCS to CCGT or IGCC[11] plant is estimated to cost less in p/kWh terms but, as we see later on, this

Figure 4: Additional Electricity cost depending on technology

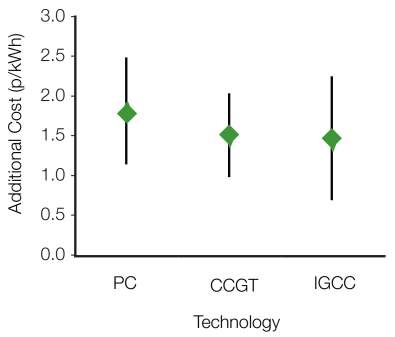


Figure 5: Additional Electricity cost depending ontechnology

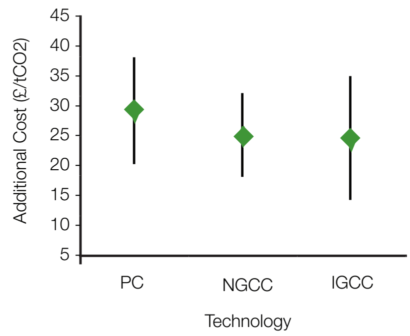
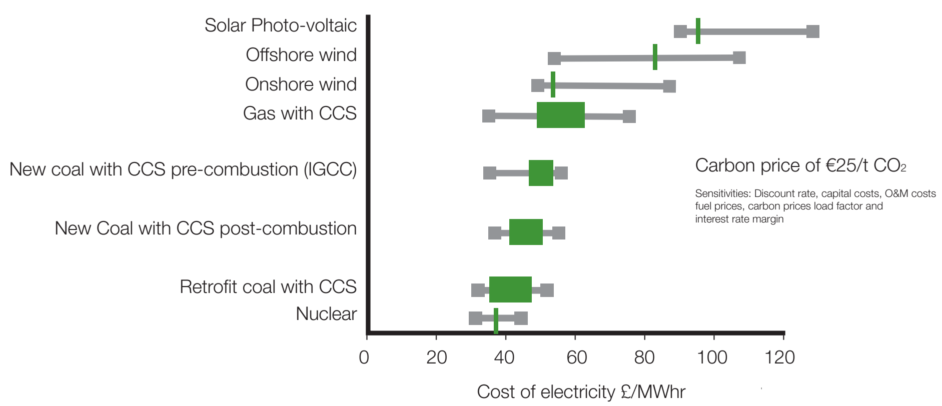


Figure 6: Cost of generating electricity for different technologies



Costs of clean fossil technologies are not yet certain. Estimates overlap with each other, with nuclear, and with developed renewables. With such uncertainty there are no compelling cost reasons to choose a winner. The situation is also likely to change. Costs of clean fossil fuels with CCS and of renewables are likely to fall as learning develops while costs of nuclear are likely to rise as more accurate cleanup costs are included. Information in this compilation is from the DTI's 2006 energy review, these are lower than the 2007 prices in the graph above.

11 See Appendix 2: List of Terms

12 Climate Change Capital, ZEP: Analysis of funding options for CCS demonstration plants, 2007, see www.climatechangecapital.com ZEP, Zero Emission Fossil Fuel Power Plants General Assembly, 2007, see http://www.zero-emission-platform.eu/website/docs/GA2/sweeney.pdf

13 DTI, Meeting the energy challenge, A white paper on energy, CM7124, May 2007, see www.berr.gov.uk/energy/whitepaper/page39534.htm Science and Technology Committee, Meeting UK Energy and Climate Needs: The Role of Carbon Capture and Storage, Westminster, HC 578-I, 2006

advantage can disappear once the amount of CO_2 emitted is taken into account.

Thus these and other figures from banks, the fossil fuel power industry[12] and from the UK Government[13] suggest that CCS will add approximately 25% to the wholesale cost of electricity.

As can be seen in Figure 6 this estimated additional cost makes electricity from CCS potentially more expensive than onshore wind but less expensive than offshore wind generation[14] and solar.

Scope for further cost reduction

The greatest hurdle for CCS is reducing the cost of Capture. At present, post-combustion capture can be undertaken with amine solvents for €60(£40)/tCO_2. This cost includes a large penalty in the energy used to separate CO_2 during post combustion capture; so that up to 25% of the thermal energy produced in a coal plant must be used in the capture and compression processes. However, new solvents are under development. One example is based on cool ammonia and is undergoing large trials on power plants in four countries commencing in 2008-09. This and other improved solvents are anticipated to reduce capture costs to €12(£8)/tCO_2 by 2012.

For pre-combustion capture systems, the inherent energy penalty of CO_2 separation can be only 5%. Even here, development is underway to produce new solvents, membranes or microporous materials, which will separate CO_2 more cheaply, rapidly and with less energy input.

The power industry objective is to build 12 full-size demonstration power plants in the EU. The experience and learning gained will reduce costs of CO_2 capture transport and storage to €25-30(£18-21)/tCO_2 by 2020[15]. This is substantially cheaper than the cost of present day environmental damage calculated in 2006 by the Stern Review[16] as $85(€55, £43)/t$CO_2$.

In the emerging economies of China and India, there is no current plan to make large scale investment in CCS Development or Demonstration. These countries expect to await the results of experimentation and innovation by richer developed nations. CCS will need to be developed first by EU nations, USA, Canada and Australia. Experience with the Clean Development Mechanism (CDM) shows that achieving greenhouse gas reductions in China and India will be cheaper than in the EU. Consequently, it will be very useful to extend the CDM to include CCS, and to build one or more CCS demonstration plant in China and crediting the CO_2 reductions to UK, or other EU states.

This is one possible outcome of the UK-China Near Zero Emissions Coal Programme[17]. A more detailed look at the current status of CCS follows.

14 Off-shore wind generation costs are in the range p/kWh 5.1 – 6.8 p/kWh according to BERR (2008b) and Anderson (2006) with RAE (2008) pricing on-shore wind (including backup generation) at 3.7p/kWh. Using Anderson's marker price for the current mix of generation of 2.6p/kWh gives an additional cost for on-shore wind of 1.1 p/kWh and off-shore wind of 2.5-4.2 p/kWh.

15 ZEP, see http://www.zero-emissionplatform.eu/website/

16 Stern, "The economics of climate change", Cambridge Press, 2006

17 NZEC, "UK-China Near Zero Emissions Coal project", 2008, see http://www.nzec.info/en/

3

The Situation Today

Worldwide

CCS is already an international activity. From being amongst the first nations to conceptualise and investigate CCS, the UK has now been joined by many EU countries (notably Norway, Germany Denmark and Holland), USA, Canada, Australia and China. The international discussion and communication body, the CSLF (Carbon Sequestration Leadership Forum) now has 21 nation state members.

There are four large scale operations underway worldwide which separate more than 1 Mt CO_2 per year. These provide insight into the CCS chain envisaged for power stations.

