Green Alliance policy insight
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The CCS challenge

Securing a second chance for UK carbon capture and storage

A second chance for UK CCS

"You may delay, but time will not, and lost time is never found again."
Benjamin Franklin

Carbon capture and storage should be an essential component of the UK's decarbonised power sector in 2030. The UK has a combination of R&D, engineering, and offshore experience which makes it amongst the best places in the world to commercialise the technology. But, far from capitalising on its advantages, the UK has delayed CCS demonstration for half a decade, putting the eventual delivery of commercial CCS at risk.

Past estimates suggest that CCS could make a large contribution to a decarbonised power sector in 2030 if it is deployed by 2025. But these assume that the first project of a two stage demonstration programme would be under construction by the fourth quarter of 2011. This opportunity has now been missed.

A delay in CCS demonstration leaves a gap in our low carbon power system in 2030 which other technologies would have to fill. Our analysis shows that the government's plan for demonstration to start between 2016 and 2020 won't leave enough time to deliver 10GW of CCS by 2030, which is the central expectation of the Department of Energy and Climate Change's (DECC's) Carbon Plan. If demonstration is delayed to 2020 and unabated gas is used instead to fill the gap, resulting power sector emissions could be nearly 80 per cent higher. To avoid these emissions, we would need to build an additional 13GW of offshore wind to bring power sector emissions down to 50gCO_2/kWh, which is the indicative emissions intensity limit suggested by the Committee on Climate Change.

Under delivery of CCS matters even more if the very ambitious pace of nuclear deployment that government expects is not achieved. In this case, if CCS demonstration is delayed until 2020, power sector emissions could be over three times higher, which would take an additional 37GW of offshore wind to fill the low carbon gap created by slower nuclear and CCS delivery.

These outcomes are not a foregone conclusion. The UK is still in a strong position to demonstrate CCS and reap the considerable economic and carbon benefits of its deployment. The UK has a second chance. But time is short, and a new policy approach to demonstration is needed.

The deployment paths now available to the UK require an active industrial strategy, which should focus on reducing costs. This requires:

1. CCS clusters to enable shared CO_2 transport and storage;
2. a long term carbon trajectory for the power sector that drives demand for CCS on coal and gas plant; and
3. a predictable financing mechanism for CCS through electricity market reform.

This strategy can reduce the time between demonstration and deployment, and increase deployment once CCS has been demonstrated. This approach is the only way the UK can retain CCS as an important and potentially cost-effective option for decarbonisation.

Why CCS matters

Over recent years media attention has focused on the rapid expansion of coal use in China, but politically important countries as diverse as the US, India, South Africa, Australia, Poland and, increasingly, the UK are concerned at the implications of an end to coal use for their domestic energy security. Addressing climate change means addressing emissions from coal, both technically and politically, starting in this decade. Although coal has been the main focus, the same issues are beginning to arise for gas across the EU. The availability of cost-effective CCS in the 2020s would reduce perceived barriers to decarbonisation and help to break the deadlock of international climate negotiations.

There is also a strong domestic rationale that should drive UK efforts to accelerate commercial deployment of CCS. First, the UK is uniquely well suited to the early development and deployment of CCS. According to the independent advisory committee on carbon abatement technologies, the UK has: "world leading experts in the key areas, an established engineering and scientific base, a selection of available and known [geological] storage sites, an industrial and commercial base that wants this to happen and an urgent domestic need for investment in CCS."[1]

Figure 1, over the page, shows the strong correlation between likely CO_2 storage sites and the UK's existing CO_2 emissions sources. This provides the UK with an immediate opportunity to develop shared CO_2 networks to capture the economies of scale and reduced project risks from clustering, particularly for industrial CCS projects that produce smaller quantities of emissions.

The UK's technical advantages are matched by its political ones. A cross-party consensus in support of CCS is in place and, unlike elsewhere in the EU, UK NGOs have engaged positively. Partly as a result, the UK has not experienced the opposition to CCS seen in Germany and The Netherlands, where local concerns have been raised about the onshore storage of CO_2. National Grid has worked with communities located close to potential CO_2 pipeline routes, while the availability of offshore storage options gives the UK a natural advantage.

