CCS in the UK: A new strategy

Advisory Group Report

A report for the Committee on Climate Change

Dr Robert Gross

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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
ETI	Energy Technologies Institute
GW	GigaWatts
LCOE	Levelised Cost of Electricity
MWh	MegaWatt Hour
R&D	Research & Development
T&S	Transport and Storage

Summary

The Committee on Climate Change (CCC) has commissioned expert input on policy, strategy and costs for carbon capture and storage (CCS). This analysis will inform the CCC in their advice to government on a strategy for CCS in the UK. The CCC commissioned Consultants Pöyry to produce analysis of potential CCS costs and strategy. The CCC convened an expert Advisory Group to help scope, steer, oversee and comment on the consultants' analysis. This report provides a Chair's summary based upon the reflections of the Advisory Group. It comments on the report the consultants have produced and the wider issues associated with this crucially important topic.

The Group notes the importance of CCS as a flexible enabler of low carbon energy – whether through continued use of fossil fuels for electricity, or by enabling industrial decarbonisation and the production of hydrogen which can be used flexibly in a wide range of end uses. CCS has the potential to play an important role in the power sector, in enabling industrial decarbonisation, low carbon hydrogen (and syngas) production and, potentially, a pathway to negative emissions in combination with bioenergy (e.g. biomass gasification with CCS).

The Group finds that the analysis from Pöyry is well-conceived and provides valuable new insights into policy and strategy to promote CCS during the 2020s. Detailed cost and strike price analysis from Pöyry suggests that the levelised costs of gas-fired capture plants connecting to a well-utilised transport and storage infrastructure could be below £100/MWh. The Group believe that this is feasible under sensible assumptions, noting that estimates of future CCS costs are subject to considerable uncertainty and there is a wide range of estimates in the literature.

The cancellation of the planned CCS Commercialisation Programme is a significant set-back to the development of CCS in the UK. However, work undertaken in preparation for the cancelled Programme has however provided important information on technology costs and in the characterisation of stores. These are now considered ready for development and have generated developer interest in follow-on projects that could in principle be retained.

The Group believes that there is a valuable opportunity to rethink strategy and policy to facilitate the creation of CCS infrastructure at lowest overall cost. The Group note the importance of separating the handling of contracting and risks for capture plants from the transport and storage of CCS (T&S). There is substantial scope to improve the allocation of risks, ensuring they are allocated to the party best-placed to absorb or manage them, thus allowing industry participants to access lower costs of capital. Moreover, if T&S infrastructure is able to serve multiple sectors it is possible to improve utilisation and increase economies of scale, which can also lower costs per unit of CO_2 stored.

There is a need for government to take steps during this Parliament to provide clarity over aspirations and objectives for CCS, both in terms of long term goals and development of early projects. The Group recommends that policy to allow development of a strategically planned CCS T&S infrastructure is given detailed attention by DECC and the National Infrastructure Commission.

Whilst international CCS developments and ongoing research and development (RD&D) are important to cost reduction they cannot substitute for developments in infrastructure and learning that are UK specific. Therefore there is a need for action on three main fronts: Funding for near-term CCS projects, an approach to risk allocation for CO_2 storage sites, and strategy and regulation to allow industry to invest in a future CCS T&S infrastructure.

Introduction

This report

The Committee on Climate Change (CCC) has commissioned expert input on the future of carbon capture and storage (CCS) in the UK. The purpose of this work is to inform the CCC in their advice to government on a strategy for CCS in the UK following the Government's decision not to proceed with the CCS Commercialisation Programme. The CCC has already recommended that the government should 'develop urgently a new approach to CCS in the UK', in view of its analysis which suggests that 'without rapid development of an effective approach to deliver CCS, much larger and more costly actions will have to be taken in sectors such as transport, buildings and agriculture'. Consultants Pöyry have produced analysis of potential CCS costs and strategy. Their report is published separately. Available at www.theccc.org.uk

The CCC convened an expert Advisory Group to help scope, steer, oversee and comment on the consultants' analysis. The CCC asked the Chair of the Advisory Group (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 Advisory Group. It considers and comments on the report the consultants have produced and on the wider policy issues associated with this complex and crucially important topic.

