

Carbon capture and storage: A consultation on barriers to commercial deployment

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What are the barriers to commercial development of CCS?

CCS is based on established technology. The next stages in its development depend upon building and operating commercial-scale plant. Thus the main barrier to commercial development of CCS is the absence of a commercial incentive for the deployment of this technology.

The need for a commercial incentive for deployment arises from the fact that effective protection of the climate against the effects of greenhouse gas emissions is only now becoming accepted as a goal of society at large. This has not yet been translated into practical restrictions on emissions on the scale needed, so there is no commercial logic for private enterprise to accept the extra costs involved.

Effective protection of the climate will require reduction in greenhouse gas emissions by at least 60% compared with baseline but probably more. This will be a very much greater reduction than envisaged in the current policy measures, such as the Kyoto Protocol or the emissions limits implemented through the European Trading System. Commercial development and deployment of CCS depends on finding ways to translate the societal goal of protecting the climate into a commercial justification for investment in suitable technology.

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?

CCS could deliver reductions in CO₂ emissions of 80-90% compared with a plant built without use of the technology. There is little difference in the scale of emissions reduction between the 3 main options for capture (pre- and post-combustion capture and oxyfuel combustion); the only relevant storage option is geological storage.

CCS could be applied to coal, natural gas, petroleum-derived fuels and biomass fuel – the difference between the emissions from power stations burning these fuels with CCS would be small (e.g. ~100g CO₂/kWh from coal, ~50g CO₂/kWh from gas); the emissions from use of CCS with biomass would be negative (taking account of the CO₂ absorbed during plant growth). However caution must be adopted about the potential for use of biomass as a fuel for CCS as this is constrained by likely availability of the fuel on a sufficient scale.

Can the life-cycle CO₂ savings be estimated comparably with those of other technologies?

Yes – life-cycle analysis has been done of various CCS schemes¹.

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

The potential reductions in emissions need to be compared in a number of dimensions, in particular capacity and cost. It is also easier to make a comparison on the basis of emissions rather than reductions in emissions.

The residual emissions from a power plant fitted with CCS would be slightly greater (on a life-cycle basis) than large scale use of wind power, or power generation from purpose grown biomass. Considering the national impact of using each of these technologies, the cost of potential emissions reduction varies much less with the scale of application than the cost of emissions reduction from renewable energy technologies – in other words the mitigation cost-curve² for CCS is relatively flat compared with the rising curve for the renewable technologies.

In this respect, CCS is similar to nuclear power which also has a finite residual level of emissions (life-cycle basis) and a mitigation cost-curve which is relatively flat.

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 technological options have been described at length in the IPCC special report on CCS³; rather than repeat what is written there, the Treasury if referred to this document. There is little difference in potential, cost and state of development between pre-combustion and post-combustion capture; other capture options are under development but are not yet as ready for deployment; the only relevant storage option is geological storage.

¹ For example see “The costs and benefits of mitigation: a full-fuel-cycle examination of technologies for reducing greenhouse gas emissions”, by H Audus and P Freund. Energy Convers Mgmt vol 38, Suppl., pp. S595-S600, Elsevier, 1997).

² A mitigation cost-curve is a supply curve for emissions reduction – thus large emissions reduction at constant cost would yield a flat curve; whereas a progressively increasing cost of emissions reduction with increasing capacity results in a rising curve.

³ IPCC, 2005: IPCC Special report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H.C. de Coninck, M. Loos and L.A. Meyer (eds.)]. Cambridge University Press, Cambridge, UK.

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?

There is great scope for deployment to both coal and gas. Natural gas will be available for many years to come and will provide an important diversity to energy supplies which will promote reliability of supply.

Two important aspects must be mentioned – retrofit and opportunities outside power generation. Retrofit to existing power stations seems unlikely to be commercially attractive since the cost of the retrofit would have to be recovered in the remaining life of the station, which is likely to be less than a new station; also the existing stations which would be retrofitted already have lower than state of the art efficiency – fitting capture would make these stations very inefficient. However, a complete refurbishment of existing stations (involving new boilers, turbines, etc.) would provide a suitable environment for incorporating capture since the above restrictions would not apply.

