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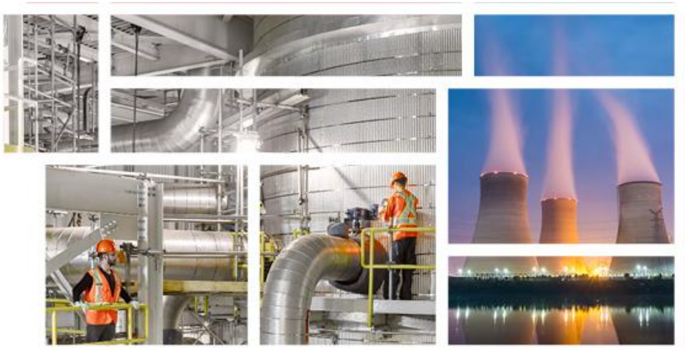
carbon capture and storage



Commercialisation of CCS What needs to happen?

Dr Leigh A Hackett, CEng FIChemE

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1 Preamble

This paper on the commercialisation of CCS is aimed at developers and policy makers as well as energy professionals and academics with an interest in the decarbonisation and optimisation of future energy markets. It is intended to provide insights into the challenges facing the development of a viable CCS industry highlighting new approaches and commercial models that could be deployed to realise the full potential of CCS in decarbonising future energy systems at lowest cost. Although based upon experiences from the recent UK CCS Commercialisation Programme and written mostly from a UK perspective with UK solutions in mind, the lessons learnt and proposed approaches can be applied globally.

In responding to the need to decarbonise the UK energy system as a whole, a dilemma is building in terms of technology selections for new electricity generation capacity. New nuclear is long-lead and inflexible, unabated CCGT risks becoming a stranded asset as carbon emission costs and control measures tighten. Expansion of intermittent renewable capacity will not meet National Grid's increasing concerns over reserve margins or balancing system supply with demand. CCS offers a flexible clean power generation solution which can complement alternative low-carbon generation technologies. It can also provide a solution for the decarbonisation of energy intensive manufacturing industry where no practicable alternatives currently exist.

The author has extensive real world experience with the development of CCS projects and was the Chief Executive of Capture Power Limited, the lead developer of the White Rose CCS project, one of the final two preferred bidders in the UK CCS Commercialisation competition cancelled in November 2015. The project was envisaged as a 450MW coal-based power station fitted with oxy-combustion CCS technology capable of providing clean power to 630,000 homes. Approximately 2 million tonnes per annum of CO_2 were to be transported and stored in an off-shore geological saline formation (Endurance) located off-shore in the Southern North Sea.

2 Introduction

Since the late 1990s, a number of flagship government backed programmes have been set up around the world with the specific intent of demonstrating the commercial viability of carbon capture and storage (CCS) as an effective and affordable way to decarbonise power generation and other energy intense industries (EII). Many of these programmes have featured financial support to off-set the costs of CCS as a means to encourage the private sector to invest in the development and deployment of CCS technology. Despite the ambition of these programmes and the scale of the support offered, progress has been minimal. To date, the Boundary Dam project in Canada at $110MW_e$ net output is the world's only "commercial scale" CCS project specifically for power generation in operation[1]. The European Union's ambition for up to 12 CCS projects in operation by 2015[2] supported firstly through the European Economic Programme for Recovery (EEPR) and latterly through the New Entrants Reserve (NER300) programme has failed to deliver a single CCS project. More success has been enjoyed in the United States through various programmes supported by the US Department of Energy. However, here too progress has been slow with Southern Company's Kemper County IGCC at 582MWe net output,

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[1] The World's first Post-Combustion Coal-Fired CCS Facility; http://www.saskpowerccs.com
[2] Brussels European Council 8/9 March 2007 Presidency Conclusions https://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/93135.pdf

currently in commissioning, being the only CCS project specifically for power generation in the US[3]. In the United Kingdom two competitive CCS procurement programmes for power generation have been run by the UK Government since 2007 with both having being abandoned without success.

