Clean Coal Technology and the Energy Review

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Contents

Executive Summary

INTRODUCTION

Since the Government's 2003 Energy White Paper, emissions of carbon dioxide have risen in the UK; investment in renewables has stalled despite financial encouragement through the Renewables Obligation; the UK has experienced record prices for gas and seen a halt to investment in gas from generating companies; and the Emissions Trading Scheme has failed to significantly affect the mix of energy generation or trigger investment in carbon emissions reduction. On top of this security of supply, environmental and cost issues are now impacting on the confidence of the UK plc - concerns over the current situation were raised by the Confederation of British Industry in December 2005.

Britain escaped the effects of the gas row between Ukraine and Russia in January 2006, but the dispute demonstrated the real possibility that overseas gas supplies could be cut. According to the International Energy Agency, proven coal reserves worldwide are equivalent to almost 200 years of production at current rates and exceed those of oil (36-44 years) and gas (66 Years) by a wide margin. Coal can be stockpiled safely in the open air and its supply increased quickly whenever it is needed.

In 2005 the Government committed to a strategy for carbon abatement from fossil fuels and backed this up with funding for research and development and demonstration. At Gleneagles, the G8 committed to research and development into carbon emissions capture and storage.

This report is based on data provided by the International Energy Agency, the Department of Trade & Industry, the Royal Academy of Engineering, Princeton University and a number of other respected sources. It sets out an agenda for Government in the short term and the long term, answering the key issues raised by the Government's current Energy Review related to power generation: the economy, the environment and security of supply.

The key findings of the report:

- Clean Coal Technology is the only short term solution to environmental, economic and security of supply challenges with a vital role as a long term solution within a diverse energy portfolio.

- Government must invest in Clean Coal to stabilise energy prices. Clean Coal solves the short term environmental and supply challenges while delivering cheaper electricity than gas or renewables.

- Government must proactively ensure security of supply through a diverse energy portfolio.
  The Emissions Trading Scheme has failed to affect the energy mix or reduce carbon emissions.

- Government must invest in Clean Coal if the UK is to close the UK's energy gap; gas prices are rising, nuclear is for the long term and renewables are clean but only supply energy intermittently.

- Government must lead industry investment in today's Clean Coal Technology, ensuring National Allocation Plan CO_2 Allowances trigger investment in this technology during the 2008 - 2012 period, mirroring Germany's recent success in this area and subsequent rush for Clean Coal.

- Government must fund demonstrations of CO_2 capture and storage during the period 2008 to 2015, proving this second stage Clean Coal Technology, removing almost all emissions. It should also ensure all future coal plants are 'capture ready' and compatible with the emerging technology.

- Government must also invest in nuclear power to replace existing plants. Nuclear energy is climate friendly, a complement to Clean Coal and essential to securing a diverse energy portfolio.

- Government policy should be determined by the suitability of technologies for global application, tapping into the export potential for UK plc and maximising the environmental impact worldwide.

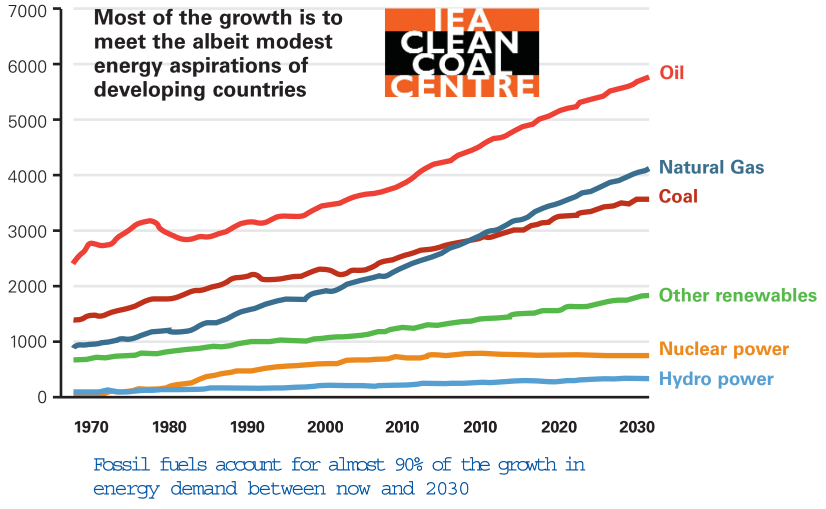
- Government policy should prescribe the levels for each energy source (max and min) within the diverse portfolio, recognising the relative prices for each and the timescales to build up capacity.

1. GLOBAL SITUATION

1.1 Global demand for energy and electricity

The International Energy Agency (IEA) in its World Energy Outlook 2004 (Ref. 1) predicts that world primary energy use will grow by 60% during the period from 2002 to 2030, with almost 90% of this growth coming from fossil fuels (see Figure 1). More than 60% of the growth in primary energy demand is from the developing countries, with the resultant carbon dioxide emissions in these countries predicted to overtake those of the OECD countries in the 2020's. Whilst the growth in energy use in developing countries is huge in absolute terms, it is modest in terms of energy use per capita. Carbon dioxide emissions from electrical power generation and transport amount to around $^1/_2$ and $^1/_4$ of the total respectively.

Figure 1: World Primary Energy Demand



The consumption of electrical energy is expected to increase to an even greater extent. World electricity demand is projected to grow at an annual rate of 2.5%, nearly doubling from 16.1 trillion kilowatt-hour (tn kWh) in 2002 to 31.7 tn kWh in 2030. Strong growth in electricity consumption is expected in countries of the developing world, where electricity demand increases by an average of 3.5% per year. The global power sector will need 4800 Gigawatt (GW) of new capacity between now and 2030 to meet the projected rise in electricity demand and to replace the ageing infrastructure. The total installed capacity is expected to increase from 3500 GW to more than 8000 GW. The exact mix of fuel input to this new generating capacity will depend on a number of factors including fuel diversity, indigenous and international availability, cost and environmental acceptability; and will vary between different regions of the world.

Coal-fired power plants provided 39% of global electricity needs in 2002, gas 19%, nuclear 16%, oil 6%, hydro 15% and other Renewables 3%.

1.2 Energy reserves and security of supply

The growth of fossil energy use is challenging both in terms of emissions and in terms of availability of resources. According to the International Energy Agency, proven coal reserves worldwide (83% hard coal) are equivalent to almost 200 years of production at current rates and exceed those of oil (36-44 years) and gas (66 years) by a wide margin.

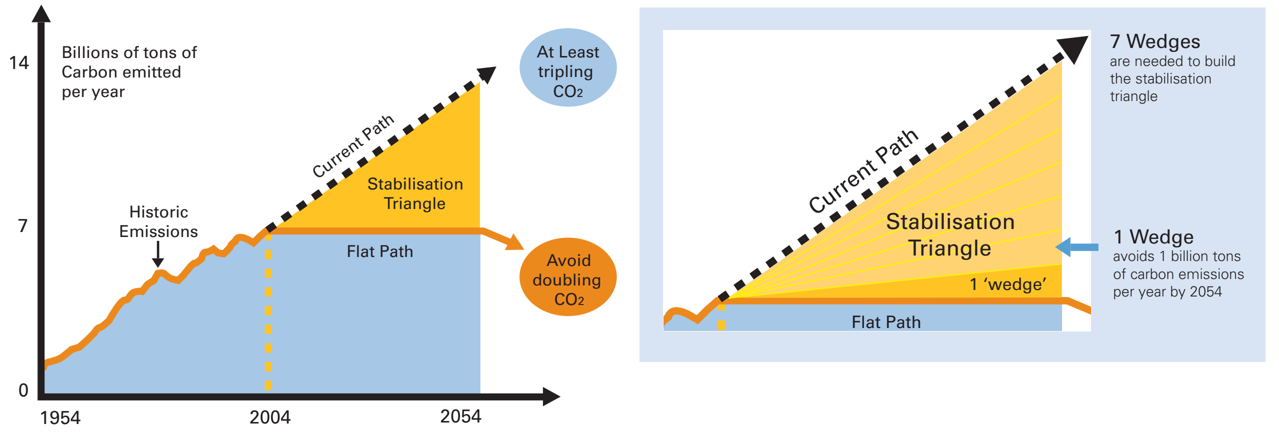
It is clear that to meet global energy demands this wide diversity of sources is essential. Coal, with more than 200 years of reserves, is, with nuclear fission, an essential bridge to a future of sustainable energy from renewable sources and potentially nuclear fusion. Increasing use of gas for power generation, often urged for environmental reasons, would be at the expense of proportionately quicker depletion of the remaining 66 years of reserves.

