MITSUI BABCOCK RESPONSE TO TREASURY CONSULTATION ON CCS

Mitsui Babcock Energy Limited (Mitsui Babcock) is an international energy engineering company, based in the UK and supplying power generation equipment and after-market services for fossil fuelled and nuclear plant plus services to the chemical process industries. It has been a leader in development of power generation technologies since the company was formed in the UK in 1891. It continues to lead particularly in advanced clean coal firing technology and has markets in Europe, Asia and USA. In China, the company's supercritical boilers have a share of about 20% of the large market. It is a leader in Europe in the development of Carbon dioxide capture technologies for coal-fired plant, including technologies suitable for retrofit to coal power plant overseas. The company is leading a large collaborative UK project (DTI 407) on retrofitting of CO_2 Carbon Abatement technologies to UK power stations. It is now able to offer "capture ready" clean coal power plants for new build or retrofit and is working with UK generators who are developing projects which will use its technology.

Mitsui Babcock believes that the UK should have a diverse, balanced fuel supply portfolio which will delivery secure supply at affordable prices with reducing CO_2 emissions for short, medium and long term. In answering the review questions we believe that we offer the means of setting up such a portfolio progressively introducing CCS. We are hopeful that the government will be able to develop a fiscal and/or regulated framework that will:

- encourage investment by financiers, utilities, technology providers and contractors;
- deliver secure, stable, affordable power supply to the UK;
- meet CO_2 targets;
- demonstrate CCS on a large scale;
- create jobs and an environment for ongoing R&D;
- create export opportunities for UK companies.

Mitsui Babcock's vision for CATs in the UK sees the building of a programme of capture-ready high efficiency coal-fired power plants, each started over the next five years and completed by 2015. In parallel, over the period 2007 – 2012, there should be a small number of selected government-supported first-of-class demonstrations of CCS in the UK covering a range of technologies and storage sites. This will lead to a point around 2012 to 2015, when the performance and costs of demonstrations are clear and the regulatory framework for CCS is established, when choices can be made on retrofitting CCS to the recently installed plant and on further new plant built thereafter.

1.31 <u>What are the barriers to commercial development of CCS?</u>

From the perspective of an equipment supplier, we see the barriers as being:

(i) No clear business case for our customers who cannot monetise the value of carbon savings – due to uncertainty on the carbon price and duration of ETS rules and lack of regulation requiring CO_2 emissions reduction;

(ii) No clear regulatory framework for CCS or certainty of the timescales for its introduction;

(iii) Risks associated with new technology. Customers in the power industry are risk-averse and do not like to build first-of-a-kind.

(iv) A significant mismatch between the greatest need (CO_2 abatement on coal-fired power plant of the types installed and being built worldwide) and the interests of the oil companies capable of storing CO_2, who naturally focus on gas-fired power plant, EOR and transport fuels.

The government has an important role in removing all these barriers.

1.32 Potential carbon reductions

Worldwide, Mitsui Babcock considers that carbon-abatement from fossil fuel power generation is the highest priority amongst all supply-side technologies. We fully support the government's objective stated in the DTI Strategy for Carbon Abatement Technologies for Fossil Fuels, i.e. "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".

CATs should be given the highest priority for the following reasons:

(i) Importance of coal globally

Power generation from coal-fired generation globally (6000 TWh) accounts for nearly 30% of global CO_2 emissions and these emissions are set to nearly double as coal use grows. Emissions from gas-fired generation are less than this but are growing faster than coal. CATs solutions are therefore needed for both fuels (coal and gas) and for existing plant, recent new build and future plant. It should be noted that the 400 GW of coal-fired plant being commissioned in China between 2000 and 2010 will be operational for 50 years plus.

(ii) UK generation gap needs coal-fired generation

The generation gap in the UK (20 GW by 2015) will be filled mainly by fossil fuel power generation, and if the appropriate policy measures are in place the new plant will use carbon-abatement technologies and set an example to the rest of the world.

(iii) Low cost electricity

Carbon-abated clean coal technologies offer relatively low costs-of-electricity compared to most other measures for reducing carbon emissions.

For the UK, we have calculated the potential carbon savings per year for different power generation technologies capable of large-scale use. For coal-fired power generation power plant we have followed the DTI's CAT Strategy and divided the Carbon Abatement technologies into Track 1 (efficiency improvement and biomass cofiring) and Track 2 (CCS).