The need for CCS as a key part of global strategies to reduce CO_2 emissions may be great[4] but so far this need has not been framed in a way that is attractive or rational for the private sector to respond to with investments in CCS projects. The physical and commercial risks associated with the development of large scale CCS projects and the associated CO_2 transport and storage (T&S) infrastructure have so far outweighed the potential rewards on offer, as evidenced by the abandonment of many tens of promising CCS projects around the world.

The development and roll out of CCS is a key element in the strategy to reduce the intensity of global CO_2 emissions, and essential to meeting the ambitious targets established for green-house gas global emissions reductions[5]. The scale of CCS deployment envisaged[6] means that increasingly from the early 2020s huge volumes of safe and secure CO_2 storage capacity will be required, interconnected by extensive transportation networks (pipelines, ship transport, road transport, etc.) to clusters of CO_2 sources.

With the failure of the various government-backed programmes to establish a viable CCS industry and in the absence of any private sector companies willing to expose their balance sheets to full chain CCS projects[7], the question arises: what needs to happen to make CCS a commercial reality? The need for CCS is becoming ever more acute and new approaches to its commercial deployment are needed as a matter of urgency if we wish to meet our carbon targets in the most cost-effective manner.

One of the key attributes of CCS is that it can be applied to all main carbon emitting sectors and is therefore ideally suited to system-wide decarbonisation efforts. A key focus in the early stages of deployment will need to be on the development of CCS infrastructure to which multiple CO_2 sources can connect so as to take advantage of economies of scale and to optimise the development pathway. In the UK regulatory and financial frameworks are already in place for low-carbon power which can be modified to fit CCS. This, together with the large volumes of CO_2 available to support large scale CCS infrastructure development, makes the power generation sector, in an increasingly electrical future, the logical first mover sector for CCS.

Selecting the right mix of technologies for a reliable, affordable and secure decarbonised electricity generation system is challenging. New base-load nuclear is expensive and has a long delivery lead time. The expansion of intermittent renewable capacity is becoming increasingly problematic for system operators and is associated with increasing levels of system integration costs[8]. Unabated flexible CCGT risks becoming a stranded asset as carbon emission costs and control measures tighten, and large scale electrical storage is still a nascent technology not yet at the commercialisation stage.

Many of these challenges can be overcome with CCS. Fossil fuelled power stations fitted with CCS generate low-carbon on-demand electricity and provide system balancing services. The technology can complement all other alternative low-carbon technologies to enable development of the optimum power generation mix, with the added benefit of establishing the basis for a wider roll out across the EII sector. CCS is an important technology that provides a bridge to, and an important long-term component of, a zero carbon future.

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[3] https://www.globalccsinstitute.com/projects/kemper-county-energy-facility
[4] http://ec.europa.eu/clima/policies/international/negotiations/paris/index_en.htm
[5] IPCC, Climate Change 2014, Synthesis Report https://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf
[6] IEA, Energy Technology perspectives 2014, Harnessing Electricity's potential http://www.iea.org/publications/freepublications/publication/EnergyTechnologyPerspectives2014.pdf
[7] Lessons and Evidence derived from UK CCS Programmes, 2008 - 2015 https://www.google.com/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=CCSA+lessons+learned
[8] NERA, Imperial College, UK Renewable Subsidies and Whole System Costs 16 February 2016

3 The value of CCS

The value of CCS derives from the fact that it is the only technology that can simultaneously address carbon reduction objectives across all main carbon emitting sectors of the economy including power generation, industry, transport and heating[9].

For EII applications there is currently no alternative to CCS for reducing the CO_2 emissions that are inherent to the manufacturing process. The decarbonisation of transport, including road transport, will inevitably involve increases in the numbers of electric vehicles. The resulting demand in electricity can be supplied from CCS enabled power stations. CCS in combination with hydrogen production could provide the low-cost route to the decarbonisation of heating as well as support the development of other aspects of the hydrogen economy including the use of fuel cells. CCS is also the only technology that can remove industrial quantities of CO_2 from the atmosphere when combined with power generation from sustainable biomass combustion (so-called BECCS) creating room within carbon budgets for sectors more difficult to decarbonise, such as aviation. Indeed, in the UK, without CCS it is unlikely that the country's 4th and 5th carbon budgets can be met[10] whilst maintaining a vibrant industrial manufacturing sector.

