



HM Treasury Consultation

Carbon Capture & Storage: A consultation on Barriers to Commercial Deployment

Response by the Carbon Capture & Storage Association (CCSA)

Question 1

1.31 What are the barriers to commercial development of CCS?

The CCSA has used this general question to summarise its position

- **No major technical barriers**

There are no substantial technical barriers to the immediate deployment of CCS in the UK and elsewhere. The technologies relating to CO₂ capture, processing, transportation and geological storage are all known and understood although there is a need to optimise and integrate designs at large scale. Improved technology and designs will follow from experience of early commercial scale installations combined with ongoing R&D effort. However, there is considerable commercial risk for early movers. Aspiring project developers would contribute better levels of process optimisation if there were direct support for the development activity and more confidence that the policy and regulatory frame work would enable the project to proceed.

- **Need for policy framework**

The single most important barrier to commercial development of CCS is the lack of a robust, consistent and enduring policy framework. That is a pre-requisite to provide a commercial environment of sufficient confidence to sustain single project investments of many hundreds of millions of pounds. (Reference is made to our detailed response to Questions 23 and 24, below).

A fiscal/regulatory regime will need to be established that reflects financially the environmental benefit of avoiding GHG emissions by storing CO₂. Without recognition of the value of CCS within a stable fiscal/regulatory regime there will be insufficient confidence to finance major CCS schemes.

The CCSA recognizes that the EU ETS should, in the longer term, be the principal instrument of policy for valuing the cost of carbon emissions and providing incentive for investment in mitigation. However, it also recognizes that the EU ETS has not yet developed a sufficiently robust forward market over a sufficiently long time scale to enable it to be a bankable instrument in the context of CCS investment. The EU ETS does not yet have a mechanism to incorporate CCS. Recognition of CCS in the EU ETS and appropriate rules for new entrants are essential.

The CCSA recommends that there should be a framework that provides business with investment confidence for at least 15 years and that this should include 100% enhanced capital allowances and a mechanism that underwrites a firm price for avoided CO₂

emissions. The CCSA would welcome a dialogue with Government on the issue of incentives as well as how CCCS projects would be treated in current taxation procedures. (Reference is made to our detailed response to Question 22, below).

- **Need for a substantive regulatory regime**

There are at present legal and regulatory barriers to investment. It will be essential to the development of commercial CCS investment that a robust licensing procedure is developed that embodies proper standards of environmental integrity, sets clear boundaries of liability and which accommodates a predetermined handover of liability at an appropriate juncture after the closure of the project. The CCSA welcomes the opportunity to work with HM Government on arrangements for licensing.

The CCSA is appreciative of the efforts made by the UK Government in relation to seeking changes to the London and OSPAR Conventions without which the opportunities for carbon storage under the UK continental shelf would be very limited. (Reference is made to our detailed response to Question 11, below)

- **Need for urgent action**

The CCSA would like to impress on the Government a degree of urgency in the implementation of policies above. Without confidence that commercially supportive policies will be put in place even currently proposed projects are likely to be put on hold. To achieve the necessary levels of investment that will ensure supply continuity over the period of decommissioning of coal and nuclear power plant will be a major logistical exercise for the power generation industry. It is imperative firstly to get started and secondly to plan for best use of resources and confidence in achieving the 2050 emissions trajectory.

The most important issue is to get some early projects under way. There are a number of projects planned in the UK at the present time. Between them they represent a broad span of CCS technologies and would form the basis of an excellent showcase of UK expertise, whilst building UK business capacity and simultaneously making a start on the deployment of CCS within the 2050 trajectory. The CCSA urges the Government to move quickly to put these measures in place.

Evaluation of options for reducing GHG emissions must include factors relating to scale of impact, timeliness, cost per tonne of CO₂ avoided and the ability to provide continuous, flexible supply. On this basis early introduction of CCS will provide government with confidence in a deliverable climate change programme.

- **Planning for an effective investment programme**

By 2020 it is conceivable that around 20 GW of newly installed power generation could be equipped with CCS. Depending on the fuel mix this might represent 50-100mtpa CO₂ saved. In a market based environment, consistent signals should ensure that capacity is built in a timely fashion and that broadly, the most economic opportunities are taken first. If CCS opportunities are to be taken, the appropriate signals need to be made to the market. Aligned with this, anticipating and planning a joint government/industry R&D programme is essential. Anticipating training needs for a major investment programme in CCS alongside other requirements also needs priority. Planning a CO₂ pipeline infrastructure, both on and off shore, will be vital in reducing costs and limiting unnecessary complexity. All of this needs to be undertaken in an atmosphere of open dialogue in the context of the energy and climate challenges facing the UK and the World. This is the only way to develop this very large infrastructure whilst carrying public favour. The CCSA stands ready to work with Government on all issues of forward planning and targeting of the uptake of CCS technology.

Given the policy development described above and with appropriate planning referred to in this point the CCSA believes that there could be at least 40 Mte CO₂ pa could be abated from power and industrial sources by 2015 and 100 Mte by 2020 making a major contribution to the 2050 UK emissions trajectory.

Question 2

1.32.1 What CO₂ savings could be delivered by CCS, and how do these savings vary between different options for deployment, different fuels, and different kinds of technology at each stage of the CCS process? Can the life-cycle CO₂ savings be estimated comparably with those of other technologies?

