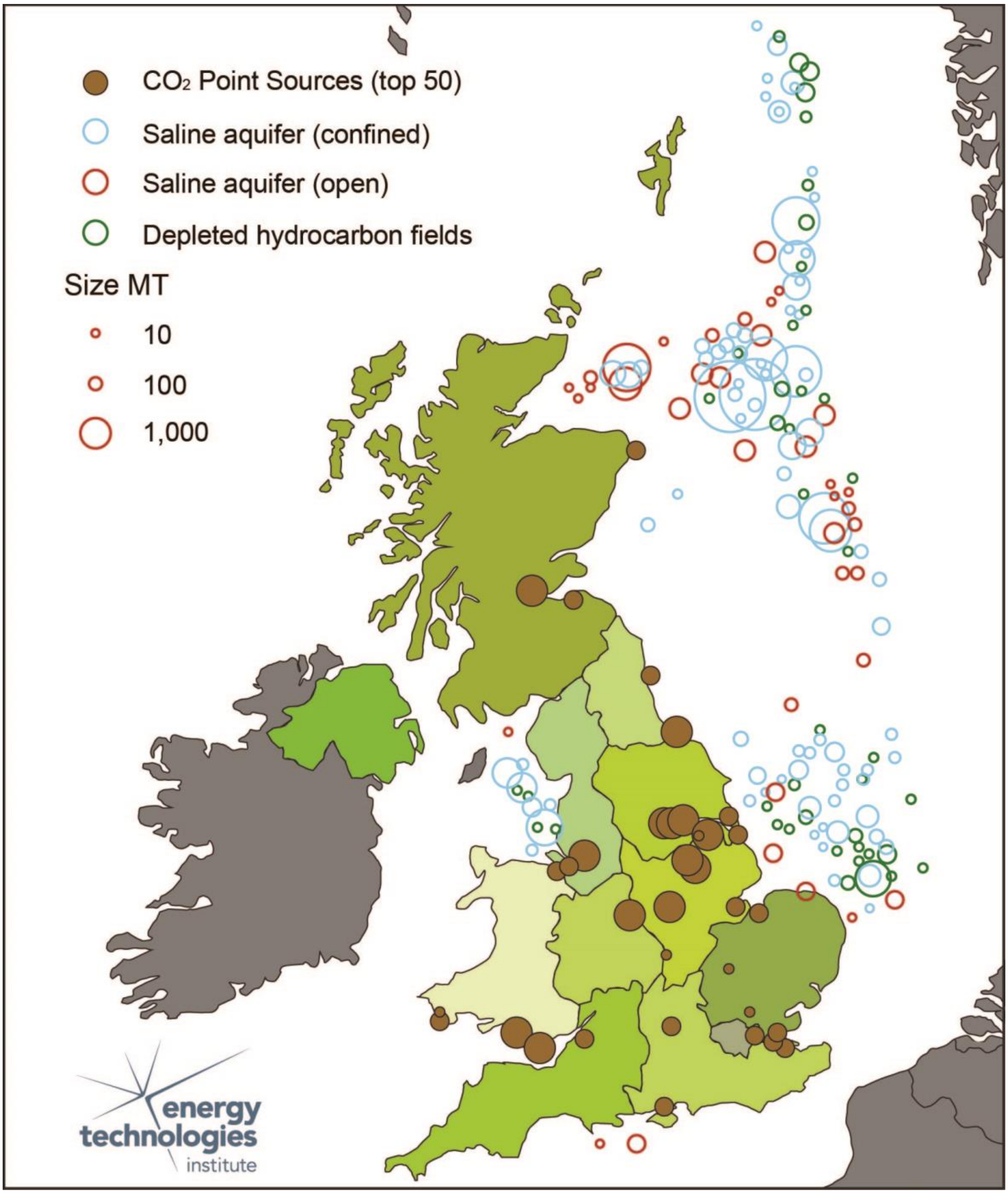
Optimising CO_2 networks to reduce CCS costs

UK Transport and Storage development group



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The optimal approach to network development will vary as the industry matures. The emphasis needs to move from end-to-end projects in Phase 1 to coordinated development of new generation plant, pipes and storage sites in Phase 2.

1.1.1 Optimisation of new network infrastructure

- Development of infrastructure sized to realise economy of scale is a key early cost driver for CCS. For trunk-lines "big is best".
- Clarity of long-term policy that drives the location and volume of CO_2 captured (including from industrial sources) is critical to delivering economy of scale.
- Early appraisal of large storage capacity is essential to underpin investor confidence in building trunk-lines and capture projects.

1.1.2 Completing the commercial chain - getting to positive FID

- HMG needs to confirm extension of the Levy Control Framework (LCF) and specific allocation to CCS, and to establish a mechanism to give long-term revenue certainty for CCS from industrial emissions.
- Contracts for Difference and LCF funding do not provide the necessary signals to incentivise investment in pre-FID storage appraisal or trunk-line future capacity that is required to deliver optimal networks in a timely manner.
- There are insufficient investors currently pursuing opportunities in CO_2 storage to ensure that optimal networks will be developed.
- HMG needs to set aside funding to (i) ensure storage sites will be appraised to underpin future capture development and the whole chain and (ii) to underpin early investment in right-sized trunk-line capacity ahead of demand, either as a capital grant or as a pipeline capacity payment mechanism.
- HMG also needs to adopt a pragmatic interpretation of the requirement for financial securities to address storage leakage liabilities.

1.1.3 Network business models

- There are insufficient incentives to ensure that optimal networks will be developed.
- UK government intervention is required to address the specific market failures remaining for investors in Phase 2 trunk-line and storage networks.
- The UK government should consider implementing some form of "Enabled Market", including an approach to cluster management that optimises the development of Transport & Storage networks.

1.1.4 Adding a new project to a network

- There is a series of issues in Third Party Access regulation (TPA) and customer charging mechanisms (including allocation of costs and liabilities) that remain unclear and need clarification before any developments for Phase 2 projects can proceed.
- There is a risk of over-regulation restricting the development of optimal networks because regulations have been developed and applied to CCS in Europe in anticipation of issues rather

than in response to issues. Regulators need to apply a fit-for-purpose approach in applying such regulation – both for Third Party Access and for storage operation.

- The Secretary of State needs to take a pragmatic approach to determinations of TPA rights to ensure that networks are tailored to accommodate high-likelihood follow-on projects, but are not delayed or made inefficient by speculative applications for TPA from low-likelihood projects.
- As part of any initial system design with State support, developers and government need clarity of any State Aid considerations for a charging mechanism for a future shared system.
- Early agreement and sharing of commercial terms for the Phase 1 Competition projects will enable follow-on projects to progress.

1.1.5 Awarding Government support

- Government support is needed to help CCS through the transition phase, in addition to that which will be provided to the first two commercialisation projects and through the creation of an effectively structured but flexible CFD. This support, in acceptably sized packages, needs to include

    - Pre-FID investment in storage appraisal
    - Investment in pipeline right-sizing for future shared use
    - An affordable interpretation of the requirement for financial support for storage liabilities
    - Risk sharing (albeit at a reduced level) for follow-on projects until industry perception of risk is reduced to yield an acceptable risk-premium
    - Appointment of a central-planning body or Board to oversee identification of target network geographies and cluster development and management.

