Approaches to cost reduction in carbon capture and storage and offshore wind

Advisory Group Report

A report for the Committee on Climate Change

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Glossary

CCC	Committee on Climate Change
CCS	Carbon Capture and Storage
CE	Crown Estate
CfD	Contracts for Difference
EMR	Electricity Market Reform
EOR	Enhanced Oil Recovery
ETI	Energy Technologies Institute
FiD	Final Investment Decisions
G&C	Generation and Capture
GW	GigaWatts
LCOE	Levelised Cost of Electricity
MW	MegaWatt
MWh	MegaWatt Hour
OFTO	Offshore Transmission Owners
RD&D	Research, Development & Deployment
RO	Renewables Obligation
T&S	Transport and Storage

Introduction

This report

The Committee on Climate Change (CCC) has commissioned expert consultancy reports on approaches to cost reduction in offshore wind and carbon capture and storage (CCS). The purpose of this work is to inform the CCC in their advice to government on strategies for deployment and cost reduction in both technologies in the period to 2030. The reasons for a focus on offshore wind and CCS are explained below. Consultants Poyry and Element Energy have produced analysis on CCS and BVG Associates on offshore wind. Their reports are published separately. Available at www.theccc.org.uk

The CCC convened expert Advisory Groups to help scope, steer, oversee and comment on the consultants' analysis. The CCC commissioned the Chair of both Advisory Groups (Dr Robert Gross of Imperial College) to produce a report that reflects on the consultants' work; the evidence base, key assumptions, methods, and areas for future work. This report therefore provides a Chair's summary based upon the reflections of the CCS and Offshore Wind Advisory Groups. It considers and comments on the reports the consultants have produced and on the wider industrial and policy issues that surround these complex and crucially important topics.

This report deals with both CCS and offshore wind in one document. The CCC convened two parallel processes to assess the two technologies and is to advise government on both. Moreover, as we discuss below, there are some important policy issues in common. Nevertheless there are important *dissimilarities* between offshore wind and CCS, and bringing them together in this report does not reflect a view that 'one size fits all'.

Background

The Committee on Climate Change has advised government that long term carbon abatement targets will require that electricity generation is substantially decarbonised by around 2030. This advice emerges from the CCC's own modelling and is consistent with analysis from a wide range of organisations including the UK Energy Research Centre (UKERC), Energy Technologies Institute (ETI), the Government's own models and independent work by leading universities and consultancies (CCC 2013; Ekins *et al.* 2013; ETI 2015b). All these analyses use some combination of renewable energy, carbon capture and storage (CCS) and new nuclear power to deliver decarbonisation. The mix of each depends upon judgements about cost reductions in emerging options such as CCS and offshore wind and constraints such as build rates and societal acceptability for new nuclear and onshore wind (CCC 2013; Ekins *et al.* 2013; ETI 2015b). It also depends upon developments outside the electricity supply sector, for example in whether electricity demand rises to help decarbonise domestic heating or road transport.

The CCC has identified offshore wind and CCS as having particular importance to UK decarbonisation. This is because offshore wind has a particularly large potential resource, does not have the landscape impacts of onshore wind (although some offshore wind farms can have visual impacts), has broad seasonal correlation with demand and has the potential for significant cost reduction. CCS offers the potential for controllable power generation, may be the only solution for decarbonising many industrial processes, and could also provide a substantial share of electricity generation. As with offshore wind, costs appear likely to be high for early projects, but there is potential for significant cost reduction over time. Some scenarios suggest that CCS could be combined with sustainable bioenergy to provide net-negative emissions.

Aspects of the technologies used in offshore wind and CCS are well proven, with offshore wind development in the UK now into its second decade of deployment and with components of the CCS system operational for several decades in parts of the world. Yet taken as a whole both are still emerging technologies that are at an early stage of commercial exploitation. They are currently expensive relative to more established low carbon options such as large hydro, onshore wind and new nuclear and a key challenge is to drive cost reduction. This can emerge through a combination of economies of scale in components and infrastructure, through so called 'learning by doing' in technology manufacture and deployment, and in operation/maintenance, and through ongoing innovation in all aspects of technology (Gross *et al.* 2013).

Policy will play a key role in driving cost reduction by creating early (subsidised) markets that allow these effects to take place. In the case of offshore wind there is already some evidence that a sustained policy of market creation is beginning to reduce costs. Governments can also support cost reduction through direct support for research, development and demonstration (RD&D). Policy support will also be necessary to assist in directing some key strategic developments – such as the CO_2 transport and storage infrastructure. Policy design can also affect risk and hence the cost of capital. For example the contracts for difference (CfDs) created in Electricity Market Reform remove the risks associated with wholesale price volatility once a contract has been awarded. However the competitive process through which CfDs are awarded *post consent* means that project developers face substantial risks in the early stages of project development. We return to these issues below.

One of the most significant challenges for policy is to determine how much deployment to support in the near term when costs are high. It is also important to ensure that early markets are large enough to drive economies of scale and encourage competition and innovation, yet avoid supply chains 'overheating' – creating cost escalations because suppliers and installers cannot keep up with demand.

For all these reasons the CCC has recommended that government publishes strategies for both offshore wind and CCS and will advise government further later in 2015. To inform this work the CCC has commissioned studies of cost reduction potential, of optimal levels of UK deployment to achieve cost reduction, and of the wider role of policy – for example in strategic development of infrastructure. Consultants Poyry and Element Energy have produced analysis on CCS and BVG Associates on offshore wind. This report provides a summary of the reflections of the CCS and offshore wind Advisory Groups on the reports the consultants have produced and on the wider industrial and policy issues in offshore wind and CCS.