- The application of Carbon Capture and Storage (CCS) provides the UK with an additional CO₂ reduction technology, which can play a significant role in enabling the UK to meet its CO₂ targets whilst at the same time maintaining a broad portfolio of energy sources and enabling it to meet its future energy requirements. CCS technology is available now, and could be deployed on a scale to enable the UK Government to achieve its ambitious 2050 CO₂ emission reduction goal.
- The UK is well-placed for the geological storage of CO₂, with many tens of gigatonnes of CO₂ capacity, mainly below the continental shelf. The deployment of CCS should not therefore be limited by the storage capacity available. There is also the additional benefit of Enhanced Oil Recovery in the Northern part of the North Sea using CO₂ from industry, which would then remain stored in the oil reservoirs at the end of operations
- CCS is a technology most efficiently applied to large point-sources of CO₂ such as power stations, oil refineries or other major industrial operations such as steel-making. There are several techniques, none of which has a clear overall advantage. Some are suitable to particular fuels; others provide flexibility in de-carbonised fuel application or are most suitable for particular qualities of CO₂ streams, whilst others are more appropriate to smaller industrial waste gas streams. CCS offers the opportunity to reduce CO₂ emissions from point-sources such as power plant by about 90% and, therefore, can play a significant role in enabling the UK to meet its CO₂ emissions goals.
- Between 2006 and 2011, the Government forecasts the closure of around 3000 MW of nuclear power station capacity. For these and other reasons associated with maintaining security of supply, the construction of new power plant is likely to begin very soon. There is therefore an opportunity beginning now to build these early CCS technology-leading power plants.
- The second impetus for CCS deployment occurs almost at the same time as the first. Under the Large Combustion Plant Directive, approximately 9000 MW of coal-fired plant has opted for closure by the end of 2015. From 2008 operation of plants in this this tranche is limited to only 20000 hours before closure in 2015. This coupled with the nuclear decommissioning programme means that by 2010 a large programme of power plant construction must be underway in the UK. Since the vast majority of the replacement plant will be fossil-fuel based, the need for CCS capability becomes an imperative. It is also certain that many new plants/replacements will need to be committed before the regulatory framework for CCS is fully developed.
- It is expected that, by 2020 over 20 GW of new plant will need to be built in order to meet new demand plus the replacement of closed plant. This is the equivalent of about 30% of existing capacity and would generate about 140 TWh p.a
- It is estimated that about an additional 40 TWh p.a. could be generated by new renewable energy sources, leaving the remainder to be achieved by either new nuclear or fossil power plant.
- 100 TWh of coal or gas power plant output produces emissions of about 90 Mt and 40 Mt CO₂ respectively. Future coal plant may reduce emissions to about 78 Mt CO₂ per 100 TWh. Currently, fossil fuel power stations contribute about 150 Mt of CO₂ to UK emissions on an annual basis.
- In the absence of a large scale nuclear new build programme, and with the penetration of renewables into the electricity market likely to be less than 20% by 2020, there is likely to be the need for at least 250 TWh p.a. of fossil power plant generation.
- CO₂ emissions associated with 250 TWh fossil plant output would be in the range 100 to 195 Mt CO₂ (an "all gas" – to an "all coal" portfolio). If CCS technology were applied to all

such fossil power plant , then the net CO₂ annual savings would be between about 90 and 170 Mt CO₂ .

- There could also be significant reductions in CO₂ emissions in the other industrial sectors such as oil refineries, cement and steel-making if CCS technology were applied within these sectors. Potential reductions could be of the order of 45 Mt CO₂ p.a.
- CCS could therefore play a significant role in achieving a 130 Mt CO₂ p.a. reduction by 2020, as required in order to remain on track to deliver the 60% reduction target by 2050.

Question 3

1.32.2 How do the potential CO₂ savings compare with other options for reducing carbon emissions?

- The cost of reducing carbon emissions with CCS compares very favourably with other options. '*.....and including CCS in a mitigation portfolio reduces the costs of Stabilizing CO₂ concentrations by 30% or more.*' (IPCC Special Report on Carbon Dioxide Capture and Storage)
- The scale of the near term savings achievable are very material compared to alternatives. It is difficult to imagine a return to large scale nuclear build on a timescale consistent with the coming replacement programme and renewable sources are constrained by the ability of the transmission system to accommodate them. Fossil fuel power generation with CCS is required to complement these other technologies, not to compete with them.

Question 4

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 CCSA has concluded that it should not contribute on the matter of project costs. Generic project cost estimates are in the public domain through such bodies as IEA, US DoE and DTI. We understand that previous DTI Markal modelling is being reviewed under revised cost bases. Project costs are completely project specific and the CCSA does not have access to the confidential cost data of its members. We are confident that the developers of the specific projects referred to in this document are in direct touch with HMT.

The CCS process can be separated into three business areas which are likely to be represented in the form of separate contracting parties:

- Capture of CO₂
- Transport from source to sink
- Storage & Monitoring

According to publications by CO₂ Capture Project (CCP) Vattenfall and others, the greatest cost (two-thirds) is for capture, with transport and storage accounting for one-third. However, both are very location dependent.

- **Capture of CO₂**

There are three main technology options for CO₂ 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 O₂/CO₂ recycle combustion).

These options are schematically illustrated in Figure 1 using the example of power generation.