The IPCC's 5th assessment report[5] stated that not only is CCS a vital technology to meet the 450ppm CO_2 atmospheric concentration limit by 2100 but that the costs of doing so in the absence of CCS will be increased by a staggering 138%, making a CCS-inclusive pathway overwhelmingly the lowest-cost route to decarbonisation. The Energy Technologies Institute (ETI) has stated that achieving the UK's 2050 carbon targets without deploying CCS is very likely to result in substantially higher costs (>2% of GDP by 2050) across the energy system[11] and warns that a delay[12] from 2020 to 2030 in the commercial deployment of CCS could increase the cost of meeting UK carbon budgets by £1-2bn per year throughout the 2020's.

The development of CCS, like all low-carbon technologies, will bring with it some additional costs. In a report prepared by the CCSA together with the TUC[13] however, it was estimated that the Gross Value Added[14] (GVA) benefits from CCS deployment in the UK would be in the region of £2bn–£4bn per year by 2030, with a cumulative market value of £15bn–£35bn (depending on whether 10 GW or 20 GW of CCS capacity is installed respectively). This is in addition to the creation of between 15,000 and 30,000 jobs.

If CCS is to form a key part of decarbonisation strategies it is important that the benefits of CCS across the economy at the total energy-system level are understood and that the long-term value-for-money case forms a central consideration in developing energy policy.

4 The cost of CCS

One of the most frequently expressed concerns regarding CCS is that it is too expensive. Indeed one of the primary reasons given for the discontinuation of the UK CCS competition was the view that the costs to consumers of the first CCS projects would be high and regressive[15] although it was acknowledged that the cost was likely to be higher for the first CCS projects as they provide T&S infrastructure that could be used by subsequent projects. In the short term the cost of CCS for power generation will continue to be compared to alternative forms of low-carbon power generation even though those

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[9] Transport and heating through increased electrification and/or hydrogen production with CCS.
[10] https://documents.theccc.org.uk/wp-content/uploads/2016/06/2016-CCC-Progress-Report.pdf

[11] (ETI) Progressing Development of the UK's Strategic Carbon Dioxide Storage Resource, April 2016

[12] https://www.carbonbrief.org/carbon-capture-delay-could-add-20bn-to-uk-climate-costs
[13] The economic benefits of carbon capture and storage in the UK, CCSA/TUC, February 2014
[14] A measure of the goods and services produced in any region, industry or economic sector of an economy.
[15] https://www.nao.org.uk/wp-content/uploads/2016/07/Sustainability-in-the-Spending-Review.pdf

alternatives (and their intermittent output) will lead to higher system-wide costs in the long run[16]. In facing up to this challenge any new approaches to CCS commercialisation will need to deliver significant short-term reductions in the costs of first mover projects.

The driving forces for cost reduction have been set out in the CCS cost reduction task force (CRTF) report[17] published in 2013 as part of the UK government's CCS roadmap[18], including:

i. investment in large CO_2 storage hubs, supplying multiple CO_2 sites connected through large, shared pipelines, with high load factors;
ii. investment in large power stations with progressive improvements in CO_2 capture capability that should be available as from the early 2020s;
iii. a reduction in the cost of project capital through a set of measures to reduce risk and improve investor confidence in UK CCS projects; and
iv. exploiting potential synergies with CO_2-based EOR in some Central North Sea oil fields

All of these drivers are as relevant today as they were when the CRTF report was issued in 2013. Based upon technology progress in the intervening years and by applying the lessons learnt from the UK CCS Competition, significant reductions in the cost of CCS first mover projects are achievable. Success will depend on the development of large scale anchor projects that invest simultaneously in over-sized T&S infrastructure with third party access rights for follow on projects.

In addition new commercial approaches will be required that balance multiple key risks *(figure 1)* and see a transfer of some of the CCS specific development and operational risk from the private sector to the public sector beyond that previously envisaged[19].