This report should be read in conjunction with the reports from BVG and Poyry/Element Energy available from the Committee on Climate Change website: www.theccc.org.uk

Overarching issues for CCS and offshore wind

The Advisory Groups for both consultancy reports were impressed with the depth and rigour of the analysis and, subject to the detailed comments below, broadly in agreement with many of the conclusions and recommendations from both sets of consultants.

Very important differences should be borne in mind when considering the common issues discussed below. In a UK context offshore wind is at a much more advanced stage of deployment than CCS, with several GW operational and some farms generating power since the early 2000s. All aspects of CCS (transport and storage of CO_2, use of CO_2 for enhanced oil recovery, CO_2 capture) are well proven internationally, yet in the UK power sector/decarbonisation applications are still pending with the two Commercialisation Demonstration Projects under development at the time of writing. Nevertheless from a policy perspective important points in common can be identified. The following high level points apply to CCS and offshore wind in the period to 2030.

A modest and stable UK market is essential to cost reduction

Cost reduction and commercialisation for both offshore wind and CCS will only be possible if an industry emerges based upon enough market opportunity to create a 'critical mass' for developers, the supply chain, installers and the investment community. The Advisory Groups were persuaded by the analysis the consultants present that in broad brushed terms the UK this is likely to require 1 - 2 GW per year for offshore wind and 4 – 7 GW in total by 2030 for CCS[1]. We comment in detail below on the precise market size that the consultants recommend (and indeed on whether it is appropriate to be precise). We note in this regard the arguments the consultants put forward around a market large enough to allow competition where possible, access economies of scale and allow a degree of learning by doing to take place. We also note that any market needs to be material enough to allow the finance community to take the trouble to become familiar with technologies and market participants, hence helping to reduce perceived risk and cost of capital. However we also note that there can be diminishing returns and diseconomies of scale. In some instances scale effects are of great importance, for example in developing an appropriate infrastructure for CCS that allows carbon capture to expand up to and beyond 2030. Nevertheless, in broad terms going too far, too fast before 2030 with both offshore wind and CCS capture projects may not yield greater cost reductions and would increase burdens on UK consumers. We discuss this in detail for each technology below.

Developments in the UK are essential if UK costs are to fall

We do not believe that the full set of achievable cost reductions would be forthcoming if the UK were to adopt a 'wait and see' approach that relies upon developments in other countries to reduce costs. This is because in the case of CCS substantial cost reductions are associated with the strategic development of a CO_2 pipeline and storage system. Moreover, whilst a wide range of CCS demonstrations are planned globally the UK is a lead market for CCS deployment. The UK plans to develop offshore CO_2 storage, and is currently targeting power sector emissions, including those from gas power stations which might be of particular strategic importance to UK decarbonisation. The resulting transport and storage infrastructure also offers strategic value for future industrial

[1] There may also be important prospects for CCS on industrial processes other than power generation but these are not the subject of this report

process decarbonisation. In the offshore wind sector the UK is already a global market leader, representing a substantial fraction of global market growth. Developments in other EU countries will also continue to drive cost reductions, but if the UK were to exit the market overall global market growth and cost reduction would slow. That said, in both instances cost reductions accrue from the *combination of* developments specific to the UK and the efforts of other countries active in these sectors. The UK is not 'going it alone' but instead should be seen as one of a number of countries leading the efforts to develop options to address climate change.

Long term clarity is essential

Both offshore wind and CCS entail the planning and development of large scale infrastructure, with long pre-construction and consenting periods and extensive and expensive pre-construction phases. For example, a typical offshore wind farm is likely to require around 5 years and £50 million of site development work prior to consent, with a further 1 – 2 years for construction. A typical full chain CCS project might take 9 years to deliver and involves four different industry sectors. In the case of CO_2 storage the pre-FID investment required is substantial and can reach the order of £100 million without any guarantee of a return. If development is to proceed during the 2020s government needs to provide a clear signal of intent early in the new Parliament. Unsurprisingly industry will not come forward with new projects beyond the CCS demonstrations and current offshore wind project pipeline in the absence of a clear indication of sustained and appropriately targeted policy support. Cost reduction is also more likely to be secured if a cycle of 'boom and bust' created by policy uncertainty can be avoided. This is because regular entry and exit of developers, supply chain providers and investors militates against the development of skills and expertise, healthy competition and the securing of learning by doing.

Policy has important qualitative and strategic dimensions

Policy design needs to pay attention to strategic direction of infrastructure and to the relationship between policy design and risk allocation. We note in particular the important role that developing a cluster of CCS power or industrial projects that can connect to an appropriately sized CO_2 pipe and storage hub infrastructure plays in the modelling of cost reduction. It is unlikely that this will emerge in the absence of strategic oversight and regulation. In addition, developing natural monopoly infrastructure on a regulated asset model has the potential to yield reduced costs through more efficient risk allocation.

Overall costs to consumers may also be reduced if some upfront/strategic risk is socialised. Again, this may apply with regards to the strategic development of a CCS infrastructure which has future utility for subsequent projects and value in industrial decarbonisation. We also note that in Denmark and the Netherlands offshore wind sites are pre-developed by the system operator prior to the auctioning of combined site/feed in tariff/grid connection contracts. Whilst the market and regulatory structure in the UK differs substantively and a similar approach may be difficult here, this appears to have helped to reduce risk for investors and lower overall costs of energy. By contrast the UK has evolved a system where offshore wind developers must bid separately for sites and for a contract for difference, and incur considerable pre-development costs with no insight into auction outcomes. This results in part from a shift in the policy landscape in the UK from the initial auction of Crown Estate sites under the Renewables Obligation (RO), then final investment decision (FiD) enabling, to the introduction of auctions for CfDs. A legacy portfolio of sites is already under development which may provide a substantial 'pipeline' of projects. However this separation of site/subsidy allocation and allocation of risk may need to be rethought. Carefully determining the point at which private sector players are best placed to manage risks and at what point in the development process competitive tendering processes can come into play is something UK policies may benefit from giving greater attention to in future.