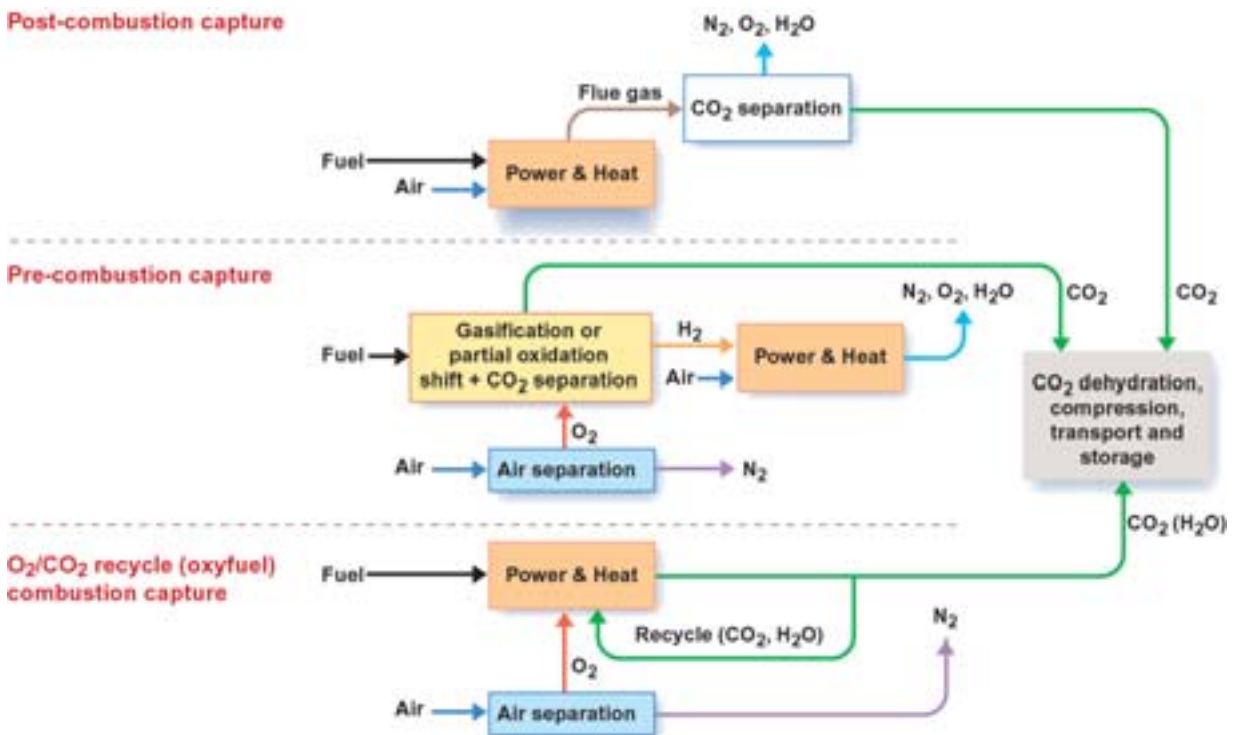


Figure 1 Main technology options for CO₂ capture from power plants

In **post-combustion** capture, the CO₂ is removed from the power plant flue gas. Commercially available technology includes CO₂ capture using absorption in an aqueous amine solution. The CO₂ is then stripped from the amine solution, 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 CO₂ 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 CO₂. The CO₂ is removed by physical absorption and the hydrogen combusted in a gas turbine. In this way the CO₂ 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 step to produce the synthesis gas.

In the **O₂/CO₂ 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 CO₂ which is re-circulated to control the combustion temperature. This gives a flue gas consisting mainly of CO₂ and water vapour which can be condensed to give a highly concentrated CO₂ stream for transport and storage.

There are a range of technologies that are available for deployment now and this is demonstrated by the development of a number of commercial scale projects both in the UK and elsewhere. The UK projects under consideration include:

- Pre-combustion capture from gas in a 350MWe project at Peterhead by SSE/BP and others
- Pre-combustion capture from coal in an 800MWe IGCC by progressive Energy at Teesside
- Post-combustion or oxyfuel capture from coal by RWE in a 1000Mwe project at Tilbury
- A 450MWe precombustion capture project by E.ON on the east coast.

This shows clearly that a range of technology approaches are close to introduction. The cost of capture is technology-dependent with capture from high-concentration, high-pressure sources of CO₂ being generally less costly than capture from low-concentration low-pressure sources.

- **Transport from source to sink**

Given the large volumes that are expected to be stored off-shore UK it is reasonable to assume that all transportation will be by pipeline. Once again pipeline costs are well documented elsewhere but the CCSA would like to make an important point about the cost of developing a pipeline infrastructure.

CCS projects should not be regarded as separate developments each with their own pipeline. In reality there is expected to be a number of capture plants feeding into a pipeline network that in turn will deliver to multiple storage locations. The cost per tonne of transport by pipeline reduces substantially as the capacity increases. Clearly there is a major opportunity to optimise costs of both on-shore collection and off-shore distribution if the infrastructure development is well planned. Whilst it would be quite impractical to attempt to anticipate the size and location of every point of entry to and delivery from the network it is clear that early pipelines will need to be constructed with a significant excess capacity in order to avoid costs into the future. It also means that subsequent projects will benefit from the earlier investment. Ultimately, it can be expected that the UK CO₂ pipeline infrastructure will be managed by commercial operators in a similar manner to the oil & gas network that currently exists. As the situation stands at present there is not a

sufficient commercial case for commercial pipeline operators to invest on a speculative basis. In this area industry/government cooperation and planning will be essential.

- **Storage & Monitoring**

Wide-spread, large storage capacity has been identified that is sufficient to store significant amounts of global CO₂ emissions over the next century. The same can be said in the UK when hydrocarbon reservoirs and deep saline aquifers are considered. Research has shown that CO₂ can be securely stored in these formations for thousands of years or longer, with ongoing work and field trials to further clarify the risks involved.

Site selection, operational management and closure of the site will be vital to containment. An approvals mechanism for CCS projects must incorporate the necessary assurances over site selection, permanence, monitoring, remediation and allocation of liability for any third party damage and remediation in the event of seepage emissions. These views are supported by the IPCC, when it concludes that:

"With appropriate site selection based on available subsurface information, a monitoring programme to detect problems, a regulatory system and the appropriate use of remediation methods to stop or control CO₂ releases if they arise, the local health, safety and environment risks of geological storage would be comparable to the risks of current activities such as natural gas storage, enhanced oil recovery (EOR) and deep underground disposal of acid gas. Observations of engineered and natural analogues as well as models suggest that the fraction [of stored CO₂] retained in appropriately selected and managed geological reservoirs is very likely to exceed 99% over 100 years and is also likely to exceed 99% over 1000 years".

The technology used to inject and store CO₂ in geological formations is proven and in common use in the oil and gas industry for enhanced oil recovery.

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 CO₂ emissions, and can they be installed on the basis of both new-build and retrofitting?

A theoretical map of options is given in the following table

	Pulverised Coal ⁽¹⁾	Coal Integrated Gasification Combined Cycle ⁽²⁾	Natural Gas CCGT	Cement, Steel-works	Hydrogen from Coal
Pre-combustion	-	√ _{N,R}	√ _{N,R}	-	√ _N
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 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 plants now being built and planned. For the UK the opportune areas for major CO₂ reduction are

- new build coal plant with CCS fitted to replace the closing tranche of conventional PF plant
- retrofitting of existing coal plant with CCS
- new build CCGT
- and perhaps retrofitting of specific non-power plant that have comparatively high concentration CO₂ streams, including hydrogen production, ammonia, steel and cement manufacture

It must be noted that costs of CO₂ abatement can vary considerably between these categories.