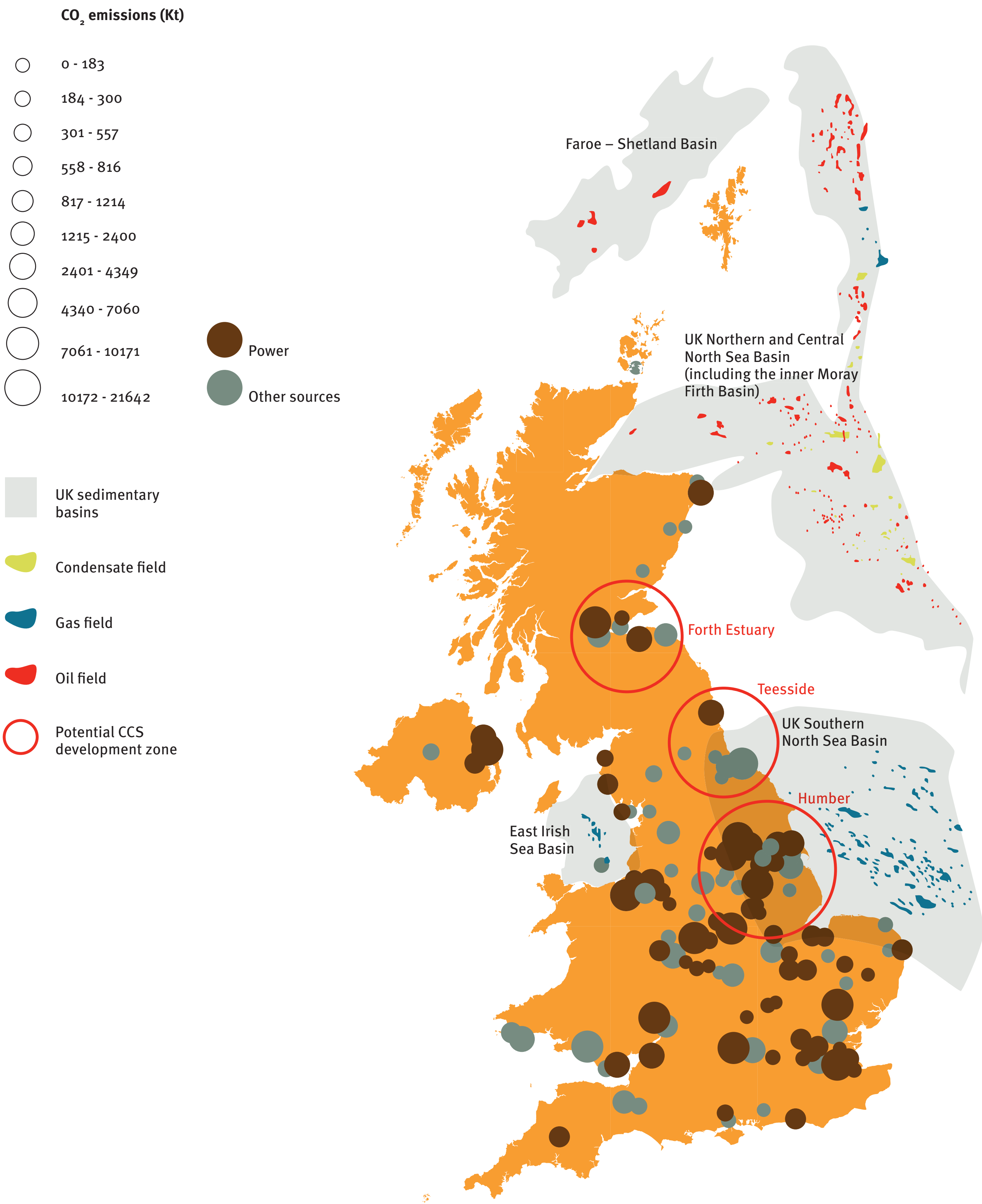
Second, the large global market for cost-competitive CCS means that those companies which have experience of installing and running CCS plants will have globally valuable expertise. If this expertise is developed in the UK, our economy stands to benefit from this international market. Importantly, the benefits extend beyond top tier manufacturers like GE and Siemens, which employ significant numbers of people in the UK, to British companies involved in the supply chain.

Third, the UK's path to a decarbonised power sector could be achieved much more easily with commercially available CCS. Since 2008, the Committee on Climate Change has advised that the UK power sector needs to aim for decarbonisation by 2030, suggesting that average emissions will need to reach around $50gCO_2/kWh$, on the basis that this will be the most cost-effective path to decarbonisation of the wider economy in 2050[2].

The government plans to use renewables, nuclear and CCS as three legs of its low carbon strategy. If CCS isn't available, this removes one of the options and means we will have to rely more heavily on the other two. Without CCS, the 30-50GW of coal and gas plant remaining in the UK by 2030 will have to be scrapped or run at low load factor. Because the government strategy counts on CCS, a significant gap in low carbon power appears if CCS demonstration is delayed. At the European scale, delay would be just as significant: the EC Energy Roadmap suggests that over 110GW of CCS needs to be delivered between 2030 and 2040.

