Programme Area: Carbon Capture and Storage

Project: UKSAP Database Analysis

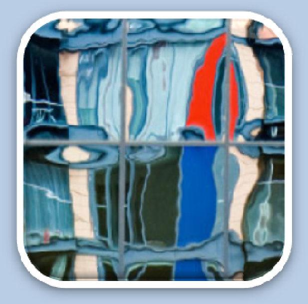
Title: Business and Regulatory Models for offshore CO2 transport and storage in the late 2020s and beyond - WP9 Final Report

Abstract:

This report sets out the outcome of a high level review of the business and regulatory framework for the development of offshore CO2 transport and storage infrastructure and services, to facilitate full development of the UK potential of CCS. It explores learnings from modelling of offshore networks, and from experience in analogous industries. It considers the market failures that will need to addressed and assesses a number of potential market and regulatory models. This forms the output from an extension to the UKSAP database analysis project and is intended to inform members strategic understanding and thinking around the development of a viable market framework for CO2 transport and storage in the period to 2030.

Context:

This project was part of the development of the UK's first carbon dioxide storage appraisal database enabling more informed decisions on the economics of CO2 storage opportunities. It was delivered by a consortium of partners from across academia and industry - LR Senergy Limited, BGS, the Scottish Centre for Carbon Storage (University of Edinburgh, Heriot-Watt University), Durham University, GeoPressure Technology Ltd, Geospatial Research Ltd, Imperial College London, RPS Energy and Element Energy Ltd. The outputs were licensed to The Crown Estate and the British Geological Survey (BGS) who have hosted and further developed an online database of mapped UK offshore carbon dioxide storage capacity. This is publically available under the name CO2 Stored. It can be accessed via www.co2stored.co.uk.



Business and Regulatory Models for offshore CO_2 transport and storage in the late 2020s and beyond