Question 6

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

- All of the carbon capture technology 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. There are no "inventions" required but careful designs and considerable scale-up of some parts of the plant is necessary.
- However, complete CCS value chains (new assemblies of commercially proven technologies) will only be considered fully commercialised when a number of projects have been completed and several years of operation have been observed.
- 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. Plant with 46.5% efficiency (700gCO₂/kWh) can be purchased with full availability and performance guarantees – i.e. fully commercialised.
- As described in answer to a previous question a number of options are sufficiently understood to the point where plants can be designed to incorporate capture. Pre-combustion capture is well established using physical solvents (e.g. the Great Plains Synfuels plant captures 1.75Mte pa) and post-combustion capture using amines is also standard technology and is now being applied to power generation. CO₂ handling and transport do not pose a high degree of novelty and injection and storage of CO₂ in aquifers is already practised in the North Sea (Sleipner has been storing 1Mte pa since 1996) and injection of CO₂ into mature oil fields has been practiced for more than 25 years in the US where 25Mte pa are injected annually.

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?

- In principle each of the capture options can be combined with each of the transport options and used with each of the storage options. However, it should be noted that not all reservoirs will be suitable for continuous injection of CO₂ for the duration of the project. This is especially true when CO₂ is used for EOR. In this case, the take of CO₂ by the reservoir will be shorter in duration (compared to the duration of CO₂ production from any give source) and varying in quantity.
- Whilst options exist now at each stage of the process there is as yet no UK experience of combining these into an integrated capture, transport and storage project and a key limitation is the need to manage the integration risk as well as the technology risk associated with each stage of the process.
- The current exploration of real projects by a number of power companies and offshore oil and gas companies and other members of the industry is seeking to address these issues.
- These are major capital intensive projects and the technology as well as the integration risks must be well managed and the investment must be made against a well structured long term market that enables an adequate return on capital

Question 8

1.35.1 What would be the costs and benefits of early adoption of this technology in the UK?

- A key benefit of CCS is that it enables coal generating plant to be incorporated into the generation mix going forward, thus limiting the dependence on imported gas. Where gas is used its environmental footprint can be further improved by incorporating CCS. The impact of CCS introduction in influencing this mix is very material as noted in the response to question 2. Security of supply in a carbon constrained power sector is the essential benefit.
- The availability of CO₂ in bulk can provide a working fluid to enable further, incremental, oil to be extracted from North Sea oil reserves that would not otherwise be extracted. Given the year-on-year reduction in oil yield from UKCS reserves this recovered oil could be significant in minimising dependence on imported oil. CCS and EOR in the North Sea will prolong the useful life of existing assets, defer their decommissioning and extend the commercial lifetime of a significant contributor to the economy.
- The UK is recognised as having a strong basis in this field (as referenced in the DTI Strategy for Developing Carbon Abatement Technologies for Fossil Fuel Use, published in June 2005). Early adoption of CCS and related technologies in the UK would take advantage of this and, as the DTI document states, 'ensure that the UK takes a leading role in the development and commercialisation of Carbon Abatement Technologies [including CCS] that can make a significant and affordable reduction in CO₂ emissions from fossil fuel use'. This would involve power plant operators, power engineering companies, process engineering companies, fossil fuel suppliers, offshore engineering and service organisations, electricity and gas shippers and project developers. A major benefit would be the working together of these companies, something that has not traditionally happened, in a manner that would equip them to trade effectively on global markets as well as satisfying needs in the UK.
- The size of this world market for Carbon Abatement Technologies for Fossil Fuel is estimated by the IEA as ~3000GW over the period 2005 to 2050, approximately half for coal. In monetary terms this represents capital expenditure in excess of £2,000b. It will be important to develop and maintain the UK skills base to address this market.

Question 9

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

- If the appropriate regulatory and fiscal frameworks are established within the next 2-3 years, there is likely to be a substantial increase in the take-up of CCS and related technologies. This would be part of the replacement/expansion of the UK generation capacity required within the next 1-2 decades but would occur in a similar timeframe to other major infrastructural actions within the UK (for example, the 2012 London Olympics in the shorter term to the expansion of the rail system/transmission and distribution network in the longer term). This would undoubtedly put pressure in the UK on the availability of appropriately trained and experienced personnel at all levels, from professional engineering status to traditional trade skills [recent indications show that although the science base in UK universities is growing (approximately by 34% compared to 1998), engineering is decreasing (approximately by 8% in the same period)], a situation that would be exacerbated by the demand for the same skills worldwide.
- This potential skills shortage needs addressing on an urgent basis at all levels within the educational system, especially in schools. One critical issue is to indicate to the younger generation that there is a worthwhile career in energy and engineering. This can only come from there being vibrant business in this area. This in turn requires strong signals from government (ie the appropriate framework referred to above) that would encourage the necessary investment to be made and so create the employment opportunities in CCS.

Question 10

1.41.1 What scope is there to develop and use CCS within the current regulatory framework?

The current regulatory framework will not enable companies to commit to capital investment in CCS projects for a number of reasons. The CCSA believes that the principle areas for consideration are:

- Treatment of CO₂ as a “waste” – OSPAR/London Convention
- Long-term liabilities for CO₂ storage
- Treatment of CCS under the EU ETS

These are the main issues that need to be addressed:

- Long-term, stable regulatory and fiscal regime that recognises the timescales over which the large capital investments required by CCS are made.
- Clarification of the applicable tax regime, and long-term certainty on how this would interface with (1) continuing offshore E&P activities; (2) future abandonment liability, particularly where extending the life of the infrastructure; and (3) the onshore regime applicable to the front end of the CCS chain.

Question 11

1.41.2 What regulatory framework would need to be put in place to support the development of CCS technology while also ensuring protection of human health and the environment?