1.3 Alternative routes to reduction of carbon dioxide emissions

The Princeton Environmental Institute analysis of solving the climate problem demonstrates the need for a wide range of measures (Ref. 2). In order to avoid tripling the CO_2 concentration in the atmosphere and stabilise CO_2 at current levels, a huge wedge needs to be taken out of the growth – see Figure 2. It is necessary to cut the annual emissions predicted for 2050 by 7 Billion tonnes (Bn tc). Fourteen prospective wedges are suggested, each of which could give a reduction of 1 Bn tonnes.

It is clear that a multiplicity of measures are needed to achieve the CO_2 reductions that are necessary. Seven possibles are listed in Figure 3.

Figure 2: CO_2 Stabilisation triangle



A combination of energy efficiency (domestic, industrial and transport), renewables, nuclear and carbon-abatement from fossil fuels is required to achieve CO_2 reductions, as well as to satisfy energy demands.

Figure 3: Potential wedges of the stabilisation triangle

Wedges	Detail	Feasibility
Efficiency	Double fuel efficiency of 2 billion cars from 30 to 60 mpg	There are 600 million cars in the world today. Projection is 2 billion by 2054. **1 wedge • Double the average fuel efficiency of the fleet**
Fuel Switching	Replace 1400 coal electric plants with natural gas-power facilities (adding an amount in 2054 almost equal to today's world gas usage)	**1 wedge • bringing one Alaska pipeline** on line every year for 50 years; or **1 wedge • 50 large LNG tankers** docking and discharging every day
Carbon capture and storage	Capture AND store emissions from 800 coal electric plants	**1 wedge • 3500 In Salah** developments (each need to last through to 2054)
Nuclear	Add double the current global nuclear capacity to replace coal-based electricity	400 nuclear plants today, **1 wedge • adding 700** more in the next 50 years
Wind	Increase wind electricity capacity by 50 times relative to today, for a total of 2 million large windmills	**1 wedge • windmills on an area approx 4 times that of UK**
Solar	Use 40,000 square kms of solar panels to produce hydrogen for fuel cell cars	**1 wedge • solar panels covering area 230 times the area of London (1/12 size of UK)**
Natural sinks	Eliminate tropical deforestation AND create new plantations on non-forested land to quintuple current plantation area	**1 wedge • new plantations with a total area 25 times that of the UK**

1.4 *Carbon-abatement for Coal-fired generation*

Against the background of growing demand and the need to cut emissions of carbon dioxide, carbon abatement for coal-fired generation is essential. The available technologies include efficiency improvement, biomass cofiring and carbon dioxide capture and permanent underground storage (CCS). As indicated above, if CCS was applied to 800 coal-fired power plants the saving would be 1 Bn Tc/year, one-seventh of the reductions needed by 2050. Reductions of around half this magnitude can be achieved by efficiency improvements (- 20 to 25%) and biomass cofiring (-20%).

The scale of the problem and the key issue of reducing carbon dioxide emissions in the developing world as well as the developed world whilst energy demand grows rapidly, is now well understood and has led to many national and international programmes on carbon abatement technologies, including CCS. The need for emissions reduction is being recognised with investment in research, development and demonstration of clean coal technologies by national programmes including USA (Vision 21, Clean Coal Power Initiative and Futuregen), Canada (Clean Coal Power Coalition), Japan (New Sunshine Programme), Germany (COORETEC), Australia (Securing Australia's Energy future) and the EU (Framework Programmes 5 and 6 and the Research Fund for Coal and Steel). The leader in terms of budgets is the US government with very large programmes targeting emissions reduction, and, longer-term, Zero Emission power generation (ZEPG). In June 2004, the Australian government announced a 500 million Australian Dollar (AUD) fund established to leverage 1 billion AUD of private investment in low emissions technology demonstrations. In August 2004 the US Department of Energy announced it had received proposals for a new generation of clean coal projects valued at nearly 6 billion US dollars, in the latest phase of President Bush's Clean Coal Power Initiative (CCPI). Bush has pledged to spend up to 2 billion US dollars in federal funding over ten years to advance technologies that can help meet the nation's growing demand for electricity, while simultaneously providing a secure and low-cost energy source and protecting the environment.

Gleneagles and the G8

At the Gleneagles G8 summit in July 2005, the G8 leaders agreed a five point action plan to accelerate the development and commercialisation of Carbon Capture and Storage (CCS) technology by:

- endorsing the objectives and activities of the Carbon Sequestration Leadership Forum (CSLF) and encouraging the Forum to work with broader civil society, and to address the barriers to the public acceptability of CCS technology;
- inviting the International Energy Agency to work with the CSLF to hold a workshop on short-term opportunities for CCS in the fossil fuel sector, including from Enhanced Oil Recovery and CO_2 removal from natural gas production;
- inviting the International Energy Agency to work with the CSLF to study definitions, costs, and scope for capture ready plant and consider economic incentives;
- collaborating with key developing countries to research options for geological CO_2 storage; and
- working with industry and with national and international research programmes and partnerships to explore the potential of CCS technologies.

During the UK Presidency of the EU, Tony Blair, following discussions with the Chinese government, announced the EU/UK near-Zero Emissions for Coal (nZEC) project. The objective is to demonstrate a near-zero emissions coal-fired power plant technology in China and Europe by 2015. The UK will fund the project feasibility study.

2. *UK SITUATION*

2.1 *Energy White Paper goals*

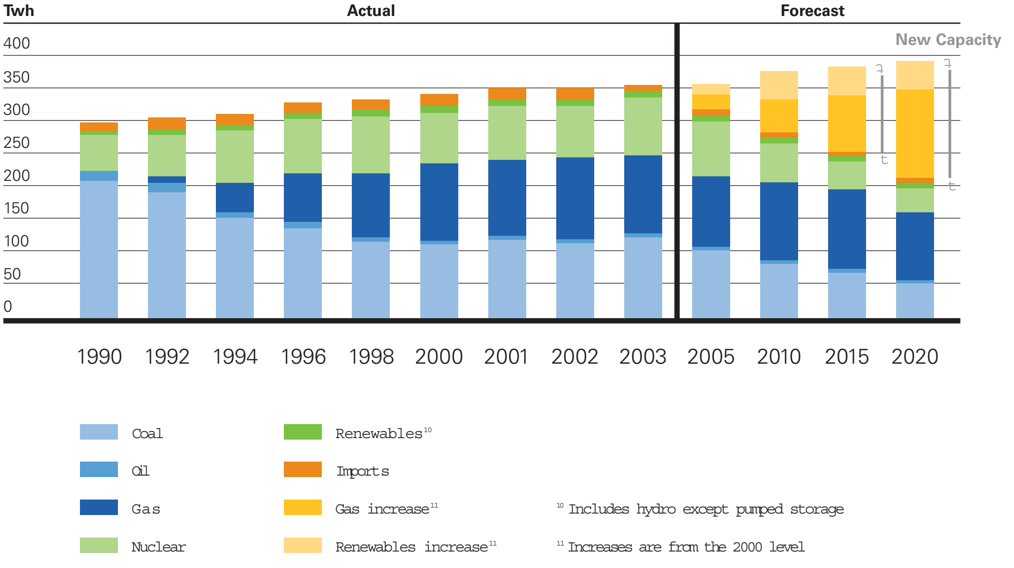
The goals of the 2003 UK Energy White Paper (Ref. 3) were stated as:-

- to put ourselves on a path to cut the UK's carbon dioxide emissions – the main contributor to global warming – by some 60% by about 2050, as recommended by the Royal Commission on Environmental Pollution (RCEP), with real progress by 2020;
- to maintain the reliability of energy supplies;
- to promote competitive markets in the UK and beyond, helping to raise the rate of sustainable economic growth and to improve our productivity; and
- to ensure that every home is adequately and affordably heated.