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 (CCC 2013, CCC 2015). In a large number of decarbonisation scenarios CCS plays an important role in the power sector before 2030 and an increasing role thereafter more broadly across the energy system in enabling industrial decarbonisation, low carbon hydrogen (and syngas) production and, potentially, a pathway to negative emissions in combination with bioenergy (e.g. biomass combustion/gasification with CCS). Analysis by the CCC indicates that CCS will also be essential to the decarbonisation of certain key industrial sectors in the period to 2050. For this to happen, CCS infrastructure needs to be in place and business models need to be fully proven in the early 2030s or earlier (ETI 2014, ETI 2015a). 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).

The CCC has identified CCS as having particular importance to UK decarbonisation because it 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. Some scenarios also suggest that CCS could be combined with sustainable bioenergy to provide net-negative emissions. More recent analysis has also considered the potential to repurpose the natural gas grid to deliver hydrogen and a leading potential route to this is to steam reform natural gas and capture and store the associated CO_2. ETI analyses have also pointed to the potential of CCS applied to hydrogen production from a range of feedstocks including biomass or coal, with hydrogen storage

providing a particularly valuable source of flexibility and energy storage in a low carbon future energy system.[1]

Analysis commissioned by the CCC from Poyry and Element Energy in 2015 examined the cost drivers for the entire CCS value chain and demonstrated how deployment of 4-7GW of CCS projects could deliver costs below £100/MWh, following on from development of one or both demonstration projects being taken forward under the UK's CCS Commercialisation Programme.

Earlier advice to government and in analysis undertaken for the CCC's advice on the Fifth Carbon Budget was based on an expectation that CCS would proceed at first through the CCS Commercialisation Programme. This offered a combination of capital grants and a Contract for Difference (CfD) to up to two CCS demonstration projects with CO_2 capture on power stations, linked to transport and storage hubs delivering CO_2 to storage sites in the North Sea. However in the 2015 Comprehensive Spending Review the Government announced that the capital grants would not be available due to fiscal constraints. At the time of writing there is also no explicit provision for CCS plants to receive CfDs during the 2020sand CCS has been removed from the National Infrastructure Delivery Plan. This leaves the future of CCS in the UK uncertain.

In a letter to the Secretary of State for Energy and Climate Change the CCC set out how the outcome of COP21 and other significant changes affect the CCC's advice on the recommended level of the Fifth Carbon Budget. The letter noted that the decision to withdraw funding for the Commercialisation Programme "must not and does not exclude CCS permanently from playing a significant role in reducing UK emissions, provided an alternative approach is implemented quickly", and committed to providing further analysis of the UK options for developing CCS at lowest cost. Given the importance of CCS the CCC are undertaking analysis to inform the Government of alternative strategies for CCS development during the 2020s and on the actions needed in this Parliament to ensure that progress is made. This paper seeks to inform this analysis.

High level comments

The Advisory Group was not tasked with evaluating the case for CCS per se, but rather with evaluating the new analysis undertaken by Poyry for the CCC. Nevertheless the Group is keen that the CCC reiterates the importance of CCS in most decarbonisation scenarios, particularly those which emphasise cost-effectiveness. The Group notes in particular the importance of CCS as a flexible enabler of low carbon energy – whether through continued use of fossil fuels for electricity, or by enabling industrial decarbonisation and the production of hydrogen which can be used flexibly in a wide range of end uses. The Group continues to believe that CCS offers a route to cost-competitive, flexible low carbon electricity generation before 2030, and that this is vitally important as a means to facilitate the development of a CCS infrastructure that can serve other energy using sectors.

The cancellation of the planned CCS Commercialisation Programme is a significant set-back to the development of CCS in the UK. Work undertaken in preparation for the cancelled Programme has

[1] http://www.eti.co.uk/wp-content/uploads/2014/04/2013-ECCSC-CCS-Enquiry-ETI-response-sept-2013.pdf http://www.eti.co.uk/wp-content/uploads/2015/02/Options-Choices-Actions-Hyperlinked-Version-for-Digital.pdf

however provided important information on technology costs and in the characterisation of stores. These are now considered ready for development and have generated developer interest in follow-on projects that could in principle be retained. In addition, the Group believes that there is a valuable opportunity to rethink strategy and policy to facilitate the creation of CCS infrastructure at lowest overall cost.