- It is considered that the risks associated with on shore processing and handling of CO₂ are adequately covered by existing regulation.
- The treatment of CO₂ as a “waste” – OSPAR/London Convention:
The CCSA supports the actions of the UK Government to remove this restriction. We consider that the Conventions were necessarily established before it was possible to consider the social and environmental benefits of CCS. We also consider that technology has developed, and research has been published, to provide assurances on the long-term integrity of geological storage sites.
Additionally we support further work on the development of regulations, tools and techniques for long-term integrity monitoring of geological CO₂ stores.
- The long-term liabilities for CO₂ storage:
Once injected into geological formations, CO₂ will be stored for geological timescales. Whilst private companies are best placed to execute the projects required to capture CO₂ and thereby abate emissions, no private company can accept liabilities on geological timescales. The CCSA consider that regulation is required to facilitate the transfer of liabilities for stored CO₂ to a public body following the cessation of injection and the installation of appropriate and agreed measures for containment and monitoring.
- The treatment of CCS under the EU ETS:
Recognition of CO₂ stored as part of a CCS operation from installations included in the EU ETS, via approval of appropriate monitoring and reporting guidelines for CCS, is a critical part of us utilising market mechanisms to cost-effectively reduce emissions.
- CDM and other GHG policy regimes:
Whilst UK policy should not be contingent on actions taken elsewhere in the World it is essential that pressure is maintained to ensure the adoption of CCS technology in other countries where fossil fuel is a continuing energy source. In particular, it is essential that rapidly developing countries such as China and India should adopt CCS technology so as not to embed high emissions in their power sectors. CCSA encourages the Government to maintain maximum political pressure in this area.

Question 12

1.41.3 What additional costs and considerations are created by the long-term liability implications attached to CCS, and how can these be best managed?

- Whilst actual costs would be restricted to periodic monitoring of storage sites, long-term liability calculations would need to take into account the financial consequences associated with any potential failure of containment. A risk based approach could be adopted in this regard. These have not been generally established.
- Whilst current research provides assurance that, with certain technical measures in place, containment can be assured within the bounds of acceptable risk over project time-scales Geological time scales are orders of magnitude greater and liabilities on this timescale cannot be carried by privately-owned companies. The consequences of leakage from individual offshore stores in the long term must be small and the climate change benefit of removing CO₂ from the atmosphere would have been obtained in the meantime in any event. As stated above, the CCSA consider that regulation is required to facilitate the transfer of liabilities for stored CO₂ to a public body following the cessation of injection and the installation of appropriate and agreed measures for containment and monitoring.

Question 13

1.41.4 What issues arise concerning (short-term) liability for CO₂ at particular points in the CCS process? Are there costs attached to these and what are they?

- The DTI has previously contracted risk assessment work on health & safety risks in capture & transportation. This is not expected to be beyond normal industry standards.
- Short term containment risks must stay with the storage operator. Experience to date suggests that this level of liability can be accommodated in the business plan whereas longer term, the risk will need to be transferred to a public body as above.
- To ensure public confidence and to provide a stable framework for investment there will need to be a well established regulatory regime in place to demonstrate well integrity. The CCSA would like to work with Government to establish the principles of regulation.

Question 14

1.41.4 What might be the likely public reaction to concerns about CCS, and how could concerns be addressed?

- Public acceptability of CCS will be an important element in the deployment of the process at a scale that is significant in terms of greenhouse gas emissions abatement. An appreciation of the current low level of public awareness of CCS - and anticipation of the concerns which may be raised by the public on gaining a greater degree of understanding - will be essential to ultimate acceptance.
- Studies of public perceptions of CCS have been carried out in a number of developed countries and note that there is a marked degree of consistency across national boundaries. The "Alliance for Global Sustainability Project" (University of Cambridge *et al.*) showed that less than 5% of the population of UK, USA, Japan and Sweden in 2004-5 were aware of CCS whereas more than 50% had been exposed to initiatives such as more efficient cars and renewables such as solar and wind energy. The study concluded that early successes and absence of vigorous objection from environmental NGOs will be key to influencing attitudes for the future.
- Further, studies by the Tyndall Centre determined that the proposal that CCS be considered as a potential solution to the climate change problem would, in principle, attract little public opposition. This conclusion was reached on the assumption of a population informed of the current importance of fossil fuels as primary energy sources and appreciative of the infeasibility of overnight transformation; in this regard, separate studies by the Tyndall Centre *et al.* have shown that 40-50% of UK adults agree that oil, coal and gas will make a substantial contribution to secure supplies of electricity in the future.
- As alluded to above, the positions of environmental NGOs will be significant drivers of public attitudes. It should be noted that the NGOs currently exhibit a wide range of positions, including:
 - Rejection on the grounds that technical uncertainties preclude deployment on a scale and timescale that would make a significant contribution to greenhouse gas mitigation;
 - Assertion that support to CCS would distract resources which would otherwise be directed to the achievement of a future based on renewables and efficiency improvement;
 - Active support for CCS in the context of a broad portfolio of actions on climate change;

These positions - and their inconsistency - imply value in continued engagement by proponents of CCS, whether governmental or industrial, with NGOs.

- The above and other independent analyses have indicated the bases upon which the public would be receptive to CCS as a valid climate change mitigation technology. These bases include:
 - Clarity of purpose - that CCS is seen in the context of the generally recognised issue of climate change;
 - Demonstration that any technical issues relating to the safety and security of long-term geologic storage of carbon dioxide have satisfactorily been addressed;
 - Perception that CCS is a technology supported by a broad and international partnership of energy suppliers, science and government - and not limited to a particular industry sector and also not the subject of vigorous NGO opposition;
 - Transparency and openness of dialogue and information sharing;

That CCS is seen as a part of a broader portfolio of decarbonisation options including renewables, energy efficiency and lifestyle change - and as a "bridging strategy" to a hydrogen-based energy system.

Highlighting the co-benefits associated with CCS such as enabling energy diversity, industry competitiveness, jobs and life extension of the North Sea industry to further recover oil and gas as well as safe, long term storage for CO₂.