CCS also provides a solution to another major source of emissions: energy intensive industry, for which it remains the only technological solution given that some industrial processes require the consumption of fossil fuels. Leading the development of CCS for the power sector is likely to reduce the cost of industrial CCS, helping to address Chancellor

Figure 1. CO_2 sources and potential CO_2 storage locations in the UK[2,3]



George Osborne's concern about "the combined impact of the green policies… on some of our heavy, energy intensive industries."

Although the UK can continue to reduce industrial costs through targeted public funding for efficiency, a sustainable strategy for energy intensive industries requires CCS. The Netherlands and France have prioritised industrial CCS projects in their submissions for European funding, while the US and China are actively looking at how using captured CO_2 for processes such as fertiliser production can provide additional revenues.

The timely availability of CCS in the UK is imperative not just to allow us to sustain both a diverse mix of energy supply technologies in the power sector, but also as a means of maintaining a broad industrial base that remains competitive while meeting decarbonisation goals.

CCS: a history of delay

The UK was an early mover into CCS but a series of delays, due to an overly prescriptive demonstration programme, public concern that CCS demonstration might enable new largely unabated coal plants to be built, and funding delays, now mean that the UK risks lagging behind its CCS competitors.

Key delays in CCS demonstration in the UK

Date	Decision	Cause of delay
2007	Demonstration competition launched. Competition limited to post-combustion coal plants	Exclusion of pre-combustion projects, including a well-developed proposal at Peterhead
2008	NGO-led campaign against unabated coal, with a focus on Kingsnorth	NGO and public concern that CCS on a small proportion of new large coal plants was a fig leaf for business as usual
2009	Following very slow progress in the first CCS competition, two bidders pull out	Uncertainty over funding during the comprehensive spending review process
2010	Coalition agreement supports four demonstration projects, but the first comprehensive spending review withdraws the CCS levy	The CCS levy, agreed on a cross-party basis, was intended to deliver funding certainty. CfD FiTs for CCS are not clarified until mid-2011, creating funding uncertainty
2011	Seven UK projects bid for support from the EU NER300 funding mechanism	NER300 funding reduces due to a major fall in the carbon price
2011	CCS roadmap and gas CCS call for projects delayed from spring to autumn 2011 (as yet unpublished)	Uncertainty over funding for demonstrations 2 – 4; an extension of the electricity market reform process; and delays in assessing UK projects bidding for NER300 funding
2011	Longannet project withdrawn, marking the end of the four year CCS competition	Project cost, including the effect of the Carbon Floor Price on the unabated part of the plant
2011	Majority of £1bn of funding for a first demonstration reallocated to the next spending review period	Withdrawal of Longannet led to concern that the £1bn reserved for CCS demonstration will not be able to be spent before 2015

Consequences of delaying CCS demonstration for the power sector

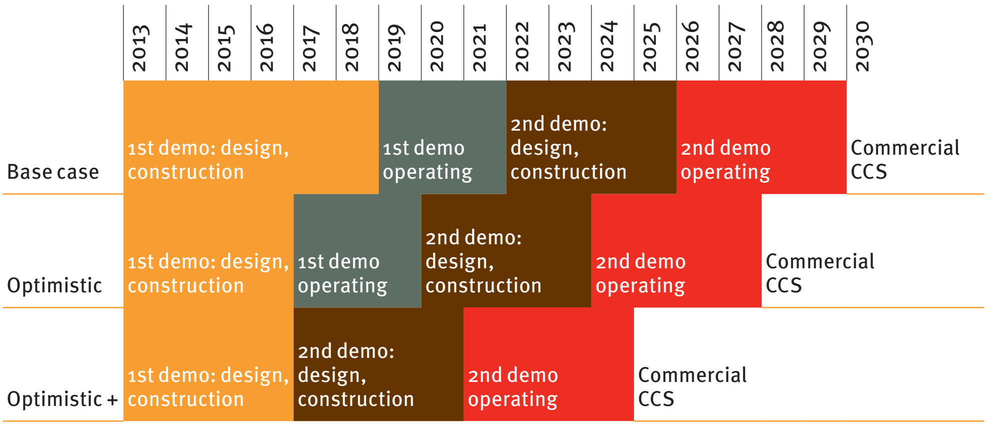
To highlight the gap between government expectations for 2030 and the long delays that have occurred in CCS demonstration, we have modelled the effect of delayed demonstration on the availability of CCS in 2030, based on two different assessments of how long it will take to develop commercial CCS.[5] We then applied these different demonstration assessments to two power sector scenarios to identify the implications for carbon emissions and low carbon power sources other than CCS.