In particular the Group note the importance of separating the handling of contracting and risks for capture plants from the transport and storage of CCS (T&S), in view of their differing technical and economic characteristics. Doing so offers the potential to deliver CCS at lower overall cost to consumers and taxpayers than a 'full chain' approach based on support through electricity prices (through Contracts for Difference, CfDs) while requiring early project investors to bear investment risks across the full value chain (including counter-party, operational and long term liability risks). There is substantial scope to improve the allocation of risks, ensuring they are allocated to the party best-placed to absorb or manage them, thus allowing industry participants to access lower costs of capital (CE & Deloitte 2016). Moreover, if T&S infrastructure is able to serve multiple sectors it may be possible to improve utilisation and increase economies of scale, which can also lower costs per unit of CO_2 stored.

A new strategy for CCS requires detailed consideration of ownership structures, policy instruments and the allocation of risk between public and private sector participants. It will be particularly important for the Government to consider how best to manage the risks associated with stores. It is likely to be necessary for government to take a role in underwriting some of the risks associated with managing CO_2 storage sites, as it must do for nuclear liabilities, and the volume and stranding risks of new infrastructure connections (as is the case under the OFTO regime for new transmission connections that enable offshore wind developments) . Detailed review of policy options and business models is beyond the scope of this report. However the Group recommends that policy to allow development of a strategically planned CCS T&S infrastructure is given detailed attention by DECC and the National Infrastructure Commission. There is also a significant link to the role of the Oil and Gas Authority in relation to decommissioning and maximising the economic potential of the North Sea.

The Advisory Group welcomed the report from Pöyry, which offers important insights into the benefits and cost implications of separating the generation and capture business from the transport and storage business. Analysis undertaken by Pöyry is well aligned with other analysis of the future of CCS and the role of policy in supporting capture and in creating an investment environment for transmission and storage infrastructure (CE & Deloitte 2016). The Group also believe that the analysis undertaken by Pöyry provides new insight into CCS costs under credible assumptions and that this also aligns well with international evidence emerging from the IEA Greenhouse Gas Programme and others.

If progress with CCS is to be made and cost reductions are to be realised there is a need for government to take steps during this Parliament to provide clarity over aspirations and objectives for CCS, both in terms of long term goals and development of early capture and infrastructure projects. Whilst international CCS developments and ongoing research and development (RD&D) are important to cost reduction they cannot substitute for developments in infrastructure and learning that are UK specific (such as enabling infrastructure, de-risking of North Sea storage, and business

models, building skills, supply chain and offshore T&S). Therefore there is a need for action on three main fronts: Separate funding for near-term capture and infrastructure projects, an approach to risk allocation for CO_2 storage sites, and strategy and regulation to allow industry to invest in T&S infrastructure.

Detailed comments and observations

Analysis of CCS Costs

The Group welcomes analysis of CCS costs by Pöyry which are credible and well-aligned with other sources. The analysis provides a particularly useful contribution to understanding CCS by moving away from a full-chain model focused on particular power sector capture schemes (which risks over-emphasis of a single £/MWh metric), and instead considers capture and T&S infrastructure costs separately. This avoids a paradox associated with the full-chain approach (and by extension the cost estimates provided for the demonstration projects), this being that early projects must bear the full cost of an infrastructure that if sized appropriately could service a large number of subsequent projects. Conceptually separating the contracting and regulation of transport and storage infrastructure from capture projects allows a more sensible characterisation of the costs of a single capture project. It would also facilitate development of follow-on capture projects in a cluster, with transport and storage costs allocated across all capture projects, rather than to the first project only.

In terms of methodology the consultants used a rigorous approach informed by sensible discussion of key assumptions and drivers of cost reduction. Analysis undertaken for the CCC in the 2015 study by Pöyry and Element Energy stressed the importance of ongoing roll out to build skills and supply chain, clusters to make best use of T&S, and processes of learning so that each new project can inform cost reductions in future projects. It continues to be the case that a steady 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 (Gross et al 2013 Mukora et al 2009).