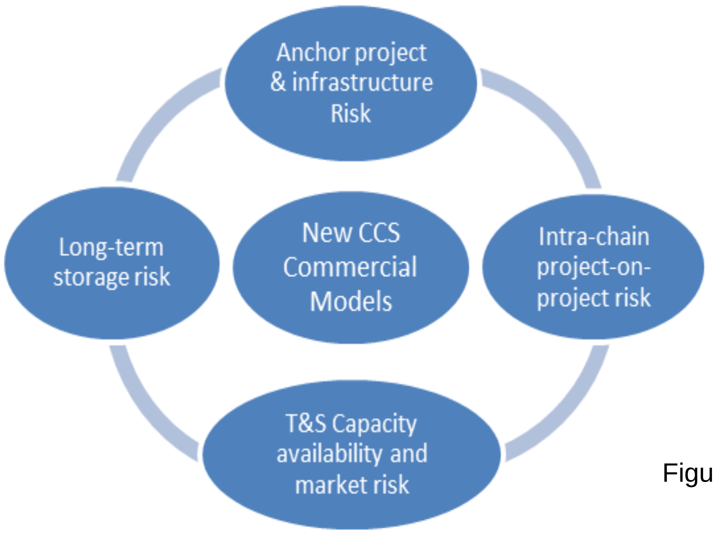

Figure 1: New commercial models need to balance multiple key risks

[16] http://www.nera.com/content/dam/nera/publications/2016/NERA_Imperial_Feb_2016_Renewable_Subsidies_and_Whole_System_Costs_FINAL_160216.pdf

[17] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/201021/CCS_Cost_Reduction_Taskforce_-_Final_Report_-_May_2013.pdf

[18] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48317/4899-the-ccs-roadmap.pdf

[19] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/531409/K04_Full_chain_FEED_lessons_learnt.pdf

The CRTF predicted that the costs for CCS in the UK would be around £161/MWh for the first mover projects and could approach £100/MWh by the early 2020s, and achieve a cost significantly below £100/MWh soon thereafter. The CRTF report was produced as part of the UK CCS roadmap and reflected the expected trajectory of cost reductions as experience and economies of scale grew against reducing capital and operating costs. The UK CCS Commercialisation Programme, itself an integral part of the CCS roadmap, was aimed at attracting developers of first mover projects to invest in full chain CCS projects through a competitive process and offered a package of support in the form of capital grant funding, market price support through a Contract for Difference (CfD) and a share in the CCS specific risks.

The CRTF predictions for the first mover projects were largely borne out by the subsequent competition projects with the high prices largely a reflection of the adopted approach to risk allocation which crucially placed the full chain technical and commercial integration risk as well as significant CO_2 storage risk with the private sector developers and operators. By adopting new commercialisation approaches that focus on the identified cost reduction drivers and include a modified risk approach that accommodates the lessons learnt from the competition projects, much of the cost reduction potential envisaged by the CRTF for subsequent projects could already be realised for the first mover projects albeit with a transfer of risk to the public sector. This would bring the cost of CCS to levels that are competitive with alternative forms of low-carbon power making CCS more affordable from the outset.

5 New approach to CCS commercialisation

5.1 CCS risk

The starting point for the development of the CCS industry has invariably been based on the premise that the private sector should deliver CCS and manage all of the technical and commercial integration risks across the full chain. Indeed there are many risks that the private sector is able to manage and price competitively especially where these are within the competences of the developers of the individual chain link elements and can be accommodated within their established business models. There are however certain risks, related to the nascent status of the industry and the lack of proven commercial models across the full chain, that the market will either only accept at a premium or indeed in some cases not accept at all whatever the price.