WP9 Final Report

For
George Day
Energy Technologies Institute

20th December 2012

Harsh Pershad
Element Energy Limited

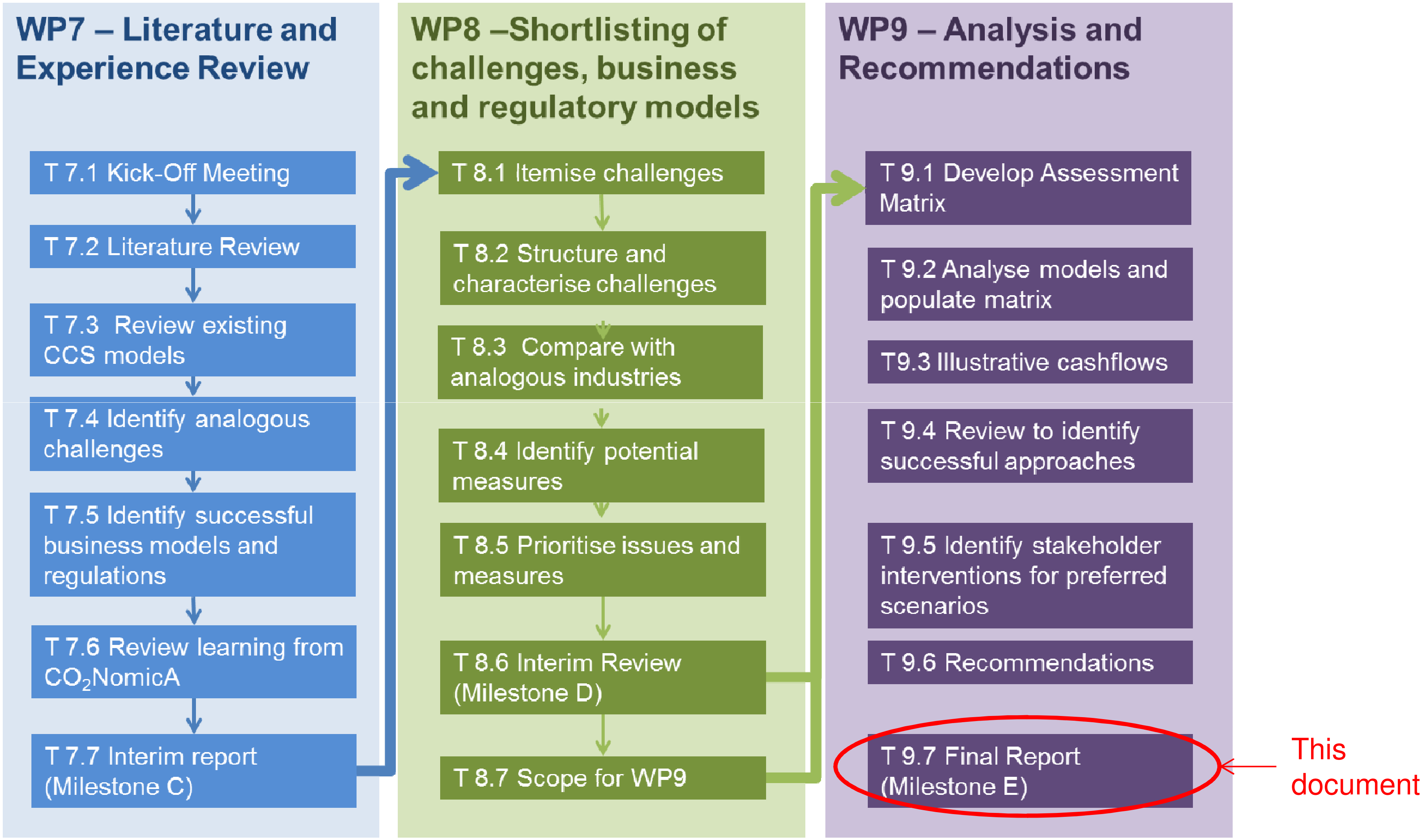
elementenergy

This report assesses business and regulatory models for delivering the offshore CO_2 pipeline and storage infrastructure that may be required for the UK in the late 2020s and beyond.

In August 2012, ETI commissioned Element Energy to provide desk-based Consultancy support to include:

- ❑ A high level review of UK and international knowledge, views and experience of business and regulatory models relevant for offshore CO_2 pipelines and CO_2 storage.
- ❑ A high level review of learning derived through the initial testing and application of the economic model developed for this project ("CO_2NomicA") to offshore transport and storage networks in the UKCS.
- ❑ A high level description of market failures, possible interventions and types of regulations/organisations/models that could develop CO_2 transport and storage. This will build on knowledge from existing studies, consider analogies from other sectors, and an understanding of existing legislation and regulations.
- ❑ High level analysis of alternative frameworks and business models, identifying any gaps and issues for further analysis and pathways for developing the appropriate frameworks.
- ❑ Analysis to focus on challenges and solutions for the late 2020s and the 2030s.
- ❑ This document constitutes "Deliverable E" and collates information from WP7-9.

Element Energy and ETI have worked closely together to identify the key challenges, review existing models for CCS and other industries, and assess approaches for delivering transport and storage infrastructure.



Key findings

- ESME modelling points to CCS having a very high value in the development of a decarbonised UK energy system. Full exploitation of this potential will require major investment in developing CO_2 transport and storage infrastructure, with a number of scenarios envisage capacities of 60 $MtCO_2$/yr or more by 2030.
- Given the lead times involved in developing CCS projects and proving storage, one pressing challenge is to bring forward sufficient 'bankable' storage capacity available ahead of investment decisions on generation, capture and transport. Action to stimulate or improve the environment for investment in storage appraisal and development should be prioritised, to keep open a trajectory for full exploitation of the value of CCS to the UK energy system in the 2020s.
- The capacity would most efficiently be developed through shared CO_2 transport and storage facilities. However, the current market environment for investment in CO_2 transport and storage facilities is characterised by project-by-project based decision making, with multiple and significant market failures and risks for developers of infrastructure that could meet future capacity requirements.
- Based on analogies with other UK industries and elsewhere, a wide range of market and regulatory solutions, with varied roles for public and private sectors, are potentially feasible to resolve remaining market failures. Further evidence should be gathered, and analysis carried out, to evaluate fully the best models for developing the UK CCS industry.