- HMG's approach to awarding this support needs to be more efficient than the competitive processes employed to date and to focus more on the creation of system, infrastructure and multi-sector value from the intervention and less on measuring the cost.
- HMG must provide greater clarity of its policy direction in order to give bidders confidence that they are not pursuing nugatory work. Specifically, HMG must demonstrate its commitment to award funds and to progress CCS at scale, and at pace, in order to give bidders confidence that they will secure a material business opportunity if successful.
- Early investment in transport and storage infrastructure is essential to enable CCS projects. It also provides a strong policy signal and opportunities to attract new entrants.

2 Introduction

This report is a follow on to the first of the seven key steps recommended by the UK CCS Cost Reduction Task Force (CRTF) report. This was: **"Ensure optimal UK CCS transport and storage network configuration"**. The CRTF recommended that this be delivered through industry-led but government supported studies to **identify options for developing configurations for the UK CCS transport and storage system for both early CCS projects and future CCS projects**, in order to minimise long-run costs. Further, the CRTF recommended that this work take into account **likely future development of CO_2 storage hubs and the related pipeline networks**.

The target audience for this report is UK policy makers wishing to incentivise delivery of future UK CCS projects to deliver the cost reductions identified in the CRTF report and thereby accelerate CCS commercialisation.

There is a fundamental market failure in the development of early CO_2 infrastructure investments for CCS because:

- on the one hand, HMG is seeking confidence that cost reductions will materialize to make CCS affordable before setting long term policy, while
- on the other hand, industry is seeking policy clarity before committing to follow-on projects.

This market failure caused by CO_2 policy uncertainty is a key justification for allowing State Aid in the form of support for early investment in CCS transport and storage infrastructure before demand for full utilization emerges.

Cross-industry thinking, together with UK Government learning from its CCS experiences, anticipates 3 phases to CCS evolution:

a) First-of-a-Kind Commercialisation Programme phase (Phase 1) - with material government support to incentivise industry to participate and invest. This is the phase we are in now with EEPR, NER300 and UK Commercialisation Programme projects;
b) Transition phase (Phase 2) – possibly building on the infrastructure of the phase 1 projects, but still deploying first-of-a-kind capture technologies and developing new storage capacity;
c) Fully Commercial phase (Phase 3) – when CCS costs have been driven down to be competitive with other low carbon technologies.

The means of developing an effective network, which is optimised to produce the best value for money spent on CCS, will vary across these three phases.

It is essential that credible storage sites are appraised in advance, in order to give investors confidence to develop an end-to-end project chain. This is the only means of starting the development of a storage cluster or hub that serves a power generating plant.

In Phase 2, the emphasis will turn to new part chain generating projects joining the existing network, and to the development of additional storage close to the initial site, to provide expansion capacity, operational security and back up capacity at lowest cost. It is a pre-requisite that transportation installed for the first project in a network has been right-sized to accommodate follow-on CO_2 throughput expansion.

In Phase 3 it is likely that new storage sites, pipes and generating plant will be attached to the developed networks almost independently.

The focus for this report is how best to ensure optimal CO_2 transport and storage network configuration to accelerate CCS the industry beyond the first Commercialisation Programme projects towards a Fully Commercial phase. It is therefore focused on activities in Phases 1 / 2.

The **2 key levers** identified in the CRTF report for cost reduction through network optimization are (a) **achieving economy of scale through development of clusters** and (b) **reduction of financing risk premia** (some of which are associated with transport and storage networks).

It is assumed that the Commercialisation Programme projects in the UK will succeed in establishing the first 2 trunk-line routes and stores (Humberside to the Bunter Formation in the Southern North Sea; and NE Scotland to the Captain Formation in the Central North Sea). Both stores and their associated pipelines have the scope and potential to be developed into CO_2 Clusters.

It is anticipated that acceleration of CCS and realisation of cluster cost benefits will be best achieved by promoting follow on projects tied to the Commercialisation Programme projects. However, it is also possible that a further new end-to-end project could be developed prior to building out from the Commercialisation Programme projects.

This report addresses 3 key areas of focus for new work to inform policymakers on how to ensure optimal UK CCS transport and storage network configuration:-

a. "Optimisation of new network infrastructure" – to inform what is needed to create a new network, which will help inform whether to build-out from the first two trunk-lines / storage sites rather than to start afresh with a new trunk-line/ storage site;
b. "Network business models";
c. "Addition of new projects to existing infrastructure" – to inform how to further develop and optimize a network cluster.

This report draws on the experience from the Commercialisation Competition projects and insights from other industry studies and work groups. In addition, a list of existing analysis and knowledge relevant to CO_2 network design is collected in the Appendix as further context for policymakers.

The factors discussed under (1) are relevant to, and should be taken into account in, the development of the first two Commercialisation Programme projects to ensure that they are designed in a way that allows future cluster development.

The recommendations of this report should therefore be revisited once the key considerations in project contract and CFD negotiations have been worked through for the Commercialisation Competition projects. Industrial CO_2 can also be reviewed at this time, as the work at Teesside (Tees Valley Unlimited) will also have been completed within this timeframe.

2.1.1 Key messages and recommendations

The optimal approach to network development will vary as the industry matures. The emphasis needs to move from end-to-end projects in Phase 1 to coordinated development of new generation plant, pipes and storage sites in Phase 2; this could also include the use of industrial CO_2.

3 Optimisation of New Network Infrastructure

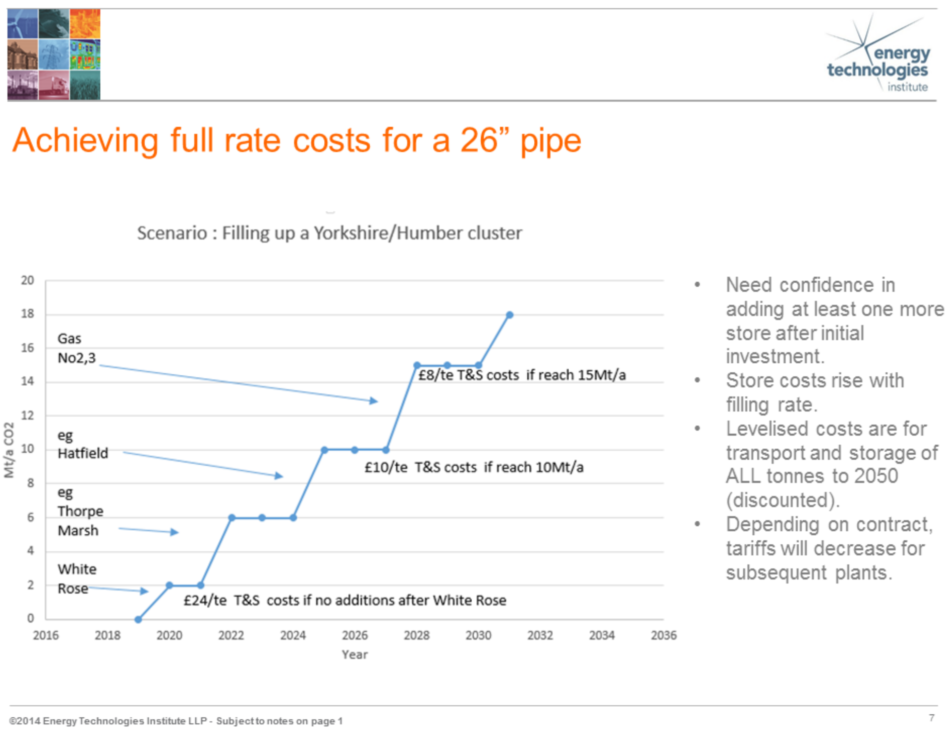
The unit cost of transporting CO_2 by pipeline decreases as scale increases. Both use and scale are important. The CRTF anticipates that transport costs could drop by more than £10-£15/ MWh for right-sized networks.