The key routes to emissions reduction were anticipated to be increased efficiency of energy use, increased use of renewable sources and fuel switching. It was expected that the growth of renewables would be driven by the Renewables Obligation. Fuel switching (predominantly coal to gas) was expected to be driven by the introduction of the European Emissions Trading Scheme (ETS) and by the closure of coal-fired stations under the pressure of the EU Large Combustion Plant Directive (LCPD).

Investment in renewables and new gas-fired Combined Cycle Gas Turbine (CCGT) capacity was expected to replace coal-fired generation and the progressive closure of existing nuclear power plants. It was recognised that the country would need to import gas from a number of sources by pipeline and ship as Liquefied Natural Gas (LNG) to replace declining North Sea supplies. The diversity of sources of gas was expected to assure security of supplies. The trends in the generation mix predicted in subsequent reports from the DTI's Joint Energy Security of Supply Working Group are shown in Figure 4.

Figure 4: Generation mix in UK predicted in 2003



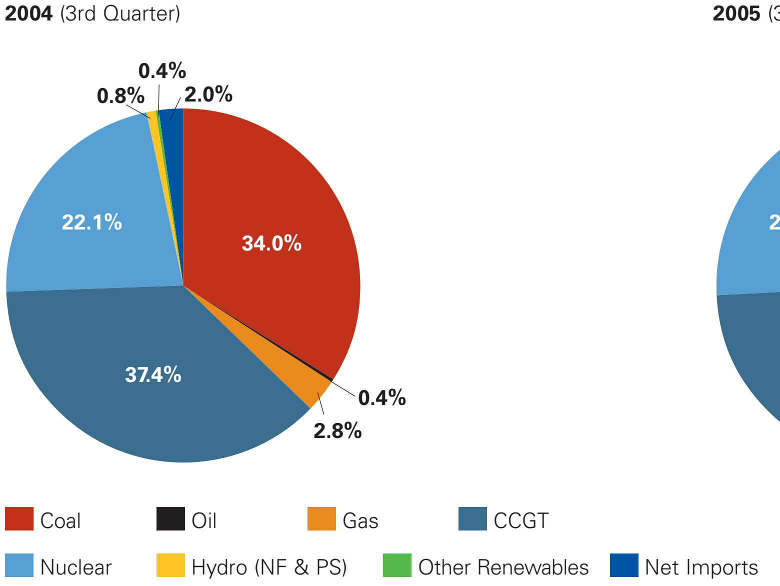
This shows a progressive reduction of nuclear and coal generation with this capacity projected to be replaced by increases in renewables and gas. By 2020 almost 60% of the generation would be from gas, and by this date 38% of the generation would be from new plant built between 2003 and 2020.

2.2 *Progress towards the Energy White Paper goals*

For a number of reasons, achievement of the Energy White Paper goals is threatened by developments not wholly foreseen in 2003.

Emissions of carbon dioxide, which fell during the dash-to-gas period in the nineties, have recently started to rise. Despite the financial encouragement of the Renewables Obligation, investment in renewables has not progressed as fast as hoped – due to planning delays for onshore wind and costs for offshore wind. Investment in gas-fired generation has stopped due to the increasing price of gas. The introduction of Emissions Trading in January 2005 has failed to significantly change the mix of generation or to trigger investment in Carbon Abated Clean Coal Technologies (CATs) projects to reduce emissions. This is demonstrated in Figure 5 which compares the generation mix in 2004 Q1-3 with that post-ETS in 2005 Q1-3.

Figure 5: UK Electricity Generation by Fuel



There is now much more concern about security of supplies than in 2003.

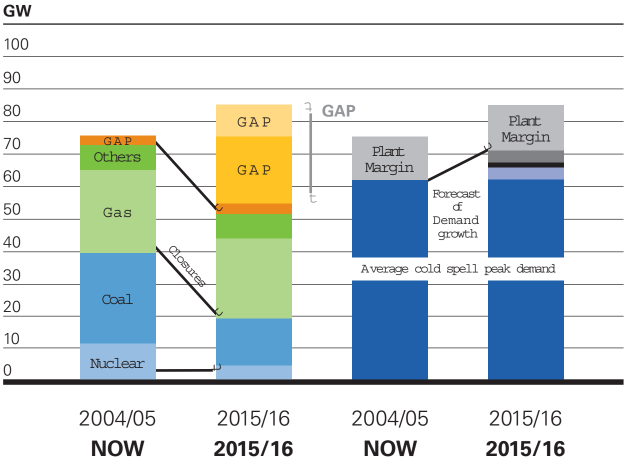
(i) Firstly, there is concern about tightness of gas supplies versus winter demand because supplies from the North Sea have declined more rapidly than new imported supplies have been established. OFGEM (the regulator for Britain's gas and electricity industries) had to indicate in November 2005 that whilst in a cold winter gas supplies should be sufficient for domestic customers, some industrial customers (including power plant) could face interruption. Although the Belgium interconnector has been upgraded and the first Liquefied Natural Gas facility (at Isle of Grain) has been installed, these have, so far, operated at less than full capacity because gas supplies have not been available.

(ii) Secondly, although Britain escaped the effects of the gas row between Ukraine and Russia in January 2006, the dispute demonstrated the real possibility that overseas gas supplies could be cut.

(iii) Thirdly, concerns have emerged regarding the developing power generation capacity gap, as electricity demand grows, the closure of nuclear plants comes closer and the Large Combustion Plant Directive (LCPD) impacts on coal plants.

The generation gap will arise due to the closure of 7 GW of nuclear stations and the closure by 2015 of the 11 GW of coal-fired stations which are expected to 'opt-out' of the Large Combustion Plant Directive. These closures are very significant – amounting to 24% of the installed electricity generation capacity in the UK, which was 75 GW in 2004/5 – and will reduce the available generation capacity at times of peak demand. In Figure 6, the available generation in 2015 is compared with the required generation capacity to meet anticipated average demand (based on current demand plus National Grid Company growth estimates) and give the required plant margin (necessary to cover the risk of generating plant unavailability and/or higher than average peak demand (e.g. due to severe weather).

Figure 6: Generation capacity gap



It is clear that a total of 29 GW (18 GW due to closures and 11 GW due to growth) of new generation plant could need to be operational by 2015, requiring 4000 – 6000 MW of projects starting each year from 2006 to 2011.

The scale of this challenge is enormous. The total current generation capacity in the UK (75 GW) was installed over a period of more than 40 years. Nearly 40% of this has to be built in less than 10 years.

For comparison, 500 MW of wind turbines were installed in 2005, twice that installed in 2004.

2.3 *Need for a diverse generation portfolio*

Experience shows that the current generation capacity mix (nuclear 16%, coal 38%, gas 33%), with a growing proportion of intermittent renewables, provides an appropriately balanced portfolio. The challenge is how to replace the large amount of generating capacity which will be retired by 2015 whilst preserving this balance and further reducing carbon emissions. The issue is not simply of switching to nuclear, gas or coal in the future. The UK has a big challenge ahead merely to maintain the status quo and then to build what is needed to meet future energy demand.

Nuclear electricity is essentially CO_2 free and relatively stable in price but it would be wrong to depend too much on nuclear because nuclear is a baseload technology. As a baseload source it cannot be quickly 'turned up' to meet demand fluctuation so needs to be backed up by generation from coal or gas that can match electricity demand when it is needed.