- The Sleipner oilfield of the North Sea has been operating CCS since 1996. A processing plant on the offshore oil platform strips CO_2 out from its mixture with produced hydrocarbon, and re-injects the CO_2 into the 1km deep Utsira sandstone for long-term storage. This clearly demonstrates the feasibility of capture and injection;
- The Great Plains syngas plant at Beulah North Dakota takes lignite (brown) coal, gasifies it, and separates the CO_2 for sale via a long pipeline to inject into the Weyburn oilfield, where around 10% additional oil will be produced. This has been operating since 2000, and demonstrates CCS connected to a chemical plant;
- The In Salah gas field in Algeria has been separating CO_2 from natural methane gas since 2004. The CO_2 is injected into the water filled part of the same sandstone which produces the gas;
- The Snøhvit gas field of the Barents Sea separates CO_2 from produced gas, and re-injects the CO_2 for storage into water filled sandstone deeper than the original reservoir. This commenced in 2008.

Numerous CCS research projects have been underway worldwide during the last 15 years. Many new projects are becoming large enough to act as pre-commercial demonstrations. A worldwide map view of CCS research, demonstration, and commercially planned sites is available at the Scottish Centre for Carbon Storage (SCCS) website[18]. About 15 projects worldwide are being seriously funded to proceed towards commercial construction. None of these have yet achieved full funding. Governments are very cautious when spending on large single projects which do not have an immediate short term appeal to voters. CCS certainly falls into that category.

This illustrates a fundamental dilemma afflicting CCS: on one side CCS is seen as environmentally essential and in urgent need of validation; on the converse side CCS is seen as expensive, unproven, and a risky option compared to unpopular nuclear plant or popular but small scale renewables.

In the UK, there have been about nine serious CCS projects publicly proposed since 2005[19]. The form of the CCS competition announced by the Department of Business, Enterprise and Regulatory Reform

18 SCCS, "Worldwide listing of CCS commercial storage projects: actual and proposed.", 2008, see http://www.geos.ed.ac.uk/sccs/storage/storageSites.html

19 "A fuller overview of the UK CCS landscape" in Bushby, "Carbon capture and storage in the UK", 2008, In Galbraith C.A. and Baxter, J.M.(eds), "Energy and the Natural Heritage", TSO Scotland, Edinburgh

(BERR) in 2007 has greatly affected progress on all these projects. This is discussed below in the Competition section.

The UK can correctly claim to be amongst the world leaders in CCS. This claim is especially valid in the work achieved in changing international marine treaties, and in designing domestic legislation. The UK claim is more equivocal when intended CCS projects are compared worldwide (Table 1). Currently the UK is certainly planning to host the largest project, but this will be storing CO_2 *several years after* large scale demonstrations have been operated in the USA, Australia, and probably Norway, Denmark and even China.

The UK

The UK has an ambition to reduce emissions of CO_2 and other Greenhouse Gases. In the recent 2007 Energy White Paper[20] there is a clear commitment to at least a 60% reduction in carbon dioxide emissions by 2050, and a 26-32% reduction by 2020, against 1990 levels. In order to do this a wide range of technologies will need to be developed.

To incentivise emerging technologies, such as offshore wind power the white paper sets out the introduction of banding to the Renewables Obligation. This would allow the scheme to support a wider range of technologies than it does at present where onshore wind is the primary beneficiary. Financially, taken together the Renewables Obligation and Climate Change Levy will provide £1 Billion annually by 2010 and £2 Billion annually by 2020. This price support for renewables of about £35 per MWh (currently £45 in 2008) typically adds at least 50% to the wholesale electricity price. The extra cost of electricity is passed on to the consumer in form of higher retail prices spread across all the electricity purchased by consumers. However the value of this has been questioned and in 2007 Ofgem stated that the Renewables Obligation should be replaced as it does not link with the EU-ETS and is expensive[21]. According to the regulator

20 DTI, "Meeting the energy challenge", A white paper on energy, CM7124, May 2007, see www.berr.gov.uk/energy/whitepaper/page39534.htm

21 Ofgem, Response to Consultation on Renewables Obligation, Jan 2007, see http://www.ofgem.gov.uk/Sustainability/Environmnt/Policy/Documents1/16669-ROrespJan.pdf

Table 1 CCS Propositions – whole chain only (*=state funds)

Country (Project)	Capture Technology	Store	Start Date	Size
USA (Mountaineer, AEP)	Post-combustion	Aquifer	2008	0.1Mt/y
USA (Shadyside)	Post-combustion	Aquifer	2008	0.3Mt/yr
France (Lacq)	Oxyfuel	EOR	2008	0.08 Mt/yr
Germany (Schwarze Pumpe)	Oxyfuel	Aquifer	2008	0.25/2Mt
China* (Green-Gen)	Pre-combustion	EOR	2009/15	1.5-2.7Mt/yr
Australia (Callide)	Oxyfuel	Aquifer	2010	0.05Mt/yr
USA (Oologah)	Post-combustion	EOR	2011	1.5 Mt/yr
Australia* (Zero-Gen)	Pre-combustion	Aquifer	2011/12	0.4Mt/yr
Norway* (Mongstad)	Post-combustion	Aquifer	2011/14	0.1-1.5Mt/yr
Abu Dhabi* (Masdar)	Pre-combustion	EOR	2012	1.8Mt/yr
USA (Sugar Land)	Post-combustion	EOR	2012	0.7-1Mt/yr
USA (North East, AEP)	Post-combustion	Aquifer	2012	1.5Mt/yr
Denmark (Vattenfall)	Post-combustion	Aquifer	2013	1.8Mt/yr
UK*(???)	Post-combustion	Aquifer or EOR	2014/19	2.0Mt/yr
Canada* (Boundary Dam)	Post-combustion	EOR	2015	0.4Mt/yr

"*there are cheaper and simpler ways of meeting these aims than the RO scheme which is forecast to cost business and domestic customers over £30 billion*". Ofgem proposed long term contracts with generators as a cheaper and simpler method.

The Government has also declared its desire to incentivise and expand nuclear power in its nuclear white paper and subsequent press statements. The price structure is, as yet, unclear although it is obvious that substantial help is needed to incentivise private developments where none have occurred in the UK for 20 years. This help may be in the form of either long-term electricity purchase contracts, low interest loans, or a reliable high carbon price to disadvantage electricity generation from unabated fossil fuel.

Both the Renewables Obligation and the potential support for nuclear power electricity are distortions of the UK electricity market, and make free competition impossible for new entrants such as CCS. The 2007 Energy White Paper did state that the EU-ETS will provide funding and incentives for companies to invest in cleaner large scale electricity generation but there was no attempt to specify how this will operate.

In fact, if the Government wishes to achieve its fossil fuel strategy it will need to act on all of the following:

- Efficiency and energy saving – from houses to big businesses;
- Support for electricity and heat generation by renewable energies, and their connection to users – by electricity wires or by heat pipes;
- Storage of fuel and power – to provide resilience against oil and gas supply variations, and to best utilise variable renewable;
- Higher efficiency fossil fuel conversion process to reduce the amount of fuel consumed and the associated CO_2 emissions. This can contribute to emission reductions of 10-30%;
- Fuel switching to lower carbon alternatives – such as natural gas and co-firing with 5-10% CO_2 neutral biomass;
- Carbon Capture and Storage with the potential to reduce emissions by 85-90%.