Estimated CO_2 savings

	Savings vs 2003 Baseline[1] mtCO_2/yr
Coal	
Track 1, Capture-ready ASC upgrade of all UK coal fleet	24
Capture-ready ASC upgrade + 20% biomass cofiring on all UK coal fleet	43
Track 2, CCS on all UK coal fleet	102
Wind	
10% of generation by wind instead of gas	5
20% of generation by wind instead of gas	10
Gas	
CCS on all UK gas fleet	40

We regard Track 1, efficiency improvement by use of Advanced Supercritical, as being an essential precursor to Track 2. Unless the plant has a high efficiency (say > 42% LHV), the consequence of the energy penalty for capture will be an unacceptable cost-of-electricity. If the plant has a high efficiency, Best Available Technology for coal, i.e. 46.5% LHV, then even with an energy penalty of 9% the resulting overall efficiency of 37.5% is better than many existing power plants.

1.34 Technology Options

1.34.1 What are the different technological options currently available and in development for each stage of the CCS process – and what are the costs of these options?

The CCS process can be separated into three parts which can be considered separately:

- **Capture** of CO_2 (including compression to 110 bar);

---

[1] 119 mtCO_2 for Coal and 47 mtCO_2 for Gas

- **Transport** from source to sink (including booster pumps/compressors if required, dependent on pipeline length);

- **Storage** (including additional compression to reach the specific injection pressure).

According to publications by Vattenfall and others, who forecast a total cost of 20 €/t by 2020, the greatest cost (two-thirds) is for capture, with transport and storage accounting for one-third. Capture costs are dependent on the technology and the fuel, whilst transport costs are dependent on distance and terrain, and storage costs are dependent on the type of storage.

Capture of CO_2

There are three main technology options for CO_2 capture from power plants:

- post-combustion capture
- pre-combustion capture
- technologies where the nitrogen is excluded from the combustion process (more commonly known as oxy-fuel combustion or O_2/CO_2 recycle combustion.

These options are schematically illustrated in Figure 1.

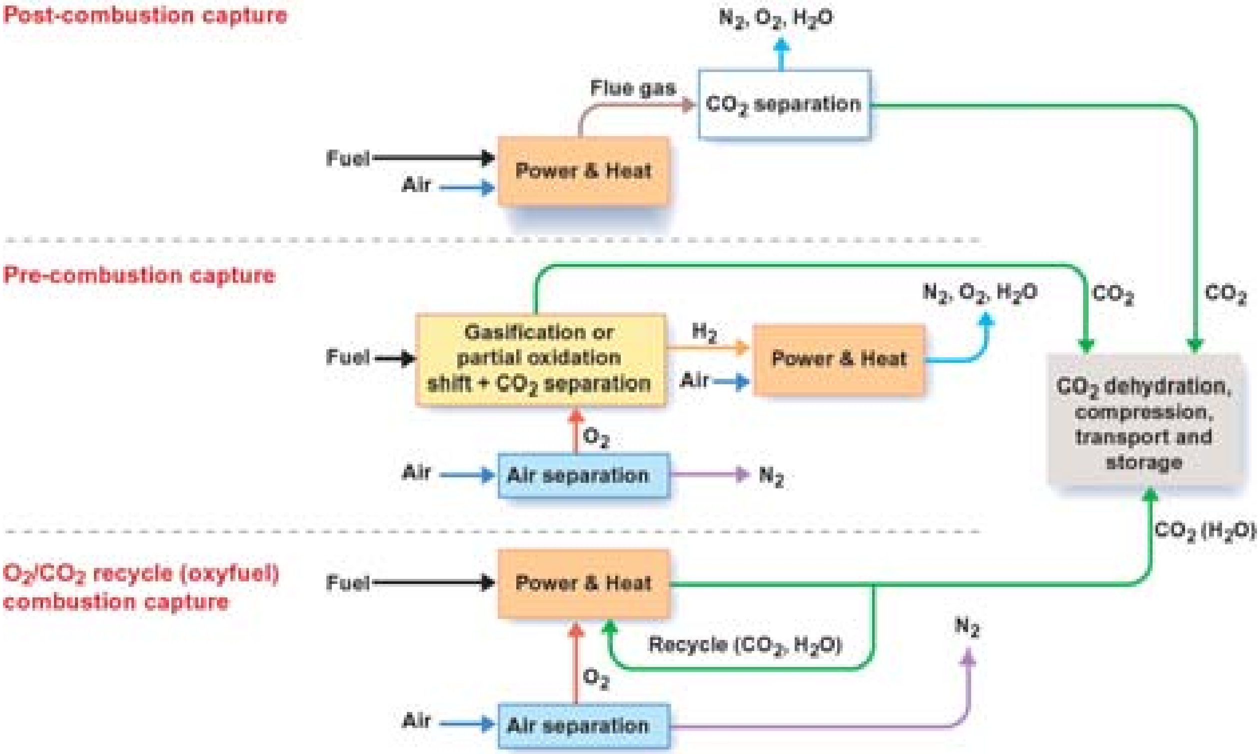

Figure 1 Main technology options for CO_2 capture from power plants

In **post-combustion** capture, the CO_2 is removed from the power plant flue gas. Commercially available technology includes CO_2 capture using absorption in an aqueous amine solution. The CO_2 is then stripped from the amine solution and dried, compressed and transported to the storage site.

