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CLEANER COAL

Climate change is high on the political agenda, gas and oil prices are increasingly volatile and concerns about nuclear power generation continue. Could 'cleaner coal' offer the perfect energy solution? Cleaner coal technologies (particularly those that reduce carbon dioxide (CO_2) emissions) are at various stages of development. Advocates believe they hold the key to a secure and low carbon electricity mix. Critics are concerned that core technologies have not been fully demonstrated and that the barriers to implementation have been underestimated. This POSTnote examines the most prominent technologies and the issues surrounding their use.

Background

Cleaner coal technologies (CCTs) are those that facilitate the use of coal in an environmentally satisfactory and economically viable way. Historically, CCTs have focused on reducing levels of acid gases and particulates from flue (waste) gas emissions. Now, in response to concerns about climate change, attention is turning to CO_2 emissions. Therefore, this POSTnote examines CCTs that reduce CO_2 emissions from coal use. It builds on POSTnote 238, which focused on the storage aspects of carbon capture and storage (CCS), and precedes a House of Commons Science and Technology Select Committee report on Carbon Capture and Storage Technology. The focus is on the power-generation sector, although it is noted other sectors such as cement production and steel works also use coal.

In pursuit of the Government's various 2003 Energy White Paper goals[1] – including securing future UK energy supplies, curbing climate change and keeping energy markets competitive – several technologies have been suggested. They include nuclear power, renewable energy and energy efficiency measures (see POSTnote 249). Although the UK is still on course to meet its target reductions of CO_2 emissions under the Kyoto Protocol, it may not meet its more stringent nationally set targets[2]. This is because energy use is not declining at the expected rate and zero CO_2-emission technologies and energy efficiency strategies are not having the impact that was envisaged. CCTs are seen by policy makers as the latest in a raft of technologies that could be used to reduce CO_2 emissions.

Coal is a cheap and relatively accessible fossil energy source, but its high carbon content also makes it the biggest CO_2-emitter per unit of electricity produced. Thus, the two key drivers for developing CCTs in the UK are:
- reducing national and international CO_2 emissions;
- creating business opportunities to sell CCTs internationally (in a market estimated to be worth potentially £51 billion to the UK[3]).

Worldwide growth in coal use

Today's global coal-fired electricity-generating capacity is about 1000 gigawatts[4]. This represents ~39% of all global electricity generation. Worldwide, the USA is the biggest coal user for power generation, although China uses the most coal across all markets. The fastest growing power users are China and India, which possess substantial coal reserves[5]. The International Energy Agency (IEA) shows in its forward projections that global electricity demand could grow by 2.4% each year and that coal-based power generation could account for 90% of this energy growth[5]. The development of CCTs is thus essential if global CO_2 emissions are to be reduced.

Policy response

The Department of Trade and Industry (DTI) reviewed the feasibility of CCS and in 2005 published *A Strategy for Developing Carbon Abatement Technologies for Fossil Fuel Use* (the CAT Strategy). The Strategy focuses on the development of CCTs and is accompanied by a £25 million budget over the next 4 years for the demonstration of such technologies. Policy makers hope that CCTs combined with carbon trading schemes that cap emissions will eventually deliver the required cuts in

CO_2 emissions. However, the high technology costs are a significant barrier to deployment, and there are a number of technological and legal issues that must be resolved.

Producing electricity from coal

Coal can be used to generate electricity either through combustion or gasification (see Box 1). All UK coal-fired power stations are combustion plants that were designed over 30 years ago; there are no coal gasification plants. Combustion is the traditional method. It first emerged in the early 1900s and major improvements in performance and reliability have been seen since then. Gasification for power generation is a more recent development. It can be carried out either at a separate site, with the gas being piped to a power plant, or be integrated into a single integrated gasification combined cycle (IGCC) plant.

Box 1. Coal combustion and gasification

Combustion

The process involves grinding coal into fine particles, pulverised fuel (PF), and injecting it with air into the lower part of a combustion chamber. As the particles burn they release heat, which is transferred to water tubes in the combustion chamber walls. This produces high pressure, high temperature steam that is fed into turbine generators to produce electricity. UK coal-fired power stations all use PF combustion with relatively low pressures and temperatures (so called 'subcritical'[6] steam cycles).

Gasification

Gasification can be used on many solid or liquid fuels, including coal. It converts them into a gas, the major components of which are hydrogen and carbon monoxide. The fuel is partially burnt during gasification, using controlled amounts of air or oxygen, and combustion is completed when the resulting gas is burned later in a gas turbine to generate electricity. The gasification stage has been employed for over a century in various applications including the production of 'town gas' and fertilizer manufacture. However, it has only recently become an option for electricity production. Previously the technology was not economically viable at large scales.