Policy can create the conditions for cost reduction but cannot assure it

Both consultants' reports derive cost reduction estimates that are contingent on a series of assumptions about developments and events that are impossible to predict with complete certainty. For example, whilst there is good evidence that technology learning (replicating projects leading to cost reductions) does take place in a wide range of sectors as an industry moves from the first project of a kind to a series of similar projects, the cost reduction that this can bring is not assured. It is possible for learning effects to be overwhelmed by other developments, such as movements in commodity prices, currency exchange rates or the exit of key market participants leading to a lack of competition or delay in innovation promulgating to other market participants (Gross *et al.* 2013). There is also evidence that learning may be slower where the unit size of projects is very large (large infrastructure projects) than where there is potential for mass manufacture of large numbers of small component units (such as photovoltaic modules) (Candelise *et al.* 2013; Gross *et al.* 2013). It is also possible for anticipated learning effects to be overestimated ex-ante or for projects to progress more slowly than expected, delaying opportunities for cost reduction to occur (Candelise *et al.* 2013; Gross *et al.* 2013).

The Group also note that in a subsidised market, particularly if competition is weak, it is possible for industry to continue to seek excess profits through sustained subsidy at levels that are higher than necessary. Auctions and tenders are one way to guard against this; another is through planned degression in support levels. Both reports produced for the CCC involve in part reportage of industry expectations of cost reduction. It will be important for government to signal clearly that ongoing support is contingent on anticipated cost reductions being realised.

2030 deployment and cost reduction is not the end game

This project is focused on 2030 in line with CCC priorities for power sector decarbonisation and cost reduction in lower carbon technologies. However the Advisory Groups for both CCS and offshore wind both stressed the importance of ongoing development after 2030 that can leverage the infrastructure developed in the period up to 2030. Developments beyond 2030 might include floating offshore turbines and expanded use of CCS in industrial processes, as well as continued expansion of CCS in power generation. Whilst policy focused on deployment to 2030 can contribute to longer term developments it is likely that additional policy actions will be needed to ensure the creation of options for the long term. For example, industrial decarbonisation is not yet a focus of policy but it will need to use CCS infrastructure, in particular storage sites, already developed in advance. Hence this infrastructure has additional strategic value but at the moment this is not measured and taken account of in the EMR framework of support. The Advisory Groups noted that 2030 is an important milestone for decarbonisation but also notes that fifteen years is a relatively short period viewed from the perspective of long term changes to the energy system. Longer term issues are not discussed in detail in this report but they are extremely important to decarbonisation policy.

Offshore wind

High level comments

The Advisory Group on offshore wind broadly welcome the report from BVG Associates which suggests that costs could fall to below £90/MWh given a European market of around 3 – 4 GW per year and ongoing development in turbines, foundations and other components, together with a reduction in the cost of capital and improving load factors. The Group notes that the headline figure is broadly aligned with other estimates, including those from the Offshore Wind Cost Reduction Task Force and ETI. In addition, cost reduction in offshore wind would appear to be beginning to materialise, based upon the findings of the Cost Reduction Monitoring Framework (Offshore Wind Industry Council 2015). The Group also notes the outcome of the first CfD allocation auction round delivered bids equivalent to an LCOE of around £100/MWh (Offshore Wind Industry Council 2015). However the Group are concerned many factors could have contributed to bids judged by many commentators to be surprisingly low and it is too early to draw unequivocal and generalised conclusions about cost reduction trends from this first auction. The Group note that costs of energy will be highly site specific, given the specificities of both construction costs and wind regimes.

The Group also broadly endorsed the BVG finding that a UK market size of 1 to 2 GW per year (as part of a European market of 3 – 4 GW) would be likely to be compatible with ongoing cost reduction. The Group agree with the consultants that cost effective offshore wind development requires a certain minimum size or 'critical mass' that allows a supply chain to flourish and creates enough opportunity to encourage competition between equipment suppliers.

Methodologically, BVG Associates have provided a detailed and highly credible parametric model of offshore wind farm cost formation that provides a clear insight into the impact of various cost-reduction drivers on overall levelised cost of energy (LCOE). The consultants informed their modelling with insights from interviews with industry stakeholders. The Group welcome this approach but note also that whilst these stakeholders are a crucial source of detailed technical, economic and market knowledge they will be likely to be predisposed towards positive prospects for cost reduction. The Group therefore note that whilst the report is thorough and highly credible any bias is likely to be towards the upside in terms of cost reduction potential.

The Group made a number of detailed observations, as follows:

Detailed observations

There is a minimum size, and the EU and UK continue to be key players.

The consultants suggest that a minimum EU market size of 3 – 4 GW with about half that in the UK would be consistent with three or four competing equipment suppliers. The Group agree that in the absence of development in Europe offshore wind development internationally is likely to be very modest. In the absence of development in the UK market growth in Europe would be likely to slow down considerably. The UK remains the leading offshore wind market internationally. Thus, the Group broadly agree with the consultants that a market of at least 3 GW in Europe and around 1 to 2 GW in the UK is likely to be needed to provide a minimum 'critical mass' for commercial deployment of offshore wind. The Group noted that rather than arbitrarily pick a mid-point (1.5 GW) CCC should continue to emphasise uncertainties and refer to a range of 1 to 2 GW, given the considerable uncertainties inherent in cost reduction modelling. The CCC may also wish to recommend further work on the part of the government to determine in more detail minimum market size based upon assumed costs and levy control budget, which would allow for the market to grow more quickly if costs come down more rapidly.