Previous studies addressing CCS demonstration timelines found two key variables which affect the deliverability of CCS by 2030:[6]

1. **Timeline to delivery:** the time it will take to prove that CCS works, going from a first demonstration plant to commercial availability.
2. **Pace of deployment:** once it is shown to work, the subsequent pace, in GW per year, at which CCS can be deployed commercially.

Timeline to delivery

The chart below summarises key dates in the first of these variables, showing the base case against our two alternative timelines:



The base case

This is the consensus view on the economically efficient approach to CCS demonstration. Notably, it assumes two distinct development stages of demonstration plants, with a gap of seven years between the two stages to allow the operational lessons from the first to inform the design of the second, pre-commercial stage. This approach could have delivered commercial CCS at scale by 2030 if a first demonstration had been agreed promptly out of the initial competition, launched in 2007.

Our timelines

Our analysis is based on two accelerated versions of this base case. The main shared assumption for these is a four year design and construction period between the decision to go ahead with a first demonstration plant (or plants) and its start date.

We describe an '**optimistic**' timeline and an '**optimistic+**' timeline. Their difference lies in the shorter gap between first and second stage of demonstrations. The **optimistic +** timeline assumes design and construction of second stage demonstration plants will begin as soon as the first stage is operational. It is worth emphasising here that the **optimistic+** timeline is unlikely to be possible under current policies.

In both cases, we assume that 1-2GW of demonstration plant (three to five projects) is built in total. Further details are available in a modelling methodology annex.

Pace of deployment

Turning to the second variable, comparisons with the first dash for gas in the 1990s show an average delivery rate of around 2.5GW of Combined Cycle Gas Turbine (CCGT) power stations per year. Similarly, the installation of flue-gas desulphurisation (FGD) equipment in the US in the 1980s occurred at nearly a 5GW per year delivery rate. However, both of these were very situation specific.

The first dash for gas took place in an exuberant post-privatisation drive to compete with older, previously state run generators. Also important was the consensus that gas was both cleaner and cheaper than the coal it displaced, and there was a very supportive political environment. Finally, CCGTs benefited from a longer development timeline than is available for CCS between now and 2030.[8]

The story of FGD includes similarly specific factors which do not currently apply to CCS. Although FGD was developed and deployed in a short time period, its costs, which rose significantly during deployment, were simply passed to consumers by monopoly utility companies. This happened as part of a technology forcing strategy which was enabled by technical experts working in the US Environmental Protection Agency.[9] A similar forcing strategy in the UK would require a new approach to CCS.

We have therefore assumed a realistic 1GW per year delivery rate of CCS from the point at which it becomes commercially available.[10] We believe that any higher rate would require a new policy approach.

CCS delivery under current policies

To understand how delays in demonstration might affect the delivery of CCS under current policies, we modelled our two timelines and the delivery rate assumption against two power sector scenarios.

Central: This assumes that nuclear power and renewables will be delivered at the pace set out in the Committee on Climate Change's *Renewable energy review*, with the remainder delivered by a mixture of unabated gas and CCS.[11]

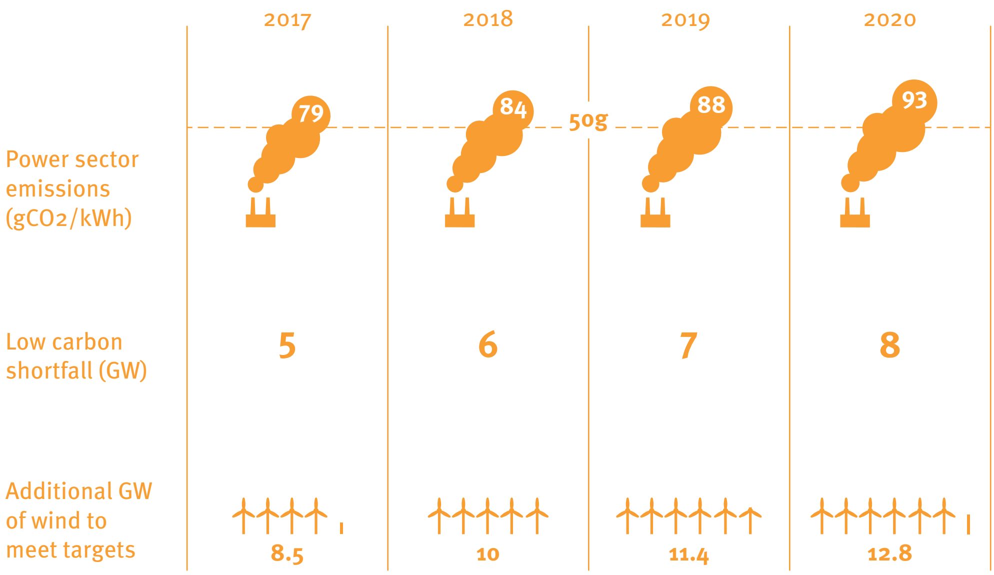
Nuclear go-slow: This models a 50 per cent shortfall in delivery of nuclear power to 2030.