There are significant opportunities for use of CCS outside the power generation sector, especially in oil refining, petrochemical production, fertiliser, cement, and iron and steel manufacture – many of these provide less costly application of CCS than power generation. In addition there is a potentially important application for the future in the production of hydrogen from fossil fuels. By use of CCS there would be minimal emissions from such plant whilst the cost of the hydrogen would be substantially less than from other sources of hydrogen. If hydrogen is to become a future vehicle fuel, production from fossil fuels with CCS would provide a less costly way of establishing the supply chain and encouraging users than obtaining hydrogen from other sources.

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

The IPCC special report examines this in detail – in brief the status of the most relevant CCS technologies can be summarised as “economically feasible under specific conditions”, based on technology which is replicated in many applications in mature markets worldwide.

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

Key limitations and steps to overcome them are:

- The established capture processes (pre- and post-combustion) are already deployed at scale of c.1Mt/y of CO₂ from natural gas sources; scale-up to larger scale (2-3 Mt/y) especially for operation in an oxidising atmosphere (i.e. flue gas) is required.
- The security of storage in geological storage is being demonstrated in 3 large-scale examples worldwide; further demonstration of geological storage which verifies reliable storage is needed to inform the public and build confidence in this mitigation option.

- Methods of financing CCS project depend on verification of storage in order to qualify under European Trading System (ETS).
- Acceptance under London Convention and OSPAR will be necessary to overcome uncertainty about the legality of geological storage offshore.

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

The Norwegian Sleipner project started operating 10 years ago; the UK can benefit from being a close follower of the leading country deploying this technology. This could bring benefits to UK industry especially in respect of power generation project delivery and management of geological storage facilities. Demonstration of UK capabilities in these areas is essential in order to win business from abroad.

Establishing the first power stations of a new type will always be more expensive than when they are ordered in series – there have been 4 IGCC's built and the cost is coming down; nuclear power plant costs quoted for the Energy review are understood to be based on those after the first eight have been built.

Establishing CCS power stations in the next decade provides relative certainty in emissions reduction due to the large-scale of the individual stations. Few other technologies could provide confidence in making emissions reduction happen.

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

In the same way as with other energy technologies, there are probably insufficient people being trained in the relevant technologies. CCS differs in one respect in that it can also take advantage of skills developed for the oil and gas production industries over the past few decades which may not be in demand as much in future years as they have been in the past.

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

The development and use of CO₂ capture can take place within the current regulatory framework for power stations and gas transportation with suitable modifications to account for the different gas. The main issues for regulation of CCS concern activities offshore, especially geological storage but also transportation. In particular, the OSPAR convention is currently a constraint on storage of CO₂ from onshore sources (although not EOR). The regulations governing the use of existing pipelines do not allow for adaptation for transporting CO₂. Other aspects of regulation which are uncertain and hence impose restrictions on use of CCS concern the legal responsibility for CO₂ underground, especially the long-term liability after injection has finished.

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?

The OSPAR convention must be adapted to allow storage of CO₂ from onshore sources.

The regulations governing the use of existing pipelines must be altered to allow these to be converted for transporting CO₂.

The legal responsibility for CO₂ underground must be defined, especially the long-term liability after injection has finished.

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

The long term liability is associated with storage. I do not have precise data on the cost of long-term liability but this does not seem likely to be of significant size. The most likely route for leakage is via the well-bore⁴ (if this does happen, it would most likely be during injection) which can be remediated quickly by standard oil industry practices. CO₂ is held in store by a number of mechanisms: geological seal, solubility trapping, residual gas trapping in pores, mineral trapping. The pressure in the reservoir will decline with time once injection has ceased, so it is unlikely that new geological pathways to surface will open up. Thus the degree and security of trapping will increase over time⁵.

One aspect of the cost of long-term liability is the monitoring of CO₂ storage - this has been assessed and found to be small in comparison with other costs for CCS⁶.

In comparison with disposal of nuclear waste, the long-term liability of CO₂ storage seems to be small.

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 liability for CO₂ in the power station with capture is broadly similar to the liabilities expected for this and related types of plant (i.e. chemical plant and plant handling combustible gases).

The liability for CO₂ in transportation is quite similar to that for natural gas, with differences relating to the explosive nature of natural gas and to the density of CO₂

⁴ In the analogous industry of natural gas storage (current worldwide capacity equivalent to 910 Mt CO₂), the frequency of well-bore failure has been found to be ~ 2 to 5*10⁻⁵ /y. This suggests the mean time between failure per well is approximately 10,000 years; designs for long-term storage of CO₂ should do even better than this.