In an IGCC plant, coal is fed into an enclosed pressurised reactor, which produces the gas ('syngas') – a mixture of carbon monoxide, hydrogen, a small amount of CO_2 and pollutants such as sulphur compounds. This raw syngas is cooled and 'scrubbed' several times to remove the various pollutants. It is essential that only negligible amounts of the pollutants remain because otherwise they would seriously corrode the gas turbines used to generate electricity. This makes gasification cleaner than PF combustion, which can operate with higher pollutant loads. IGCCs operate a 'combined cycle'. First the syngas is fired in gas turbines to produce electricity. Then the hot 'exhaust gases' are used to generate superheated steam in a heat-recovery generator to drive a steam turbine, producing more electricity.

Reducing carbon emissions

There are three key ways to reduce carbon emissions from coal combustion and gasification:

- biomass co-firing (see Box 2);
- improving efficiency, so that less coal is burned per unit of electricity generated;
- adding CCS.

Potentially these three approaches can be combined in any permutation with both gasification- and combustion-based plants.

Box 2. Biomass co-firing

Biomass, such as energy crops and forestry waste, are considered carbon neutral (although there will be carbon costs associated with cultivation, harvesting and transport). Co-firing of biomass with coal is currently seen as a transitional stage in the process of replacing fossil fuels and reducing carbon emissions. Several UK power stations with PF combustion technology now co-fire up to 10% biomass with coal with no adverse effects. Research is underway to raise the level of co-firing to 50%. In the longer term, the application of CCS to plants that use biomass would be a means of removing CO_2 from the atmosphere permanently[7].

Improving efficiency

Combustion plants

All UK coal-fired power stations use subcritical[6] PF combustion processes with efficiencies of ~36–39%. The efficiency of subcritical plants can be improved by retrofitting more advanced components. The DTI, European Union and others are involved in a number of feasibility studies exploring possible retrofitting of advanced supercritical boiler and turbine technologies (along with CCS) to existing subcritical coal-fired power stations. However, there is some debate among industry experts and academics about the economic viability of such retrofitting. Efficiency can also be improved through building more efficient new plants using advanced technologies. Supercritical plants operating in Denmark and Germany reach efficiencies of 47%. Ultra-supercritical designs purported to reach efficiencies of >50% have been proposed, but the advanced materials necessary to implement such technologies have not yet been fully tested.

IGCC plants

Worldwide there are four IGCC plants running on coal: none are in the UK. They run at efficiency rates of ~37−43%. The US Government predicts that its new $1 billion Futuregen project – an integrated power and hydrogen generation and carbon storage project announced in 2003 – could improve on these efficiency levels and ultimately provide IGCC technologies that reach >60% efficiency[8]. However, some academics and industry experts have doubts about Futuregen's viability, saying it is too ambitious and overly complex.

Carbon capture and storage

Components of CCS are at various stages of development: they can be assembled from existing separate technologies that are mature and economically feasible under specific conditions, but in combination may be less so[7]. There is some argument over whether combustion or gasification CCS technologies are the most desirable (discussed later). CCS could be integrated into new plants or retrofitted onto existing ones. Retrofitting will only be appropriate for some plants: space constraints, remaining plant life and plant efficiency are issues. However, retrofitting would be the only way of substantially reducing CO_2 emissions from existing PF combustion plants.

Best estimates from industry and academia indicate that for both PF- and IGCC-based systems it may be possible to capture ~85% of the CO_2 produced for storage. In summer 2005, the Department for the Environment Food and Rural Affairs (Defra) and the DTI announced £3.5 million in funding for a 2–3 year feasibility study based in China. The project will assess the viability of CCS, with the aim of building a coal-fired demonstration plant there by 2015. In addition, energy company BP is working on a full scale CCS system at Scottish and Southern's Peterhead gas-fired power station. The captured CO_2 will be used for enhanced oil recovery (EOR) and long-term storage by injecting CO_2 into a depleted oil field to extend its lifespan. Such technology is not new: since 2000 CO_2 has been taken from the coal-using Great Plains Synfuels Plant in North Dakota and piped to the Weyburn oil field in Canada for EOR. Although Peterhead is a gas- not coal-fired power station, the project is an important step forward in the demonstration of CCS in the UK at a commercial scale.