Wind generation is attractive because of its sustainability and near zero carbon emissions, but it is clear from Danish and German experience that too large a proportion of intermittent generation from wind causes grid stability issues. Also, as intermittent capacity wind needs to be fully backed up by alternative capacity for times when there is little or no wind, or too much wind.

The advantage of gas is its relative cleanliness (versus coal) but its disadvantages are relatively limited global resources (60 years compared with 200 years for coal), sourcing from less secure countries, and volatile prices. Three countries, Russia, Iran and Qatar, hold 55% of global gas reserves. Reserves in OECD countries are 10% of current production. There is also evidence that total lifecycle Greenhouse Gas emissions from gas can exceed those from coal. This is due to methane leakage from pipelines, CO_2 stripped out when gas is produced, and CO_2 produced during liquefaction and regasification of Liquefied Natural Gas. A large proportion of the price of gas-fired electricity is the price of the fuel.

Whilst generation from old coal-fired power stations produces more carbon dioxide than gas-fired combined cycle gas turbines (CCGTs), modern clean coal power stations are closer to CCGT.

The Government's aim to safeguard security of supplies, reduce emissions and hold down escalating electricity prices can only be satisfied by a diverse portfolio of electricity generation. A diverse portfolio of nuclear, renewables, gas and coal helps to safeguard security of supplies against fuel shortages/interruptions, moderates the costs of electricity against fuel price hikes and allows varying of generation to match seasonal and daily variations in load demand.

Future government policy should be based on realistic targets (max and min) for each contribution to the diverse portfolio. Such targets should recognise the relative prices of electricity generated by each technology and also the timescales necessary to build up capacity. Policies to promote technologies should also be determined by the suitability of the technologies for global application.

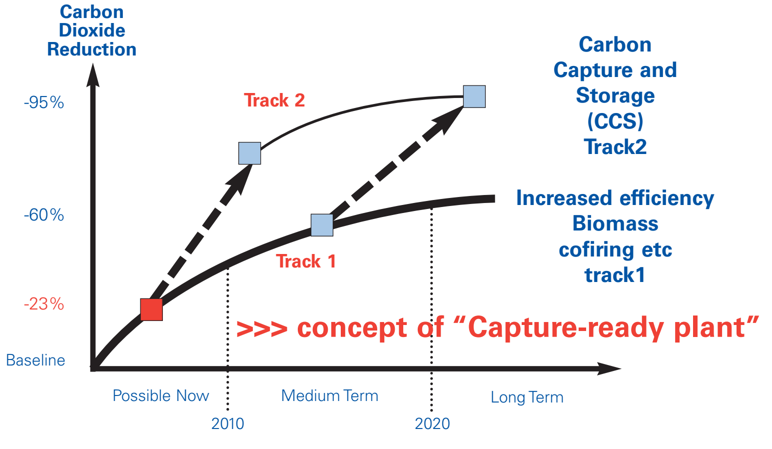
All the options available will be more expensive than the very low-cost electricity generation that the country enjoyed until 2004, on the back of written-off coal plant, low gas prices and low-cost nuclear generation. The cost of clean electricity should be the prime arbiter of choice but only within ranges that achieve a diverse portfolio.

3. CARBON ABATED CLEAN COAL TECHNOLOGIES (CATs)

3.1 Twin Track Approach

Two approaches to carbon-abatement for coal-fired power plant are widely recognised, referred to in the DTI's Carbon Abatement Technologies Strategy (Ref. 10) as Track 1 and Track 2 respectively – see Figure 7.

Figure 7: Twin-track approach to Carbon Abatement



The Track 1 approaches are available now. They bring reduced CO_2 emissions per unit of electricity generated. Track 1 approaches include improved efficiency by introduction of Advanced Supercritical (ASC) boiler/turbine technology and biomass cofiring (substitution of up to 20% of the coal fuel by biomass which is CO_2 neutral). More detail is given in section 3.2 on Mitsui Babcock's preferred technology and in section 3.3 on alternatives.

The Track 2 approach, carbon dioxide capture and permanent underground storage, is necessary to achieve much larger reductions, up to 95%. More detail is given in section 3.4.

Efficiency improvement is an essential precursor to CCS. (The efficiency improvement affects the energy penalty of the capture equipment) and both approaches are necessary to achieve a near-zero emissions power plant.

It is now possible to introduce Track 1 improvements whilst designing the plant for subsequent addition of Track 2 CCS. Such a plant is known as "Capture-ready".

A comprehensive review on Zero Emissions Technologies (ZETs) has been presented by the International Energy Agency Clean Coal Centre. (Ref. 4)

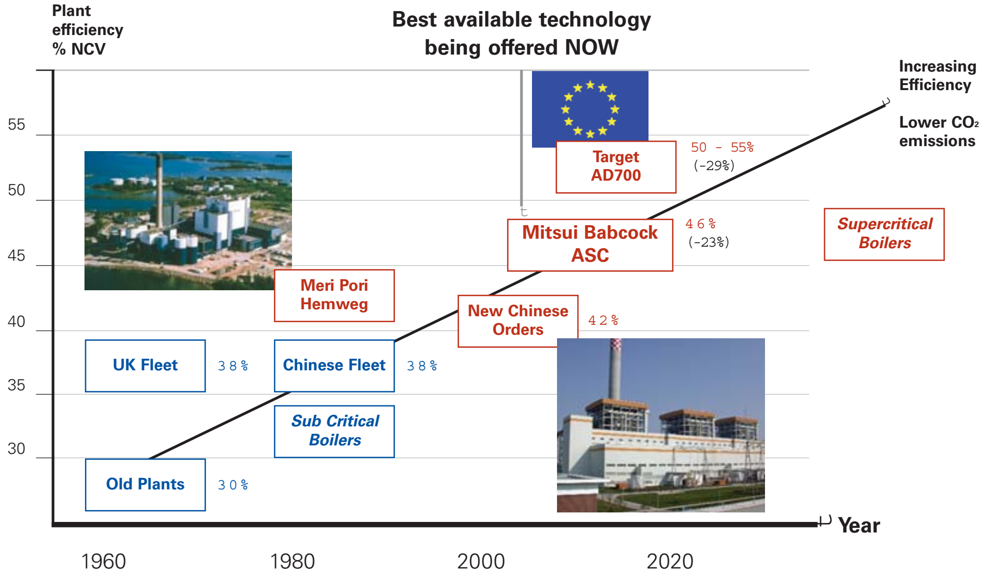
3.2 Advanced Supercritical Coal-fired Power Plant

In the short-term major improvements in carbon dioxide emissions are possible by improvements in generation efficiency (giving a reduction in carbon dioxide per megawatt of electricity generated) and by substituting a proportion of the coal by biomass (biomass cofiring).

For new-build, in China, Mitsui Babcock is supplying supercritical boiler plant of 42 per cent net efficiency (steam conditions up to 259 bar, 571°C) (reference plant at Hemweg in Holland and Meri Pori in Finland) and is tendering advanced supercritical plants capable of 46 per cent net efficiency (steam conditions up to 295 bar, 595°C) with full efficiency, emissions, availability and build-programme guarantees. The progressive improvements in power plant efficiency and related reductions in CO_2 emissions are shown in Figure 8.

Many old plants around the world have efficiencies of only 30%. In the UK, the range is 32% to 38%, with an average of 35%. In the 1990's, the coal-fired boilers being built in China were around 38% efficient. Since the mid-80's in Europe (Hemweg and Meri Pori) and since early 2000's in China, Mitsui Babcock has been supplying "supercritical boilers" with steam conditions which would give an efficiency of 42% in the UK. The best available technology would now give an efficiency of 46%. In the future, the target for this technology is 50-55%. This is the subject of collaborative European-funded projects in which Mitsui Babcock participate.