Achievements So Far

Looking at CCS the UK has led many international and national innovations and can be justifiably proud of its achievements:

- International treaties regulate disposal of waste in the sea and beneath the seabed. The UK has played a major part in negotiating permission for CO_2 storage beneath the seabed in the London Convention Protocol for worldwide effect, and in the OSPAR treaty for NW Europe;
- International technical leadership and communication has been enabled by an active role in the Carbon Sequestration Leadership Forum;
- European legislation on CCS has been shaped by UK influences and advice;
- The UK is the first nation to commit to legally binding values of greenhouse gas reduction in the Climate Bill of 2008;
- The UK has framed the world's first comprehensive offshore CCS legislation and regulation in the 2008 Energy White Paper;
- The UK has advised and assisted with the creation of carbon reduction targets and carbon markets worldwide – notably in California;
- The UK has successfully engaged with China to commence on the NZEC project which may build a CCS plant in China by 2014;
- The UK has been amongst the first nations to develop methods for evaluation of its CO_2 storage resources.

Yet more needs to be done. Carbon capture and storage in the UK has not reached the stage of a real development of a real project and is quickly being eclipsed by efforts in other countries.

To move forward on CCS the Government announced a Competition in 2007 to build CCS fitted onto a coal-fired power plant in the UK. Examined in more detail in subsequent chapters, we estimate here that it will cost £1.5 billion to build and operate.[22] Even if this single plant does get built, it is hard to see how this will create a CCS industry in the UK, either by encouraging other coal and gas plants to be built, or encouraging the development of multiple industries supplying design, skills and components to the UK and internationally. Multiple CCS projects are needed to create a new supply industry, to provide a flow of work and a diversity of experience.

What is needed has been clear for some time. Commercial developers of CCS projects have persistently stated that price support is needed to enable the introduction of CCS. The predicted price of allowances within the EU-ETS is only €35 from 2013, and this will not cover the initial additional costs of CCS. Developers have requested **price support** either less than, or similar to, the Renewable Obligation. Without such price support, the Development and Deployment of CCS in the UK is not commercially viable, and cannot exist in the UK electricity market system.

22 This is based on a calculation by the report authors, based on typical 2008 prices

4

Moving Forward: Developing CCS in the UK

In light of current events the UK has two priorities for developing CCS. It must provide a framework to support the development of not just a single project, but a new industry in CCS. In addition, with power companies already proposing to build more fossil fuel power stations such as Kingsnorth, it must also ensure that, if built, these stations are ready for CCS when it is adequately developed.

Recent History

The prospect of CCS as a large scale opportunity to mitigate GHG emissions of CO_2 first came to wide public prominence in the UK at the 2005 G8 international leaders' summit, chaired by the UK. The summit provided a large political impetus for CCS in the UK. However the concept was not new. CCS was first suggested in the UK in 1994 by the IEA Greenhouse Gas unit[23] based in Cheltenham. The British Geological Survey has been leading European work on CCS since 1996[24]. Since 2002 the Department of Trade and Industry (formerly DTI now BERR) has been undertaking a consistent small-scale programme of work within the cleaner fossil fuels programme[25], including an assessment of the feasibility of CCS in the UK in 2003[26]. This stated that:

"Large-scale deployment of CCS may be needed for electricity generation and hydrogen production from about 2020, but earlier deployment could occur to tie in with the pattern of electricity plant replacement. In addition CCS in combination with Enhanced Oil Recovery (EOR) could be implemented from around 2010."

However, it was not until June 2005 that CCS became formalized within the DTI Carbon Abatement Technologies (CAT) strategy[27]. Here the vision was to undertake gradual improvements in technologies which act as components in coal-fired power plants, leading to a commercial-scale project with CCS by 2010-2012, and economically viable deployment sometime after 2020. From 2005-08, a sum of £20 million was allocated, which was subsequently increased to £30 million in total.

The March 2005 Budget announced that the UK Government was examining the potential for new economic incentives to support the development of carbon capture and storage technologies and applications. Following the Gleneagles G8 summit in July 2005 the UK presidency announced,

"We will work to accelerate the development and commercialisation of Carbon Capture and Storage technology"

The BERR Competition for UK CCS power plant

Subsequent to the G8 and CAT strategy, the Government moved at a slow pace to develop a CCS option. The Government Energy Review of 2006 stated that a logical next step for CCS in the UK would be the construction of a full-scale Demonstration plant. The Pre-Budget Report in December 2006 announced that an independent firm of consulting engineers (PB Power) would examine CCS costs. The details of this report have not been made public but the March 2007 Budget confirmed that a CCS competition would be held. The 2007

23 IEA GHG IEA/GHG/SR3, The disposal of carbon dioxide from fossil fuel fired power stations, June 1994

24 BGS JOULE II Project No. CT92-0031, The underground disposal of carbon dioxide, British Geological Survey, 1996 Holloway, Energy Conversion and Management 38, S193-S198, 1997

25 DTI Capture and geological storage of carbon dioxide: a status report on the technology. URN No: 02/1384, 2002

26 DTI, A review of the feasibility of carbon dioxide capture and storage in the UK URN 03/1261, 2003

27 DTI, CAT strategy : a strategy for developing carbon abatement technologies for fossil fuel use URN 05/844, 2005

Estimated costs of one 400MW coal CCS capture

- Capture equipment at the power plant £600M;
- New build pipeline £200M;
- New subsea injection facility offshore £50M
  (Or offshore platform modification £100M);
- Offshore Operation and Monitoring costs £10M/r for 10 yr = £100M;
- Operation of capture at power plant £40/ton x 2.0Mton CO2 x10 yr,
  Less EU-ETS price @ £20/ton = £400M.

2014-2024 TOTAL: £1,450 M

Energy White paper[28] then announced that a UK competition would be launched in November 2007.

On 9th October 2007 the Secretary of State for Energy announced that the Competition would be restricted to one power plant, and would consider only post-combustion options. The reason given was that post-combustion and retrofit, will be most applicable to the existing UK fleet, and especially for its application to the worldwide coal fleet – including China.

Finally on 19th November 2007, the UK Prime Minister[29] formally announced the CCS competition, to be operational by 2014.

Submission of the first stage Pre-Qualification Questionnaires for the CCS competition closed in March 2008, with nine statements of interest. BERR will select from these, and then invite final bids, with the intention of closing the financial contract with the wining consortium in early autumn 2009. That CCS system has to demonstrate the full chain of capture, transport, and storage at 50MW scale by 2014 and at 400MW scale "as soon as possible" thereafter.

But what exactly does this mean for CCS? Three aspects are important in understanding the implications of the Competition for UK CCS: funding, the novelty of the project for BERR and the choice of technology. These are examined in more detail below.

Funding

The BERR competition[30] aims to focus on just one subset of CCS technologies: post-combustion CO_2 capture from coal fired power plant. The competition will provide funds for the additional costs (on top of normal generation) of capture and compression, transport, and storage. Although no figures have been published by BERR, these costs can be estimated as £1,450 million from 2014 to 2024 (see *Estimated costs of one 400MW coal CCS capture*)[31].