In **pre-combustion** capture, the carbon content of the fuel is removed prior to combustion in order to produce a hydrogen rich fuel and a CO_2 by-product stream. For coal this can be done via gasification. After gas cleaning, the synthesis gas is shifted to produce a hydrogen-rich fuel gas mixed with CO_2. The CO_2 is removed by physical absorption and the hydrogen combusted in a gas turbine. In this way the CO_2 is removed at a higher concentration in the gas stream and at high pressure. A similar scheme can be applied to natural gas, where the gasification step is replaced with a reforming stage to produce the synthesis gas.

In the **O_2/CO_2 recycle combustion process**, nitrogen is removed from the air using an air separation unit, and the fuel is combusted with oxygen in an atmosphere of CO_2 which is re-circulated to control the combustion temperature. This gives a flue gas consisting mainly of CO_2 and water vapour which can be condensed to give a highly concentrated CO_2 stream for transport and storage.

The available techniques for CO_2 capture have been reviewed recently by the European Technology Platform "Zero Emissions Power Plant" (ETP ZEPP WG1) (Mitsui Babcock is a member). The techniques listed above are those judged likely to be suitable for commercialisation up to 2020. They can be applied as CO_2 capture technologies using commercially available equipment with some modifications and developments, although significant equipment scale-up may be required. There are other options at the development stage – listed, for example, in the IPCC Special Report on Carbon Dioxide Capture and Storage 2005 – but these are further away from commercialisation.

Costs of options for capture

There are many published studies of the estimated costs of CO_2 capture by the technologies listed above.

The ETP ZEPP has recently pulled together a concensus view on the costs, making use of IEA studies, studies under the ENCAP project and various national studies – mostly Germany. Table 1 is an extract from the ZEPP draft report at 11 April 2006, converted from Euro to £ at the exchange rate of 1.40 Euro/£.

There is additional confidence in some of these cost estimates through their validation by recent contracts or proposals. For example, Mitsui Babcock quotations and contracts for recent coal-fired supercritical power plant in Europe and USA have re-validated the cost of ~75% of the content of the estimated cost of an Advanced Supercritical Coal-fired Power Plant with CO_2 capture by either Post Combustion or Oxyfuel and additionally have validated the claim of 46.5% efficiency (LHV) for a UK site. Further support for some of the estimates is provided from the ENCAP project (an EU-funded collaborative project). See specific references in the Table 1.

In the UK, in support of the Energy Review, the UK Energy Research Centre (UKERC) is undertaking MARKAL modelling of the energy system. To provide updated input of investment costs and cost of electricity to the model, an industry workshop was held on 10 April 2006. The cost estimates submitted by Mitsui Babcock are presented in Table 2.

Table 1: Investment Costs for CO_2 capture – Coal and Gas

		Hard Coal Power Plants							Gas Power Plants			
		1	2	3	4	5	6	7	8	9	10	11
Technology		Base: State of the art Supercritical Pulverised Coal w/o capture	Base: State of the art Capture-ready Supercritical Pulverised Coal w/o capture	Base IGCC plant w/o capture	Pre-combustion capture IGCC	Base PF plant w/o capture	Post-combustion capture Supercritical Pulverised Coal	Oxyfuel Supercritical Pulverised Coal (b)	Base: State of the art CCGT w/o capture	Pre-combustion + CCGT	Base NGCC plant w/o capture	Post-combustion + CCGT
Data source		Derived from NRW 2004	Mitsui Babcock 2006	IEA GHG 2003 Option A1 (Shell)	IEA GHG 2003 Option B1 (Shell)	IEA GHG 2004	IEA GHG 2004	IEA GHG 2004 / Mitsui Babcock		IEA GHG 2005/1	IEA GHG 2004	IEA GHG 2004
Performance Data Net electric power output	MW	555.5	694	776	676	758	865	750	420	694	778	662
Net electric efficiency (LHV)	%	44.4%	46.5%	43.1%	34.5%	44.0%	34.8%	37.6%	58%	41.4%	55.6%	47.4%
Gross Power output	MW	600		910	896	831	827	1033	427	785	800	740
Availability	%	89	89	85	85	85	85	85	92			
Plant load factor	Hours/yr	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500
CO_2 CO+ capture rate	%	-	-	-	85	-	87.50	90	0%		-	85
CO_2 delivery pressure	Bar	-	-	-	110	-	110	110	-	110	-	110
Fuel Fuel Type		Hard coal	Hard coal	Hard coal	Hard coal	Hard coal	Hard coal		Natural Gas	Natural Gas	Natural Gas	Natural Gas
Heating Value (LHV)	MJ/kg	24.80							45.21			
Emission Factor	g/MJ_2	85.5							58.3			
CO_2 content	t/MWh el.	0.775	0.740	0.783	0.954	0.743	0.940	0.950	0.362		0.378	0.443
CO_2 released	t/MWh el	0.775	0.740	0.783	0.143	0.743	0.117	0.095	0.362		0.378	0.066
Economics Total Inv Cost incl. Owners costs 15%	£/kW net	754	850	991 (a)	1345	857	1233	1075 (c)	338	788	340	609