Based on the UK lessons learnt[7] and the Key Knowledge Deliverables[14,20] the CCS specific key risks that present the greatest challenges and could most benefit from additional public sector risk support to overcome barriers to CCS development and drive down costs through reduced risk premiums include:

i. Cross chain default (also referred to as “project on project”) risk
ii. Post decommissioning CO_2 storage risk
iii. Sub-surface CO_2 storage performance risks impacting on storage rates and capacity.
iv. Decommissioning cost sufficiency and financial securities related to the CO_2 storage permit.
v. Insurance market limitations for CO_2 T&S operations

Risk i) applies to all individual chain link elements, whereas risks ii) to v) apply almost exclusively to the CO_2 storage aspects. Risks i) and ii) would in all likelihood need to be absorbed by the public sector potentially for the lifetime of a specific CO_2 T&S system, whereas risks iii) iv) and v) may be time limited and transferrable back to the private sector as practical experience is gained and operating confidence increases. By introducing commercial models that entail a transfer of these risk categories to the public sector, not only can barriers be removed that have thus far prevented the private sector from investing in CCS, but also project financeability would increase and the risk premium added to the cost of capital funding would be significantly reduced.

[20] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/531384/K01_Full_chain_FEED_summary_report.pdf

With private sector confidence in the deliverability of CCS being at a low ebb presently, together with the current lack of appetite to invest in the development of storage capacity where all of the risks i) to v) apply, there is a strong argument for the public sector to take direct responsibility for the realisation of the T&S infrastructure. The creation of a publicly owned national transport and storage company (NT&SCo) to provide secure long term CO_2 storage capacity, as recently recommended in a report by the parliamentary advisory group on CCS, chaired by Lord Oxburgh[21], would provide much needed certainty and boost confidence in the deliverability of CCS. Such a company would provide a strong counterparty and a significantly de-risked T&S infrastructure to potential private sector developers of generation and capture (G&C) assets. The use of public sector financing for the T&S assets would also bring benefits by lowering the overall cost of finance and as a consequence the cost of transporting and storing the CO_2.

The Lord Oxburgh report goes a step further and also considers public ownership of the G&C assets with a view to privatisation after a period of successful operation. Private sector investment at a later stage would still require sufficient financial shielding from shortfalls in the availability of the T&S infrastructure (cross chain default risk). This could be achieved through permitted unabated operation with assured revenue stream mechanisms for example through continuation of CfD payments or through switching to capacity market payments. Combining both CfD and capacity payment mechanisms for a single generator would however require amendments to current regulation. The private sector investor would also need to be shielded from liabilities associated with continued payment of T&S capacity reservation and use-of-system fees should the G&C assets suffer prolonged outages for example through contracting for capacity on a pay as you use basis with limitations of liability for non take-up.

Whether or not it is necessary for the public sector to take responsibility for the delivery of the G&C assets rather than the private sector will depend upon confidence in the deliverability of CCS in the UK and the degree to which CCS specific key risks are transferred to the public sector, whether that occurs at the outset or at a later stage following initial operations. Whichever route is followed it will be important to leverage the skills and competences of the private sector that has established a good track record in the delivery of power generation assets since privatisation of the electricity markets in 1990. Though there are many ways to structure the commercial arrangements between the various stakeholders in a CCS network including direct public sector engagement, regulated asset based models, etc., success will depend upon the appropriate balance of risk between the private sector and the public sector taking into account the listed CCS specific key risks. It will also be important that models form a robust template for the long term development of the CCS industry that is most likely to develop along the lines of clusters of users alongside CO_2 T&S services providers with a clear transfer of liability for the CO_2 to the T&S service provider, potentially a NT&SCo in the UK, at the factory boundary *(figure 2)*.

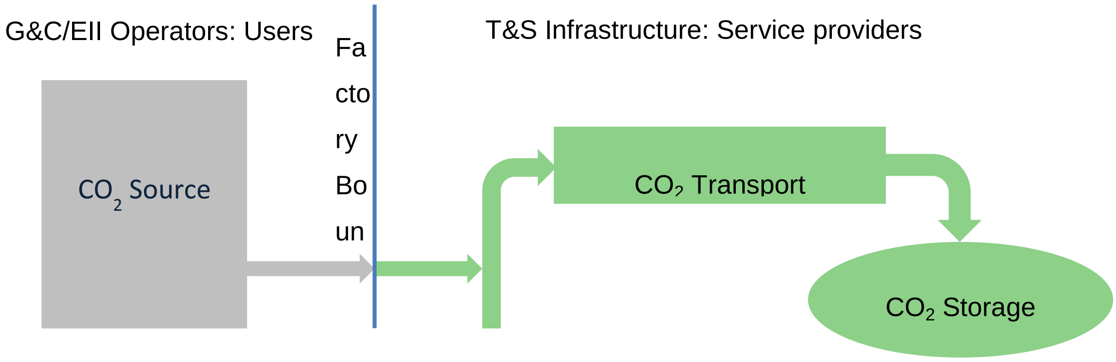

Figure 2: Industry market development, users and service providers.