At present it appears that this will be paid for from public funds, i.e. from taxpayer income to Treasury. Alternative funding mechanisms, based on market systems, are examined below. These can pass costs onto electricity users, a fairer system which minimises risk and cost to Treasury, and can fund multiple projects. There is still time to switch to an alternative funding mechanism, or to run two systems – one as procurement, the second as a commercial market.

Timeline for delivery

The timeline to demonstrate the full CCS chain, from capture to transport to storage, is 2014. However, cautious wording by BERR permits only 50MW to be operational by end 2014, with the full capacity demonstrated, "*As soon as possible thereafter.*"

Although the intention may be to have a CCS system operating on a full power

28 DTI, Meeting the energy challenge, A white paper on Energy. May 2007 CM7124, see www.berr.gov.uk/energy/whitepaper/page39534.htm

29 No 10, CCS competition, 2007, see http://www.number10.gov.uk/output/Page13791.asp

30 BERR, UK CCS competition, 2007, see http://www.berr.gov.uk/files/file42478.pdf

31 See footnote 20.

Advantages of the CCS Procurement Competition:

- A good understanding is gained by government of the costs at each step;
- A functioning power plant will be obtained;
- The type of power plant is suitable for large numbers of sales worldwide;
- Accurate cost discovery enables setting of support levels in future.

Disadvantages of the CCS Procurement Competition:

- Reduced flexibility to react to events;
- The cost limits are not well defined at the outset;
- Funding comes from Treasury, not from users;
- One project does not create a diverse supply chain of UK businesses;
- Choosing one technology reduces UK expertise in IGCC or gas plant;
- Competition is delayed and does not drive down prices;
- Reduced ability to create a pipeline network, or subsequent plan.

plant, this wording leaves it open to the winning power company to add-on a large pilot plant to an existing power station, remove CO_2 from a site by boat, avoid building a pipeline, and only seriously address the full-size aspect when the EU requires it, for example after 2020. Consequently, there is a risk that the procurement rules are not sufficiently rigorous.

The procurement project also states:

> *"When the UK Project is operational, by 2014, it will be a world leader in this globally important technology. As well as being one of the first full-scale CCS demonstrations, it will be the first to demonstrate post-combustion capture of CO_2 at scale on a coal-fired power station in the world."*

This may have been true at the time it was written in early 2007, but is a hard claim to substantiate into the future. As can be seen in the previous chapter it is very apparent that combinations of state and private funding are set to develop full scale coal-fired CCS plant in Australia, USA, China and Canada – with full scale gas-fired plant also being planned and funded in Norway and Abu Dhabi[32]. It is clear that multiple demonstrations of CCS components will occur from 2008 onwards, especially using new solvent capture methods, and using injection into a diversity of geological deep storage sites. Several claims are being made that commercial sized plant will start operation in 2012 to 2015, including both new-build for gas and retrofits on gas and coal.

Does that matter? The UK project will provide a reliable and well-documented procurement, and is likely to be amongst the first in the world. In that sense, it will achieve its objectives. However the UK is recognizing that there are substantial new business opportunities being created in CCS, renewable energies, and carbon trading.

To take advantage of those opportunities requires development of practical expertise in real projects. In a competitive world market, being number three or number eight to arrive in the marketplace, even with an excellent single product is a high-risk gamble. This is what the outcome of the BERR Procurement will provide. It is better perhaps to arrive as number two in the marketplace, with a diversity of rapidly evolving and flexible products. This outcome could be the result of creating opportunity now for businesses to design, fund, build and operate multiple

32 SCCS, Worldwide listing of CCS commercial storage projects: actual and proposed. 2008, see http://www.geos.ed.ac.uk /sccs/storage/storageSites.html

Benefits of Post-combustion

- Can be fully or partially retrofitted to existing plants (with a suitable design) and is a very powerful means of substantially reducing their greenhouse gas intensity.
- Can also be integrated into new plants, or as "capture ready" plant.
- Can be very flexible during operation (zero to full capture operation) in response to varying demand from National Grid electricity.
- If necessary, CCS can be turned off to deliver full electric power to the Grid.
- Has the ability for staged implementation, which is not possible with competing technologies.
- Can be fitted to capture CO2 from gas fired power plant, or other large stationary sources of CO_2, such as steel, paper, fertiliser or cement.
- Can easily be upgraded with improved components such as solvents or compressors as these become available.

CCS plants in the UK. What is needed is a funding mechanism which is 'blind' to the type of CCS, and can support several CCS projects in a competitive market setting.

A unique Government project

This CCS procurement project is unique in the history of BERR. Never before has a project this size been handled in this way. The technology is viewed by BERR as "undeveloped", giving less certainty about the results and prices. The companies involved, dominated by the power industry, are not experienced in dealing with Government on this scale.

Choice of technology: Post-combustion

As part of the CCS Competition, BERR has chosen to focus on post-combustion capture, or oxy-fuel retrofit, to existing or new-build coal fuelled power plant. BERR's reasons for this are that Post-combustion capture is considered to have greater UK-wide applicability, and a greater applicability for retrofit to coal fuelled power plants in China and India. However it does have the consequence that the UK is making an early choice of one CCS technology, which may prove to be only part of the technology spectrum. The UK usually professes to be against technology choices – but has made choices frequently in the past – for example by investing in onshore wind power devices, or investment in particular nuclear power rectors.

Post–combustion capture on a coal plant does have particular advantages (*Benefits of Post-combustion*). One of these is the speed at which the equipment can be developed and improved. A major cost of CCS, and penalty of additional energy used for CO_2 separation, is the capture and compression steps. Because post-combustion is not essentially integrated into the combustion process, the capture and compression equipment, and different solvents or membranes and materials use for capture, can be individually replaced and improved during the evolution of the power plant over years or decades. Consequently, the benefits of experimentation, and benefits of learning from other power plants in the world, can be used without the time delay and huge expense of rebuilding an entire power plant.

CCS Project Failures in the UK

BP (British Petroleum) investigated CCS as early as 2003 in the UK. That project was to supply 2Mt CO_2/yr from the Grangemouth oil refinery, to enhance oil recovery from the Forties oilfield.

That project did not proceed, because of the low price of oil at that time, the expense of offshore engineering, and ironically because a long-term supply of CO_2 could not be guaranteed. Forties oilfield was sold to Apache, and oil is now produced using sea water injection.

In 2005, BP announced a second CCS proposition for the UK. This was timed to coincide with the opening of the G8 at Gleneagles, chaired by the UK. This was a bold proposition for the world's first integrated CCS power plant, in partnership with Scottish and Southern Energy, which would have started operation in 2009. This would have taken an existing feed of natural gas into the Peterhead power station, derived from the northern North Sea. The gas would have been chemically split to form hydrogen – which would have then been burned to generate electricity, and the CO_2 transported offshore, via an existing CO_2-resistant pipeline, to produce additional oil from the Miller oilfield.