RD&D is important but a market led approach is likely to be key to cost reduction

The importance of learning by doing

The Group note that moving to larger turbines is important in the cost reduction modelling undertaken by BVG, and that the investment and innovation needed to develop larger machines is driven in large part by the expectation of a vibrant market for new technologies. Cost reduction is also associated with a broad range of innovations in foundations, installation and other equipment. The consultants argue that the best way to drive this development is through enabling a healthy and competitive market for offshore wind to sustain through 2030, whilst ensuring policy places strong downward pressure on costs. This approach is broadly consistent with existing studies of offshore wind cost reduction and the wider literature on cost reduction through 'learning by doing' (Heptonstall *et al.* 2012; Gross *et al.* 2013; Harris G 2013).

An innovation fund?

The Group note that it is possible to envisage a scenario where technology development takes place ahead of market growth, perhaps through an 'innovation fund' focused on RD&D. Governments could for example support a competition to develop a commercially viable 10 MW turbine, with the offer of a reward in the form of a future market for the winning developer/s. This model would see governments funding technology development directly rather than encouraging innovation through market growth. This could have the benefit of avoiding 'lock in' to ongoing subsidy (CfD) payments to wind farms using intermediate (and more expensive) classes of turbine, built during the intervening period. However, there is limited evidence as to the success and cost effectiveness of such 'supply push' initiatives where governments seek a particular technological winner and indeed several historical examples where such efforts failed (Garrad 2012). Moreover, this approach would require the development of new funding and institutional arrangements and creates new risks associated with non-delivery and the capture of grant funding streams by technology developers.

The Group also note that this model would not sustain the ongoing development of skills in the wider supply chain/installation or in financiers. Indeed, abandoning market led growth in favour of RD&D would undermine the industry/installation/supply chain into which a new technology could be launched. Finally, important sources of cost reduction are associated with large scale production rather than innovation or up-scaling of components. For example, important cost reduction opportunities exist in turbine installation (such as standardised foundations), which require the existence of a stable and adequately sized market to be realised.

However, the Group do not take the view that it is *impossible* to envisage a role for innovation funding that focuses on more radical innovation and longer term prospects such as floating turbines that could continue to drive cost reduction and deployment after 2030 (see below). Importantly, this may require support for large scale demonstration and early deployment rather than research and small scale testing. One lesson from UK experience with offshore wind in the period from 2008 to 2014 is that it is important to find a cost effective route through early stage deployment when engineering challenges are particularly high and costs can rise before they fall – a point that is also noted in academic reviews (Gross *et al.* 2013). The challenge is to ensure that funding of such nature does not undermine the development of skills and industrial capacity. The Group recommends that the CCC considers additional analysis on the nature of policy support that best bridges RD&D and the earliest stages of deployment support.

On balance, whilst innovation funding and support for R&D are important particularly longer term, the Group suggest that a with a view to 2030 cost reduction and improvements to existing designs of bottom mounted turbines, a market led approach to offshore wind development is likely to be the most realistic and successful approach to driving cost reduction.

A larger UK/EU market would not necessarily lead to larger cost reductions

The Group note that whilst there are certain threshold effects associated with a *minimum* market size there may also be diminishing returns associated with moving to far too fast. Indeed supply chain pressures have been documented as a source of cost escalation in offshore wind (Heptonstall *et al.* 2012). In this respect the Group are cautious about the consultants' conclusion that a larger market would yield yet more cost reduction and would not support an early policy prescription of even larger market growth. Factors relevant here include the capacity of the supply chain to expand, access to capital and timely availability of grid connections.

The Group note that rapid expansion of offshore wind during the early part of the current decade has created a substantial legacy of projects with support from the RO or FiD enabling. We believe that in comparison to projects developed during the 2020s these early stage projects will probably appear expensive. They will of course continue absorb a sizeable share of the funds available through the Levy Control Framework through until 2028 when subsidies for the earliest projects will end. Whether this represents an important and essential injection of funds for 'pump priming', or principally a product of excessive market expansion driven mainly by the European 2020 target is a matter of debate. The view of the Group is that support for early and relatively expensive projects is essential but that there is evidence that the UK market was rather overheated in the period until around 2014. This debate is not the subject of this report. However, important lessons can be learned about ensuring policy bears down on costs and that markets grow fast enough to create the conditions for cost reduction but that policies do not push too far, too fast.

Auctions and tenders, clarity about future market size, and de-risking

The strengths and weaknesses of auctions

The Group note that capacity auctions of the kind now used by the UK government to allocate CfDs have a widely discussed set of strengths and weaknesses. A key weakness in any purely cost based auction of this nature is "winner's curse", where over-optimistic bids lead to a situation where developers are unable to deliver projects at the price level promised (Mitchell & Connor 2004; Mackley 2008). This can lead to either project developers pulling out of proposed projects and/or to developments that are loss making – a phenomenon well documented in UK renewable energy policy in the 1990s (Mitchell & Connor 2004). Either outcome may be detrimental to ongoing long-term cost reduction because it may lead to market participants exiting the industry; hence reducing competition, undermining supply chain competencies and losing skills. Governments can partially guard against this outcome through stringent penalties for non-delivery. However auctions (or more accurately, *competitive tenders*) *can* be designed such that bidders are evaluated against a range of criteria including those that assess ability to deliver as well as bid price. This approach was used in the UK by the Crown Estate for competitive tenders for *sites* – but CfD auctions are based largely upon price (DECC 2014). Similarly, bidders for UK offshore wind connections (the OFTO regime) were assessed upon their financing plans and revenue (ofgem 2014). The key point here is not that the Group endorses the particular tender approaches taken for offshore wind sites or for the OFTO regime but rather that it is possible for tender processes to evaluate quality as well as price (a point well covered in the academic literature, see for example Mackley (2008)). The Group also notes that Dutch and Danish auctions for sites and contracts include an explicit evaluation of bidder credentials and/or of qualitative dimensions of the proposal. Going forward the Group suggests that UK policy should consider the potential to evaluate bids for CfD contracts in terms of credibility and deliverability as well as on price.