[21] http://www.ccsassociation.org/news-and-events/reports-and-publications/parliamentary-advisory-group-on-ccs-report/

The use of Enhanced Oil Recovery (EOR) to boost production levels in the mature fields of the North Sea holds out the prospect that CO_2 will, at some point in the future, command a material financial value potentially increasing the rewards available for the storage element of CCS. There is currently however no indication that these rewards would be sufficient for an EOR operator to underpin the associated development risks of the upstream elements of the CCS chain. It is more likely that EOR will develop in the North Sea once CCS is established in the power generation sector using sub-surface geological storage sinks, and hence only after reliable and predictable flows of CO_2 become available off-shore[22].

5.2 Economies of scale

In order to benefit from economies of scale, future programmes for the commercialisation of CCS should be based on the establishment of a large scale anchor project with 10-15 million MTA CO_2 T&S capacity. The aim should be to maximise the clean power output to reduce the unit cost of CCS per MWh. CO_2 intensity in terms of tCO_2/MWh should be as low as possible to minimise the scale up factor for the CO_2 capture technology. This would also be advantageous in minimising the initial capacity reservation in the T&S system allowing more capacity for follow-on third party users thus achieving a critical mass as soon as possible. Based upon these considerations and given the current status of CO_2 capture technology in terms of proven operation at commercial scale, the optimum anchor project should feature a c.a. 1GW gas combined cycle plant with post combustion capture technology currently available competitively from a number of suppliers.

To maximise the future benefit of the established T&S infrastructure, the anchor project should be sited in a CO_2-intense industrial cluster. In the UK, there are several such clusters, located mostly along the east coast. This would also reduce transportation distances to the vast potential for CO_2 storage sites in the Central and Southern North Sea. Keeping pipelines short and avoiding overland pipelines as far as possible will help to keep costs down and avoid protracted, complex and costly easement negotiations with a number of landowners.

6 Funding of CCS

The funding of CCS requires that a predictable and secure revenue stream is available to cover the costs of CCS and allow the developer to meet all of its financial needs. This will invariably require non-market derived sources of income and/or beneficial tax incentives for the generation of low-carbon power with CCS and the long-term storage of CO_2.

In the UK, power generation is currently the only sector for which existing regulation and financial frameworks are in place to support low-carbon technology through market price support mechanisms established through the electricity market reform (EMR) and as enshrined in the 2013 Energy Act[23]. CCS is recognised as a low-carbon technology and as such qualifies for financial support through the Contract for Difference (CfD) mechanism. Minimising the need for legislative adoption is an important factor in facilitating CCS rollout.

6.1 Contract for Difference

The allocation of funds from the Levy Control framework (LCF) for CCS projects is key for the development of CCS projects with power generation. The revenue certainty provided through a CfD linked to a strike price for clean power generation is fundamental to the financial viability of a CCS project. However, clarification of the LCF budget (£7.6 billion in 2020/21)[24] available to CCS following the recent cancellation of the UK CCS Commercialisation competition, as well as the detailed terms and conditions of the CfD, is required from government.

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[22] http://www.sccs.org.uk/images/expertise/reports/co2-eor-jip/SCCS-CO2-EOR-JIP-Report-SUMMARY.pdf
[23] http://www.legislation.gov.uk/ukpga/2013/32/pdfs/ukpga_20130032_en.pdf
[24] https://www.gov.uk/government/news/government-agreement-on-energy-policy-sends-clear-durable-signal-to-investors

The development of a CCS project can take several years with costs running into several tens of millions of pounds. It is crucial therefore that the CfD allocation process provides developers with a high degree of certainty that a fully funded CfD will be available at the right strike price once they are ready to take a final investment decision on their projects. Even with such certainty however, a degree of public sector compensation of CCS project development costs is likely to be needed to mitigate to some degree the perceived political risk in such development programmes.