A well designed pipeline network and storage hub allows:

- new capture and storage sites to join the network over time;
- multiple storage sites to operate together; and
- operational switching between storage sites when necessary.

Reduction of risks to follow-on projects by building on an existing, well designed network rather than creating a new network, can lead to a reduction in the cost of capital and development time for subsequent projects, resulting in more affordable finance. In addition, if a network is developed with multiple storage types (namely depleted hydrocarbon reservoirs or new formations), the reliability of the storage will be increased, so lowering risks for developers in each element of the chain.

3.1 Sizing the trunk-line – big is best



The diagram above from a recent ETI presentation[1] clearly demonstrates the economic benefit of appropriate pre-investment in driving down unit costs for CO_2 transportation.

High pressure CO_2 transportation in pipelines, especially in networked clusters, is the best way to achieve significant cost savings through economy of scale.

Oversizing infrastructure to accommodate further industry expansion does increase the cost of the first project, which potentially conflicts with a perceived need to keep the investment in the initial

[1] "CCS Infrastructure Development Presentation at All Energy, May 2014 "

infrastructure down. However, the economies of scale achieved as further projects join the network reduce the unit cost dramatically. This, together with the reduction of risk and consenting time for follow on projects is fundamental to reducing the costs of CCS.

3.2 Identifying the start point – CO_2 capture prediction

Obtaining reliable information from potential future system users regarding the future capacity they may require is a major challenge for investors in shared infrastructure. Even in mature markets, reliable statements of demand for system capacity are, in practice, difficult to obtain from multiple users because of commercial sensitivity. One common method of alleviating this difficulty is for the system developer to share the risk of speculative investment in system capacity with potential future system users through joint investments or paying for options on future capacity use.

Predicted future volumes and locations of CO_2 to be captured from large, single point emissions (required for efficient gathering) depend on power policy in the UK, and on industrial policy both in the UK and in competing markets. These predictions depend on the clarity and consistency of long-term policy, and on the confidence of generators and industrial investors when taking financial investment decisions to capture CO_2.

There is significant political risk to CO_2 supply volumes for transport investors. The introduction of Contracts for Difference (CFDs) under the Electricity Market Reform (EMR) process provides some long-term revenue certainty, for individual power generators (see 4.1). However, it does not overcome the investment issues for the transport and storage parts of the chain and does not incentivise networks (see 4.2). Nor does it incentivise capture by industrial emitters.

Similarly, the location of future CO_2 supply is subject to political risk. The fundamentals that drove the original placement of existing power and industrial plant create some inertia and confidence in continuity but the concentrations of large, single point CO_2 emissions today may not be in the same place tomorrow. Shifts in population and changes in fuel feedstock, both of which can be significantly influenced by government policy, tend to be slow but the economic lifespan of a CCS project is long (and will be longer still for a cluster). The lead-time between concept origination and first income can easily be 10 years which is at the upper limit of the market look-ahead for UK power and gas grid planning, let alone the subsequent revenue generating operations period.

3.3 Identifying the end point – firm up anchor storage first

Development of a large store or a portfolio of nearby smaller stores is necessary to provide confidence that permanent CO_2 storage capacity exists for the life of a pipeline. The availability of stores can change with time (as depleted gas fields become available, stores fill up, and performance evolves during their lifetime) leading to the need for development of new storage sites. The location of early potential storage clusters is well known[2] (stores are immovable) but they are subject to performance (injectivity, seal integrity, dynamic capacity) risk and their effectiveness needs appraising.

Sound appraisal of a large store is essential to underpin investor confidence in picking the best exit point for a pipeline. A portfolio of stores could mitigate store appraisal risk - but at a cost. A nearby back-up store (preferably with different risk characteristics from the first store) may be necessary to provide confidence that a store will be available when required.

Storage Cluster Selection

- The vast majority of pore space is in saline formations although depleted hydrocarbon fields will contribute to the CO_2 storage portfolio - structures suitable for storage in saline formations can be larger than hydrocarbon fields and there are more of them accessible in the near term as the majority of UK hydrocarbon fields are still producing.

- Depleted hydrocarbon fields and saline formations have contrasting risks affecting their suitability for CO_2 storage. The capacity and injectivity of depleted hydrocarbon fields is relatively well understood from production history but the presence of multiple well-bores poses an integrity risk. Saline formation storage is subject to geological uncertainty that can affect understanding of capacity and injectivity through to the end of a store's life. Uncertainty over saline formation store integrity is greatest at the start of injection while the seal is tested. The actual integrity risk of both store types will increase with injection as pressure is increased.

- The costs of appraising storage sites vary with structural, stratigraphic and geological complexity, as well as with legacy infrastructure. Generally, large saline formations benefit from economies of scale, optionality over injection locations, and upside expansion potential from initial development. Depleted hydrocarbon fields may suffer from the need to undertake assurance of a large number of well penetrations

- Attractive stores can suffer spatial conflicts with neighbouring / overlapping developments that can inhibit their development.

The cost, time, skills and experience required to appraise storage for CCS are similar to those required for hydrocarbon field exploration and appraisal and would be straightforward for those involved in the oil and gas industry. However, due to more attractive opportunities in their existing industry and the

[2] A Picture of CO_2 Storage in the UK (Gammer, 2013)

market failures associated with CCS (see 5.1), those companies with the relevant experience are generally not interested in pursuing CO_2 storage today.

3.4 Key messages and recommendations

Development of infrastructure sized to realise economy of scale is a key early cost driver for CCS

Clarity of long-term policy that drives the location and volume of CO_2 captured (including from industrial sources) is critical to delivering economy of scale

Early appraisal of large storage capacity, in a manner that mitigates risk and provides upside beyond the appraised region, is essential to underpin investor confidence in developing new trunk-lines and building confidence of emitters to invest in follow-on capture projects.