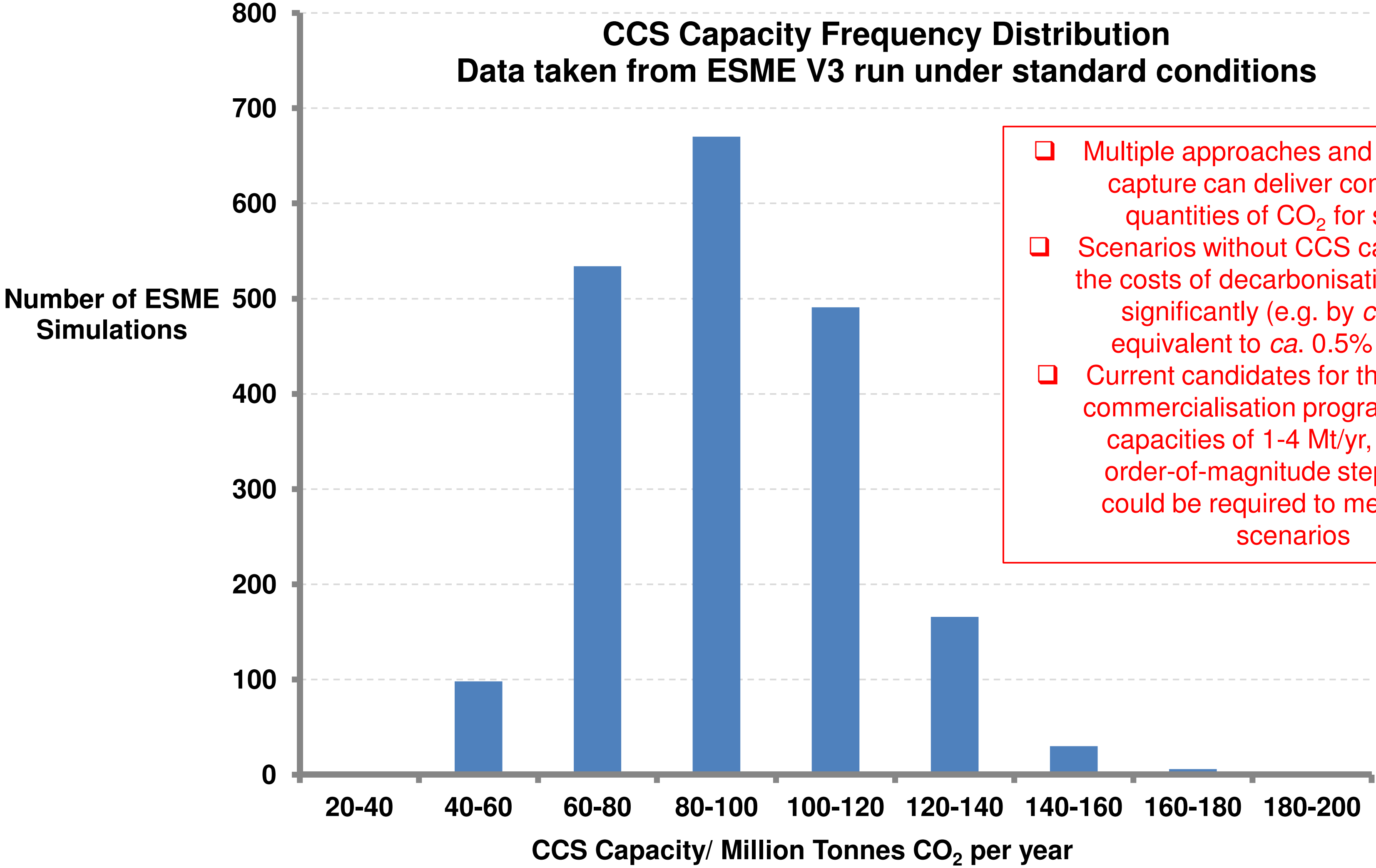
Outline

- The need for CO_2 transport and storage in 2030
- The challenge in delivering efficient CO_2 transport and storage infrastructure
- Options for delivering major infrastructure
- Measures for delivering CO_2 transport and storage infrastructure
- High-level assessment of measures
- Illustrative roles and responsibilities
- Opportunities for further ETI activities
- Appendix