- Based on the evidence summarised above, it is the opinion of the CCSA that CCS can successfully be offered to the public as a valid, environmentally positive and economically acceptable option for the reduction of greenhouse gas emissions. Furthermore, the congruence of advantage with security of energy supply, through diversity of sourcing, can only enhance its acceptability.
- The conclusion of the CCSA is that it is important not to raise false concerns in the public domain but to treat the public acceptance of CCS as part of a broad energy information package that enables a better informed public to make rational judgments on energy policy imperatives.

Question 15

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

- The CCSA has no information on company/country R&D spend that is not already in the public domain. Individual members are likely to make their own representations in confidence.
- There is an ongoing need for further technology R&D to deliver the next generation of technologies that will substantially reduce the cost of this technology.
- An important point to make here is regarding the very large cost of developing individual projects to point of placing orders. Current projects that are under development are an act of faith in an early introduction of CCS policy. If policy is not forthcoming existing projects will be shelved and no new projects will be forthcoming.

Question 16

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

The CCSA has no comment on R&D expenditure but would like to draw attention to cost reductions likely to occur subsequent to the introduction of commercial scale plant as follows:

- **Pre-combustion**

Reductions are expected from advances in the performance and a reduction in cost of key components. Improvement in reliability will also occur allowing the risk-adjusted hurdle rate applicable to such investments to be lowered. For example both IGCC and CCGT exploit advanced modern gas turbine technology and further incremental improvements are expected in line with past performance. 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 both gasifier and CO₂ separation technologies.

The pre-combustion approach produces a hydrogen-rich syngas and this hydrogen can be purified and used in fuel cell applications for either power generation or transport applications. In the longer term when fuel cell technology costs have reduced it is possible that this approach could lead to very cost effective, and environmentally benign, electricity generation and transport.

- **Post-combustion**

There is a similarity with FGD and CCGT whose costs fell by a large factor after commercial introduction. Therefore some prospects for cost reductions of scrubber/reboiler plant.

Also, some prospects for operational cost reductions as better amines are introduced. CO₂ compression is relatively mature.

- **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

CO₂ compression is relatively mature.

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.

- **CO₂ compression – applicable in all cases**

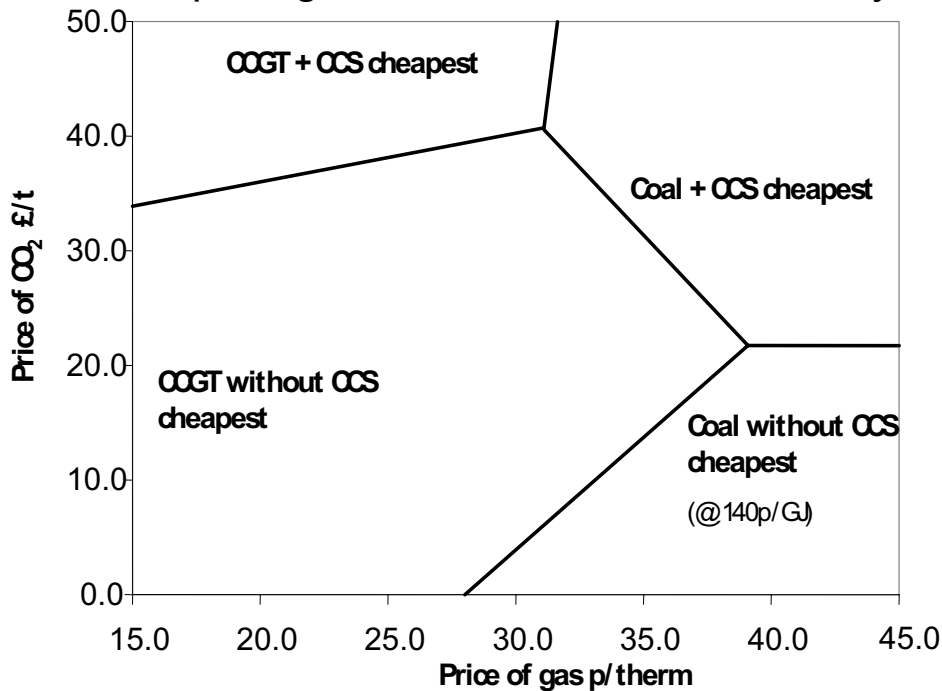
CO₂ compression technology is mature and unlikely to yield much savings.

QUESTION 17

1.48.3 How might changes in the relative prices of coal and gas in the framework governing emissions of CO₂ and other pollutants affect the costs and profitability of CCS?

- Since the introduction of the EU ETS In 2005 energy companies have become accustomed to trading in a multi-dimensional market place in which the prices for different fuels and the price for EUAs are interdependent. The relativities in these markets have influenced decisions on which power plants are run. There is currently no mechanism in the EU ETS for crediting carbon abated by CCS. Whilst the ETS has provided a decision framework for which existing power plants are despatched it has not provided a sufficiently robust framework to underpin investment decisions with or without CCS.
- Changes in fuel input cost will significantly affect the economics of CCS build. The chart below shows the relative economics of unabated coal, unabated gas, Gas+CCS and Coal+CCS under different gas and carbon prices. (Please note that we have used a fixed coal price in producing this chart as coal prices have historically been more stable than gas and carbon. We have also assumed single technology costs where in reality costs are very uncertain and site specific. The costs assumed are intended to be representative of future technology once first-of-a-kind costs are overcome i.e. they are not likely to be representative of the costs associated with the first few plants of any type).

Which option gives the lowest cost of electricity?



- The chart shows the carbon price needed to make CCS build for the assumed technology and coal costs. It is clearly dependent on the gas price. In the future, it is possible that the cost of carbon will be sufficient to make CCS economic; however the current methodology behind the EU ETS, and the current lack of long term global commitments on climate change abatement, make long term carbon price forecasting difficult.