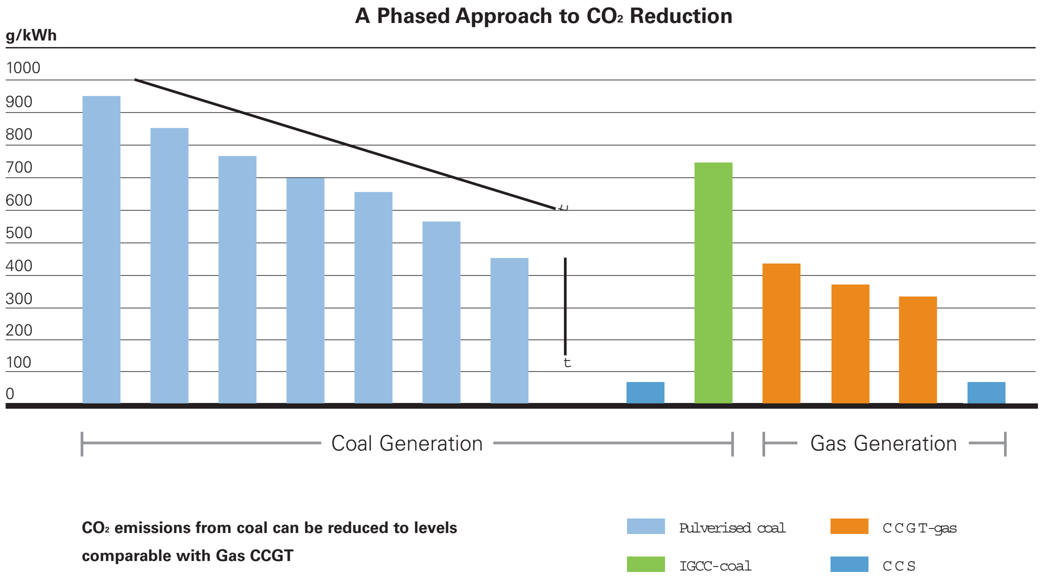
Figure 8: Progressive Abatement of Carbon Dioxide emissions by improvements in Plant Efficiency



For new power plant, advanced supercritical boiler/turbine plants offer the highest efficiency and lowest CO_2 emissions (~ 700 g/kWh). Comparative studies by International Energy Agency and by a number of utilities have shown that such plants, fitted with state-of-the-art emissions control equipment generally give the lowest cost-of-electricity, highest availability and lowest specific CO_2 emissions for a wide range of coals from sub-bituminous through bituminous to sub-anthracite.

Compared with the average existing plant in the UK with an efficiency of 35% Low Heating Value - (LHV), reductions of 23 per cent in carbon dioxide emissions (and fuel consumption) are possible by fitting Advanced Supercritical Boilers and steam turbines. Further reductions of 10 to 20 per cent are possible by use of CO_2 neutral biomass (typically 5-10 per cent by pre-blending biomass with coal and a further 10 per cent by direct injection of biomass through dedicated ports or burners). Additionally, around 10 to 20% further reduction is possible by using gas turbines or further biomass for Feed Water Heating. In total these measures can bring the carbon dioxide emissions down to around 450 g/kWh, close to the levels of gas-fired CCGT plant (see Figure 9).

Figure 9: Carbon abatement technologies



The Mitsui Babcock Advanced Supercritical Boiler design is equally suited to new-build and retrofits. It is a two-pass design, similar in overall shape and size to the two-pass natural circulation boiler it replaces, and can be fitted inside an existing boilerhouse. The best available technology would incorporate Mitsui Babcock's low mass flux Posiflow™ vertical tube once-through furnace with the advantages of a positive flow characteristic, reduced weight and faster response. More detail on this advanced supercritical boiler/turbine technology is given in the recent DTI Best Practice Brochure (Ref. 5).

3.3 *Alternative coal technologies*

Competing clean-coal technologies such as Integrated Gasification Combined Cycle (IGCC) or Circulating Fluidised Beds (CFBs) have a complementary role to play for particularly high sulphur or high ash coals, albeit with slightly lower efficiency and higher costs. IGCC is strongly promoted in the USA (e.g. in the Futuregen project) but is not widely favoured in Europe due to the experience of extended commissioning times and poor availability at the two demonstration projects in Spain and Holland. IGCC with pre-combustion capture or post-combustion capture of CO_2 can be used for production of hydrogen and is regarded as necessary for a future hydrogen economy.

3.4 *Carbon dioxide capture and storage*

Carbon dioxide capture and geological storage is a longer-term solution. This involves a chain of technologies for CO_2 capture, transportation and storage underground.

Mitsui Babcock is particularly interested in the carbon dioxide capture technologies that can be retrofitted to existing plant and plant currently being built (e.g. in China) as well as being used with new plant.

Two technologies – Amine scrubbing and Oxyfuel firing – are being explored in many projects around the world and both are realistically expected to be available on the scale required and at an acceptable cost by 2012/15.

Figure 10 summarises the amine scrubbing process concept. Absorption based amine scrubbing processes are well suited to CO_2 capture from power plants with some process modifications needed to overcome particular problems posed by some of the low concentration chemical species present in flue gas from power plants, particularly those with coal fired boilers. The suggested modifications are being demonstrated on "slip-stream" projects at power plants in Canada, Denmark and Japan.

Figure 10: Amine Scrubbing Process for CO_2 Capture

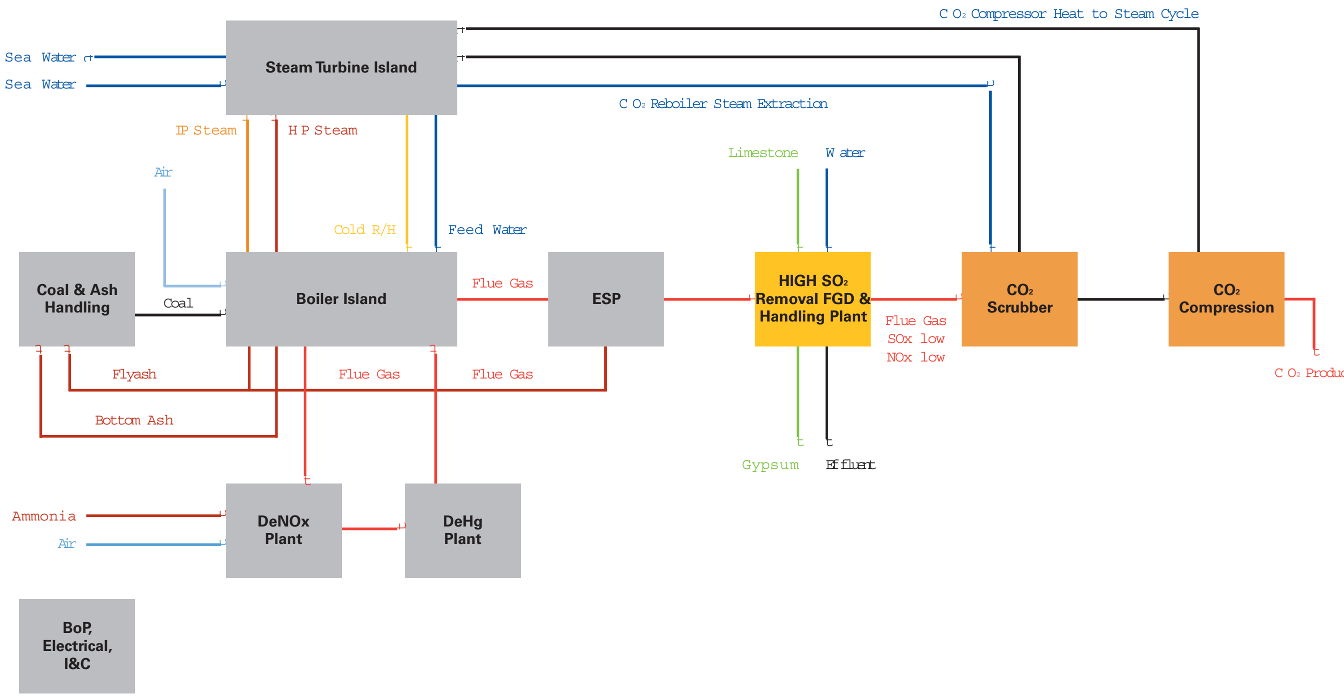
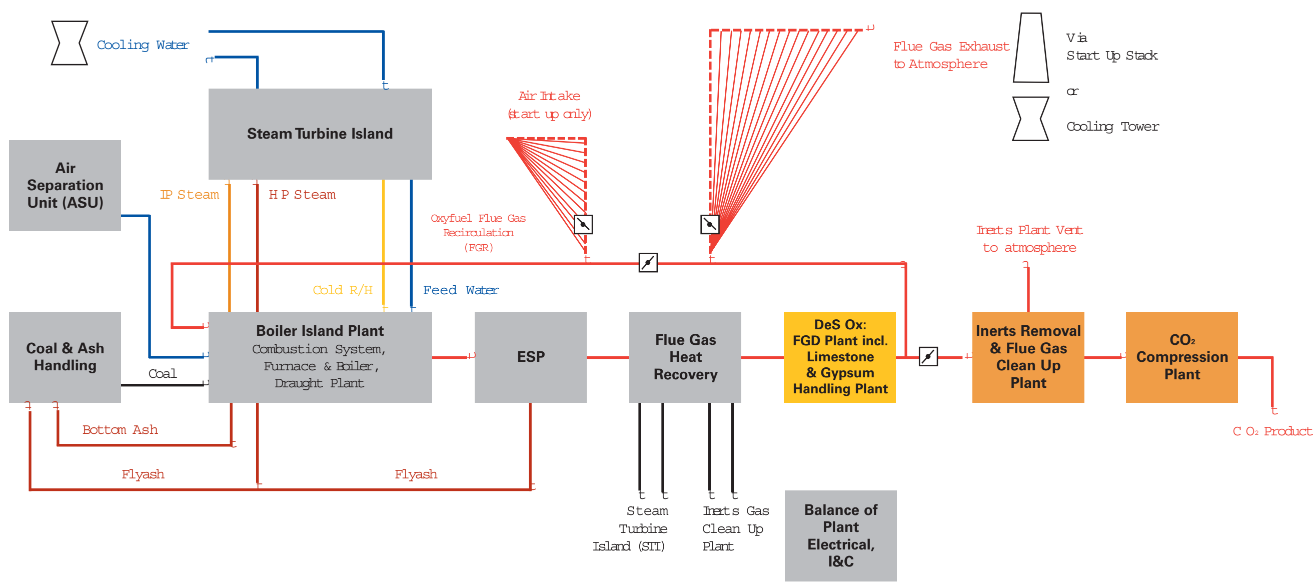