In both, where there is a shortfall in CCS delivery, we have assumed that unabated gas would be built to meet demand.

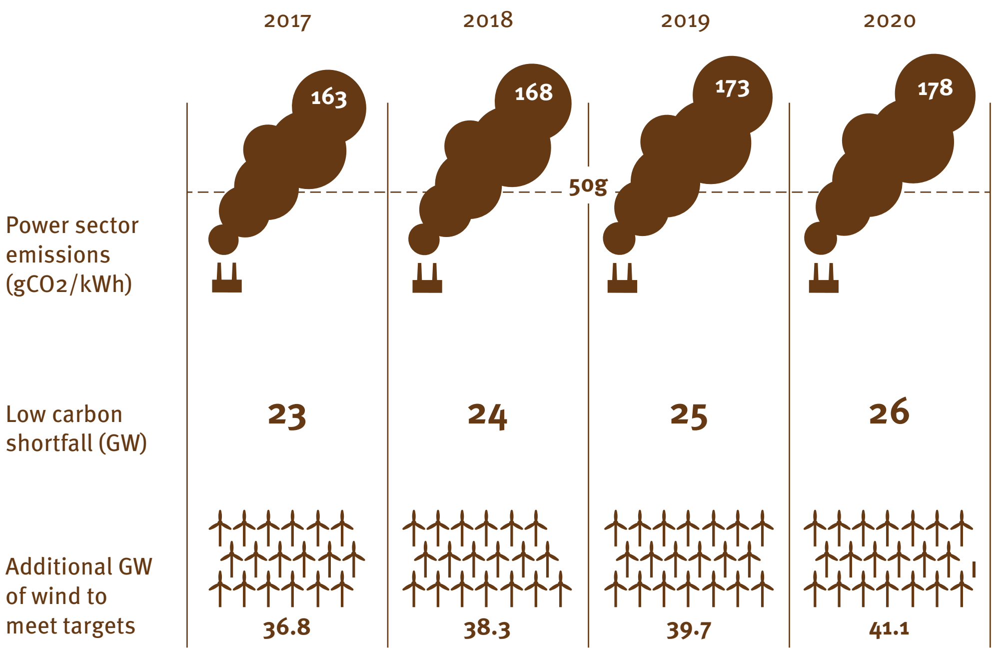
The impact of delays in CCS demonstration on the ability to deploy it by 2030 is then applied to each scenario, showing the resulting power sector emissions intensity, and how much additional offshore wind might be required to bring emissions down to the Committee on Climate Change's suggested 50gCO_2/kWh emissions limit.

On page 8 we illustrate the best and worst case scenarios based on our assumptions and the current policy environment. Neither scenario is a recipe for doom: as WWF's *Positive energy* report demonstrates[12], even without CCS and nuclear, it is possible to decarbonise our power system by 2030, but only in a 'stretch' scenario with very high interconnection capacity and highly responsive demand.

Central, 1GW/year, optimistic timeline (best case current policies)



Nuclear go-slow, 1GW/year, optimistic timeline (worst case current policies)



"Outlining how CCS serves the UK's interest should be at the heart of the government's approach"

CCS delivery under a strategic approach

CCS, however, makes decarbonisation easier, and the scenarios illustrated could be unduly pessimistic if the UK demonstration programme can both reduce the gap between demonstration and deployment, and create the conditions for a higher pace of deployment after CCS is demonstrated. If this were the case, a plausible outcome could be:

Central scenario, 2GW/year, optimistic+ timeline

Demo start date	2016	2017	2018	2019	2020
Power sector emissions (gCO_2/kWh) (50g line)	25	35	45	54	64
CCS by 2030 (GW)	15	13	11.5	9	7
Additional GW of wind to meet targets	n/a	n/a	n/a	1.3	4.2

To make this happen, a co-ordinated industrial strategy for CCS must be developed. To understand how, it is instructive to look at the history of UK CCS policy.

Learning from the history of UK CCS policy

The history of delay outlined above shows how CCS policy has changed in response to new drivers while attempting to maintain consistency with the previous approach. This has introduced delay and has meant that CCS policy has struggled to align itself with the timescale necessary for, and rationale behind, the decarbonisation of the energy sector.