4 Completing the commercial chain – getting to a positive FID

4.1 Gaining revenue certainty

Confidence in a future revenue stream is essential to justify transport and storage investment. There are three fundamental questions that need to be addressed in gauging the confidence to invest in transport and storage, the first two of which are entirely dependent on political risk:

- Will the flow of CO_2 justify my infrastructure investment?
- Is there sufficient reward for abating CO_2 emissions to justify investment in the whole CCS chain?
- Will I be able to access a big enough share of the reward to compensate my investment and risk?

Confidence in the future availability of CO_2 is dependent on government energy policy and, in the case of industrial emissions, on industrial policy both in the UK and in competing economies. The level of reward for capturing, transporting and storing CO_2 is also dependent on government policy.

An energy policy accepted by industry as providing long-term consistency of direction would reduce this risk, with the double benefit of attracting industry participants and reducing the cost premium associated with this risk. Currently the incentive to decarbonise exists through the ETS and the Carbon Price Floor. The EU ETS is recognised as an inadequate driver of investment on its own because carbon prices are too low. While action is being taken to bolster the EU ETS as part of the EU's 2030 climate and energy package, the impact on carbon prices in the medium term remains uncertain. The UK government has implicitly recognised this problem by instituting its carbon price floor policy within the power sector, but even so delivering the expected trajectory of increases is subject to considerable political challenges. The emerging EMR regime that applies to CCS as well as other low carbon generation technologies (particularly nuclear and wind) anticipates awarding FiT CFDs under the LCF to provide long term revenue certainty for low carbon power generators. There are significant differences between the dynamics of nuclear, wind and CCS power generation, which requires a different treatment for CCS (see 4.2).

There is no corresponding instrument to reward investments in reducing industrial emissions of CO_2 as CfDs are only applicable to power generation. The work being undertaken on industrial CCS by Tees Valley Unlimited (under the Tees City Plan) needs to be considered when completed.

Finally, the policy instruments that do exist are designed for and targeted at and focus on the capture end of the CCS chain. Transporters (and storers) need line of sight to a revenue stream to recover their investment. Intra-chain agreements are needed to access an agreed share of the emitter's CfD income and to ensure that the chain is both physically and commercially complete. The projects in the Commercialisation Programme are currently exploring this relationship. Transfer of learning from these experiences will be critical to the success of follow on projects.

4.2 Making policy work for CO_2 transport and storage networks

The ETS might ultimately set a CO_2 price that will provide sufficient input to the CCS industry when the Fully Commercial phase (Phase 3) is reached, and the CfD mechanism (with or without the Carbon Price Floor) can provide the necessary operating revenue support in the meantime.

There are uncertainties about the development of CFDs for CCS that apply to all the technologies covered, as well as around the approach that will be taken in practice to judging the overall number and value of CFDs to be allocated to each technology. However, fundamental differences between CCS and the other technologies covered by CfDs means that modification to these policy instruments is needed to manage CCS through to the end of the Transition phase (Phase 2).

1) The nuclear and wind industries have received substantial government support in the past in progressing down the technology learning curve and establishing the critical mass and industry maturity necessary to enable a fully commercial model. The level of any CfD for CCS will therefore need to reflect this 'catch up' support until the playing field is levelled.
2) CCS is exposed to fossil fuel price volatility (unlike the other CFD technologies) and any CfD for CCS needs to be designed to reflect this exposure. The use of fossil fuels for CCS power generation enables flexible generation, which is necessary to accommodate larger proportions of inflexible nuclear and interruptible renewables on the power grid. This ensures national security of supply levels at a systemically low decarbonised cost.
3) CCS is dependent on creation of a new industry (transport and storage) to complete the value chain in parallel with the addition of CO_2 capture to power generation. The nuclear industry also has a need for creation of a new industry to dispose of its waste but it has had the luxury of being able to rely on a temporary solution for very many years in the absence of that part of the value chain emerging. CCS needs to deliver the 'waste disposal' part of the value chain up front.

The first two distinctions mean that the levels of uncertainty for CCS around strike prices, reference prices and other aspects of risk allocation within the contract terms are appreciably higher than for other technologies. This is partly inevitable due to the lack of precedents for CCS compared with the other technologies. The terms agreed for projects in the DECC Commercialisation Programme should go some way to resolving this. Clarity of these terms is required to enable negotiations with follow-on projects to be progressed and in turn, inform predictions of the future network throughput.

The third distinction is particularly relevant because the majority of power generators (the principal counterparties for CFDs) are not used to creating new industries and are not sufficiently familiar with the different requirements of the transport and storage industries to ensure these are reflected in policy instruments. The key differences (described in more detail in 4.3 and 4.4) relate to the need for substantial earlier investment and financial cover for liabilities long after the power generation project has ended. On its own, a higher carbon price will not resolve all market uncertainties, and additional policy support is needed to incentivise the early investment that is required in trunk-lines and appraisal of stores to optimise networks. This could be in the form of capital grants.

4.3 Pre-investment in networks – the need for government support

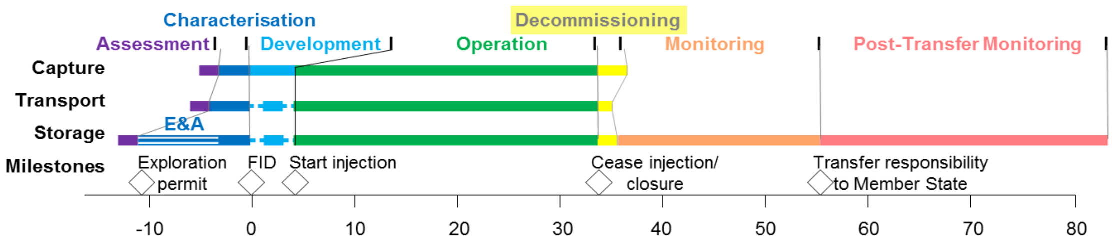
Realising the benefits of a networked cluster requires upfront investment in a trunk-line and associated infrastructure that is right-sized and appropriately routed for the future anticipated throughput.

Investment in additional pumping capacity and metering required for the ultimate throughput can be deferred provided provision is made for subsequent expansion (e.g. physical tie-ins). Detailed design parameters such as specification, pressure rating, isolation valve locations and routeing between exit and entry points will follow the practices for single user CO_2 pipelines.

There is currently no incentive to invest in pipeline capacity in a way that realizes economies of scale ahead of demand materialising. A cluster network investor will look for (i) assurance of payment to recompense capacity pre-investment (ii) assurance of storage capacity, and (iii) shorter payback than the full asset life. Agreeing CFDs upfront with multiple projects is unrealistic given the different levels of maturity that projects will have achieved. A capital grant to cover pre-investment in capacity may be required or a long-term contract guaranteed capacity based income to cover the cost.

4.4 Aligning investment decisions – the need for pre-investment in storage

The investment wavelengths and key development works for investors in capture, transport and storage are significantly different. The diagram reflects recent ZEP work on business models for commercial CO_2 transport and storage[3].



All investors in a CCS chain need to know prior to committing to investment that the other parts of the chain are technically, politically and commercially viable and that they will be operational for the duration required of each other's project.