This project had several unique advantages to the UK:

- a A cheap entry point to North Sea storage would be gained with re-use of an existing pipeline saving £200 million of costs;
- b A secure storage site – proven to have stored both oil, gas and CO_2 for many million years;
- c A tax take to the Treasury of 40 million barrels of extra oil production (i.e. £1,000 million if oil is £50/barrel and taxed at 50%);
- d Timely establishment of a pipeline pathway to Enhanced Oil Recovery using CO_2 in the North Sea, by a financially secure trans-national oil company, with a potential of 1,500 million barrels on the UK sector and a further 1,500 million barrels in the Norwegian sector;
- e A worldwide lead in CCS deployment of 3 to 6 years.

Following the G8 statement on "accelerating and commercializing CCS" augmented by positive statements in the March 2005 Budget and 2006 Energy Review, a flurry of commercial interest was created in the UK to develop CCS projects.

In early May 2007 there were nine commercial propositions for CCS in the UK.

This was by far the greatest number, and greatest diversity, of commercially proposed CCS plant in the world.

Were all these to have been built, 20% of UK baseload electricity could have been decarbonised by 2015. However this number was reduced as BERR refined the specification for the procurement Competition. In March 2008, a different nine proposals have been submitted to BERR for the CCS Competition, of which just one may be developed on part of a power station, sometime after 2014. Is this the rejection of another gift-wrapped opportunity for CCS?

Why did Peterhead fail?

From their initial announcement in mid-2005, BP made it clear that that:

1. This offer was limited in time, because the Miller field would start to be decommissioned in 2007;
2. This offer would require price support by the Government, because of its 'first of a kind' nature, and the lack of explicit support from the EU-ETS.

The request from BP was for a "decarbonised Renewable Obligation Certificate (ROC)" of £30 per MWh, to take the wholesale electricity price to £60 per MWh. This compared favourably with the ROCs given for onshore wind power, resulting in an income to the plant operator of £70 per MWh. If the decarbonised electricity was 400MW, at 8,000 hr/yr plant operation, then that would require £96 million per year of subsidy – and half of that when CCS becomes included within EU-ETS from 2013. BP provided the UK Government with a ready-made CCS package. However nothing happened. The Government let the opportunity slide away, and with that, gave up leadership in CCS projects, and the chance for a low-cost link to storage of CO_2 in oilfields.

On 23 May 2007, timed to coincide with the publication of the Energy White paper, BP very publicly withdrew its offer of Peterhead-Miller from the UK. An identical plant developed by BP is now scheduled to be commercially operating in Abu Dhabi by 2012.

The electricity subsidy would have cost consumers (not the Treasury) £1,150 million over the project life. Set against this would be the tax income of about £1,000 million, and creation of many hundreds of jobs. This compares very favourably with the projected £1,450 million of tax income that the Treasury will provide to BERR for the current CCS Competition. A simple conclusion is that the UK is now about to embark on a difficult CCS venture, when a less expensive pre-packaged solution was not taken up.

The inertia by Government during the Peterhead-Miller debacle is explained away with reasons such as a lack of certainty on costs, a need to discover operating costs, and lack of sufficient enabling legislation. An alternative explanation is that this was in reality an immense failure of foresight, which led to the Government being caught unawares by a large commercial proposition. Faced with insufficient established information and uncertainty on precise costs, the Government experienced a lack of will to take rapid and bold decisions to control the situation on a commercial timescale. Instead of learning that the commercial world can move rapidly and flexibly, the Government still seems intent on controlling the details of CCS development by means of the CCS procurement competition. An alternative method is to loosen direct control, and set up a market system to enable commercial creativity.

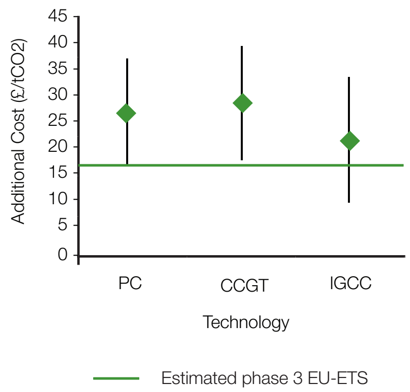
An Additional UK Route to CCS Deployment

It is proposed here, that a second route be developed to encourage building of CCS power plant in the UK. This could be more rapid and simpler than the current competition, be commercially based, create multiple projects, and leave most of the risk with the developer. The concept is simple: five projects were disallowed by the BERR stipulation of the power plant technology; nine projects have been proposed in March 2008, only one can win the Competition. Will any of the 13 disallowed or losing projects wish to take a different route? If just 3 or 4 do, the UK will be extremely well-positioned for rapid CO_2 reduction, and future CCS business.

The crucial barriers are funding, licensing, and regulation. UK efforts have ensured that the second and third are on the way to being solved. Can the UK create a method of solving the financing?

As CCS would provide generators with a means of reducing their CO_2 emissions, payments from the European Union Greenhouse Gas Emission Trading Scheme (EU-ETS) could be used to pay for electricity produced by CCS-fitted plant. Restating the additional costs of CCS in terms of £/CO_2 saved gives an estimate of **around £27/tCO_2.**

Figure 7: Additional cost of abatement depending on the estimated EU-ETS level



However as seen in Figure 7 the level of subsidy provided by the EU-ETS from 2013 onwards (Phase 3) is only estimated to be around €35/tCO_2.

In addition the significant variability in the prices in earlier Phases means that there is quite a lot of uncertainty over this estimate. This uncertainty would probably be sufficient to deter investment in CCS even if the estimated value covered the estimated additional cost of CCS.

In fact this is an inevitable result of the way the EU-ETS works – it sends a price signal from the market based on the mix of technologies currently available to provide emissions reductions.

In the power sector the most important of these opportunities to reduce emissions is the switch from coal to gas (both without CCS). There are also energy saving technologies for industry that help keep the ETS price relatively low. So left on its own the ETS is a way of paying for deployment of existing technologies not development of new technologies.

Given this reality, CCS will need a subsidy in much the same way as on-shore wind power has required a guaranteed subsidy to move from the demonstration to what the Government terms a reference Phase.

How much?

The current government-funded CCS competition will reduce the uncertainty over costs (mainly for PC plants) once one is built in 2014. That is to say that the error bar around the central point for PC in Figure 7 will get smaller but there is still likely to be a gap between this central point and the EU-ETS level. Hence if the UK wants to develop CCS there will be a funding gap that has to be filled until the costs of CCS fall to enable it to survive on the EU-ETS (or whatever sets the carbon price for generation in future).

Our best estimate for the required initial level of subsidy (based on the central points in Figure 2) is £22-£29/tCO_2. To cover the full range of potential costs the subsidy would be £11-£40/tCO_2.

The way this subsidy is delivered (as well as its level) matters for getting CCS built. There are a number of reasons for this:

- The very large private sector capital investment will require a commitment on the time the subsidy will be available and the conditions for revising it as CCS costs fall. Lowering uncertainty reduces the cost of financing and makes it more likely that CCS will be built;
- The private sector is best placed to bear risks related to construction costs (where it has more information, experience and control than government). The subsidy should therefore be paid on delivery of CO_2 stored;
- Information generated on the costs of CCS as early plants are built should be shared to reduce the uncertainty for new investment. Information sharing could be made a condition for receiving funding.