<u>What is in an auction?</u>

A final set of issues surround the separation in UK between the decision to bid for and develop to consent a *site*, and the auctioning of a *subsidy contract*, a CfD. This contrasts with the Danish and Dutch auction models where substantially pre-evaluated sites and subsidy contracts (together with a grid connection) are auctioned as a package – leaving the developer responsible principally for wind farm development and construction (Danish Energy Agency 2013; Norton Rose Fulbright 2014; Netherlands Enterprise Agency 2015).

The Group discussed the merits of governments commissioning aspects of pre-auction project development, which can be particularly costly for offshore wind. The Danish and Dutch models are to auction sites where aspects of pre-development have already been completed by the System Operator or other agency, funded centrally (winning bidders then reimburse these costs). The Group notes that current UK regulatory and market arrangements, such as the licence conditions for the transmission System Operator, are not compatible with such an approach. Nevertheless, the Dutch/Danish model may be able to reduce overall costs to consumers because it avoids the need for private sector competitors to finance offshore site pre-development, pre-auction and at risk, and represent a more efficient risk allocation between government and private developers.

It is important to note that there are strengths and weaknesses with both approaches. The pre-auction model does give developers more certainty at an early stage by providing sites and paying for the work that partly validates their suitability in advance of them bidding in to convert to an asset. However, either developers or another agency will have to take on some risk since site selection, stakeholder engagement and other aspects of pre-development may result in a site being abandoned. There is an important question of who bears the losses for assessing unsuccessful sites. The argument in the UK has largely been that only the developers have the skillset necessary to choose locations, size arrays and manage stakeholder issues efficiently. The Group notes that the Dutch and Danish models would suggest that this need not be the case, or at least the issue is worthy of additional investigation and analysis by government and/or other interested parties such as the Crown Estate and CCC.

<u>Relying on legacy projects is not a long term policy</u>

The Group notes that at the time of writing a substantial volume of pre-development is already under way in UK offshore wind. However in the main, UK developers bid for sites and began pre-consent activity *before* the government moved to auction CfD allocations. A large amount of development was initiated under an expectation that there would be a route to market through the Renewables Obligation or that CfD strike prices would be administered rather than auctioned. Looking to the long term it is questionable whether developers will continue to invest tens of millions of pounds pre-consent when even after gaining consent they can lose out to an alternative project in an auction. This risk is particularly acute if the overall volume of build amounts to no more than one or two large wind farms per year.

In the longer term it is important for government to think carefully about the relationship between policy design and risk-allocation, which risks arise pre-auction, and how these factors interact to affect overall costs, industry competitiveness and long-term policy objectives. The Group notes that the consultants suggest that pre-auctions would have limited impact on overall cost reduction at present. However, this reflects in part the recognition by industry interviewees that a large volume of pre-development was already under way before CfD allocation was moved to competitive tender. Current auction rounds therefore benefit from a *legacy* of private sector site development initiated under different policy expectations. This is largely fortuitous and does not undermine the importance of getting the fundamentals of policy design right for the longer term.

Improved clarity over which sites go forward is essential if industry is to be confident that development will take place at 1-2 GW a year and it is arguable that if developers competitively develop sites there may be too many or too few to ensure cost competitiveness and consistent build rate. Too few and costs could rise due to lack of competition, too many and industry will begin to perceive the losses associated with getting to auction as too large a risk and withdraw from UK offshore wind development.

2030 is not the end of the story

The Group discussed the role of offshore wind in decarbonisation beyond 2030. Whilst this was out of scope for the consultants' report there is important potential for ongoing innovation in offshore wind. One aspect of this could be repowering early offshore wind sites with newer, larger and more cost effective turbines, should the economics of doing so prove to be attractive. Further development could also focus on turbines that can be deployed in areas where wind conditions are particularly attractive and competition with other maritime sectors may be reduced. This may be made feasible through the development of floating turbines. In addition, floating turbines could be deployed in a wider range of geographical locations around the UK in order to benefit from meteorological diversity. Floating turbines may also offer reduced installation costs in the long term, if the engineering challenges associated with floating designs can be overcome. In all cases these developments could reduce the levelised cost of energy from offshore wind, and/or system/grid costs.

Detailed discussion of developments after 2030 and the potential for floating turbines or other radical innovations is beyond the scope of this report. However the Group recommends that the CCC emphasises the importance of *both* deployment and cost reduction before 2030 *and* the importance of longer term developments that may become possible after 2030. As noted above this means that a key policy challenge for decarbonisation is to support both longer term technology innovation (for example through funding demonstration of floating turbines) *and* economies of scale, learning by doing and industrial/supply chain capabilities in contemporary, bottom mounted technologies.

Conclusions and final observations on offshore wind

The principal conclusions the Group draw for offshore wind are that substantial cost reduction is possible in the period to 2030 and that steady and sustained market creation by the UK Government is the central need if this is to happen. At the time of writing there is no clear policy for offshore wind beyond the end of the current Levy Control Framework in 2020/21. If the government wishes the development of offshore wind to continue in the UK it needs to provide a great deal more clarity about the role it envisages for offshore wind early in the coming Parliament. In the absence of this, once the existing 'pool' of projects coming through the consenting process is exhausted then offshore wind development in UK waters will probably cease.