As noted above, in the new analysis Pöyry has explicitly set out to disaggregate *capture costs* from *transport and storage costs.* The analysis assesses each category of costs separately on the basis that policy could provide support for capture (for example through a CfD) and strategic approach to T&S infrastructure (various ownership and risk sharing models are possible and discussed below). This offers extremely important new insights, which allow the UK's approach to CCS to be improved.

Depending on assumptions about cost of capital (hurdle rates), length of CfD, gas prices, learning effects and build rates the analysis suggests that the CfD strike prices needed for gas-fired generation with CCS lie in a range from approximately £85/MWh to around £125/MWh. The analysis separates the cost of transport and storage, estimating this to amount to around £6 - 9/MWh of the total, assuming the T&S infrastructure is well utilised[2].

[2] The Group notes that T&S infrastructure costs are best conceptualised in terms of cost per tonne of carbon dioxide stored, noting that CO2 from non-power sector sources would not be costed in terms of £/MWh. T&S costs incurred by power sector plants are subject to assumptions about overall T&S size, utilisation and regulatory arrangements discussed below.

The Group believes that these estimates are credible and within the range of other recent analyses. A recent systematic review on the topic indicates that estimates for the costs of CCS on power generation lie in a wide range (Budanis et al 2016). However, relative to some analyses the assumptions Pöyry make are cautious, suggesting that CCS costs could turn out to be *lower* than the estimates provided by Poyry. It is important to note also that the analysis provides estimates of CfD *strike prices* and *not* levelised costs of energy. The latter are lower, since CfD prices need to factor in the policy risk associated with CfDs (Poyry 2014).

In summary the Group is satisfied with the rigour of the analysis carried out by Poyry of CCS costs for these purposes. The analysis indicates that levelised costs for CCS on gas-fired power plant built in the 2020s and connected to a well-used T&S system could be well below £100/MWh under sensible assumptions.

However the Group also notes that cost reductions in CCS will almost certainly depend on progress with real-world projects in the UK. The cancellation of the Commercialisation Programme creates an opportunity for new thinking about enabling CCS infrastructure and for strategic shaping of support for early development of the sector. This does not obviate the need for *some form* of early stage deployment support for capture projects in the UK or in collaboration with partner countries. The main rationale for the CCS Commercialisation Programme was to provide the essential first step in any emerging technology – full scale deployment of the first prototype. Doing so reveals new information about the practical deployment, operation and integration of technology components that are essential if future roll out is to proceed. The Group are mindful of Government aspirations to develop a technology neutral approach to low carbon technologies from 2025 (Rudd 2015). Prior to this however it will be necessary for government to provide some form of support that enables early capture projects by providing strategic support and risk sharing for key enabling infrastructure.

The government has an opportunity to devise an approach to supporting capture that is more effective and cheaper than the cancelled programme. However a 'wait and see' approach, even one funding new desk studies or R&D would not deliver meaningful cost reduction or allow the UK to begin to realise the benefits – both environmental and industrial – of a significant capacity to capture and store CO_2.

Separate policies for T&S infrastructure and capture

The 2015 report for the CCC from Poyry and Element Energy assessed in detail the cost reduction that could be delivered through strategic infrastructure and regional onshore clustering of projects that efficiently utilise large shared pipelines delivering to offshore storage hubs, building on existing research in this area (CE 2014, CE et al 2013). A central conclusion of the work is that development of this strategic infrastructure unlocks the biggest and most reliable share of cost reduction. For this to happen, developers will require a long term government commitment and visibility of policies that remove market failures and deliver certainty for companies taking investment decisions.

With the cancellation of the CCS Commercialisation Programme the Government has an opportunity to rethink the approach to transport and storage infrastructure delivery. Pöyry's new analysis includes preliminary assessment of the some possible business models for T&S operation and ownership. The analysis also considers risk allocation and the role of government in underwriting some of the risk associated with managing CO_2 stores. There is an opportunity for fresh thinking

about the development of CO_2 infrastructure, possibly through a review of the topic by the National Infrastructure Commission. The Group believes that the CCC should draw the attention of policymakers to the potential for a range of ownership structures and regulatory and commissioning arrangements for CCS pipelines, hubs and stores. Poyry's analysis provides initial analysis of the impact on risk allocation and hence cost of capital. Further work in this area would be extremely beneficial (see below).