Much of the system-wide value of CCS derives from its ability to operate as flexible generation capacity alongside base load technologies like new nuclear and intermittent renewables. The CfD however as currently designed encourages base load operation as the marginal costs of production can always be covered. If the full value of CCS is to be realised mechanisms should be developed that reward flexibility.

The term of the CfD for CCS projects is set at 15 years in the generic CfD contract. By increasing the term to 20 years, significant reductions in the strike price can be achieved. Other design aspects that warrant further development include valuation and reward for negative emissions (BECCS) and application or alternative mechanism for industrial EII projects for which there is currently no CfD equivalent.

6.2 Alternative funding mechanisms

Part of the reason that the strike prices anticipated for the two preferred bidder projects under the second UK CCS commercialisation programme were relatively high, compared to alternative forms of low carbon power generation, lies in the fact that they carry the costs of oversized infrastructure for future users. As long as this approach is taken the leveraging effect that this has on the required strike price for a relatively small clean power output capacity will disadvantage any anchor project in a simple numerical comparison with strike prices of established alternative forms of low-carbon generation. If the potential benefit for follow-on projects is not taken into account in terms of pre-paid and de-risked T&S infrastructure leading to significantly lower strike prices for such follow-on projects then this bias is likely to continue to prevent the CCS industry from developing.

Alternative funding mechanisms across the full chain could be considered that would eliminate this bias. Currently, an unabated fossil fuel power generator can emit CO_2 to atmosphere for a relatively low cost[25] and, along with its customers, be forever freed from any future liability for the CO_2 from the moment it leaves the stack. The CCS-enabled generator carries the cost of development of T&S infrastructure for its own and future users' needs and has long-term liability for the safe and secure storage of the CO_2 captured. Under the principle of the polluter pays consideration should be given to spreading the costs of the T&S infrastructure over all fossil fuelled power generators and potentially other CO_2 emitters either through a hypothecation of carbon floor price levies, a carbon tax, or a form of CCS obligation certificate similar to the renewables obligation certificate first introduced in 2002 that was instrumental in supporting the early deployment of renewable technology in the UK[26].

Such an alternative approach to funding of the T&S infrastructure would significantly reduce the strike price required by the CCS enabled generator to a level more competitive with alternative forms of low-carbon generation. It would also ensure that the value that CCS brings at the total energy system level in terms of decarbonising the economy is paid for more broadly across society and provide the economic drivers for further decarbonisation technology development using tax (or similar levies) as a behaviour modifier.

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[25] September 2016, ETS (€4.5 - €5/t CO_2), UK carbon floor price €23/t CO_2
[26] https://www.ofgem.gov.uk/environmental-programmes/ro

6.3 Other financial support

6.3.1 Grant funding

Grants provided by government as a means of promoting CCS projects bring many benefits. In addition to reducing the financial commitment from the private sector for CCS projects, it also demonstrates government CCS delivery commitment to developers, suppliers and financiers, etc. There remains however the question of how best to deploy grant funding, with most programmes providing grant funding to the developer of a single full chain project. Providing the grant in this way does not change the risk profile of the project, but serves only to reduce the developers' financial exposure to full chain risks regardless of their nature including many business as usual risks. For future programmes it is worth considering targeting any grant funding to those risks in the full chain where there is a lack of market appetite particularly relating to the storage element. Deploying grant funding in this way for a multi-user store, without the requirement for a return on investment built in to the T&S capacity reservation and use-of-system fees, would provide several G&C and EII developers with low-cost CO_2 T&S services representing a far better outcome for the public funding deployed.

6.3.2 Loan Guarantees

Many private sector developers of a G&C asset including independent power producers (IPPs) are likely to look to limited or non-recourse debt finance structures (project finance) as the preferred approach to capital formation. The providers of project finance will in turn evaluate the credit worthiness of a CCS enabled power generation project on its stand-alone merits i.e. the ability of the project to meet its debt service obligations even when operating under certain adverse physical or economic conditions. The revenue certainty provided by the CfD mechanism, contracted through the low carbon contracts company (LCCC), is very attractive from a project finance perspective. However, to reach an investment grade rating in order to secure such finance, the investor group will need financial shielding from the risks associated with the transport and storage of CO_2, as already discussed.