Investors in generation and capture have direct access to the CfD mechanism, and would prefer to simply hand over CO_2 to the transporter at their boundary fence. This may be possible in a Fully Commercial market (Phase 3) but until that time, they will need to assure themselves that the required transport and storage will be available to complete their chain.

Transporters need confidence that both ends of the chain will be developed before they can progress their planning significantly and so are dependent on both capture and storage concept maturity before they can commence their detailed routing and consenting work. In addition, onshore pipelines require significantly more consenting effort and time than that required for a single location capture plant or an offshore transport and/ or storage development.

[3] ZEP: Business Models for Commercial CO_2 transport and storage (2014)

Storage operators face a disproportionate upfront exposure. Emitters expect stores to be appraised prior to engaging into serious negotiations. This requires investment in long lead-time exploration and appraisal (which is a large proportion of their overall project development costs and has significant geological risk) well ahead of any substantial investment by the rest of the chain. In addition, storage operators need to factor into their investment decision their exposure to liabilities for monitoring and remediation long after the rest of the chain has ceased operation. A recent ZeroGen report[4] concluded that the vast majority of their pre-feasibility cost was in storage appraisal and, given the geological risk associated with this, that it was not appropriate to enter into any level of engineering on the rest of the chain until the appraisal was complete (5-10 years).

Companies who have the skills to develop CO_2 storage currently lack a clear demand or price signal for their services. No potential storage operator is willing to make this upfront investment without significant support (as was available for Shell to appraise Goldeneye with DECC Demo Competition 1 funding; and for National Grid Carbon to appraise 5/42 with EEPR funding). A major deterrent to any potential storage investor is the potential liability ascribed to storage leakage; this will remain unacceptable if it is uncapped and at a level that is disproportionate to the value of any storage business.

4.5 Key messages and recommendations

HMG needs to confirm the extension of the Levy Control Framework (LCF) and specific allocation to CCS, and to establish a mechanism to give long-term revenue certainty for CCS from industrial emissions.

Contracts for Difference and LCF funding do not provide the necessary signals to incentivise investment in pre-FID storage appraisal or trunk-line future capacity that is required to deliver optimal networks in a timely manner.

There are insufficient investors currently pursuing opportunities in CO_2 storage to ensure that optimal networks will be developed.

HMG needs to set aside funding to (i) ensure stores will be appraised to underpin future capture development and the whole chain and (ii) to underpin pre-investment in right-sized trunk-line capacity, either as a capital grant or as a capacity payment mechanism.

HMG also needs to adopt a pragmatic interpretation of the requirement for financial securities to address storage leakage liabilities.

[4] CCS major project development lessons from the ZeroGen experience, University of Queensland (2014)

5 Network business Models

5.1 The case for intervention

Early investment in the development of CCS is affected by multiple market failures. Potential investors face high risks and uncertain rewards. Market failures are particularly strong for first movers who face greater uncertainty but little prospect of higher rewards to compensate: while potential followers push for favourable terms for themselves through TPA arrangement without having had to take upfront risks and limit scope for first movers to extract advantage.

Major market failures that affect the first end-to-end CCS full chain projects in Phase 1 include[5]:

- Carbon price, and long-term policy credibility – there is no clear price signal to drive investment in CCS, let along the transport and storage networks required. Indeed, there is no clarity within government or industry that policy will be put in place to incentivise CCS beyond the current Commercialisation Programme.
- Regulatory uncertainties – e.g. store leakage and post-closure liabilities under the CCS Directive; interactions with hydrocarbon interests; third party access (TPA rules have been put in place but not yet been tested). CO_2 transport and storage could have some natural monopoly characteristics and therefore carries the risk of future regulatory intervention. This is likely to affect investors' perceptions of the future returns available, particularly if policy is not clear or perceived to be punitive for upfront investors in assets.
- Knowledge transfer barriers – the application of state support to CCS comes with an obligation to transfer learning to enable and accelerate follow on projects. This is positive for establishing a CCS industry and should help in optimising networks, particularly with learning about business models and interactions of players along the CCS value chain. However, there is a risk for early movers that followers capture the benefits from the early mover investment in breaking down barriers, creating an incentive to be followers rather than early movers. A knowledge barrier also has the potential to limit access to assets that may be of value to developing a CCS network (e.g. disused pipelines and depleted gas fields) because there is no obligation on the current asset holders to make available data relevant to the assets.
- Counterparty risk - CCS requires a combination of skills and assets, which few individual companies have. This limits participants and choice of partners and counterparties. Those companies with the relevant experience are generally the major oil and gas companies that are not currently attracted to long-term investment in CCS, because of the significant perceived risks coupled with the limited prospects for reward.
- Industry structure risk - there is a general expectation that the CCS end-to-end chains will fragment over time, as is typical in maturing industries. This expectation can hinder optimising 'whole chain' returns as opposed to returns within each part of the chain.
- Cost uncertainty - compounded by a lack of clarity around the terms on which insurance or other risk mitigation is to be provided to CCS projects.

In the UK, Government policy has aimed to overcome these market failures for the first end-to-end "full chain" projects CCS in the Commercialisation Programme through the following:

[5] Options to Incentivise UK CO_2 Transport and Storage (Hare, 2013)

- FEED cost support (for Demo 1, EEPR and Commercialisation Programme projects)
- Providing capital grants;
- Providing CfDs;
- UK Government sharing in some risks specific to the novel CCS features of the projects.

However, these market failures will remain for follow on projects in Phase 2.

The development of multi-user CO_2 transportation and storage networks (either from new or from end-to-end chains created in Phase 1 projects) adds other risks– namely higher investment, increased complexity in selecting trunk-line end-points and the need for a larger storage portfolio. The risks are further increased when considering a portfolio of capture projects that may not be mature at the time of the initial infrastructure investment decision. Networks may be expected to operate for longer than the original end-to-end projects, increasing the likelihood of policy changes over the longer-term investment lifetime.

In the absence of further intervention to address at least some of the market failures identified Phase 2 CCS network development will be inhibited. In this case, CCS is likely to develop only smaller point-to-point solutions in a relatively slow sequential fashion. There is a real risk that follow-on projects will not emerge, resulting in a hiatus extending into the 2020s and loss of early cost reduction benefit from economy of scale.

5.2 Business models for optimal network configuration

Work conducted recently (2014) by ZEP (the Zero Emission Platform) identified three categories of possible business model for development of T&S infrastructure.

1) **Liberalised Market** - The model underpinning current UK government CCS policy broadly follows some of the features of the "Liberalised Market" approach described by ZEP[6][2014]. This is based on development of Phase 2 CCS projects entirely by the private sector, with a CfD being awarded to the developer which includes remuneration for the transport and storage operator(s).
2) **Enabled Market** - "Enabled Market", a hybrid comprising state intervention in some parts of the market and managed competition elsewhere. This model involves a company acting as a regulated "Market Maker" with two key roles:
   a. To manage the development of primary infrastructure (trunk-lines and anchor storage sites), including making judgements on the need for pre-investment in trunk-line capacity and commissioning storage appraisal.
   b. To provide an aggregation service (e.g. with a 'store of last resort') to take all captured CO_2 (whenever it is delivered) and ensure corresponding storage is available, thus avoiding the time discontinuity between capture and storage development, reducing cluster development risk and enable early part-chain developments. The Market Maker would not necessarily own or control all the infrastructure, but would have control over sufficient assets to act as a "storer of last resort".
3) **Contractor to the State** - The final model described by ZEP is that of a "Contractor to the State". Under this model the private sector would be contracted by the state to deliver CO_2 transport

[6] Business Models for Commercial CO_2 transport and storage (2014)

and storage to companies capturing CO_2. Several variations of the model exist around ownership, investment and operatorship, but in all the models the state would have overall commercial control of the planning, development and operation of CCS storage and much of the transport infrastructure. This is the model adopted in the UK for Phase 1.