However the single key requirement for these projects to move from the desktop to the concrete foundations is a suitably high, and especially a reliable, income stream.

There are already a wide range of subsidy mechanisms for renewable energy within the EU.[33] It makes sense to adapt one of these for CCS as using an existing instrument reduces uncertainty.

Policy mechanisms to enable wider CCS Deployment and Diffusion

A suite of established policy options are available which could be applied to CCS. These need to address the following funding questions:

- Is the base price secure enough for commercial CCS development in the UK?

33 See for example, Oxera, Renewables support in selected countries: report prepared for the National Audit Office, 2005,

- How can funds be raised and distributed simply?
- Can this fit well with existing UK and/or EU mechanisms?
- Will this method for CCS damage investment in renewables?
- Can a competitive UK market develop from this start-up system, to reduce cost, and add to UK export potential?
- Is the risk low enough to Government and to consumers?
- Does this help achieve the Government environmental objectives?

Although the present UK electricity supply system is supposed to be a 'free market', it is currently distorted by the existing ROC funds and by the Government's preference for nuclear[34] as base-load plant in the medium term. These distortions tend to favour the choice of those technologies over clean fossil with CCS. The challenge to provide electricity sustainably is on three timescales:

- Near term (to 2020) – providing enough electricity during plant closures, whilst demonstrating a variety of renewables and CCS;
- Medium term (2020 to 2050) – making renewables and CCS routinely profitable and reliable;
- Long term (2050 onwards) - decreasing reliance on fossil fuels and providing abundant reliable and cheap renewable energy.

Mechanisms for the UK of providing secure financial support during the transition to routinely commercial CCS can be considered in related themes:

Working within EU-ETS

1. Free award of EU-ETS permits based on historic emissions within EU-ETS, which could be sold profitably by CCS plant operators in the high carbon price market.

This is flawed, as the price of EU Allowances (EU-A) from 2013 is predicted to be only around €35, rather than the €60-80 required. There is no guarantee that the plant will run, and operators could maintain dirty plant to gain EU-A's. The EU-A becomes an opportunity to make profit, rather than an imperative to reduce cost.

2. Advance sale of future EU-ETS permits at low present prices, to enable future sale by company at higher price.

This can create a market in EU-ETS futures. The advantage is that emitters can buy in advance at a cheap cost, install CCS so that the emission allowance is not needed and then, at a later date, sell the EU-Allowance into the carbon market of the day at a higher price.

Advantages of this method are its market basis, uniformity across the EU, and ability to extend to larger markets as they emerge worldwide.

Disadvantages are the lack of certainty over future EU-A prices, which would still need to double, to achieve the required income. Prices in the power sector EU-A would need to be separate from, and substantially higher than, the industry sector.

3 Auctioning of EU-ETS permits to the power sector.

Free allocation of permits is not working. Phase 2 of the EU-ETS is producing perverse profits of €6-15 billion in the UK over 5 years, which stay as windfalls with the power companies[35].

Auctioning has been proposed (January 2008) by the European Commission, and requires uniform EU action, because the market spreads across the entire EU. This has dual benefits, as the carbon will become a cost to power producers (rather than the profit opportunity in EU-ETS Phase 1), and a large new income will be received by the Member State.

For the UK, at a carbon price of €30/ton and power sector emissions of 160Mt/yr CO_2, the new income will be

34 Secretary of State John Hutton, "New Nuclear Build: How do we make progress?", 26 March 2008, see http://www.berr.gov.uk/pressroom/Speeches/page45417.html

35 WWF, EU ETS Phase 2- the potential and scale of windfall profits in the power sector, Point Carbon Report for WWF, 2008 (March), see http://assets.panda.org/downloads/point_carbon_wwf_windfall_profits_mar08_final_report_1.pdf

€4,800 million per year. However, according to the EU, this system may increase electricity prices to consumers by €100 per year. This crucially relies on the Member State to capture the benefits by voluntary spending to support CCS or renewable energy projects. The UK has indicated that it will not be bound by a stipulation to allocate funds to any topic[36].

In principle, this new income could easily provide the entire funding for one 400MW CCS project each year in the UK. In summary, this is an excellent "stick" to encourage power industry take up of CCS, but the "carrot" is unreliably controlled by Member States, who have priorities which are not CCS.

4. Multiple allocation of free EU Allowances to CCS plant (MEUA).

This appears paradoxical, as the polluter is rewarded not charged. But if the multiple allocations are paid after CO_2 is stored, this becomes a reward for cleanup.

This is a simple and powerful method. Free permits would be allocated to coal and gas plant fitted with CCS, but would only match the amount of CO_2 captured and stored. These permits would not be needed, and could then be sold at the EU market rate into the power sector.

About 9% of the total power sector permits would enable 12.8GW of power plant, storing 60Mt/yr CO_2[37] by 2020. To cover the initial costs of CCS it is probable that double, or even treble, allocations would be needed. Power plant with no CCS would still need to buy EU-A on the capped market. Free permits incentivise CCS plants to be both built and to operate. Benefits are that this is conceptually simple, with low monitoring and transaction costs, and that permits are directly controlled by Brussels not the Member State.

The costs of the current EU-ETS are already priced into UK electricity[38] so to fund demonstration projects consumers will experience minimal price change. Full CCS deployment will increase electricity prices but by less than the costs of buying expensive EU-ETS allowances in future. If the Clean Development mechanism is extended to include CCS, it could pay for CCS projects in China to be operated from the UK and paid for by Multiple EU-Allowances.

Disadvantages are that this could be perceived as giving permits to polluters rather than charging them; and the price of EU-ETS is not guaranteed. Therefore companies would need to share some risk if the short term price dropped, and a ceiling price may be necessary to prevent unintended profits if the EU-ETS price increases. This system is just for start-up of CCS, and has to be transitional into a medium-term timescale post-2020, because all power plant will eventually be included if the system is successful. A taper to zero free allowances is required, in synchronisation with a rising EU-ETS base price. Consequently, to terminate this method of funding requires a link to high EU-ETS prices outwith the power sector, which may not be desirable.

Working within UK systems

5. Government underwrites the EU-ETS minimum base price.

This involves a risk for Government, to provide baseline funds of €30 to 60/ton CO_2 if the EU-ETS market remains low. It is not clear how the Government recoups its money, except by waiting to sell EU-A at a high price some years later, or by cross-subsidy from the new Phase 3 Auction revenue.

6. Regulation to enforce CCS on all new-built plant from 2008, operational by 2020.

Such a policy would reduce the 'lock-in' of CO_2 production from newly-constructed plant during its 30 + year lifetime. There is however no current requirement to fit CCS, as demonstrated by the application from E.ON to build a new coal-fired plant at Kingsnorth. The developer has offered

36 DEFRA, Consultation on EU-ETS Phase 3, 2008, see http://www.defra.gov.uk/corporate/consult/euets-2013amendments/consultdoc.pdf

37 Climate Change Capital, ZEP: Analysis of funding options for CCS demonstration plants, 2007, see www.climatechangecapital.com

38 Ofgem, Response to Consultation on Renewables Obligation, Jan 2007, see http://www.ofgem.gov.uk/Sustainability/Environmnt/Policy/Documents1/16669-ROrespJan.pdf

"capture ready" for this plant, but it remains unclear how a transition would be enabled from capture ready to the costs of building a full capture plant, and then the increased running costs of operating that plant. This could create a moratorium on new coal plant in the UK, but provide no remedy elsewhere in the world. In isolation, without extra funding, this will not promote CCS projects.