Question 18

1.48.4 To what extent does EOR reduce costs and increase the commercial viability of CCS?

- The extent to which EOR may reduce the costs and / or increase the economic viability of CCS projects is highly situation dependent. It is likely that CO₂ EOR will be able to recover material incremental oil. However substantial costs are involved in platform modifications and the provision of necessary infrastructure. The North Sea is a relatively high cost and mature environment and the economics of CO₂ EOR are not clear at present. For EOR to make a contribution to the viability of CCS, it will be essential that the configuration of the initial capital-intensive infrastructure achieve maximum economies of scale. The infrastructure should enable progressively greater amounts of CO₂ to be transported from new capture plant to the maximum number of potential reservoirs.
- In the case of the Forties reservoir that BP evaluated for CO₂ EOR between 2000 - 2002, studies indicated that between 100 – 200 million barrels incremental recovery would be possible. However, under the then-prevailing circumstances, this was not economically attractive as a stand-alone oil development.
- It is also essential to note that CO₂ will be produced at a fixed flow rate over the lifetime of the power station. However, for physical and economic reasons, few CO₂ EOR projects will either want, or be able, to accept a constant flow rate of CO₂. Indeed we expect that supply and demand will be poorly matched (physically and economically) in general unless the infrastructure is sufficiently robust to divert the CO₂ to the optimum sink. This could be a CO₂ EOR project, a saline aquifer or a depleted gas reservoir in the Southern North Sea.
- Any incentive for CCS should be related to abated CO₂. The fact that this makes CO₂ available for EOR should be regarded as a national bonus and treated under a separate policy/revenue regime.

Question 19

1.48.5 How does EOR using CO₂ compare in cost terms to EOR using other means?

- The economics of an EOR project are situation-dependent. Gas injection is the most commonly applied form of EOR for the light oils that are primarily typical of the North Sea. Where hydrocarbon gas has an export route to market, it will normally be more economic to export the hydrocarbon gas. In places such as the West Texas Permian basin where there is extensive regional gas collection infrastructure, CO₂ has replaced hydrocarbon gas as the injectant of choice.
- The technical and economic analysis used to assess EOR options will include evaluation of the benefits of potential injectants e.g. the incremental barrels, against all the incremental costs for each option e.g. lost sales for hydrocarbons vs cost of supply for CO₂ and the incremental operational costs involved with managing scale, corrosion, separation of CO₂ from produced fluids etc.

Question 20

1.48.6 Is the use of CO₂ for EOR appropriate on the UK continental shelf and at what stage in the life of a specific field is it appropriate to use EOR?

- The issue governing use of CO₂ EOR on the North Sea Continental Shelf is one of economics rather than technical feasibility.
- CO₂ EOR is a valid technical option for increasing the recovery from some oil fields on the UK Continental Shelf. Studies by BP for the Forties reservoir indicated the potential for additional oil recovery of c. 4% of Oil Initially In Place. Experience from the Permian Basin in the USA where there are in excess of fifty operating CO₂ EOR projects has shown recoveries between 5 – 15% of Oil Initially In Place. The difference can be accounted for largely by the larger well spacings used in the offshore North Sea environment. Recoveries for other reservoirs will need to be assessed on a case-by-case basis.
- The optimal timing for the start of CO₂ injection in any given reservoir depends on a number of physical and operational factors. There is no simple rule of thumb, but it almost never follows the point at which cessation of production from secondary recovery would otherwise occur.
- It is also important to note that the demand for CO₂ from any individual EOR project might be relatively short in duration (say 5 to 15 years) compared to the longevity of the CO₂ emitter (40-50 years) and that the demanded flow rate will be highly variable during the life of the EOR project.

Question 21

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?

- There is considerable discussion regarding the definition of what is 'capture ready' and the costs naturally depend on the actual definition. CCSA members have taken part in DTI-supported studies looking at retrofitting coal-fired pre-combustion capture to an existing CCGT (Connah's Quay) and an existing coal-fired unit at Ratcliffe. In both cases, it was technically possible to fit carbon capture, the only real constraint being the need to acquire some additional land. Could one therefore argue that these plants are capture-ready by default? That said, these plants were not designed with CCS in mind, so there would be additional costs and inefficiencies in the new capture plant as neither the plant layout nor the thermodynamic cycle would be fully optimised. The minimum requirements for "capture-ready" new build plant are:
 - Sufficient land availability
 - Design of the plant layout with CCS in mind
 - An export route and storage sites available for the CO₂
- **Capture-ready IGCC**
Some designs of IGCC planned for use in the UK are inherently capture ready, i.e. they incorporate the CO₂ shift reactor and a hydrogen-fuelled gas turbine from the onset. In other cases, consideration has to be given to make these modifications at a later date.
- **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, E.ON and Air Products are partners and members RWE, SSE and E.ON 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 air separation unit (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 close to that of a new build with capture.
- The CCSA would like to point out that building capture-ready plant is not sufficient to meet the government's objectives – capture and storage is necessary to meet the deep cuts in CO₂ emissions which are needed. We therefore advocate measures to facilitate a series of CCS projects as soon as possible.

Question 22

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?

- The CCSA does not believe that CCS is currently profitable in any sector without a policy to reflect the value of abated emissions. It would become profitable if the market were to provide a long term carbon price sufficient to cover the incremental investment and risks. The very 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.
- The CCSA is currently developing a proposal for incentives to enable the early CCS projects to go ahead. This is likely to consist of two components:
 - a) 100% Capital Allowances – available for a period of at least 15 years
 - b) Government underwriting for a firm CO₂ credit price for approved CCS projects for a minimum period of 15 years. This underwriting is consistent with EU policy. The mechanism for CCS project selection and the CO₂ support price are for discussion.
- The CCSA is aware of a number of issues relating to how low carbon projects are treated in the current tax structure. There are issues relating the taxation procedures both on shore and off shore that members of the CCSA would like to review with Government to ensure a successful introduction of incentives without the creation of unforeseen barriers,