Notes:

(a) Recently validated by 285 MG IGCC Southern Company Orlando contract published as £1085/kW
(b) New build Oxyfuel or Capture-ready Supercritical as column 2 plus Oxyfuel retrofit
(c) Recently validated by ENCAP study to be published June 2006, £1151/kW net.

Table 2: Costs of Electricity for Carbon-abated Coal Options

		Total Investment Cost £/KW^e net	Cost of Electricity (CoE) p/kWh	Coal Price £/tonne	Coal Price US$/GJ	Load Factor	Discount Rate	Owners Costs	Gross MWe	Net MWe	Plant Effcy %LHV.net
1	Clean Coal (Advanced Supercritical) New Build Power Plant (Capture Ready)	850	2.8 3.1	20.0 30.5	1.42 2.17	85% 85%	10% 10%	17% 17%	750 750	694 694	46.5 46.5
2	Clean Coal (Advanced Supercritical) Retrofit (Capture Ready)				1.42 2.17						
	- Excluding FGD and SCR	355	1.6 1.9	20.0 30.5	1.42 2.17	85% 85%	10% 10%	17% 17%	507 507	476 476	44.7 44.7
	- With FGD and SCR	546	2.2 2.5	20.0 30.5		85% 85%	10% 10%	17% 17/5	507 507	476 476	44.7 44.7
3	Clean Coal (Advanced Supercritical with CO_2 capture	1075	3.4 3.8	21.6 30.5	1.5 2.17	85% 85%	10% 10%	17% 17%	1033 1033	750 750	37.6 37.6
4	Capture Ready Advanced Supercritical Retrofitted with CO_2 capture	240	3.8 4.2	20.0 30.5	1.42 2.17	85% 85%	10% 10%	17% 17%	737 737	535 535	37.6 37.6
5	Clean Coal (IGCC)	991	3.4	21.6	1.5	85%	10%	15%	910	776	43.1
6	Clean Coal (IGCC) with pre-comb. CO_2 capture	1345	4.5	21.6	1.5	85%	10/5	15%	896	676	34.5

Cost of Electricity (p/kWh or £/MWh) takes into account estimates of operation and maintenance costs and fuel costs, the latter being highly dependent on the price of coal (see Table 3). These figures show the increase in cost of electricity due to CO_2 capture on a coal-fired plant to be less than the increase due to a +20p/therm increase in the price of gas (see Table 3).

Table 3

	Coal Price	
Coal fired Power Plant	£20/tonne 1.42 USD/GJ	£30.5/tonne 2.17 USD/GJ
Adv. Supercritical New Build, Capture Ready	2.8	3.1
IGCC	3.4	-
Adv. Supercritical with CO_2 capture	3.4	3.8
IGCC with pre-combustion capture	4.5	-

	Gas Price	
Gas fired Power Plant	30p/therm 5 USD/GJ	50p/therm 8.3 USD/GJ
CCGT without capture	3.8	4.8

Carbon dioxide transport

Carbon dioxide is compressed to around 110 bars (11 MPa) for transport by pipeline. Construction costs for 1 metre diameter pipe are about £0.8M/km. This number is increased for offshore construction. For difficult terrain, or through populated areas, it can double. Specific transport costs are around £1 per tonne of CO_2 per 100 km at 3 m/s, with 54% of the costs due to capital depreciation, 31% pumping and 15% O+M[2].

For UK situations, the transport costs are thus likely to vary from £1 to £10/ton of CO_2.

According to the IPCC report on CCS (2005)[3], costs of transportation by ship are less than for pipelines for distances over 1000 km, and for amounts smaller than a few million tonnes of CO_2 per year.

Carbon dioxide storage

The costs are made up of the costs of drilling wells, primarily depth related, and the operational costs. For offshore, there is the additional cost of an offshore platform (for drilling and injection).

A range of costs in £/tonne CO_2 for various storage options is given in Table 4, from the TNO ECOFYS 2004 report.

---

[2] TNO ECOFYS “Global Carbon Dioxide Storage Potential and Costs” 2004

[3] Inter-government Panel on Climate Change Report, “Carbon dioxide capture and storage – summary for Policy makers”, 2005

Table 4

	Depth of storage (m)		
	1000	2000	3000
Aquifer onshore	1.8	2.7	5.9
Aquifer offshore	4.5	7.3	11.4
Natural gas field onshore	1.1	1.6	3.6
Natural gas field offshore	3.6	5.7	7.7
Empty oil field onshore	1.1	1.6	3.6
Empty oil field offshore	3.6	5.7	7.7
	Low	**Medium**	**High**
EOR onshore	-10	0	10
EOR offshore	-10	3	20
ECBM	0	10	30

Clearly, storage offshore is 2-3 times more costly than onshore.