A good example of this can be seen in the case of coal CCS. It was originally proposed partly to support diversity of power production and traditional coal areas, and partly to support global decarbonisation through CCS retrofit in China. The reduction in concern about gas availability from early 2010 meant that coal CCS no longer appeared to be in the UK's direct interest and, as interest in maintaining the coal industry waned, political support for providing £4 billion of public funding evaporated. Climate altruism, in the form of UK funded demonstration of technology to decarbonise China, could not be justified in a time of austerity.

Given this history, the government faces a challenge of restoring momentum and a sense of optimism to UK CCS policy. Outlining how CCS serves the UK's interest should be at the heart of the government's approach. Because the UK has a large amount of gas plant which will need to retrofit CCS or run at very low load factors in the 2020s, gas CCS is clearly in the UK's interest. Similarly, justifying a coal CCS demonstration can still support the government's aims of maintaining power sector diversity, and exporting coal CCS know-how to more coal dependent countries is a major export opportunity. Finally, developing and characterising UK offshore storage and transport infrastructure would put the UK in a

"The low intervention, low cost development option is no longer available to the UK"

leading position to sell its North Sea CO_2 storage space to countries like Germany, which has restricted access to storage.

The government starts from a strong base. The UK still has six entries out of a remaining 11 projects bidding for European NER300[13] funding, and a further 14 expressions of interest have already been received by DECC following their presentation of outline plans for the revised UK CCS programme. Interest is clearly still high.

UK CCS projects competing for public funding

Promoter	Location	Cluster potential	Funding
Boc, Drax, Alstom & National Grid	North Yorkshire	High	NER300
Peel Energy	Hunterston, Ayrshire	Low	NER300
2Co	Don Valley, Yorkshire	High	NER300
SSE	Peterhead	Medium[14]	NER300
C.GEN	Killingholme, Yorkshire	High	NER300
Progressive Energy	Teeside	High	NER300
Summit Power, Petrofac, & National Grid	Forth Estuary	High	UK demonstration

Accelerating demonstration

Green Alliance has engaged extensively with industry, NGOs, academics and other stakeholders on CCS over the past few years. The history of its development shows that successive governments have lacked stable long term goals for CCS when adapting policies to changed circumstances. The government instead took a hands-off approach, removing itself from taking strategic decisions in favour of 'letting the market decide'. It has sought to deliver the policy certainty needed to invest in this new technology through a mechanism best suited to flexible delivery of established technologies: the market. At the same time, it designed a market reform process founded on the idea that the very same market was failing to deliver other, more established, low carbon technologies.

The low intervention, low cost development option, as our modelling shows, is no longer available to the UK. Simply put, half a decade's delay in demonstration since 2007 means the government must actively guide CCS development if it is to enable it to play a significant role in meeting the UK's 2030 low carbon energy needs.

There is a short window of opportunity to pursue an accelerated two stage demonstration programme, the success of which is dependent both on government co-ordination and support, and on the ability of industry to fund and deliver CCS at the pace it has promised.

Keeping to this timetable will be challenging, and there is a second alternative pathway to greater deployment by 2030: expansion of the second stage of pre-commercial CCS projects, supported by feed-in tariffs (CfD FiTs). This would mean procuring more CCS by offering higher CfD FiT levels, potentially raising the cost of the development programme. There may be good reasons why the government should consider this. It may wish to keep open a low carbon competitor to nuclear power or to maintain power sector diversity, for example. But it would be difficult to justify doing so without a concerted industrial strategy which was demonstrably reducing the cost of CCS.

Two alternative deployment paths for CCS to 2030

Approach	Deployment pace	CCS by 2030	Funding level	Government co-ordination
Optimistic business as usual case	1 – 2GW in two stages of demonstration, with 1 GW/year deployment following demonstration	1 – 5GW	Low	Low
Optimistic+ accelerated demo and commercial deployment	1 – 2GW in two faster stages of demonstration, with 2 GW/year deployment following demonstration	6 – 15GW	Low	High
Higher pre-commercial deployment	4 – 6 GW in two stages of demonstration, with 2GW/year deployment following demonstration	9 –20GW	Medium	High

Business as usual will not deliver the 10GW of CCS expected by 2030. Both of the potential deployment paths now open to government require an active industrial policy. Below we outline the key elements of such a policy.

Recommendation 1 – Support CCS clusters

An active CCS industrial policy does not mean that the government should pick technology winners[15]. But, given the location specific nature of geological storage sites for CO_2 and the distribution of emissions sources, it is clearly necessary for the government to be willing to pick locations. Doing so can provide more options for demonstration: the greater the support for CCS clusters, the greater the scope for flexibility for individual demonstration projects.