The Group recognises that the current costs of offshore wind are high and the early projects receiving support through the RO and FiD enabling are absorbing a large fraction of the subsidy available under the Levy Control Framework. Nevertheless, allowing offshore wind development to grind to a halt would be regrettable for several reasons. First, because costs do now appear to be falling and there are good reasons to believe that costs could be much lower in future. Secondly, because offshore wind represents a particularly large resource in the UK and offers the potential to play a large role in UK power sector decarbonisation. If costs can be reduced then offshore wind could be a secure source of low carbon energy long into the future, without placing an excessive burden on consumers. The Group note that as the subsidised period for offshore wind farms ends there is the prospect that farms will continue to operate without subsidy (delivering very low marginal cost electricity) or be repowered using better technology. Finally, at the time of writing important investments in UK industrial capabilities are beginning to be realised. This report is not focused upon industrial policy, but the potential for UK companies to benefit from opportunities in offshore wind would be reduced significantly in the absence of a UK market.

The Group would also stress the importance of a far-sighted and strategic policy approach to offshore wind (and CCS as we discuss below). Moving too early to an entirely 'technology neutral' approach that seeks to be agnostic about the strategic direction of the mix of power generation technology could cut off support before cost reductions can be realised. It may also be difficult to reconcile technological neutrality with the timely development of power network infrastructure. The most important component of a strategic approach is to provide a clear view of the anticipated role of offshore wind during the 2020s provided costs are reducing in line with expectations. This would also include attention to the process for commissioning and assessing potential sites, grid access, and how this relates to CfD auctions.

Competitive processes and commercial pressures will be central to driving costs down. However this does not mean that long term strategic decisions can be avoided. In many respects offshore wind offers policymakers a self-fulfilling prophecy – if we believe costs can be driven down in the right policy environment they probably will be. If policy creates an insecure and unattractive environment in the interests of 'not picking winners' then the attendant risks and uncertainties appear likely to ensure that investors are wary, progress is limited and costs stay high. Overall, the Group believes that the CCC has good grounds to recommend that government adopts a more clear-sighted and long term view of the role of offshore wind.

Carbon Capture and Storage

High level comments

The Advisory Group welcomed the report from Poyry and Element Energy, which builds on existing analyses for the Crown Estate, ETI and others and offers important new insights into the role of UK CCS developments and infrastructure in a global context (CE CCSA & DECC 2013; CE 2014b; CE 2014a; ETI 2014). The Group welcomes in particular the focus on strategic development of transport pipeline and storage hub networks to allow onshore clusters of capture plants to be developed over time. The report also provides important insights into the value of enabling a continuous sequence of development to maximise opportunities for cost reduction through learning by doing and optimising infrastructure utilisation.

The Group believe that the report is credible and well aligned with other recent studies and that based upon the analysis therein broadly endorse the headline finding that the right policies to deliver transport and storage infrastructure can facilitate a build of 4 – 7 GW by 2030, using a clustered approach, could be consistent with costs below £100/MWh in 2030. This infrastructure could also provide capacity for potential industrial process CCS projects.

The Group notes that cost estimates for CCS contain particularly high levels of uncertainty. Unlike offshore wind, there is no empirical current-cost baseline against which to assess cost reductions. Defining a baseline is further complicated by the CCS chain comprising three different technology and industry sectors. With no full chain power projects yet under construction in Europe the figures used in most studies are parametric estimates based on other industries or applications of CCS that differ from the UK power sector proposition. It will be helpful to see the cost estimates for the UK Commercialisation Programme projects when they are published in the next year. However at the time of writing it is important to note that any analysis of cost reduction opportunities must of necessity start from a partially hypothetical baseline. This does not invalidate or render such analysis useless but it does add to the uncertainties around CCS relative to technologies that are beyond the demonstration stage.

In terms of methodology the consultants used a rigorous parametric approach informed by sensible discussion of key assumptions and drivers of cost reduction. The Group particularly welcomes the attention paid to infrastructure for transport and storage, which is in some respects the most important and certain of the cost reductions the report considers. The Group agrees that a steady and continuous build of power plants with capture, subject to key and uncertain assumptions about learning and economies of scale is an important source of cost reduction through learning and increasing size. Finally, the report makes useful observations about finance and the potential for the utilisation of CO_2 in enhanced oil recovery (EOR) to create a value proposition for supporting CCS infrastructure deployment.

The Group made a number of more detailed comments, and these are set out below:

Detailed observations

Cluster development using shared infrastructure and storage hubs

Strategic Infrastructure is critical

The Group note that the report from Poyry and Element Energy makes a new contribution to knowledge in assessing in detail the role in cost reduction of strategic infrastructure through regional onshore clustering of projects that efficiently utilise large shared pipelines delivering to offshore storage hubs. A central conclusion of the work, and one which the Group believes the CCC should emphasise in advice to government, is that development of this strategic infrastructure unlocks the biggest and most reliable (if follow on projects ensue) share of cost reduction. For this to happen, developers will require a long term government commitment and visibility of policies that will remove market failures and deliver certainty for taking investment decisions.

The policy framework for transport and storage needs to be right

The Group notes that the relationship between the Electricity Market Reform framework and a realistic business case for strategic infrastructure development is not part of UK policy thinking. Without the right policies the interdependency between capture, transport and storage leads to access and volume risk. This will discourage capture development without assurances of access to infrastructure, and discourage speculative oversizing of pipes or appraisal of larger storage sites to allow sharing with future projects.