Figure 11 below presents an indicative diagram for an Oxyfuel CO_2 capture system. For low sulphur coals the flue gas desulphurisation (FGD) plant can be omitted. An air separation unit is used to separate the oxygen and nitrogen, and the coal is burnt in oxygen diluted by recycled flue gas (predominantly carbon dioxide). This has the advantage of significantly concentrating the CO^2 concentration.

Figure 11: Indicative Oxyfuel Capture Process (as shown for High Sulphur Coal hence FGD included)



This has the advantage of significantly reducing the flue gas volumes, but the separation process has a performance penalty.

Mitsui Babcock has a long track record in R&D on oxyfuel firing of coal. The company carried out successful trials of oxyfuel-firing of coal in the mid 90s on its test-rigs in Renfrew, Scotland.

Further information on the application and process integration of the above CO_2 capture technologies for new build Advanced Supercritical Boiler/Turbine coal-fired CO_2 Capture power plant is provided in references 6 and 7.

Results from these studies indicate that ASC with CO_2 capture by amine scrubbing or oxyfuel firing will be competitive with IGCC and pre-combustion capture, and, significantly, give an electricity cost inclusive of CO_2 capture and storage less than the cost of electricity from renewables such as offshore wind, wave, tide or photovoltaics (see Section 3.7).

3.5 Status of Clean Coal Technologies and timescales for implementation

The 'Track 1' technologies are available now:

(i) Advanced supercritical boiler turbine power plant with specific CO_2 emissions of 700 g/kWh (cf 950 g/kWh for most UK plants) are being tendered and will be built in Europe, beginning in Germany and Italy.

Mitsui Babcock offer the boiler island for such plant, incorporating biomass cofiring, and if required and can design the plant to be "capture-ready", i.e., suitable for the later retrofit of carbon dioxide capture equipment.

(ii) Advanced supercritical boiler turbine retrofits are possible now at UK power plants, including flue gas desulphurisation (FGD) and Selective Catalytic Reduction (SCR) of NOx to meet the 2016 requirements of the Large Combustion Plant Directive. Such retrofits could also be designed for biomass cofiring and to be "capture-ready".

The 'Track 2', carbon dioxide technologies, are sufficiently understood to allow the design of the rest of the plant to be made capture-ready. A combination of pilot scale trials (underway) and large scale demonstrations (anticipated between 2007 and 2012) are needed to prove the technologies. In parallel, governments, with the UK playing a leading role, are developing the criteria for choice, approval, validation and monitoring of CO_2 storage sites.

Mitsui Babcock is leading an industry collaborative project (Project 407, Ref. 8), supported by the DTI, to evaluate and optimise how such retrofits (Tracks 1 and 2) can be accomplished on the UK fleet of coal-fired power plants. The partners in the project are Mitsui Babcock, E.ON, Alstom, Air Products and Imperial College. Sponsors, in addition to the DTI, are E.ON, Drax Power, EDF, Scottish and Southern and RWE.

3.6 Benefits of Mitsui Babcock Retrofit philosophy

Mitsui Babcock has deliberately focused on technologies for carbon abatement of coal-fired generation which are suitable for progressive retrofit to existing plants and plants under construction as well as being suitable for completely new plants. The reasons for this focus are:

(i) If global targets for CO_2 reduction are to be met as well as global needs for energy security, CATs will be needed on existing plant, plants under construction (in the period 2006 – 15) as well as future plants (from 2015 to 2030). Many new plants will be built or committed before carbon dioxide storage is commercial.

(ii) In developed countries, including the UK, opposition is strong to new plant at the planning stage. Re-use of existing sites is therefore preferred, allowing continuity of employment and maximising use of existing infrastructure (grid connections, coal and ash handling, road and rail links).

(iii) Retrofits allow CATs to be introduced more quickly and at much less cost than new build.

(iv) Retrofits allow innovative technologies to be proven in shorter timescales and at less risk and cost than on complete new plants, making demonstrations more affordable and more valuable within a national CAT development strategy.

(For example, Mitsui Babcock's Low NOx burners and Staged Combustion solutions were first demonstrated at full-scale through retrofits and then subsequently adopted on new boiler plant. More than 45,000 MWt of such burners have now been installed world-wide on Mitsui Babcock and other original equipment manufacturer's (OEMs) plant. Another 30,000 MWt are being installed in China. Many such retrofits have included other boiler refurbishments and other plant improvements, in some cases involving replacement of almost all the boiler pressure parts (furnace, reheater, superheater, economiser, etc). Retrofits of Advanced Supercritical Boilers and associated turbines will require additional work but the new Mitsui Babcock Posiflow™ low mass flux two-pass advanced supercritical boiler design retains the advantage that it can be installed quickly within the existing buildings and support steelwork).

3.7 *Costs of Carbon-abated Clean Coal*

A comparison is given below of the relative investment requirements, costs-of-electricity, timescales, flexibilities and risk levels of the technologies that can be used for new electricity generation. Prices quoted are from the Royal Academy of Engineering report (Ref. 9) and other back-up sources.