We cannot afford to delay demonstration by developing clusters first, but the location of and investments in demonstration projects can stimulate or hinder the subsequent deployment of CCS. Missing opportunities to future proof CO_2 pipeline networks for the inclusion of future emissions sources may prevent the best pipeline routes from being available to subsequent projects, increasing overall costs.

In contrast, demonstration projects with provision for shared infrastructure may unlock opportunities for industrial CCS. Shared pipeline and storage infrastructure also helps to make capture ready plants more likely to retrofit CCS. To achieve the benefits of clusters, government should:

Declare 2-3 CCS development zones:

CCS development zones around core locations with demonstration plants, such as Yorkshire /Humber, Teeside and the Forth estuary, could be prioritised for the development of shared CO_2 infrastructure, starting with an assessment of additional CO_2 sources, such as industrial emitters, and timelines to enable future proofing of infrastructure.

Fund FEED studies and shareable transport and storage infrastructure:

Capital allocations need to reduce project risks to drive down the total cost of CCS demonstration. Funding studies of, and providing incentives for, transport and storage investments which can be used by multiple projects will help to improve the economics of

"Government should set a power sector emissions reduction trajectory in the forthcoming energy bill"

each individual project. Because uncertainty over the bankability of CO_2 storage is a key limiting factor in the ability of power plants to realistically retrofit CCS, data from these studies should be open access.

In this way, public money can bring forward more CCS demonstration and eventual CCS capacity per pound spent. Funding shared infrastructure also reduces delivery risk by letting developers focus more on their project than on end-to-end co-ordination. This would make our **optimistic+** timeline achievable by reducing the time required to design and deliver projects, enabling demonstration plants to come forward more quickly, and increasing the potential deployment rate of commercial CCS.

Recommendation 2 – Set a low carbon trajectory

The CCS industry, other low carbon investors, and NGOs share an interest in seeing clarity over the level of decarbonisation required to 2030. For industry this provides confidence over the scale of the market opportunity for CCS, which helps to reduce the cost of finance. For NGOs it provides confidence that decarbonisation goals will be met, and helps to underpin support for those CCS projects that represent steps towards achieving this aim.

To provide this confidence, the government should set a power sector emissions reduction trajectory in the forthcoming energy bill consistent with the Committee on Climate Change's indicative 50gCO2/kWh average emissions limit for 2030.

Government should also adjust the proposed grandfathering provisions for the Emissions Performance Standard in the energy bill to ensure that unabated gas will not be simply exempted from having to retrofit CCS until 2045. The possibility that a large volume of unabated gas will be able to compete unequally with CCS in the 2020s is a powerful disincentive to potential CCS investors who have yet to secure a CfD. To ensure that owners of planned gas plant can invest now, the government should offer these owners a choice: join a pre-qualification process to retrofit CCS in the 2020s, building on shared CCS cluster infrastructure with the possibility of CfD support, or accept grandfathered emissions and lower running hours in the 2020s as average power sector emissions fall.

These clarifications reduce policy risk, helping to underpin private sector investment in CCS equipment and supply chain development.

Recommendation 3 – Outline long term revenue

Reduced capital funding and a shorter timeline can be addressed by taking a long term approach to CCS funding. Demonstration funding must not simply incentivise individual projects, but should create the enabling conditions for accelerated deployment of CCS. To capitalise on this approach, the government should:

Create a funding stream:

The demonstration programme needs to facilitate first movers rapidly via public funding, but also needs to outline how support from CfD FiTs can provide a business case for longer term CCS operation. With reduced capital funding available, CfD FiTs may now need to contribute the majority of public support for CCS demonstration projects. If so, the government will need to clarify if CfD FiTs are intended primarily as a revenue stabilisation mechanism, as for nuclear CfDs, or whether they will include an element of technology support, as for renewable CfDs. CfDs for first of a kind demonstrations need to differ substantially from FiTs designed for more mature plant, as the risk profile of CCS is different from biomass, its closest renewable comparator. Indeed, support for demonstration using CfDs will be very complicated, as it will need to cover retrofit, part-retrofit, entirely abated new build CCS, and partly abated new build CCS. A large amount of detail needs to be worked through but, ideally, future indicative strike prices should be outlined to encourage the development of further projects to come on stream in the 2020s.

"There is a second chance for CCS in the UK but the window of time available to prove its commercial viability is closing"

Set up a CCS cost reduction task force:

To protect consumers, government should pursue a cost reduction strategy similar to the one it developed for offshore wind. This should focus on learning lessons from the first demonstration projects, but needs to draw on international demonstration as well. Large international manufacturers can transfer experience gained from their involvement in demonstration outside the UK. This would help to bring forward the date at which they can offer guaranteed performance contracts for CCS equipment in the UK, and reduce the gap between first and second stage demonstrations, building the supply chain to deliver commercial CCS more rapidly.