Concerns about cross chain risk were emerging prior to the cancellation of the Commercialisation Programme. Indeed the Group would draw attention to the following observation made in our previous (2015) report to the CCC on CCS costs, referring to projects following the initial two demonstrations:

"…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."

A forthcoming report from the CCSA on 'lessons learned' from the Commercialisation Programme suggests that the 'private sector financed full chain model' that would have been used in the Commercialisation Programme is now very unlikely to deliver the first UK CCS projects in a hub.

Overall the Group suggests that CCC advice to government recommends that DECC and/or the National Infrastructure Commission undertake a review of prospective ownership and regulation arrangements for CCS T&S infrastructure. The review would consider the full range of ownership, regulatory and risk sharing models and policy interventions which could better enable CCS T&S infrastructure, including by entities independent of the power sector/capture plants.

The overarching objective of such as review would be to ensure that by the end of this Parliament a framework is in place that allows investment in carbon capture by a range of entities - including power stations, industrial plants and potential hydrogen production facilities.

Risk allocation, business models and reducing the cost of finance

The Group noted in its 2015 report the importance of improving investor confidence and increasing the involvement of the financial sector in reducing the cost of CCS, through the establishment of 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.

The additional analysis by Pöyry and others (CE & Deloitte 2016) places greater emphasis on the different roles that Government might play with regards to capture plant and storage sites. Given the global scope for competition in capture technology there is very little reason for direct government involvement in the ownership or operation of the former – provided some form of financial incentive is provided for early capture plants. Later projects would be able to compete for financial support under a carbon price or technology neutral CfD. However the ongoing liabilities associated with storage infrastructure are long-term and complex. Detailed evaluation of these

issues is beyond the scope of this note, but the Group believe that it is likely that some combination of underwriting/guarantees, public sector participation or limited liability will be needed to ensure that storage sites in particular are investable for private companies. The analysis from Poyry reflects emerging ideas about ownership structures and business models (CE & Deloitte 2016). The Group notes that it might be possible to manage ownership in the private sector in a manner similar to other large infrastructure projects. This is referred to as the 'Thames Tideway Tunnel' or contractual risk allocation model (Ibid) and a summary schematic of the ownership structure and business model is provided in their report – however there are a wide range of possible financial and regulatory models which should be considered in more detail.

Leaving aside the particular risks associated with storage sites the Group note the importance of allowing investment in CCS infrastructure to be low risk in a financial sense – perhaps allowing investment under a regulated asset base and ensuring that CCS can be treated as a low risk asset by institutional investors.

The Group recommends that in advice to Government on the need to develop an a framework for CCS investment the CCC pays particular attention to the risk allocation associated with CCS infrastructure and that a key objective is to allocate risk appropriately and minimise cost of capital.

Conclusions and final observations

Many commentators on energy and climate policy issues viewed the removal of funds from the Commercialisation Programme with some shock and as a major setback for CCS. There is widespread agreement that CCS is essential in many decarbonisation scenarios, not only for controllable low carbon electricity, but also for industrial decarbonisation, flexible low carbon fuel production (e.g. hydrogen) and delivering negative emissions (in combination with biomass for energy technologies). However the Programme has already realised useful results in the form of characterisation of stores and in detailed cost and technology appraisal, much of which can be built upon. The 'full chain' approach taken in the Programme imposed high costs on early plants and was not necessarily conducive to least cost development of CCS T&S infrastructure over the longer term. There is now an opportunity to progress an alternative CCS development strategy which can build on lessons from the competition and provide a pathway to cost-effective CCS deployment during the mid-2020s. There is however significant urgency for the Government to progress an alternative route to real CCS deployment by the mid-2020s, as failure to prove the deployment of CCS within these timescales will increase the costs and risks of meeting carbon targets[3].