	Capital Costs £/kW^e	**Cost of Electricity** p/kWh	**Timescale** Planning/ Licence	Project	**Baseload/ Load Following**	**Project Risk**
Clean Coal (Advanced Supercritical Retrofit) (Note a)	£200 - 250/kW	2.0 – 2.2 p/kWh	1 year	2 years	Load Following	Low
Clean Coal (Advanced Supercritical) (Note a)	£700-£860/kW^e	2.5	1 year	3.5 years	Load Following	Low
Nuclear (Note b)	£1150/kW^e	2.0 – 2.5	5 years	5 years minimum	Baseload	High
Gas – CCGT (Note c)	£300/kW^e	3.8	1 year	3 years	Baseload/ Load Following	Low
Renewables (Wind) Onshore (Note d)	£630 – 740/kW^e	4.8 - 5.3	2 years	2 years	Intermittent	Medium
Renewables (Wind) Offshore (Note d)	£780 – 920/kW^e	6.3 - 7.2	2 years	2 years	Intermittent	High
Clean Coal (ASC) with CCS (Note e)	£825 - £1300/kW^e	3.5 – 4.3 p/kWh	5 years	4 years	Baseload/ Load Following	High
Clean Coal (IGCC) (Note f)	£800-1000/kW^e	3.2	1 year	4 years	Baseload	High
Clean Coal (IGCC) with CCS (Note e, f)	£1000 - £1250/kW^e	4.2 p/kWh	5 years	4 years	Baseload	High
Gas CCGT with CCS (Note e)	£494/kW^e	4.8 p/kWh	5 years	4 years	Baseload/ Load Following	High

Notes:

(a) The cost-of-electricity for coal is given on the basis of a coal price of £30.5/te, which is the current cost of UK and world traded coal. The estimate is a company estimate supported by the Royal Academy of Engineering estimate. [Ref. 9]

(b) Nuclear costs are a range encompassing the estimate from the Royal Academy of Engineering report (2.3p/kWh).

(c) The cost-of-electricity quoted for gas – CCGT and gas CCGT with CCS – is highly dependent on the price of gas. The range quoted is for a gas price of 50p/therm.

(d) Renewables (Onshore and Offshore Wind) costs are derived from the Royal Academy of Engineering report.

(e) Cost for CCS include Capture but not Storage. No credit is given for Enhanced Oil Recovery. Estimates derived from International Energy Agency GHG Programme reports. [Ref. 6 and 7]. Low end of range is for ASC Retrofit + CCS.

(f) There is a very wide range of estimates for IGCC. Promoters of IGCC in the USA indicate it is around 25% more expensive than Clean Coal (Advanced Supercritical).

It is clear that Clean Coal (Advanced Supercritical), whether New-Build or Retrofit, is very cost-competitive with Gas-fired CCGT and Renewables.

4. NEW CLEAN COAL IN OVERSEAS MARKETS

4.1 Market estimate for CATs

There is a huge potential market for CATs.

Mitsui Babcock estimates the total world market for "capture-ready" coal-fired power plant to be around 2000 GW out to 2050 – worth £1300 Bn. (This may be conservative – compare the International Energy Agency World Energy Outlook estimate for 4800 GW total extra generation by 2030).

The addition of carbon dioxide capture would add about 33% to this market estimate. To achieve the Gleneagles targets of 60% reduction in CO_2 by 2050, at least 60% of the plants would need CO_2 capture fitted.

4.2 International approaches

CATs research, development and demonstration programmes have been announced by the EU and US, Canada, Australia, Norway and Japan governments. The EU, UK and China are co-operating in the NZEC (Near Zero Emissions Coal power plant) project. There is broad international collaboration through the G8, International Energy Agency and the US-led Carbon Sequestration Leadership Forum.

Many of these programmes cover capture technologies (for coal and gas) and storage in oil fields (with enhanced oil recovery - EOR) depleted oil and gas fields, saline acquifers and unmineable coal seams (with enhanced coal bed methane – ECBM). It is expected that technologies proven full-scale in OECD countries will find large markets around the world post 2012 when it is anticipated that global CO_2 reduction targets will be adopted.

5. SCENARIOS FOR NEW CLEAN COAL IN THE UK

5.1 Background

The decisions of UK generators on whether to opt-in or opt-out coal-fired plant under the Large Combustion Plant Directive will have a significant impact on both security of supplies and carbon dioxide emissions. The more plants which opt-out the greater pressure on security of supplies but the greater the reduction of carbon dioxide emissions. Opted-out plants are restricted to 20,000 total operating hours from 2008 and must close at the end of 2015. Opted-in plants must meet emission limit values for NOx, SOx and particulates from 2008 but have no restrictions on load factor, operating hours or carbon dioxide emissions. Both types of plant will need to purchase carbon allowances for emissions in excess of their allocations in the 2008 – 12 National Allocation Plan. The two groups of plants each provide opportunities for New Clean Coal. There is an opportunity for Clean Coal to be installed on all coal powered plants, whether they are opted in or opted out of the Large Combustion Plant Directive, but Government needs to step in to encourage industry to invest and reduce emissions in this way.

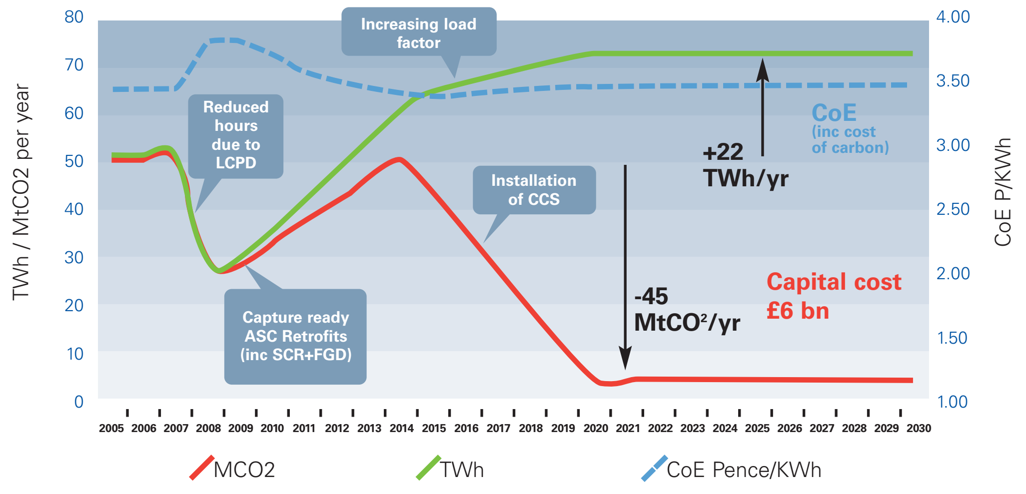
5.2 Opted-out Coal Plant

Currently (January 2006), 11 GW of coal-fired plant have not announced plans to fit FGD and are therefore expected to Opt-out.

The annual CO_2 emissions and electricity generation from these plants will reduce from the current level over the period 2008 – 15 (on the assumption that most plants will spread out their operating hours over the eight year period) and 11 GW of generating capacity will be lost from the grid by 2015. Some plants will close earlier than 2015 either because they use up their hours more quickly or because of plant failures which will be uneconomic to fix. Decisions on the replacement of this capacity will have to be made before CO_2 capture and storage technologies are fully commercialised.

If, by way of illustration, each of these opted-out plants was retrofitted with capture-ready advanced supercritical boiler-turbine technology between 2008 and 2015, and if each was further retrofitted with CO_2 capture and storage between 2015 and 2021, the broad pattern of generation, emissions and cost of electricity would be that shown in Figure 12. By 2021, these plants could be producing 44% more electricity (22 TWh/yr), with near zero emissions (CO_2 emissions reduced by 45 Mt CO_2/yr) and a cost-of-electricity (including CO_2 capture) of 3.5 p/kWh.

Figure 12: UK Opt-out coal plant replaced with ASC and CCS



If, instead, the opt-out plant were replaced with gas and CCS, the total capital cost would be £5 Bn, but for a gas cost of 50p/therm, the cost of electricity would increase to 5.4p/kWh. Using wind (50% onshore : 50% offshore), the total capital cost would be £26 Bn and the cost of electricity 5.25p/kWh.