The IPCC report states: “When storage is combined with EOR, ECBM or (potentially) Enhanced Gas Recovery (EGR), the economic value of CO_2 can reduce the total cost of CCS. Based on data and oil prices prior to 2003, enhanced oil production for onshore EOR with CO_2 storage could yield net benefits of 10-16 US\$/tCO_2 (including the costs of geological storage). However, the economic benefit of enhanced production depends strongly on oil and gas prices. In this regard, the literature basis for this report does not take into account the rise in world oil and gas prices since 2003 and assumes oil prices of 15-20 US\$ per barrel. Should higher prices be sustained over the life of a CCS project, the economic value of CO_2 could be higher than that reported here.”

Question 5

1.34.2 What scope is there for applying these technological options to different forms of power generation (particularly gas and coal) and other large-scale sources of CO_2 emissions, and can they be installed on the basis of both new-build and retrofitting?

	Power generation		Other CO_2 sources		
	Pulverised Coal (1)	Coal Integrated Gasification Combined Cycle (2)	Natural Gas CCGT	Cement, Steel-works	Ammonia Production, Hydrogen from Coal
Precombustion	-	√ N, R	√ N, R	-	√ N, R
Post combustion	√ N, R	√ N, R	√ N, R	√ N, R	-
Oxyfuel	√ N, R	-	-	?	-

Notes:
N = New Build
R = Retrofit
(1) = Also oil and gas-fired boilers
(2) = Also petcoke

All of the technologies are suitable for New Build, and all can be retrofitted to existing plant, e.g.

- pre-combustion capture could be retrofitted to an IGCC, a CCGT or a hydrogen-from-coal or ammonia production plant
- post-combustion or oxyfuel can be retrofitted to existing (modern) coal-fired power plant. This is very important given the large number of such plant now being built and planned world-wide.

Such retrofits will be easiest if the power plant has been designed with a view to the later fitting of CO_2 capture – i.e. it is "capture-ready" – see Q. 1.48.

Question 6

1.34.3 At what level of market readiness are these various technological options?

It must be emphasised that technologies are available for deployment today. No inventions are required but careful design and considerable scale-up of some parts of the plant is necessary.

All of the options are sufficiently understood to the point where plants can be designed to be capture-ready or first-of-class new build plants with capture can be designed. In each case, a site specific "front-end engineering design" study is required to optimise the design. Projects under consideration now include:

Gas

- Peterhead/Miller 350 MW^e gas and EOR (BP/SSE/Shell/Conoco);
- 860 MW^e gas and EOR on Drangen (Shell/Statoil).

Coal

- 1000 MW^e Tilbury supercritical coal with CCS (RWE);

- 2 X 500 MW Ferrybridge capture-ready supercritical coal (SSE);
- 450 MW IGCC project on East Coast (E.ON);
- 900 MW Hatfield IGCC with CCS (Powerfuel)
- Teesside 800 MW IGCC with CCS in mature oil fields (Progressive Energy).

All of the UK projects are dependent on the outcome of the Energy Review and the Treasury Consultation on CCS.

The technologies will be considered fully commercialised only when a number of relevant projects have been completed and several years of operation have been observed and several players are in a position to offer each technology.

At the present time, there are many GW of supercritical boilers in operation, in construction (Germany, USA, China, India) and new plants are currently being tendered in these countries, with progressively increasing steam conditions and efficiencies. Advanced Supercritical plant with 46.5% efficiency (700g/kWh) can be purchased with full availability and performance guarantees – i.e. fully commercialised, but there are higher risks/innovation with Retrofits. The related carbon-capture technologies (Amine Scrubbing and Oxyfuel) require full-scale demonstration. Projects are planned and in Europe, USA and elsewhere, as well as UK. Full commercialisation is anticipated from 2015.

IGCCs are not so commercialised. To date there are only four operational on coal, each in the range 250-335 MW, each commissioned about ten years ago. There have been major availability issues with all four plants. Only one plant, for one year, has achieved 80% availability. Several IGCCs are to be built in the USA, and just two of these – "Futuregen", to be commissioned 2013 for coal, and BP Carson to be commissioned 2011 for PetCoke – will have CO_2 capture incorporated. A number of projects for IGCC – with pre-combustion capture, have been mooted in Europe, including EON (UK), RWE (Germany) and Nuon "Magnum" (The Netherlands). Based on the experience of these first-of-class plants in UK, Europe and USA, full commercialisation can be anticipated around 2015.