Question 23

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

- CCS technologies are sufficiently developed to allow large scale deployment now and there is a strong interest from industry in investing in CCS projects both in the UK and elsewhere.
- Specifically in the UK projects totalling more than 2500MWe are being considered by BP/SSE and their partners, by Progressive Energy at Teesside by RWE at Tilbury and by E.ON also on the East Coast. There is substantial interest in CCS projects from other parties.
- Elsewhere in Europe Shell/Statoil and RWE have announced CCS projects and a number of projects are under consideration in the USA including by BP at Carson.
- These project proposals underline that the technology has reached the stage where commercial scale projects are under active development now and also indicate the willingness of industry to consider such plants.
- However carbon capture and storage is associated with real additional costs that are not recognised and rewarded in the current UK policy framework and this means that it is unlikely that a decision to invest in the projects above or any other projects will be made until policy is changed.
- Energy market investment is determined by the choices available and their relative competitiveness. For electricity - the prime initial market, but not sole market, for CCS projects - the market shape and hence the relative attractiveness of different technologies is determined by a raft of measures.
- The Renewable Obligation covers on and offshore wind, high quality CHP projects using mixed wastes (a recent addition), landfill, biomass conversion projects, tidal, and many other emerging technologies. We note that not all of the technologies covered are pure renewables or indeed necessarily truly emerging technologies.
- ECAs and exemption from the Climate Change Levy are granted to high quality CHP projects irrespective of the primary fuel used and ECAs are available for many other emerging technologies and related investments
- The EU ETS as currently structured influences operational and some rapid-payback investment decisions on existing plant both in the power sector and in other sectors for installations included in the scheme. As currently structured the scheme does not drive major long term investment decisions.
- Despite providing cost effective carbon abatement as well as the prospect of making material reductions to UK carbon emissions within the next decade, there is no economic incentive or encouragement to invest in CCS projects.
- The current policy framework as expressed in the DTI CAT Strategy of 2005 appears to have been developed against a belief that CCS technology will not be available for substantial deployment until around 2020 and hence attention has been focussed on relatively long term R&D together with a recent commitment to provide some limited demonstration monies. This policy view of the technology status is unnecessarily pessimistic.
- The CCSA reiterates its support for the conclusion in February 2006 of the House of Commons Science and Technology Committee investigation of the status of CCS after consulting industry and academia that:
'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, 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 a market position where the rapid introduction of CCS projects is possible

Question 24

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 CO₂ emissions in the UK economy?

The CCSA is of the view that the following are key issues when considering policy mechanisms:

- **A firm commitment with early implementation using existing mechanisms**
The drivers listed above, the availability of technology now and the willingness of industry to consider investment, drive a desire to put in place appropriate market support as soon as possible. Refer to response to Q22.
- **Seek to integrate introduction measures with long term market mechanisms notably the EU ETS**
In the longer term the EU ETS is directly related to the environmental benefit and offers a market mechanism suitable for providing the primary driver for investment in ultra-low emission plant with CCS. However the current position is that the EU ETS does not provide a mechanism that can be used to justify the major investments involved: the scheme has no formal standing beyond 2012, provides only a 5 year commitment period which is short compared to the operational time for investments, and is open to regulatory and other government decisions (including decisions in other Member States) that can impact the market price very considerably.
An essential requirement of any EU ETS-related measure in the present system involving grandfathering of allowances is that CCS projects receive carbon credit allowances for the CO₂ abated for the investment lifetime, say 20 years.
Should an auctioning system be introduced then “ring fencing” of an element of this for CCS projects would enable an element of price discovery to be introduced.
- **Recognise the potential of non-power sector and smaller point sources to capture CO₂**
A key element associated with early CCS projects is the provision of pipeline infrastructure and the proving of storage sites. Whilst the costs associated with this can be reconciled against materially large capture projects this is not the case for smaller capture projects. Availability of the infrastructure for disposal will allow other smaller scale CO₂ capture projects to come forward. Possible examples include hydrogen production plant and ammonia production plants but early demonstration projects across a range of industries and technologies may become possible. The availability of this infrastructure may also play a role in attracting new investment in the UK in plant that would otherwise emit. Certainly the lack of infrastructure may provide a disincentive for such investment.
- **Recognise that, as with all technologies the existence of a commercial market will promote technology advance.**
The CCS projects under consideration cover a variety of capture approaches and disposal targets. Pre-combustion capture of CO₂ from gas and coal is proposed (using different technologies) and post-combustion capture from advanced coal is also under consideration. Oxyfuel systems are also being evaluated. Disposal sites cover depleted oil and gas fields both with and without an element of enhanced hydrocarbon recovery from the storage site. Since only CO₂ stored as part of an enhanced oil or gas recovery project is currently allowed under OSPAR and the London Convention/Protocol, most projects (including those involving saline aquifers) require amendments to these treaties before they can go ahead Industrial R&D investment is always referenced to the market opportunity and risk and the demonstrable existence of a UK market will drive further investment to improve the technologies involved across the whole chain. In all cases further advances are expected to reduce capital costs and the parasitic energy loss involved.

- Understand that different technologies and fuels have different economics**
 CCS covers a range of capture technologies as noted above, a range of storage options, differing project frameworks and differing CO₂ transport costs between capture and storage locations. Hence specific project investments incorporating CCS can be associated with very different costs. The different technologies all have their own advantages and disadvantages and at this point in the development of CCS technology it is not appropriate for Government to treat them differently when considering an appropriate market framework.
- The potential benefits from introducing CCS projects early into the UK energy mix are very large:**
 CO₂ abatement could reach 40Mte pa by around 2015 and over 100 Mte pa by 2020
 New generation plant involving CCS could provide 30TWh pa by 2015 and 70 by 2020
 Incremental, otherwise unrecoverable, oil from the UKCS could potentially exceed 500 million barrels and be equivalent to the discovery and exploitation of a 'Mega' oil field.
- No change in the current policy is a lost opportunity:**
 The UK has an opportunity to show international leadership in climate change mitigation by putting in place a market framework that ensures investment in CCS projects. Not only will this make a major contribution to the UK emissions target but it will also put UK industry on track to benefit from large scale business elsewhere in the world.