Co-ordination of pipeline and storage development may help to provide a lower risk, lower cost of capital environment for both infrastructure providers, and capture projects. However it brings greater risk of infrastructure that is not fully utilised if a sufficient volume of capture plant development is not forthcoming. The Group notes existing work by the Crown Estate and others on this topic and suggests that the CCC highlight the importance of an effective and strategic approach to transport and storage infrastructure in realising lower cost CCS for the long term. More specifically:

- Industry commentators tend to agree that the current government package of support for CfDs, capital grants and sharing CCS risks has the potential to overcome almost all of the economic and financial problems of first/ early projects CCS in the UK utilising the initial infrastructure.
- However, for subsequent projects industry observers are less convinced that the “cross chain risk” market failure, concerning the commercial relationship between generation and capture (G&C) developers and transport and storage (T&S) developers in the event of either part of the chain breaking down, can be overcome. They suggest a different “business model” for T&S, in which government plays a much more active and direct role, might be needed.

Hubs and Clusters

The consultants and existing ETI analysis (ETI 2015a) points to the value of delivering in onshore clusters and offshore hubs, and the Group are persuaded of their importance. The Commercialisation Programme competition comprises two projects with different storage sites and if these projects are both developed two offshore hubs will be established in different geographic regions. These two hubs will provide excellent options for onshore clusters to develop in Grangemouth, Teesside and the Humber.

Steady deployment & scaling up will assist cost reduction – but caution is needed

Project development cycles and learning effects – a challenge for policy

The consultants argue that steady deployment and a gradual increase in the size of capture plants will aid cost reduction. Steady deployment would allow an industry to emerge that maintains a skills/knowledge base, contributes to falling cost of capital, while also allowing time for learning and risk reduction. The consultants also argue for close *sequencing* of capture projects – delays (for example between the first commercialisation projects and second phase of development) could lead to a loss of momentum and skills. However it is important to note that the approach taken by the consultants contains an *assumption of learning each time a power/capture project cycle is completed.* An important implication is that cost reduction *requires* that each phase completes before the next initiates so that that lessons can be learned. In practice this might be difficult to deliver, given the potential for early stage projects to experience delays.

The Group notes that the gestation period of projects is a key issue not mentioned in the report. It takes a minimum of 9 years (and often more) to get large infrastructure projects like the full CCS chain to commissioning. Without a policy of steady growth of the industry developers may not be willing to keep a pool of projects going through this length of development, with associated expense. Storage appraisal also takes a considerable time and is central to investor confidence. So a long term approach is necessary if CCS is to succeed.

This creates important decision points for government. And some trade-offs, since any aspiration to achieve meaningful deployment or cost reduction by 2030 places the start of a roll-out on the critical path now. The dilemma is whether the government should award CfDs to further projects before the first commercialisation projects commission and demonstrate their reliability. If they wait then little more can happen before 2030, as developers will not bring projects forward in such a “wait-and-see” environment. If Government wish to achieve cost reduction and support CCS, Phase 2 projects need to get CfDs before 2020 and before the first projects are fully developed.

The Group would also caution against an overly simplistic and slavish application of concepts related to learning through ‘n of a kind’ cycles. In the view of the Group such concepts are useful simplifications of a more complicated real world where innovation takes place on a range of fronts. Developments are unlikely to proceed exactly as planned in terms of timing, and cost reduction can occur both more slowly and more rapidly than ex-ante modelling predicts (Gross et al 2013).

Overall, the Group note that the core idea of steady deployment that aims at gradual improvement/up-scaling of capture plants and avoids boom and bust cycle is very sound; steady expansion is extremely likely in general terms to help deliver cost reduction. A key caveat is that transport and storage infrastructure is built for the longer term and multiple sectors, and will be deployed and expanded in larger capacity tranches. Therefore there will be periods of underutilisation that still retain value and lower the risk and cost for future capture projects in both power generation and industrial processes.

Global learning?

The report provides a very useful snapshot of international development prospects. The consultants also discuss the role of global learning effects – in effect they model an exogenous (to UK roll out) reduction in the cost of capture technology. This is without question correct in principle. CCS will be a global industry and as in all international markets learning takes place through project development everywhere (Mukora *et al.* 2009; Gross *et al.* 2013). However the Group note that the UK is likely to play a leading role in the role out of CCS for the power sector, in offshore storage, and in capture from gas-fired power stations in particular. In addition, pace of development internationally remains uncertain. Methodologically it is also somewhat surprising to note that the consultants envisage significant 'n of a kind' cost reductions on a relatively small number of plants installed in the UK, but also refer to the need for 200-300 GW of global role out to deliver significant global learning effects. This is in part due to the distinction between innovation in standard capture components (where learning is incremental and global), and installation/construction related cost savings and the economies of scale at the level of individual plants. However there is a degree of uncertainty about both effects that needs to be weighed carefully in assessing the confidence that it is possible to place on any estimate of cost reduction.

Overall the Group believe that the role of international learning effects on UK cost reduction needs to be assessed with some caution and that its importance to UK cost reduction before 2030 should not be overstated.

Enhanced oil recovery and fuel choice for CCS

Enhanced oil recovery

The Group welcomes the discussion of enhanced oil recovery (EOR) that the report provides, whilst noting that EOR brings with it a number of drawbacks such as its interdependence with volatile fossil fuel prices for financial feasibility and potential opposition from some stakeholders on environmental grounds – EOR of course liberates new sources of CO_2 emissions. However, EOR offers the possibility of a commercial value being created for 'waste' CO_2. The most straightforward aspect of this being that if the oil and gas industry can use CO_2 for EOR then aspects of CCS may possibly 'pay for themselves': CO_2-based EOR covers some of the cost of storage (and possibly offshore transport) for CCS. However, how and when this value gets shared between the different commercial entities in the CCS chain is complex.

Further, the Group notes that EOR can assist with the fiscal/consumer burden associated with CCS, though taxation rules would need to be changed in order to allow this opportunity to be realised. Oil production from EOR could bring in incremental tax revenue, since the more CCS is developed the larger the EOR revenue stream, which could in principle be used to partly or fully cover the cost of the CfDs needed for further CCS projects. The Group note the difficulties associated with hypothecation of tax revenues, however in principle at least with EOR CfDs for CCS could be partly or fully "self-funding".