5.2.1 Liberalised Market in the UK context

Whilst no policy on Phase 2 yet exists, the implication so far is that no Government support or risk sharing other than a CfD would be available to Phase 2 projects. Transport and storage operator(s) would therefore be expected to carry all the risks associated with their developments, including any short and long-term storage liabilities that may arise, up to 20 years after the store has ceased operations. As a consequence appraisal of future storage, coordination of timing for investments, and the knock-on impact of performance problems in any part of the chain would all be issues to be managed by the private sector investors.

After Phase 1 projects develop their initial stores, the UK CCS Third Party Access (TPA) regulations require Transport & Storage operators with spare capacity to offer a Transport & Storage service to follow on projects, with the Secretary of State available as arbiter if commercial terms cannot be agreed between the parties.

The existing and potential markets failures in this model are listed in section 5.1. Whilst the transport and storage activities for the Phase 1 projects in the Commercialisation Programme are currently being developed by the private sector, it is not clear that private sector investors will be forthcoming for Phase 2 projects under the regime described above. It certainly appears from private sector interest expressed to date that there are insufficient investors currently pursuing opportunities in CO_2 storage or transport to ensure that optimal (or even any) networks will be developed.

5.2.2 Market Maker in the UK context

In the UK the "market making" period and model would be characterised by system-level management and government support. The functions of "market making" could be split from each other, and could also be sub-divided by regions / geography. So, for example, a Cluster Manager could be appointed to develop and operate an optimised regional network, or a national CCS management Board could be created, that would need to include all the relevant entities in the regions. Different variants are possible to operationalize the market making function, address market failures and investment risks, ensure system-level optimisation, and manage government support within an enduring framework for the duration of Phase 2.

The scale of a Cluster Manager(s) activity would be expected to shrink over time as the cluster matures (as has been the case for similar energy infrastructure industries). Ultimately, in a Fully Commercial CCS world (Phase 3) they will become unnecessary and a Liberalised Market model would apply.

Given the current perceived lack of interest by the private sector in developing storage for Phase 2 projects, it appears important that the UK government:

- address the specific market failures remaining in the "Liberalised Market" model which underpins current government policy, probably through further financial support and risk sharing; and
- consider implementing some form of the "Enabled Market" model including an approach to cluster management.

5.3 Key messages and recommendations

There are insufficient incentives to ensure that optimal networks will be developed.

UK government intervention is required to address the specific market failures remaining for investors in Phase 2 trunk-line and storage networks.

The UK government should consider implementing some form of "Enabled Market", including an approach to cluster management that optimises the development of Transport & Storage networks.

6 Adding a new project to a Network

6.1 The case for shared infrastructure

The lack of available CCS transport and storage infrastructure capacity on known terms is a major barrier to operators of large CO_2 emitting plants taking the decision to invest in CO_2 capture plant and installing CCS. The ability of follow-on projects (e.g. new store or new capture plant) to access some of the infrastructure established by the Phase 1 Commercialisation Programme projects is crucial to enable these projects to proceed, along with the CfDs, etc. Confidence in the availability and price of transportation and storage services would allow follow on CCS investment decisions to be made with confidence.

Disincentives against shared use include the associated increase in technical and commercial complexities; the potential increase in operational constraints; and the risk of interference or interruption to one user's operations due to the actions or omissions of another user. All of these issues can be satisfactorily addressed by a shared-system operator through suitable contractual and technical frameworks.

6.2 Access considerations

6.2.1 TPA issues

Third Party Access (TPA) regulations allow for third parties to make an interest in the modification of a planned pipeline known to the Secretary of State (SoS) and ask for a determination to change the pipeline design.

It is helpful to distinguish first-comers or 'Anchor Tenants' (those committed to paying for capacity at the original FID) from 'Follow-on Users' that expect to commit to system capacity after the point at which the project is commercially viable. The Anchor Tenant's commitment to procure initial system capacity, and the terms of that commitment, will need to be sufficient for the system developer to take the decision to develop the system. Without any form of further coordination or incentive it is then possible that a system with only the capacity required by the Anchor Tenant could tenably be developed. The opportunity to provide capacity required by Follow-on Users, with the attendant economies of scale may then be missed.

It is important that the possibilities for sharing all infrastructure investments are considered before contractual terms are agreed before a FID for the initial investment. If the system is not designed to be shared from the outset, subsequent introduction of a new entrant could lead to major challenges in future expansion, and in imposing new cost and liability sharing models on to the Anchor Tenant.

While accommodating third parties is aligned with achieving the benefits of a network cluster, managing the timing of any such determination is critical to ensuring the speed of optimal network development.

The acquisition of consents for new transportation and storage infrastructure requires lengthy design studies and application procedures to be carried out. A material alteration will necessitate a reworking of design studies and a full or partial re-application (for a new build pipeline). Amendments to a system's design capacity, brought about by the introduction of an additional user part-way through the consent application process, has the potential to delay the relevant development project, increase consenting costs and, in some circumstances, lead to the potential refusal of consents that would otherwise be granted.

A cut off time is required for TPA applications that do not lead to repetition of expensive and lengthy design and consenting work. The recommendation for government support for pre-investment in initial trunk-line capacity, should help in determinations of whether third party projects are sufficiently mature to warrant such a determination.

The question of whether system capacity can be acquired by parties that do not intend to make direct physical use of the system is a potential issue. Some system users may wish to sub-let capacity to future system users at a profit. The UK's CCS legal framework suggests capacity in CCS infrastructure should be freely tradable which presumably includes 'non-physical investors'. The key issue for the system operator is that investors making applications to the SoS are held fully financially accountable for the cost to the system of any repercussions. It will be for the regulator to decide what rules, if any, are required to manage monopolistic behaviours

TPA regulations also apply to storage. Any consideration of changes to trunk-line design or inclusion of follow-on third party volumes must include an updated assessment of the capacity of the storage site. Given the geological and dynamic uncertainties regarding storage capacity, the understanding of capacity will vary through the life of a store. A standard is required for defining the capacity which can reasonably be made available and therefore assigned under contract (together with liabilities).

6.3 Customer charging mechanisms

The system developer will incur expenditure in developing, owning and operating a shared infrastructure system and will want to recover this expenditure, plus a reasonable level of return, via a combination of fees, charges and capital contributions.