Question 7

1.34.4 What limitations exist when it comes to selecting from the options at each stage to form a full CCS process?

Each of the capture options can be combined with each of the transport options and used with each of the storage options.

An important limitation is the availability of pipeline infrastructure. Small individual projects cannot justify pipelines.

1.35 Engineering and Manufacturing Capability

Mitsui Babcock is well placed to comment, as a developer of Carbon-Abated Technologies for coal-fired plant, both high efficiency advanced supercritical boiler/steam turbine plant and carbon dioxide capture, the only UK OEM for coal-fired boilers and a major supplier of such plant in China over the last ten years[4]. The company is leading an industry-wide project (DTI 407) on the retrofit of high efficiency capture-ready plant and CO_2 capture to the UK generation fleet. The company's partners in the project are Alstom (Steam Turbines), E.ON UK (balance of plant), Air Products (Air separation unit and CO_2 cleaning and compression), Imperial College and Fluor UK (amine scrubbing) is a subcontractor. Sponsors are E.ON, Drax Power, SSE, RWE, EDF and ScottishPower.

The UK has a strong business capability with carbon abatement technologies generally. This capability takes in design, development and manufacture relevant to this type of technology. More broadly, we have experience of designing and constructing fossil fuel power plant, both coal and gas. We also have strong capabilities in offshore engineering, oil and gas extraction and geological science needed to appraise, operate and monitor CO_2 storage sites.

With this position, UK companies can lead the "roll-out" of these technologies to other countries, developing and developed, bringing environmental benefit and economic benefits to the UK. We have estimated that the global market for CATs for coal-fired generation will be worth £1500 Bn over the period to 2050[5], broken down as shown in Table 5. The UK should be able to secure 10% or more of this market by a range of business models from equipment supply to technology licence and consultancy, bringing a large financial return on the government's investment.

Table 5: Mitsui Babcock Estimate of Global Market for CATs

		Global Market (in £Bn)
Retrofits in	2005 - 2020	24
New Build	2005 - 2020	524
New Build	2021 - 2030	382
New Build	2031 - 2050	433
CCS	2005 - 2030	83
CCS	2031 - 2050	75
		£1,520Bn

---

[4] Details of these technologies are given in Mitsui Babcock document "Clean Coal Technology and the Energy Review", www.mitsuibabcock.com, and in DTI Best Practice Brochure, BPB010 – Jan 2006 – "Advanced Power Plant using high efficiency Boiler Turbine"

[5] Private communication, Mitsui Babcock to Scottish Enterprise

The need for, and benefits of, the roll-out to developing countries are recognised in the Gleneagles G8 targets and in the announcement of the UK/Europe “Near Zero Coal Fired Power Plant project for China” by DEFRA.

It is therefore essential that the government supports both R+D in CATs and full-scale demonstration/first-of-class projects in the UK. This will show the government is serious about reducing CO_2 from fossil power plants and allow it to speak with authority in international discussions on the topic.

Support for R+D in Carbon Abatement Technologies (including CCS) is a key priority in the DTI Technology Programme within the government's 10 year Science and Innovation Framework. The government "is committed to stimulating the development and deployment of these technologies" both because of their contribution to the UK's climate change and energy security goals and because they represent a major business opportunity to the UK, as global demand for these technologies is set to expand significantly in future years. This support is very welcome and the industry is responding by organising major collaborative R+D programmes that will underpin the carbon abatement technologies for coal (including Oxycoal firing, Amine Scrubbing, Gas turbine combustors for hydrogen, etc., etc). It is essential that the R+D support at its present level is sustained in order that the industry can make plans for the next ten years.

With respect to demonstration projects, a similar forward commitment is needed. Mitsui Babcock's vision for CATs in the UK sees the building of a programme of capture-ready high efficiency coal-fired power plants, each started over the next five years and completed by 2015. In parallel, over the period 2007 – 2012, there should be a small number of selected government-supported first-of-class demonstrations of CCS in the UK covering a range of technologies and storage sites. This will lead to a point around 2012 to 2015, when the performance and costs of demonstrations are clear and the regulatory framework for CCS is established, when choices can be made on retrofitting CCS to the recently installed plant and on further new plant built thereafter. Demonstration/first-of-class projects are an essential step on the research, development, demonstration and deployment (R D D and D) chain and it is recognised[6], that the lack of support for "Demonstration" is a significant gap in the chain and barrier to deployment. Whilst the £35M committed by DTI for CATs demonstrations in 2006 is a good start, and in combination with appropriate ETS rules should be sufficient to enable a Capture-ready ASC retrofit demonstration, more substantial budgets will be needed to trigger full CCS projects. The industry (APGTF) [7] originally indicated £100M/year would be needed. For example, demonstration of retrofit of Oxyfuel-firing for CO_2 capture would be likely to cost £125M, plus transport, plus storage. The total cost in terms of CO_2 abated may be less than £25/tCO_2. Hence a combination of a capital grant (say £30M to £50M) and a guaranteed price (contract-for-difference) for the CO_2 allowances would be sufficient to make a project happen.