CCS T&S infrastructure needs to be in place from the mid-2020s to maximise the potential of CCS to enable cost-effective decarbonisation, or at the latest by the early 2030s if CCS is to provide a significant contribution in the period to 2050. If CCS costs are to fall UK deployment (either on power plants or industrial sites) will be essential and early projects will require financial support and significant risk-sharing from government. The Group recommends that future strategy should separate support for capture plants (paid through a CfD on power or fit for purpose scheme for industry, perhaps ultimately through a carbon price) from enabling investment in a T&S infrastructure. The latter will be delivered most cost effectively if a new regulatory and investment

[3] http://www.eti.co.uk/wp-content/uploads/2016/01/ETI-letter-to-Chair-on-Future-of-CCS.pdf

framework is developed that allocates risk cost effectively, underwrites some of the liabilities associated with stores and ensures that infrastructure is well-sited to allow clusters of capture plants to connect.

During the course of this Parliament the Government should carefully evaluate the approach to handling risk, business models, industrial support mechanisms and liabilities for early CCS projects, with a view to enabling tangible progress towards investment in projects starting during the early 2020s. A revised framework for investment and risk sharing could create the enabling conditions needed to allow CCS infrastructure to be developed by the private sector, using lower cost sources of finance. Doing so has the potential both to unlock a key option in decarbonisation and provide an opportunity for UK industry and investors to take a leading role in an essential new infrastructure sector.

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References

Budanis, Krever, Mac Dowell, Brandon and Hawkes, 2016, Can technology unlock unburnable carbon? Imperial College Sustainable Gas Institute White Paper http://www.sustainablegasinstitute.org/wp-content/uploads/2016/05/Can-Technology-Unlock-Unburnable-Carbon-White-Paper-May-2016.pdf?noredirect=1

CCC (2013). Fourth Carbon Budget Review – part 2. London, Committee on Climate Change.

CCC (2015). Fifth Carbobn Budget Advice. Committee on Climate Change, London.

CE (2014b). Optimising CO2 networks to reduce CCS costs UK Transport and Storage development group. London, The Crown Estate.

CE CCSA & DECC (2013). CCS Cost Reduction Taskforce: Final Report. London, Crown Estates, Carbon Capture and Storage Association and Department of Energy and Climate Change.

CE & Deloitte (2016) A need unsatisfied: Blueprint for investing in CO2 storage. Published by the Crown Estate http://www.thecrownestate.co.uk/energy-and-infrastructure/carbon-capture-and-storage/

DECC (2013). CCS in the UK Government response to the CCS Cost Reduction Task Force. London, Department of Energy and Climate Change.

Ekins, P., I. Keppo, J. Skea, N. Strachan, W. Usher and G. Anandarajah (2013). The UK energy system in 2050: Comparing Low-Carbon, Resilient Scenarios, UKERC Research Report. London, UKERC.

ETI (2014). Carbon Capture and Storage: CCS could clear a path to the UK's carbon reduction targets. Loughborough, UK, Energy Technologies Institute.

ETI (2015a). Carbon capture and storage Building the UK carbon capture and storage sector by 2030 – Scenarios and actions. Loughborough, UK, Energy Technologies Institute.

ETI (2015b). Options Choices Actions: UK scenarios for a low carbon energy system transition. Loughborough, UK, Energy Technologies Institute.

Gross, R., P. Heptonstall, P. Greenacre, C. Candelise, F. Jones and A. C. Castillo (2013). Presenting the Future: An assessment of future costs estimation methodologies in the electricity generation sector. London, UK Energy Research Centre.

Mukora, A., M. Winskel, H. F. Jeffrey and M. Mueller (2009). "Learning curves for emerging energy technologies." Proceedings of Institution of Civil Engineers: Energy **162**(4): 151-159.

Poyry 2014, The levelised cost of power from tidal lagoons, http://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010049/2.%20Post-Submission/Representations/ExA%20Questions/Round%201/Responses/2.1.2%20Poyry%20Report.pdf

Rudd 2015, 'Energy Policy Reset' speech, https://www.gov.uk/government/speeches/amber-rudds-speech-on-a-new-direction-for-uk-energy-policy