6.3.1 Costs

The costs of developing, operating and decommissioning CO_2 transportation and storage infrastructure fall into a number of categories - capital expenditure, fixed and variable operational expenditure, financial security provision, post-closure obligations, and decommissioning.

In addition, when adding a new user to a system, there is a need for a connection charge to allow the system operator to recover, with a reasonable rate of return, any additional costs incurred in performing connection works, including the present value of any additional decommissioning.

If the capacity demands of further system users exceeded the capacity of the initial storage site and led to a requirement for a second separate storage site, then the incremental costs associated with the development of that site and its connection to the wider system would produce a further step change in the cost

6.3.2 Allocation of costs

In any scenario where two or more parties were to procure capacity in a shared system, a question would arise as to how the costs and liabilities of developing, operating and decommissioning the shared system should be distributed amongst the system users.

A central issue regarding the distribution of the costs between Anchor Tenants and Follow-on Users is whether that part of the costs for the initial system capacity should be borne entirely by the Anchor Tenant alone or shared with the Follow-on Users, and how these might be shared. The marginal cost of providing additional system capacity is never zero but it can be significantly lower than the unit cost of the initial system capacity.

a) If the initial system capacity costs were to be borne entirely by the Anchor Tenant then this would allow Follow-on Users to purchase incremental system capacity at the true incremental cost of that capacity which would be significantly lower than the cost allocated to the Anchor Tenant. This would mean that system capacity would be far more attractive to late entrants which may enable less economic projects, drive costs down, and accelerate CCS deployment through optimal utilisation of the infrastructure. However, this could create a distortion in the energy market as competing power generators with CCS would be paying significantly different prices for their transportation and storage system. In addition, it would not reflect the additional risk taken by early entrants in developing the original infrastructure.
b) An alternative methodology would be to share the system costs between all system users in proportion to the system capacity they own. This would remove the 'early-mover' disincentive and should incentivise early movers to actively encourage additional parties to acquire system capacity. However, this methodology would not allow projects to make use of the lower incremental cost of additional capacity, which may prevent the development of some projects.
c) Competition Law must also be borne in mind when designing a mechanism to set charges for access to infrastructure, the use of which has the potential to significantly affect the price of the energy produced by its users and therefore the markets for those products. Methodology (a) could distort competition if applied too early in an industry's evolution, but could work well in a mature market, once the high cost of the initial underlying investment has been depreciated, diluted or removed from the Anchor Tenants in some other way. Methodology (b) may be required in the earlier stages of market evolution.

If the high cost of the initial underlying investment is diluted in some way through some form of State support, then care needs to be taken of any State Aid considerations. Either cost allocation methodology could be considered to lead to cross-subsidy by a State supported project of a new project for which State Aid has not been approved.

6.3.3 Allocation of liabilities

The creation of a shared system, by the addition of follow-on projects to the anchor project upon which initial investment was based, will increase some risks and liabilities for all users, while reducing others. For example, each user will be exposed to the risk that the other user(s) will introduce off-spec CO_2 which could have a consequence for pipeline or well corrosion. Similarly, the increased injection into a shared store could increase the liability, should the store leak. In the same way as with allocation of costs, the allocation of liabilities between users can be handled on an incremental or a shared basis. The solution should mirror that for cost allocation. So if the new entrant only bears the incremental cost, the he should bear the incremental risk impact that is held by users (as opposed to the system operator). If the costs are shared between users (at least for Phase 1 and the start of Phase 2), then the users should also share the liabilities.

6.4 Regulation - and over-regulation

The TPA regulations for CCS now in place in the UK are borne out of the EU CCS Directive, and out of experience and practice in other industries, especially the oil, gas and chemical industries, for governing common use of providing fair and open access to infrastructure.

Perversely, these regulations, which are intended to facilitate sharing, create economies of scale and create value for money by reducing costs, can have the opposite effect. This is a particular risk when regulation is developed in the abstract, in anticipation of conceptually possible problems rather than problems that are likely to occur.

This concern applies both to the TPA regulations, and regulation of CO_2 storage.

Regulators need to actively and consciously apply a fit-for-purpose approach in applying such regulation.

6.5 Key messages and recommendations

There is a series of issues in Third Party Access regulation (TPA) and customer charging mechanisms (including allocation of costs and liabilities) that remain unclear and need clarification before any developments for Phase 2 projects can proceed.

There is a risk of over-regulation restricting the development of optimal networks because regulations have been developed and applied to CCS in Europe in anticipation of issues rather than in response to issues. Regulators need to apply a fit-for-purpose approach in applying such regulation – including on the regulation ofCO_2 storage.

The Secretary of State needs to take a pragmatic approach to determinations of TPA rights to ensure that networks are tailored to accommodate high-likelihood follow-on projects, but are not delayed or made inefficient by speculative applications for TPA from low-likelihood projects

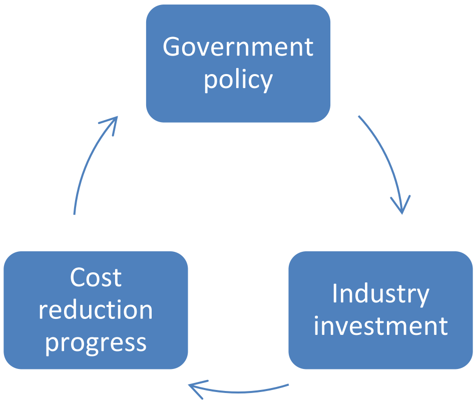
As part of any initial system design with State support, developers and Government need clarity of any State Aid considerations for a charging mechanism for a future shared system.

Early agreement and sharing of commercial terms for the Phase 1 Competition projects will enable follow-on projects to progress.

7 Awarding government support

7.1 The need for government support

There is a cycle of interdependence that governs the maturation of CCS technology to fit in its rightful place in the energy mix.



Government is looking for confidence that CCS will be affordable before it enacts policy-supporting CCS. This confidence is primarily dependent on the belief that costs will decline. Evidence of progress in cost reduction is dependent on industry investing which is in turn dependent on industry confidence in government policy. Positive interventions, both by government and industry, are required to ensure this is a virtuous rather than vicious cycle. Given the importance of policy clarity when faced with market failures (see 5.1), industry expects government to make the first interventions, while government expects industry to respond positively.

Government expects to limit the current ‘one at a time’ development of CCS end-to-end chains (which is costly, time consuming and fails to realise economies of scale) and rely on a generic CFD to stimulate investment. This approach will require additional government interventions to ensure optimal CO_2 network development. Current candidates for such interventions in the UK include:

- Providing financial support for appraisal of further storage, including expansion of the first two sites;
- Providing capital grants or capacity payment guarantees to underpin pre-investment in right sized trunk-lines;
- Identifying target geographies for network creation; and
- Creating a business model to attract organisations (e.g. Cluster Managers) to manage network design and development.

The cost of the first two interventions is expected to be in the range of £100m each. In terms of size, these appear considerably more manageable investment decisions when set alongside the primary policy instrument, namely the award of CFDs under the LCF which are expected to require several billions of pounds Sterling.