A series of competitions similar to the competitions under NFFO for renewables and waste-to-energy projects could be used to find the most cost effective

---

[6] For example in the Energy Research Partnership

[7] Advanced Power Generation Technology Forum submission to the CAT Strategy consultation

demonstrations. Support for demonstrations should be targeted to avoid unnecessary overlap with projects planned elsewhere in the world. We recommend this approach rather than a flat-rate incentive because, as demonstrated in the Renewables sector, a flat-rate can be more generous than necessary for the lowest cost options and insufficient for other higher cost options which are also needed.

Targeting should take account of:

(i) The need in the UK and in developing countries for CCS on hard coal in order to meet CO_2 reduction targets;

(ii) The importance globally of CATs technologies that can be retrofitted, and the relatively strong position of UK companies in developing and owning retrofit technologies;

(iii) The USA is largely focussed on demonstration of new-build Integrated Gasification Combined Cycle (IGCC) plant (e.g. Futuregen), Germany is giving priority to brown-coal (lignite), Norway is focussed on gas.

It is important to open up the lower cost CO_2 storage options, depleted gas fields and saline acquifers, as soon as possible.

1.35.2 Are there skills gaps that could create barriers to the development of CCS in the UK?

Although currently there are no skills gaps (except in offshore engineering), it has to be expected that there will be a skills shortage as investment in power generation, transmission and distribution grows substantially. The anticipated growth in the UK coincides with similar huge requirements in Europe and the USA, as well as China and India.

Mitsui Babcock has continued to recruit graduates and trade skills but is concerned that the science/engineering base in UK universities is in decline (-8% since 1998).

The potential skills shortage should be seen by government as an opportunity to create a large number of skilled jobs, in engineering, project management, installation, commissioning, etc., etc. These jobs would range from graduate level to craft level and could bring ‘quality’ employment to school-leavers and young people, as well as graduates.

Cost

1.48.1 What are the costs currently associated with the development of different potential CCS technologies and forms of deployment

Please refer to our answer to 1.34.1 where we give investment costs for different technologies for CO_2 capture and estimates of costs for transport and storage.

1.48.2 How might these costs change over time and what is the evidence for any estimates of this?

Over time the costs quoted will change for a number of reasons:

(i) Increase due to general inflation and in particular inflation of materials costs;
(ii) Decrease as suppliers become more confident through learning by doing and the market becomes competitive;
(iii) Decrease due to cost reductions of specific parts of the plant as follows.

- **Pre-combustion**

Reductions are expected from advances in the performance and a reduction in cost of key components. Improvement in reliability is essential and this would allow the risk adjusted hurdle rate applicable to such investments to be lowered. The costs of oxygen production are likely to fall as advanced membrane separation technologies are adopted and there is scope for cost reductions and efficiency improvements in gasifier technologies.

- **Post-combustion**

There is a similarity with FGD, whose costs fell by a large factor after commercial introduction. Therefore there are prospects for cost reductions of scrubber/reboiler plant. Also some prospects for operational cost reductions as better amines are introduced.

- **Oxyfuel**

Boiler and FGD are mature technologies and costs are unlikely to change dramatically. However, note that advanced oxyfuel plants may be able to dispense with FGD plants in favour of cheaper, more efficient and more compact processes. Oxygen production – prospects for cost reduction as described above. Overall, oxyfuel looks promising in the longer term and has the potential for large future cost reductions.

1.48.3 How might changes in the relative prices of coal and gas in the framework governing emissions of CO_2 and other pollutants affect the costs and profitability of CCS?

The “profitability” of CCS depends on the cost of fuel (gas or coal), the cost of electricity and the price of CO_2 allowances over the life of the plant. For coal, at about £30.5/tonne (£1.20/GJ), coal with CCS could be more profitable than coal without CCS for a CO_2 price of about £20/tonne of CO_2.

1.48.7 What are the costs associated with building capture-ready plant and how do they differ from the cost of constructing fully operational CCS

facilities? To what extent can any additional costs be mitigated by decisions on design, location, etc?

Capture-ready Plant

- **Capture-ready Advanced Supercritical**

The steps necessary to make an Advanced Supercritical Boiler/Turbine power plant "capture-ready" are being studied in DTI Project 407 in which CCSA member companies Mitsui Babcock, Alstom, EON and Air Products are partners and members RWE, SEE and EON are amongst the sponsors.