Combustion plants

There are two possible technologies to facilitate carbon capture: flue gas scrubbing (which would happen after combustion) and oxyfuel firing (which would happen during combustion). They are described in Box 2.

IGCC plants

IGCC plants can be designed to capture CO_2. As mentioned previously, coal gasification produces syngas, which is mainly a mixture of hydrogen and carbon monoxide with a little CO_2 (~10%). The carbon monoxide is then reacted with steam over a 'shift catalyst' to produce more hydrogen and CO_2 and some heat. The CO_2 and hydrogen can then be separated with commercially available physical solvents for compression and storage. The IEA Greenhouse Gas Programme (IEA GHG) estimates the energy penalty attached to this process is ~6–9 percentage points[9]. Although the fuel conversion steps are elaborate, the higher concentrations of CO_2 in the syngas and higher pressures at which the reactions take place compared with combustion-based systems make CO_2 separation easier.

Barriers to making coal cleaner

This section focuses on carbon capture. Capture costs represent around two-thirds of the total cost of CCS.

Technology issues

There is consensus that "learning-by-doing" is the way forward and that full scale demonstration of carbon capture technology on a coal-powered IGCC or PF combustion plant is needed soon.

Gasification or combustion?

The IEA Clean Coal Centre (IEA CCC) and IEA GHG note that both combustion and gasification technologies have potential. It is likely that if global CO_2 emissions are to be reduced, carbon capture will be needed on both existing plants and on new builds. For new build, supercritical PF plants are considered a lower technological risk because, apart from the CCS element, the technology is reliable and mature. In contrast, there have been a number of issues with the reliability of IGCC plants. IGCC plants are more complex in design and although the constituent parts of the system can work well in isolation, integration has caused problems. Some academics and industry experts are optimistic these issues have been resolved. However, new IGCC plants would probably need to run at baseload (constantly), as operating them intermittently – according to demand (as PF plants are) – could cause technical problems.

Box 3. CO_2 capture on combustion plants

Flue gas scrubbing

This process involves the separation of CO_2 from flue gas after combustion. Combustion takes place in air, which consists of~20% oxygen and ~80% inert gases, mainly nitrogen. The oxygen is required for combustion but the inert gases are not, and passing them through the system has a significant energy penalty[9]. The flue gas produced after combustion is cooled and scrubbed to remove pollutants such as acid gases and particulates. Next it is scrubbed with chemicals (usually an amine-based solvent) to remove CO_2. This solvent is then heated to release high purity CO_2. It is vital that most pollutants (>99%) are removed before CO_2 scrubbing because otherwise they react with the solvent causing unacceptable solvent consumption rates and corrosion of the plant. The IEA GHG estimates an ~8–9 percentage point energy penalty attached to this capture process. (Other CO_2-removal techniques such as membranes and cryogenics are also possible, but tend to be more costly and have higher energy penalties).

Amine scrubbing is a proven technology – it has been in use for more than 60 years. However, most of this experience is with the removal of hydrogen sulphide and CO_2 from natural gas streams rather than with flue gases produced from power plants. Current commercial operations are at a smaller scale than is needed for power plants. The largest operating unit – at Trona in California, USA – captures 800 tonnes of CO_2 a day, less than 10% of the capacity needed for a 500 MW coal fired power station[3].

Oxyfuel firing

This technology is still in development. It involves burning PF in an oxygen/CO_2 mixture instead of air. This greatly reduces the volume of gas flowing through the system. Oxygen is supplied by an air separation unit. CO_2 is added to reduce combustion temperatures by recirculating flue gas to the combustor. The CO_2-rich flue gas, containing sulphur and nitrogen oxides and water vapour, goes through successive stages of compression, cooling and condensation to produce liquid CO_2. During this process it is envisaged that the sulphur and nitrogen oxides could be removed easily using conventional scrubbing techniques to leave CO_2. A key issue is how clean the CO_2 stream must be. There may also be issues with acid gases in the flue gas, which if not removed could severely corrode the condenser. The Advanced Power Generators Technology Forum (APGTF) notes that the necessary air separation plant adds expense and results in a energy penalty of ~8–9 percentage points.

In general, if carbon capture is not a consideration, supercritical PF plants are likely to be favoured for new build. However, if carbon capture is required, technological uncertainty tips the balance to favour the IGCC format. This is reinforced because the technology choice for investors may be determined by costs, which favour IGCC[7]. Currently, there are no plans to build new PF power stations in the UK. However, proposals to build IGCC plants in the UK are being developed. For example, Progressive Energy – a clean energy project development company – is currently working on four proposals for UK-based IGCC with carbon capture.