7.2 Ensuring effective government spend

Government needs to be assured that its support is deployed efficiently. To date, it has pursued procurement competitions to award support to competing end-to-end projects as its model for efficient funding support. However, this process for disbursement of CCS-specific incentives has been ineffective to date. The limitations resulting from State Aid and Procurement legislation, better suited to a more mature industry, have impacted the effectiveness of this approach and significant amounts of public and industry money have been deployed without a project yet progressing. This has introduced delay to the introduction of CCS, and drawn down goodwill from rejected developers.

7.3 Attracting investors

Two key changes to the current approach are needed to attract investors with the required characteristics to invest in and operate CO_2 networks:

- HMG must provide greater clarity of its policy direction in order to give bidders confidence that they are not pursuing nugatory work

  Specifically, HMG must demonstrate its commitment to award funds and to progress CCS at scale, and at pace, in order to give bidders confidence that they will secure a material business opportunity if successful

- HMG must offer acceptable terms and conditions designed to attract investors to develop early CCS projects. Emphasis can be placed on testing the investors' acceptance of increasingly commercial contractual terms once initial projects have progressed.

  Specifically, to incentivise optimised CO_2 network investment, HMG and industry should clarify where they wish to see networks developed and define an enduring transitional (Phase 2) framework to attract organisations to manage network development. The ZEP work provides options and guidance for such models (see section 5.2).

7.4 Key messages and recommendations

Government support is needed to help CCS through the transition phase, in addition to that which will be provided to the first 2 commercialisation projects and through the creation of a generic CFD with LCF extension. This support, in acceptably sized packages, needs to include:

- Pre-FID investment in storage appraisal
- Investment in pipeline right-sizing for future shared use
- An affordable interpretation of the requirement for financial support for storage liabilities
- Risk sharing (albeit at a reduced level) for follow-on projects until industry perception of risk is reduced to yield an acceptable risk-premium
- Appointment of a central-planning Board to oversee identification of target network geographies and cluster development and management.

HMG's approach to awarding this support needs to be more efficient than the competitive processes employed to date and to focus more the creation of value from the intervention and less on measuring the cost.

HMG must provide greater clarity of its policy direction in order to give bidders confidence that they are not pursuing nugatory work. Specifically, HMG must demonstrate its commitment to award funds and to progress CCS at scale, and at pace, in order to give bidders confidence that they will secure a material business opportunity if successful.

Optimising CO_2 networks to reduce CCS costs

Early investment in transport and storage infrastructure is essential to enable CCS projects. It also provides a strong policy signal and opportunities to attract new entrants.

8 APPENDIX – CO_2 specific design factors

This appendix provides a compendium of additional existing relevant knowledge for policymakers to draw on as required.

8.1 Pipeline Routeing

The routeing of a CO_2 pipeline (offshore or onshore) is predominantly 'business as usual' for high-pressure pipeline operators. National Grid's work programme for the Yorkshire and Humber CCS Project[7] addresses two "CO_2 specific" matters for onshore CO_2 pipeline routing. These relate to (i) the need case for the infrastructure (linked to UK government policies) and (ii) consideration for venting of CO_2 during the operation of the pipeline and associated infrastructure.

Separation distances for large-scale CO_2 transportation pipelines was not addressed historically in PD8010 (the code of practice for pipelines in the UK) and attention has been paid to this since the first full scale CCS project considered in the UK (the BP-SSE Peterhead – Miller project). The general conclusion of this work is that (i) it is appropriate to apply the 'individual risk' approach adopted for natural gas pipelines to gaseous phase CO_2 pipelines; and (ii) the risk levels around dense phase CO_2 pipelines are likely to be low because of the thick walls. However, it is most appropriate to apply the 'societal risk evaluation' approach to dense phase pipelines because the maximum hazard distances could be considerably larger[8]. An update to the PD8010 code of practice, which accepts this conclusion, is currently in draft form.

8.2 CO_2 specification

The system operator will specify a fluid composition specification with which the users will have to comply for their CO_2 to be accepted. A pipeline can be designed to transport a wide range of different CO_2 rich mixtures. However, there is a cost penalty associated with transporting higher concentrations of impurities because an increase in impurities increases the susceptibility of (dense phase) CO_2 pipelines to the propagation of running ductile fractures. An economic trade off calculation is required to balance the increased cost of conditioning CO_2 against the increased pipeline wall thickness. The COOLTRANS Project[9] has allowed the relationship between impurities and required pipe thickness to be established, which in turn allows the CO_2 entry specification to be defined.

In addition, an increase in certain impurities decreases the solubility of water in CO_2 and hence can lead to free water in the pipeline and increased risk of corrosion[10]. The University of Nottingham is undertaking a programme with UK CCS Research Council funding (UKCCSRC) to examine the impact of impurities on water solubility. In the meantime, pipeline designers are taking a very conservative water content specification to ensure a dry pipeline. It is possible that higher water content levels can be accommodated in the future when the impact of impurities is better understood.

Co-ordination of CO_2 entry specifications between networks may be required in future to enable networks to join up.

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[7] Yorkshire & Humber CCS Project Consultation Website (National Grid Carbon Ltd, 2011)
[8] The Application of Individual and Societal Risk Assessment to CO_2 Pipelines (Cleaver, 2012)
[9] The Saturation Pressure and Design of Dense-Phase CO_2 Pipelines (Cosham, Dr Andrew (Atkins), 2012),
[10] Towards a CO_2 Pipeline Specification: Defining Tolerance Limits for Impurities (Race, 2012)

8.3 Pigging

CO_2 pipelines will be designed to transport dry CO_2. Velocities in the pipeline are expected to be low initially (assuming pre-investment to optimise network design) and there may be a requirement for pigging in order to prevent any liquids settling in the line in case liquids (water, diesel, etc.) are carried over into the pipeline. The National Grid and Shell designs for the Longannet to Goldeneye CCS project[11] included permanent pigging facilities at both ends of both the onshore and offshore pipelines, for use during commissioning, subsequent pigging and inspection runs. A baseline intelligent pig run is expected to be performed before commissioning the pipelines for CO_2 operations.

8.4 Metering into storage

Payment under CfDs for generation of clean electricity from CCS requires that the associated CO_2 is stored permanently. Injection of CO_2 into a pipeline system that is dedicated to the transport of CO_2 to storage is the first step in permanent CO_2 storage. Barring an accident the CO_2 in the pipeline will enter permanent storage.

There is disagreement between industry and government on:

- whether the CO_2 line-fill can be recognised as CO_2 being passed into storage;
- the location of the metering point used for triggering CfD payments.

It is important for the development of the CCS industry that it is recognised and agreed that for CfD purposes both the pipeline system and the store are recognised as permanent storage and that CO_2 passing into the trunk-line system does trigger payment under the CfD.

8.5 Key messages and recommendations

There are no real technical issues that cannot be resolved by an industry that is incentivised to invest in the future of CCS

[11] National Grid and Shell Pipeline FEED Studies (Scottish Power CCS Consortium, 2010)

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10 UK Transport and Storage development group

The Steering group members are:

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