7. Create a new band of Decarbonised Renewable Obligation Certificate (DROC).
Such a method, focused on decarbonised fossil fuel – either coal or gas, could run in parallel with the present Banded ROC, at a level to be decided.

The recent innovation of Banding is a response to the great success of onshore wind (supported by 1.0 ROC), but a paucity of development for offshore wind (ROC 1.5), or wave and tide (ROC 2.0). There is a similar need to financially incentivise CCS. Industry predicts that CCS at maturity would need less than 1.0 ROC.

The advantage of DROC is that it works within the existing UK system. However, extra costs to the consumer may arise in addition to the EU-ETS costs already priced in to fossil-fuelled electricity and it is not clear if primary national or regional legislation is needed, or whether this can be adapted from the present Energy Bill.

Disadvantages are that: it is unclear exactly what level is appropriate for Demonstration plant; perverse profits can be made from sale of DROC derived from non-operating plant; the system is complex and according to Ofgem[39] not the route to cheapest electricity.

Once decided, the DROC agreed into the future for Demonstration projects has to be maintained, not reduced. In the medium term (post 2020), the correct DROC price will be known, and will also be less if the EU-ETS price continues to rise. This requires continued government intervention.

8) Creating a Decarbonised Obligation to Supply Electricity (DOSE).
A national DOSE could be set, for example as a percentage of fossil-fuel electricity from each generator. Those without CCS plant would need to purchase off rivals, resulting in an incentive to build and operate plant. Decarbonised fossil electricity could be imported from Germany, Norway or Holland if their plant was operating first. The increased DOSE price would be combined into the tariff to consumers from each generator, so that all would move forward at a similar rate.

Advantages are periodic opportunities for government control: the DOSE within the UK could grow at a defined rate, with forward visibility for 10 to 15 years. This creates some incentive to develop CCS capability within each generators portfolio.

Disadvantages are that a too-ambitious defined growth curve may reduce the opportunity to transfer power generation from fossil to renewables and to nuclear (if that is what is desired), and would amount to a technology choice for clean fossil. This requires continued government intervention.

9. Tax exemption to provide enhanced capital allowances on construction of facilities.
This doesn't really help the long term running and operation costs and is an insufficient single incentive.

10. Tax allowances at 100% for losses on a new project.
This doesn't really help the long term running and operation costs and is an insufficient single incentive.

Working within other systems
11. Create a decarbonised electricity feed-in tariff (DEFIT).
This type of approach originated in the USA, where it is sometimes known as a Power Purchase Agreement. This is a long-

39 Ofgem, Response to Consultation on Renewables Obligation, Jan 2007, see http://www.ofgem.gov.uk/Sustainability/Environmnt/Policy/Documents1/16669-ROrespJan.pdf

term contract to buy power from a company that produces electricity. The providing company assumes the risks and responsibilities of ownership when it purchases, operates, and maintains the generation facility.

A key benefit is that the known price enables the electricity company to borrow money to construct the facility. This approach has recently been very successful in producing large availability of renewable electricity from small-scale sources, notably in Germany and also in Denmark and Spain. However it has not been favoured in the UK, because it is not based on a market price.

Such a method would oblige Ofgem to purchase this electricity from producers for a price higher than the minimum, and then sell to suppliers on the UK grid where the extra cost is spread over all consumers. Contracts can be signed for 5, 10, or 20 years into the future. The setting of the price is by negotiation with the Government (or other controlling organisation).

Other advantages of this method, are the enabling of a diversity of CCS supply types, and the ability to price independently of, and outlast, the EU-ETS.

A disadvantage is that it does not explicitly drive down prices, and the true price of CCS to set for the opening years is not yet known from operational experience. However this can be mitigated if the DEFIT decreases into the future.

A method to set the percentage of decarbonised supply may be needed, to enable competition with conventional 'dirty' coal and gas, to avoid crowding-out renewable generation, and to reach an appropriate balance with nuclear generation. As a further finesse, it could be considered that the setting of price is least well done by Government, who are typically interested in short-term trends, and long term pricing may best be achieved by an independent body, analogous to the way interest rates are set by the Bank of England and not the Government.

Which one?

As seen above many options exist but *4) Multiple allocation of free EU Allowances to CCS plant (MEUA)*, *7) Create a new band of Decarbonised Renewable Obligation Certificate (DROC)*, or *11) Create a decarbonised electricity feed-in tariff (DEFIT)*, would be the most effective.

Of these, the only one to work within the EU-ETS market is the allocation of multiple allowances. This can also enable building of CCS plant in China, if the Clean Development Mechanism is adapted to include CCS.

The advantages of these three systems are firstly that costs lie with the consumer, not with the taxpayer via government. Secondly, several projects can be developed, with several different carbon capture technologies, and several different storage sites. Thirdly, this programme will enable a CCS supply industry to develop in the UK, which can reduce costs by learning on several domestic projects, and can then design and develop projects worldwide.

On their own the implementation of any of these would be sufficient to support the development of a CCS industry in UK. Which one to choose is thus up for politicians to decide.

Having supported the creation of an industry we now turn to making sure we are ready for it when it comes.

Making Ready

Capture Ready (CR) is a concept which tries to address the probability that new coal and gas plant will be built in the UK, in the EU, and worldwide before a fully functioning CCS market exists.

The fundamental concept of CR is that new plant will be built in a way which permits (and certainly does not preclude) the fitting of CO_2 capture equipment at some time in the future. What this actually formally entails in the UK remains obscure.

In the intervening time, many UK and EU power plants will close because they reach the end of their working lifespan, or because of NOx and SOx emissions regulations affecting coal plant. It is estimated by RWE npower (and many other power industry organizations) that the UK will need 20-40 GW of new power plant by 2020. This renewal of power plant provides an opportunity to construct renewables, nuclear, or new efficient coal and gas fuelled electricity generation. Simultaneously this also raises a problem of what to do before CCS is ready and fully-proven. Does the plant get built, to add to CO_2 emissions? Or does the plant get banned, until CCS is ready – risking the security of electricity supply?

A detailed analysis of CR[40] suggests that the CR concept is simple on a site, but much more complex if it is to be a means to operating CCS. In this larger view, then CR is really better considered as CCS-ready, as that is the ultimate purpose. If this is adopted, then CCS-ready includes an assessment not just of fitting carbon capture equipment to a power plant, but also evaluation of the method and route of CO_2 transport, and evaluation of the storage site, development of skills and capability to operate CCS in the power company, the chain of business connections to achieve the capture transport and storage, and the imposed regulatory and financial systems to enable the enterprise to be profitable. Lastly, there needs to be a set of conditions, based on technical progress with CCS worldwide, to trigger mandatory conversion to CCS operation.