'Technology' and fuel choice

The Group endorse an approach where government is agnostic about the choice of coal or gas for CCS and allow industry to make decisions about both the fuel input to a CCS project and the capture technology used. Indeed, the word “technology” when applied to CCS in the UK has often conflated the fuel used and the G&C technology used. It is probably timely to make a distinction between fuel choice and G&C technology choice, as it becomes increasingly apparent that all technologies can be applied to both gas and coal. The Group notes that previous policies have tended to promote CCS for coal rather than gas and welcome the move to a more fuel neutral basis.

The report does not specifically address the issue of fuel choice as a cost driver. Evidence to date elsewhere has pointed generally but not decisively in the direction of gas as having a cost advantage over coal in a UK context where EOR is not a driver. The CCC led a shift in thinking about CCS as a technology that could help the UK to retain coal to a technology that could help provide flexible and dispatchable power stations – probably gas fired.

Reducing the cost of finance

The Group believe that the consultants are right to draw attention to the importance of improving confidence and increasing the involvement of the financial sector in reducing the cost of CCS. It is important to note that this overlaps with aspects of CCS cost reduction discussed above. For example through the establishment of proven storage sites and successful demonstration of capture technologies. As experience in offshore wind has demonstrated, as a stable and increasingly mature market emerges the financial community devote greater attention to a sector, gaining skills and exposure, and hence opening up the possibility of lower risk premiums. In some respects therefore reducing the cost of finance can emerge through ‘doing all of the above’ rather than through specific policies that target the financial community. Notwithstanding this, the group very much welcome the comments made by the consultants about the boundaries around liabilities and the development of an insurance proposition for CCS transport and storage.

Conclusions and final observations on CCS

As with offshore wind, the most important implication for policy that emerges on CCS is that policy needs to take a clear and far-sighted approach to the development of CCS in the UK. In the case of CCS the role of policymakers in providing a route for the development of transport and storage infrastructure emerges as the most important high level finding from the research. The other sources of cost reduction are subject to considerable uncertainty that will be reduced in part by the first Commercialisation Demonstration Projects (DECC 2013).

Some of the conclusions highlighted for offshore wind also apply to CCS – stability and clarity, and a slow and steady approach to roll-out of capture projects seem likely to be the core requirements for effective cost reduction. And as with offshore wind successful and cost effective deployment of CCS appears unlikely to be achieved if policymakers seek to prioritise a technology neutral approach to all aspects of energy policy. However, CCS brings with it important additional challenges related to the importance of strategic oversight of the T&S infrastructure. There is potential for market failure between incentives that are currently best suited to target individual capture projects and the importance of strategic development of appropriately sized T&S capacity that can be used by future capture projects in the power sector and potentially by other industrial processes.

Concluding remarks

In many of its publications the CCC has taken a leading role in the UK energy policy debate by linking the literature on technology and innovation and insights from technology modelling to policy advice. The Committee has also sought to gain insights into contemporary technological developments, through engaging with low carbon technology developers and industry experts. The studies discussed in this report continue this tradition, offering rich and detailed reviews of technological and market developments and how they might lead to cost reduction. Despite their differences CCS and offshore wind are both emerging technologies with limited markets and it is inevitable that evaluating cost reduction potential and future policy needs takes place under conditions of considerable uncertainty. The commentary provided above discusses where uncertainties are largest. It is extremely likely that any analysis of future costs will turn out to be wrong – and the evidence suggests both the optimists and the pessimists get it wrong at times (Gross *et al.* 2013).

However uncertainty about the future is simply an unavoidable (and rather obvious) fact. The potential to get things wrong does not undermine the value of making predictions or projections, and in particular of assessing the potential for technologies to improve or economics to change. Moreover, the principal value of trying to work out what might, or *could happen* is so that decision makers can take steps to try to ensure that desirable outcomes can or *do happen.* Both CCS and offshore wind offer policymakers exactly this challenge.

The reports provide some clear indications of what needs to happen if costs are to fall. A large part of this rests upon industry – if for example the offshore wind industry claims that 10 MW turbines are feasible or the CCS sector argues a well sized CCS T&S system can offer economies of scale it is up to the private sector to deliver on these promises as long as appropriate policies are in place to enable this to happen. The analysis suggests that policy can create the right enabling conditions for this to take place. If future UK governments are serious about decarbonisation then they must also get serious about creating the conditions that allow a competitive industry to get costs down in wind technology and capture plants and, in the case of CCS, deliver T&S infrastructure for future decarbonisation – both future power sector capture developments and in other industrial processes.

The analysis reviewed in this report points clearly to the need for policy to provide clarity, a long term view and important elements of strategic decision making with regards to infrastructure. Policy may also need to set the private sector important challenges; perhaps through auctions, perhaps through setting cost reduction targets, making clear there are no blank cheques. However a key theme that emerges for both offshore wind and CCS is that policy is unlikely to be successful if it ducks strategic decisions, attempts to leave to the market key choices that the market is unable to make on its own, constantly seeks to back all horses or refuses to take a long term view.

UK energy policy debates often focus on ideology – not picking winners, letting markets decide – ignoring evidence of what works from history, other countries or other sectors. In advising government on CCS and offshore wind the CCC has an opportunity to take a robust, evidence based and intelligent approach. This needs to balance the need for strategic direction of a system, and in setting the framework, against opportunities to use markets to drive down costs. Cost reduction in emerging technologies is never assured. The key challenge is to create the conditions that give secure, low cost, low carbon options that meet the UK’s energy needs the best chance to arise.

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