As additional support the availability of government backed loan guarantees for example through the UK Guarantees Scheme (UKGS) would help to increase the credit rating of a G&C project in turn reducing the cost of financing. The combination of the CfD, cross chain default risk support and loan guarantees could increase the credit rating of a G&C project sufficiently to open up the possibility of long-term funding from institutional investors and/or the debt capital markets further reducing the cost of capital.

7 Conclusions

To date, efforts around the world to develop a commercially viable CCS industry have largely failed despite the levels of government intervention and support that have been considered. If this trend is to be reversed the lessons of the past need to be learned and new approaches developed.
The private sector is very unlikely to deliver fully integrated CCS infrastructure and projects without increased public sector support and clear government policy that supports CCS. It is imperative therefore for governments to take firm decisions on whether or not CCS technology will form a key part of their long-term low-carbon future energy strategy.

Where the case for CCS is made, a clear and stable CCS energy policy with a comprehensive roadmap for delivery will be required. This is necessary to build confidence in the deliverability of CCS and to attract the necessary private sector investment. In the UK a new strategy for CCS commercialisation is needed as a matter of urgency as each year of delay in deployment substantially increases the costs of decarbonisation of the UK economy in future years.

CCS can support carbon reduction efforts across all major carbon emitting sectors and represents an essential component of the low-cost pathway to energy-system-wide decarbonisation. Development of CCS will create some costs; however a vibrant CCS industry will bring significant GVA to the economy as well as generate substantial employment potential.

For CCS to take off as a commercially viable and financeable proposition, the public sector will need to accept more of the development and operational risks that have thus far proved to represent insurmountable barriers for the private sector, most notably in terms of commercial integration of the full chain and the development and operation of storage sites in a multi-user environment.

By optimising the structure, scale, location, technology choices and introducing new commercial models with modified risk reward structures, on the basis of increased public sector allocation of certain CCS specific key risks, the cost of CCS can be reduced significantly. Strike prices that are competitive with alternative forms of low-carbon generation should be achievable including for the first mover anchor projects.

In the UK, the creation of a government backed national CO_2 T&S company, with responsibility for the development of T&S infrastructure guaranteeing the long-term availability of CO_2 storage capacity for G&C and EII users, would be necessary for the successful development of the CCS industry. The availability of a de-risked T&S infrastructure would provide a much firmer basis for the private sector to develop G&C and EII assets in the UK.

The financial viability of CCS in the power generation sector currently requires a source of funding out with that which can be derived solely from market trading to cover the extra capital and operating costs and provide investors with an adequate return for the risks involved. In the UK, the CfDs available to CCS-enabled power generators are a good example of how this can be achieved. As the market adjusts to further penetration of low carbon generation technologies, as CCS design and operating experience grows and capital and operation costs reduce, the additional funding required via the CfD will reduce accordingly. If CCS is to be successfully deployed by EII operators a comparable mechanism will need to be devised.

In order to reduce the costs of the first mover projects, large scale power generation anchor projects (c.a. 1GW) connected to multi-user T&S CCS infrastructure should be envisaged from the outset. CCS technology is ready for large scale deployment.

The benefits of CCS are economy wide however the costs have invariably been seen as the responsibility of the developer operator of a CCS project. Alternative funding mechanisms could be considered to spread the costs of CCS infrastructure across all major emitters. This would align with the principle of the polluter pays and also reduce the cost to the consumer of the low-carbon electricity generated.

UKGS financial guarantees should also be considered to support UK developers of G&C assets in securing the finance needed for their investment bringing increasing project credit ratings and reducing costs.

If the lessons of previous unsuccessful CCS development programmes are learnt and the remaining challenges to full commercialisation resolved though new commercial approaches, there is every chance that CCS will be able to play its envisaged key role in supporting the cost effective decarbonisation of energy use across the economy starting in the early 2020s.

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