⁵ US research projects which have tried to remove CO₂ from geological storage after a few months have found it difficult to extract more than a small fraction of the injected amount, if any at all.

⁶ Benson, S., M. Hoversten, E. Gasperikova, and M. Haines, 2004: Monitoring Protocols and Life-cycle costs for geologic storage of carbon dioxide. Published in Greenhouse Gas Control Technologies (M. Wilson, T. Morris, J. Gale, K. Thambimuthu (eds.)) pp1259-1264. Elsevier, Amsterdam.

(which affects the dispersion of leaks); these factors can be expected to be taken into account in the design of these facilities.

The liability for storage of CO₂ should be broadly similar to that for storage of natural gas underground.

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

We can speculate about the likely public reaction but until proper surveys are done we will not know for certain. Preliminary results from the Tyndall Centre work on public attitudes suggest that many (but not all) people would accept CCS as part of a portfolio of measures for mitigation of climate change. The concerns can only be addressed by providing access to good quality scientific information, by enabling those with concerns to seek answers to their questions, and by providing access to disinterested advice on the various mitigation options available.

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

According to the report⁷ of the House of Commons Science and Technology Committee, the use of CCS would add 1.1p/kWh to the cost of generating electricity from coal and 0.9p/kWh to the cost of electricity from gas (at £3/GJ). This is consistent with some of the figures in Table 1 of the consultation document. It is expected these costs could be achieved once several CCS plant had been constructed and a pipeline network (e.g. one capable of transporting >10Mt/y CO₂) was in place for carrying CO₂ to the North Sea fields. The earlier plants would cost more than this; later plants would probably cost less as experience is gained with the technology (in the same way as has happened with the related technology of flue gas desulphurisation).

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

The evidence for cost reduction over time is based on analogy with other technology so is not established to the same standard as engineering estimates of plant costs. Because of the established technology base for CCS, it is likely that the cost reduction with increasing scale of use will be less than for technologies which have started from small-scale R&D and which are susceptible to large scale manufacturing processes (e.g. photovoltaics). The economies of scale of all of the main components (i.e. capture, pipelines, injection for storage) can be predicted by analogy with related uses of similar technology. Capture costs are likely to reduce in a similar way to the cost reduction of flue gas desulphurisation technology in the recent past.

⁷ HC 578-1

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?

The relative prices of coal and gas will have greater influence on the cost of generating electricity than on the additional cost of CCS. It is not clear to what extent the use of CCS will be profitable – this will depend on the nature of and participants in the emissions trading market in future, which is inherently unpredictable. Use of CCS will involve reduction of other regulated pollutants so this provides additional benefit which helps offset the cost of CCS but this is not expected to be a large part of the overall balance of costs and income.

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

It is not clear that EOR reduces costs of CCS to a significant extent. The use of EOR affects the commercial viability of CCS by encouraging oil companies to consider this technique for use in operational oil fields. As EOR is probably the only rationale for injecting CO₂ from onshore sources into subsea geological formations which is currently allowed under OSPAR, EOR provides a potential opportunity for application of CCS technology which is not available through other routes.

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

The various different means of EOR will have costs which vary with the geological formation and the source of the gas/fluid used so it is not possible to make any generalisation about the costs relative to use of CO₂. Norwegian oil companies have made several assessments of EOR projects using a variety of fluids including CO₂ – the fact that several of these did not favour CO₂ indicates that CO₂ was not the cheapest for these particular fields; the fact that 2 projects have recently been announced suggests that CO₂ may now be the most attractive option for EOR in some forthcoming projects.

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?

In suitable fields, it may well be appropriate to use EOR. Given the availability of platforms and pipelines, it would be remiss of the UK government to ignore the opportunity to achieve incremental oil production from the existing fields – this would be equivalent to throwing away a valuable resource since it seems unlikely that fields could be re-opened once they had been abandoned. It is noted that few EOR schemes anywhere in the world have proceeded without public support in some fashion.

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

There is some ambiguity in the term “capture-ready” plant. In principle the term refers to the opportunity for decisions made at the design stage to retain options for future modification of the plant. Otherwise opportunities for later fitting capture to the plant might be closed off, for instance by choice of plant layout or because of excessive cost.