The UK has already consented to four new gas-fired plants being constructed as being Capture Ready, without any definition of what this means. In 2008, the application by E.ON for a new coal-fuelled power plant at Kingsnorth was temporarily withdrawn after Greenpeace and media interest in its Capture Ready proposals exposed the lack of definition within the BERR rules on capture ready.

Capture Ready can become an opportunity to mandate and enforce CCS at an early date in the UK, or it can become a battleground for confrontation between green activists, Government, and power companies. CR can be an excuse for companies to build new fossil fuel power plant, without a clear means for conversion to CCS, or it can be a strong signal from Government that CCS is required and inevitable.

Putting into practice

Capture Ready may be simple in concept, but it is hard to specify, and requires detailed regulation and intervention by Government. A simpler route may be to control Greenhouse Gas emissions from a power plant.

This method, of performance standards, is used elsewhere in UK Government. In principle, it is similar to the standards pro-

Table 2 Emissions data for new plant (Rubin 2007)

Kg CO_2/MWh	Coal		Gas
	PC	IGCC	NGCC
w/o capture	736-811	682-846	344-379
with capture	92-145	65-152	40-66
Reduction, %	81-88 %	81-91 %	83-88 %

40 WWF, How ready is capture ready? Scottish Carbon Capture Centre report for WWF. 2008 (May), see http://www.geos.ed.ac.uk/sccs/publications.html

posed for the emission of a mass of CO_2 per km of car driving. Transferred to a power plant, that would be emissions (kg CO_2) for each unit of electricity produced (MW hr). The emissions for different types of power plant are well known now, and can be predicted with CCS (Table 2).

Using emissions standards to covert the UK fleet of fossil fuel power plant to CCS requires at least three steps. One possible method is simplistically outlined here. Numerous complexities are possible, not least the choice of different emissions standards for different types of plant, with different fuels, with and without Combined Heat and Power.

First, Government rules that all new fossil fuel power plants built after 1 January 2009, must have average annual emissions from the whole plant of 350 kg CO_2/MWh.

> " If Government takes heed and acts now we can ensure that CCS does not become just another missed UK opportunity "

This would eliminate new-build coal with no CCS, and still enables gas, to avoid power shortages. Developing new coal plant with CCS is still feasible within this emissions limit. Existing plants continue unaffected. Power companies can experiment with post-combustion capture, if desired, by fitting experimental capture equipment to cleanup part of the flue gas stream. RWE has stated that their experiment from 2008 of 1MW (8,000 t/yr) capture facility on Aberthaw will cost £8.5M, and RWE plan a further 25MW (200,000 t/yr) pilot unit at one of their own plants. These costs may be reduced, if power companies create shared facilities – as in the EU-funded project at Esbjerg Power Station operated by Elsam in Denmark (CASTOR 2008), where 30 organisations share the results, for a total price of £12.5M for 8,000t CO_2/yr over four years.

Second, the emissions standard then must step down to become even more stringent for new plant.

This is for two reasons, firstly to bring gas into the CCS requirement; secondly to bring coal fully fitted with CCS into the requirement. This standard could be introduced from 2015, and be 170 kg CO_2/MWh for the whole plant, which permits IGCC with CCS, and Pulverised Coal with CCS operating most of the time, but allowing venting of CO_2 during ramp-up and ramp-down of electricity generation to follow electricity sales to the grid. A separate standard of 70 kg CO_2/MWh could be considered for gas plant, to gain maximum decarbonisation benefit.

These plants will not be commercially viable unless financial support is provided to exceed the expected EU-ETS price of €30 per ton, and give a guaranteed floor price of at least €40-80 per ton for the interim period until the EU-ETS price reaches a similar level. Any CCS plants commissioned before 2015 will also need this floor price guarantee. A hgher price for CO_2 is not expected until after 2020 or 2025, but could be sooner if tighter emissions caps are enforced across the EU from 2020. That is not in the UK's control.

Third, the older existing plant is brought into the system, by CCS retrofitting.

This can share the same standard of 170kg CO_2/MWh for coal, and potentially 70 kg CO_2/MWh on gas, for the same reasons as discussed above. The date for enforcement is logically from 2020, if the EU-ETS base price can be guaranteed from 2020 by the capped market. This gives the opportunity for 5 years operational experience after the first demonstration plants start in 2015. Substantially longer experience may be gained if companies invest in their own, or shared, pilot facilities. Commercial capture by retrofitting is expected to be demonstrated from 2012 in the USA, Norway and Australia. The pace of transition to CCS is important. A fast pace is required if climate change imperatives are dominant. This can benefit the early deployment of CCS in the UK, and hence assist creation of a diverse UK supply chain for CCS. A slow pace is allowed if conservative industry interests and 'security of supply' arguments are dominant.

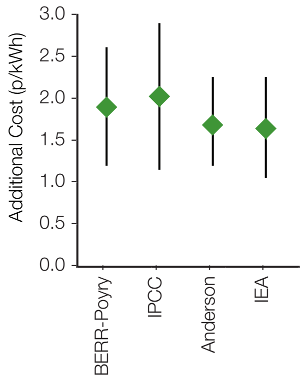
Into The Future

If Government takes heed and acts now we can ensure that CCS does not become just another missed UK opportunity. A wide range of options exist to make sure we develop our industry and if done properly we can ensure we are ready to take advantage of it when it comes.

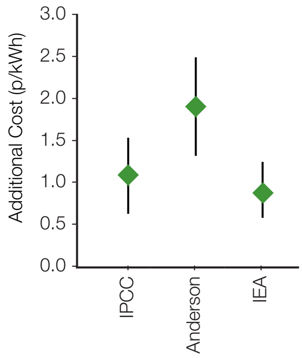
The UK was first to industrialise. The UK can be first to decarbonise.

Appendix: Study Estimates and Key Assumptions

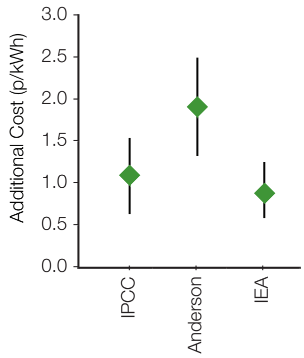
Study estimates for additional cost of PC technologies



Study estimates for additional cost of CCGT technologies



Study estimates for additional cost of IGCC technologies



Key assumptions in the studies used:

	BERR_Poyry	IPCC	Anderson for Stern review	IEA
When in operation	2015	Now	Within 10 years 2006 prices	2010
Counterfactual	Existing coal station	Existing station of same type	Unknown	Existing station of of same type
CCS technology	Upgrade to super critical and retrofit MEA	New build	Unknown	New build
Coal price	£3.78/MWh	£2.73/MWh	unknown	£2.75/MWh
Gas price	£11.95/MWh	£7.85/MWh	£14.4/MWh	£5.50/MWh

Notes: The average cost range for IPCC and Anderson is applied to BERR and IEA estimates

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