For Post-combustion capture, consideration must be given to the provision of steam for use in the Amine re-boiler and to the use of the waste heat from the CO2 compression unit in the overall cycle. For Oxyfuel capture, the capture-ready design incorporates provision for CO2 recycle, use of waste heat from the ASU and CO2 compression in the overall cycle and provision for the auxiliary power requirement for the ASU. By suitable capture-ready design, the final cost of capture-ready plus CO2 capture will be very close to that of a New build with capture.

e.g.

Item	MW gross	MW net	£
Capture-ready Advanced Supercritical Power Plant	750	694	589M
Addition of CO_2 capture	750	535	128M
		TOTAL	717M

The capture-ready plant is a relatively low risk option. The design is optimised to minimise the long-term cost (with carbon capture).

- **Capture-ready IGCC**

To make an IGCC "capture-ready", consideration has to be given to the incorporation of the CO2 catalytic shift reactor, CO2 scrubber and CO2 compressor, plus major modification of the gas turbine to burn hydrogen.

If the Shift reactor is included in the capture-ready plant then the modified gas turbine to burn hydrogen is also required. The first-of-class capture-ready IGCC plants are high risk since they incorporate novel items.

Location

With respect to location of plant, it is difficult to generalise. New-build plant built close to the East Coast will benefit from shorter transport distances but retrofit or new build at existing sites will benefit from the existing infrastructure (coal and ash handling, transmission lines, cooling water supplies, buildings, rail and links).

All power plants cannot be relocated to the East Coast so it will be necessary to find CO2 storage sites for each. The government should develop a “Vision” for a cost-efficient approach which will include a CO2 transmission system linked at one end to the EOR Storage sites in the northern North Sea and at the other end to the Depleted gas reservoirs and Saline Acquifers in the southern North Sea.

1.48.8 Is the use of CCS currently a profitable option for businesses in the electricity supply sector and other sectors and, if not, what is the shortfall? Under what conditions might it become profitable?

We do not believe that CCS is currently profitable in any sector. It would become profitable if the market delivers long term high gas, oil and carbon prices, although the first projects may still require support due to additional “first-of-a-kind” costs. However, in order to deliver the large scale investment decisions to build CCS, confidence in the long term price of carbon needs to be significantly greater than it is at present. The current shortfall depends on the perceived commodity price forecasts, the chosen technology for power generation and the site for carbon storage. As such, it is not well defined and likely to be both project and company specific.

1.54.1 What is the impact of the current policy framework on the development of CCS?

As stated by the Scientific and Technology Committee of the House of Commons in February 2006:

> “There are no fundamental barriers to the development and deployment of CCS in the UK, apart from the lack of a suitable policy framework to provide industry with the incentives and confidence it requires to make the substantial investments entailed in CCS projects. The Government must put this framework in place as quickly as possible”.

CCS is no different from any other emerging technology area. There is a substantial introduction risk and further technology development can be expected and will be driven by the existence of a long term market and learning from early projects. The current policy does not provide the long term market nor does it allow the introduction of a tranche of early projects. The policy position is at variance with the market position where the rapid introduction of CCS projects is possible and can make a major contribution to:

- Underpinning UK energy security by allowing diversity in the use of coal plant with ultra low emissions.

- Enabling the UK to demonstrate leadership in carbon abatement using CCS and for UK industry to create an export industry for the raft of technologies involved. The uncertainty over the timescale when the world's climate reaches a 'tipping point' after which global climate change is irreversible dictates that the precautionary principle should be followed and early and large scale reductions in CO_2 emissions should be sought.
- Maintaining UK oil production, limiting the effect on the balance of payments associated with a reduction in oil production.

1.54.2 Are there any particular issues that need to be taken into account with regard to CCS when considering the use of policy mechanisms to reduce CO emissions in the UK economy?

We believe that CCS needs to be developed as a further measure, additional to energy efficiency, renewables and nuclear to reduce carbon emissions from power generation and other sources. Implementation of CCS is the only feasible way to achieve deep cuts in emissions from fossil fuels – clearly necessary in the major coal-using countries of the world.

We recommend that incentives for CCS are initially focused on a small number of first-of-class projects and that more general incentives or regulations are developed after some further experience is gained.

Support for, say, five first-of-class projects by a guaranteed carbon price could be very cost effective. Assuming 3000 MW of coal-fired generation capacity was replaced by CCS, the CO_2 saved per year would be circa 15 million tonnes – significant in itself as this is the same saving as if 30% of the gas generation was replaced by renewables. For there levels of support in £/tCO_2, the annual cost can be calculated and this can be converted into a cost in pence/kilowatt-hour if the cost was recovered across all the electricity supplied in the UK:

Support Level (£/t CO_2)[8]	Annual Cost	Uplift on electricity cost (p/kWh)
10	£150M	0.04
20	£307M	0.09
30	£461M	0.13
50	£768M	0.22

---

[8] Support is difference between guaranteed carbon price and actual