New power plant could be designed to be ready for fitting CO₂ capture at a later date in various different ways. At the very least, this would involve allowing sufficient space on the site for the subsequent installation of capture and compression equipment. A much higher standard of “capture-readiness” would be to select a plant design where a high concentration of CO₂ is already available in the process, thereby making CO₂ separation relatively inexpensive (in energy as well as cost terms). At the highest level, the plant design would already involve CO₂ separation even though the compression was not installed so as to prepare the CO₂ for transport (this would be the least cost option for capture-readiness).

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

There is significant opportunity to mitigate the additional costs by decisions at the design stage. Rutkowski⁸ reported on a study on the cost of retrofitting an Integrated Gasification Combined Cycle (IGCC) plant with CO₂ capture, either adding capture to a plant which had not been prepared for it, or adding capture to a plant which had been designed for later retro-fitting. The cost of electricity generation was 3% greater in the plant which had been prepared for retrofit compared with the one which had not (using 15% capital charge). In contrast, once capture had been retrofitted, the cost of electricity from the plant which had been prepared was 3.5% lower than from the plant which had not. This would seem to suggest that, under suitable circumstances, it may be cost-effective to make preparation for capture when building a new IGCC even if capture were not installed until some years later.

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?

The use of CCS is not a profitable option for business in the electricity supply sector or other sectors at present. The extent of the shortfall depends on circumstances but is likely to exceed the additional cost of CCS given in the recent Select Committee report.

Under what conditions might it become profitable?

CCS might become profitable once society recognises the need to make deep reductions in greenhouse gas emissions and implements this by, for example, regulating emissions and establishing means for industry to remunerate the extra costs involved, such as by trading emission rights.

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

The principles of environmental policy making, as set out in the consultation document, may be appropriate for micro-optimisation of the environmental impact of policy. However, the changes in emissions needed to tackle climate change (i.e. reductions of 60% or more) will be much more aggressive so the current policy

⁸ Rutkowski, M.D., R.L. Schoff, N.A.H. Holt, G. Booras, 2003: Pre-Investment of IGCC for CO₂ Capture with the Potential for Hydrogen Co-Production. Presented at US Gasification Technologies Conference, 2003.

framework seems unlikely to provide an appropriate basis for development of CCS. In particular, the long timescale involved in taking effective action on climate change and the unpredictability of the environmental changes (because they would be so far outside human experience, especially outside scientifically measured experience) suggest that the call for evidence-based decision making should be tempered with judgement about the risks of inaction. Protecting the climate may be such an important objective that it has to take precedence over wider economic and social objectives. It is the role of technology to ensure that the impact is minimised but there may still be significant impact.

The current policy framework includes a number of measures developed on historical and therefore inconsistent bases. In addition to the climate change levy, the enhanced capital allowances and the ETS, there is also the Renewables Obligation and, in the past, the Non-fossil fuel obligation. This multiplicity of inconsistent measures promotes inefficient decision making. It would be much better for government to rationalise these incentives so that a single system operated which was blind to the technology options so that in each sector of industry could implement the least-cost means of achieving societal goals.

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?

Key issues which should be taken into account with regard to CCS include:

- Its relevance and importance in achieving the energy policy goals of diversity of supply and reliability of supply whilst minimising cost and reducing climate impact.
- The need for open information so as to ensure the comparison between options is done on an even-handed basis. In particular it is necessary to ensure all relevant issues are considered in setting policy and are handled in a consistent way. For example, the back-end costs of the CCS cycle are openly examined and tested but the same may not necessarily be true of the nuclear fuel cycle, in particular dealing with the dangers of international proliferation of plutonium from spent fuel.
- Recognition that the UK has a unique opportunity to develop geological storage of CO₂ which would help establish the UK at the forefront of a new industry as well as providing opportunity for operators of UK facilities to develop business for storing CO₂ from sources in other European countries.
- The need for a serious examination of the practicability of achieving emissions reductions of 60% or more in light of the difficulty of achieving 10% reduction by 2006. This would be important for understanding which options have real and practical potential for helping the nation meet those objectives.
- Recognition in the strategy for hydrogen as a vehicle fuel that more emphasis must be given to the other parts of the supply chain, not just the development of suitable vehicles as tends to be the case at present. Unless this is done, and suitable policy framework developed, there is unlikely to be a suitable supply low greenhouse gas hydrogen fuel available.