Grasping the opportunity

The UK faces a choice. Does it make up for lost time by actively brokering the development of a UK industry or does it continue to focus on process rather than outcomes? A failure to deliver soon would result in leading CCS companies refocusing their attentions away from Europe and towards emerging markets such as China. The UK would then need to import these technologies in coming decades, rather than leading the market and capitalising on existing skills and experience. It will also be forced to support offshore wind in far greater volumes than government is currently planning, since this is the technology that can be deployed most rapidly to make up the low carbon supply gap.

Our recommendations make a shortened CCS demonstration and delivery timeline more realistic, and can increase the deployment rate of CCS post-demonstration. If we are able to begin a demonstration programme soon, there is a real prospect of having a significant quantity of CCS available by 2030, assisting the industrial sector to decarbonise quickly and at lower cost, and capturing the considerable economic benefits that leadership on CCS promises. There is a second chance for CCS in the UK but the window of time available to prove its commercial viability is closing.

Endnotes

1. *Accelerating the deployment of carbon abatement technologies: with special focus on carbon capture and storage*, p.6, advisory document from ACCAT, retrieved from http://www.berr.gov.uk/files/file50419.pdf
2. Map based on Figure 4-1 from *Industrial carbon dioxide emissions and carbon dioxide storage potential in the UK*, 2006 , British Geological Survey for the Department of Trade and Industry
3. Source: http://www.nationalgrid.com/uk/EnergyandServices/NonRegs/CCS/Projects/, version also available in 'Building the pipeline together', CO_2 *Sense*, October 2011 (Image adapted from IEA Greenhouse Gas R&D Programme (IEAGHG), 'Updating the IEAGHG global CO_2 emissions database: developments since 2002,' 2006-07, February 2006.)
4. The cost-effectiveness of a 50gCO_2/kWh approach is robust to under delivery of either nuclear or CCS, implying that slower delivery of CCS should not affect the pace of power sector decarbonisation. See p.284 of *The fourth carbon budget - reducing emissions through the 2020s*, Committee on Climate Change, December 2010
5. In line with our literature review, we consider 'commercial CCS' to be CCS which is has an understood risk profile, enabling investors to price this risk into their investment decisions, and for the product to be roughly cost competitive with other power sector decarbonisation options.
6. See, for example, *Carbon capture and storage: milestones to deliver large scale deployment by 2030 in the UK*, Poyry for the Committee on Climate Change, 2009, retrieved from http://downloads.theccc.org.uk/Poyry_-_CCS_Timelines_and_Milestones_for_CCC_2009_final.pdf, and *Carbon capture and storage demonstration: analysis of policies on coal/CCS and financial incentive schemes*, Redpoint for DECC, available from http://www.redpointenergy.co.uk/images/uploads/decc_ccs_policies_20091113_FINAL.pdf.
7. The average of all the timelines we analysed would result in commercial CCS being available from 2029
8. For a fuller analysis of factors contributing to CCGT development, see Jim Watson, *The `success' of the combined cycle gas turbine*, Opportunities and Advances in International Electric Power Generation, International Conference on (Conf. Publ. No. 419), 1996, available from http://ieeexplore.ieee.org/Xplore/login.jsp?url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel3%2F5185%2F14025%2F00643450.pdf%3Farnumber%3D643450&authDecision=-203
9. For a fuller analysis of FGD and CCGT development, and how these might apply to CCS, see Jim Watson et al, April 2012, *Carbon capture and storage: realising the potential?*, UKERC Research Report. London: UK Energy Research Centre

[10] For reference, the CCC Renewables Review has an implied rate of delivery of about 1.5GW/year

[11] CCS emissions are modelled at 50gCO_2/kWh. Some technologies, notably post-combustion coal CCS, produce electricity with a higher emissions factor. If these were included, power sector emissions would be higher and, consequently, requirements for additional low carbon power would also be higher

[12] *Positive energy: how renewable electricity can transform the UK by* 2030, 2011, WWF UK, available from http://assets.wwf.org.uk/downloads/positive_energy_final_designed.pdf

[13] NER300 is the name of a financing instrument for CCS and renewables, managed jointly by the European Commission, European Investment Bank and Member States

[14] Although there is relatively little opportunity to co-locate onshore infrastructure, the Peterhead project can support the characterisation of offshore storage and the development of a pipeline network to UK central North Sea basin storage sites

[15] It is ironic that this is what happened when the first CCS demonstration competition was limited to post-combustion technology

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