Economic and policy issues

Because CCS on a power plant has not been demonstrated at full commercial scale, there is much uncertainty over costs. Retrofitting existing plants is always more expensive than new build and it is expected this will apply to CCS technology[7]. For new build, the IEA GHG estimated in 2003 the capital cost of building a Shell-designed IGCC could cost $1371 per kW of electricity produced without carbon capture and $1860 with it. For a 500 MW IGCC plant this translates to capital costs of around $686 million or $930 million, respectively[10]. DTI and Defra officials hope that CAT Strategy grants along with carbon trading will provide sufficient incentives to promote the deployment of carbon capture technologies. However, CO_2 is currently trading at €20–30 per tonne, and power companies suggest it would have to stabilise at around €60 before investment could be contemplated. A key issue for potential investors is that the costs would need to be recouped over long payback periods (typically 25 years). Industry believes these long payback times combined with uncertainty about whether carbon trading will continue after the Kyoto Protocol expires in 2012 are not conducive to investment.

Reducing economic risk

Cost reduction is seen as a priority for making the technology economically viable. Experience shows that the wide deployment of new technologies usually ultimately reduces their costs. Flue gas desulphurisation units, which reduce sulphur oxide emissions, decreased in price fourfold over a decade. In the shorter term, industry experts and others have suggested an economic instrument that promotes investment in carbon capture technologies could be used. Green Alliance has concerns that this would only serve to further complicate an already complex policy raft of measures aimed at promoting a low carbon future. Greenpeace acknowledge that carbon capture may eventually play a role in reducing CO_2 emissions from emerging economies but opposes further UK public investment in cleaner coal as a means of mitigating climate change. It believes the technologies are not fully proven and that instead the focus should be on 'proven' low carbon technologies such as renewables.

Legal issues

CO_2 could potentially be stored in onshore or offshore structures. For the UK, the storage of CO_2 in offshore structures such as depleted oil fields is of particular interest because the use of CO_2 for EOR in North Sea could offset the cost of CCS. However, activities in the North Sea are subject to international treaties that were drafted without specific consideration of CO_2 storage. These treaties include the London and OSPAR Conventions, which govern the placement of matter into the sea or underlying seabed. The CAT Strategy states that the injection of CO_2 for EOR is not prohibited under these treaties. However, injection of CO_2 under the seabed for pure storage is more restricted. Currently, the UK is taking a proactive approach to resolving some of the legal issues CCS raises. But the timescales required to do this and to develop national regulatory frameworks may span many years. It is widely agreed that if the EOR or storage options in the North Sea are to be utilised, construction of the required infrastructure must start in the near future. This is because many of the depleted oil and gas fields in the North Sea that might benefit from EOR will start to close in 2005–2010. If such North Sea opportunities are to be realised fully, they must be evaluated before decommissioning and abandonment of platforms and pipelines takes place.

Overview

- Technologies that could reduce emissions of CO_2 and other pollutants are available for deployment now.
- However, some of the carbon capture technologies have not yet been proven at a commercial scale.
- There is a consensus that commercial-scale demonstration of CO_2 capture and storage from coal-fired plants is needed.
- There are high costs and risks associated with both retrofit and new build options.
- If carbon capture becomes widely adopted, the IGCC format for power generation may be favoured. However, PF combustion plants dominate today's markets and so it will be important to have carbon capture options for them.
- The current UK policy framework is considered insufficient to support commercial investment in CCS.

Endnotes

1 DTI (2003) *Our Energy Future: Creating a low carbon economy.*
2 DTI (2005) *Creating a Low Carbon Economy: 2nd annual report.*
3 APGTF (2004) *A Vision for Clean Fossil Power Generation*.
4 1 gigawatt equals 1 billion watts.
5 IEA (2002) *World Energy Outlook*.
6 'Subcritical', 'supercritical' and 'ultra-supercritical' refer to the steam pressure (as a rough proxy for efficiency) of electricity-generation.
7 IPCC (2005) *Special Report on Carbon Dioxide Capture and Storage.*
8 http://www.fossil.energy.gov/programs/powersystems/futuregen/
9 Energy penalty refers to a reduction in plant efficiency, which is a percentage measure of the electricity produced compared with the total heat energy put into the plant. A penalty of 8 percentage points would reduce plant efficiency from 44% to 36%.
10 Uncertainty over capital costs amounts to ±30%.

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POST is grateful to all contributors and reviewers. For further information on this subject, please contact Ingrid Holmes at POST.

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