5.3 *Opted-in Coal-fired Plant*

16.6 GW of coal-fired plant are expected to fit FGD and Opt-in. These plant can be expected to operate to 2016 with relatively high load factors, buying carbon allowances if necessary. These plants have FGDs that are designed with 20 or 25 years life – out to 2020 or 2025 but boilers and turbines that will almost all be more than 45 years old by 2015. By the end of 2015, under the Large Combustion Plant Directive, these plants will have to fit Selective Catalytic Reduction to reduce their NOx emissions to 200 mg/Nm3.

Retrofitting of CATs (advanced supercritical boiler turbine) requires a twelve month outage, so early retrofits to the opted-in plants are unlikely because the generation capacity is needed to meet winter demand and generation from coal is highly profitable as long as gas prices remain high. Retrofits may be possible once there has been investment in other new or retrofit plants to ease the capacity gap, or if a boiler, turbine or main steam pipework of an existing plant suffers a plant failure that would force major refurbishment.

A possible scenario is that between 2015 and 2025 each of the Opted-in plants would be retrofitted with advanced supercritical boilers and turbines and CO_2 capture. By 2025 the carbon dioxide emissions of these plants would be reduced by 70 Mt CO_2/yr.

5.4 *Clean Coal in a diverse portfolio*

Consideration of the capacity needed, the wish to retain diversity, the need to reduce emissions and the timescales necessary for building new or replacement plant points to the following common sense 'plan' for investment in the UK generation portfolio.

Component of portfolio	GW	Appropriate technology
Short term growth and nuclear replacement (Up to 2010)	7	Renewables, Gas and New Clean Coal
Replace Opt-out Coal (2008 to 2015)	11	Retrofit Clean Coal
Nuclear closures (2010 to 2020)	5.7	New Clean Coal or Gas (early closures) then new Nuclear
Replace Opt-in Coal (2015 to 2025)	16.6	Retrofit Clean Coal
Medium-term growth (2010 to 2025)	?	New Clean Coal or Renewables
Long-term growth (2025 +)	?	New Clean Coal or New Nuclear or Renewables

6. *UK GOVERNMENT ACTIONS RELATED TO CARBON ABATEMENT FROM CLEAN COAL*

6.1 *Carbon Abatement Technologies Strategy*

The government (DTI and DEFRA) announced its CAT Strategy in June 2005 (Ref. 10). The Strategy has the declared objective:

"To ensure the UK takes a leading role in the development and commercialisation of Carbon Abatement Technologies that can make a significant and affordable reduction in CO_2 emissions from fossil fuel use."

The Strategy includes a ten-point action plan and significant progress has been made on some of these actions:

	Action	Present Status	Comment
1.	**Support research, development and pilot-scale demonstration of CATs.**	Action implemented quickly by the Technology Strategy Board. First call November 2005.	Important to have continued calls on a regular basis to ensure continuity and allow industry to be able to plan with visibility and assurance.
2.	**Support the demonstration of CO_2 capture-ready plant.**	DTI reviewing options and preparing application for State Aid approval. Budget for 2005-09 increased from £25M to £35M.	Very welcome, especially as a facilitating fund, but still well below that recommended by industry. Need to have a successful programme in order to argue the case for increased expenditure.
3.	**Support the demonstration of CO_2 storage.**		
4.	**Facilitate international collaboration in UK-based CAT development and demonstration projects.**	Major EU-wide initiative established through ZEFFPP European Technology Platform launched in December 2005. Strategic Research Agenda and Deployment Strategy now under development for mid-2006.	Likely feature is that a series of demonstration plants will be recommended – at least one should be in UK utilising EC support. This will be dependent on the UK finding adequate top-up funds.

	Action	Present Status	Comment
5.	**Facilitate and support UK collaboration in CAT development and demonstration projects based in other countries.**	Memorandum of Understandings signed with US, China, Norway. UK/EU initiative on China Near-Zero Emissions Power Plant (nZEC).	These will assist but it will be essential to ensure that the focus of work undertaken will lead to 'win-win' actions and that benefits will accrue to the UK through export of products, services and research. Excellent initiative by DEFRA/DTI supplements the intent of the CAT Strategy.
6.	**Examine possible measures to encourage the initial commercial deployment of CCS.**	Consideration of incentives is underway in DTI/DEFRA but this is now subsumed in the Energy Review.	Very important. It is recognised that the Renewables Obligation is leading to investment in Renewables. But there are no comparable incentives for CATs and the EU ETS is too short-term. Incentives need to cover all CATs as well as CCS.
7.	**Facilitate the acquisition and transfer of knowledge and Know-how.**	UK DTI have taken a lead role in the Carbon Sequestration Leadership Forum (CSLF) and bilateral discussions.	Important to continue to play active roles in international treaties such as the Carbon Sequestration Leadership Forum and so maintain dialogue/action with developing countries especially.
8.	**Lead in preparing the national and international regulatory frameworks and market systems.**	Strong lead taken by DTI and DEFRA.	Good progress.
9.	**Increase public awareness and stimulate an informed debate on the role of CATs.**	?	Accepted as an in important aspect and needs a co-ordinated approach with industry / government / research as yet not defined
10.	**Develop and maintain a route map for the development of CATs in the UK.**	In preparation.	

Actions 2, 3, 6 and 8 are absolutely vital for achievement of the government's Objectives. The 2006 Energy Review should prioritise these actions, injecting additional staff and financial resources.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary of Messages to Government

- Carbon-abated fossil fuels (including CCS) can complement end-use energy efficiency, renewables, nuclear and fuel-switching to reduce carbon dioxide emissions.

- A large number of new or replacement carbon-abated power plants will need to be operational by 2015 and need to be started between 2006 and 2011.

- Phased introduction of carbon-abated clean coal is the lowest risk win/win/win approach to meet all three EWP objectives relatively quickly:

  o clean coal delivers cheaper electricity than gas or renewables;
  o clean coal provides the means to achieve global emission targets;
  o clean coal in a diverse portfolio can reliably close the UK's looming generation gap.

- The earliest and least expensive opportunities for carbon-abated clean coal will be retrofits at the Opted-out plants.

- A programme of capture-ready coal-fired plant followed by retrofit of CCS will set an excellent global example.

7.2 Recommendations to the Government

- A much clearer commitment is needed to clean coal within a diverse power generation portfolio with the objective of achieving investment in clean coal plant to fill the generation gap and maintain the diversity of the portfolio – 15 - 20 GW of capture-ready plant operational by 2015 with the further addition of Capture and Storage by 2025.

- Prompt action ahead of the completion of the Energy Review is necessary to ensure the rules for the National Allocation Plan for CO_2 allowances in the period 2008 – 2012 incentivise investment in new capture-ready carbon abatement technologies. The rules in Germany have been devised in this way and in Germany utilities are investing in clean coal.

- Positive financial incentives for investment in Clean Coal should be related to the carbon dioxide abated compared with the average current UK coal-fired plant. These incentives should apply to both Track 1 and Track 2 CATs.

- Accelerate actions implemented under the DTI Carbon Abatement Technologies Strategy to deal with regulation and ETS issues for CCS.

- Additional government funding is necessary to support the government CAT strategy with demonstrations of carbon dioxide capture and storage during the period 2008 to 2015. These demonstrations should include amine scrubbing and oxyfuel firing on hard bituminous coals to parallel the likely demonstrations in Germany and elsewhere on lignite.

- The Government should impose a requirement that any new (or substantial retrofit) project should be designed to be capture-ready. As a further step, the Government could signal the introduction of Emission Limit Values for CO_2 from, say 2020, so that when generators are making decisions regarding the Large Combustion Plant Directive in 2016 they are aware of the long-term situation. The Emission Limit Values should match "best available technology" for gas or coal as appropriate.

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Further information is available from:

Mike Farley
Director of Technology Policy Liaison
Mitsui Babcock
+44 (0) 141 885 3942
mfarley@mitsuibabcock.com

Julie Kelly
Group Communications
Mitsui Babcock
+44 (0) 1293 584683
jkelly@mitsuibabcock.com