ESME modelling indicates significant need, but assumes that CO_2 transport and storage infrastructure are available when and where required.

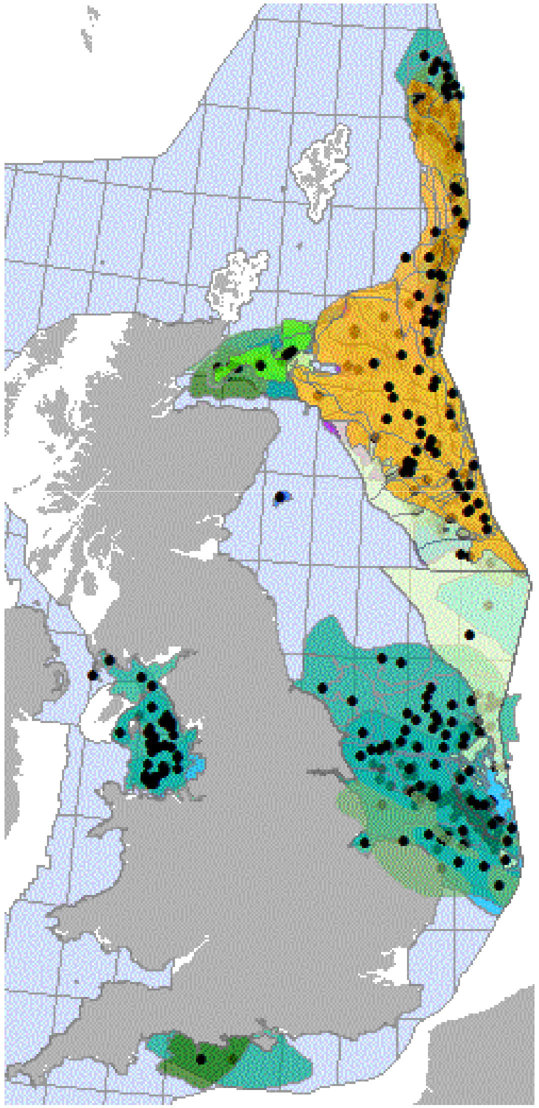
- Energy system modelling, inevitably relying on numerous assumptions, suggests that "efficient" CCS deployment could be *ca.* 100 $MtCO_2$/yr from the 2030s, to meet the UK's legally binding 80% CO_2 reduction target for 2050.
- However there is at least a two order-of-magnitude uncertainty over the actual amount of CO_2 storage capacity required.
- If CCS development is slow, or more difficult /expensive than alternative decarbonisation pathways, or if the target is reduced, clearly CCS capacity could be much smaller.
- Conversely, if alternative decarbonisation pathways are more difficult/expensive to implement, or if CCS development and cost reduction exceeds the model assumptions, the CCS capacity required could be considerably higher.
- To date energy system modelling assumes that CO_2 transport and storage infrastructure will be available when and where required.
- However, ETI's UKSAP reveals the storage is heterogeneously distributed, in storage units with different locations, capacities, geophysical properties, risks, costs, with huge differences in the quality of data and understanding available.
- Element Energy has built for ETI a tool for CO_2 Network Economic Analysis (CO_2NomicA) to evaluate potential investment profiles associated with given user-defined infrastructure designs.

95% of ESME simulations indicate a UK CO_2 transport and storage capacity of *at least* 60 Mt/yr in 2030 to meet the Climate Change Act requirements.



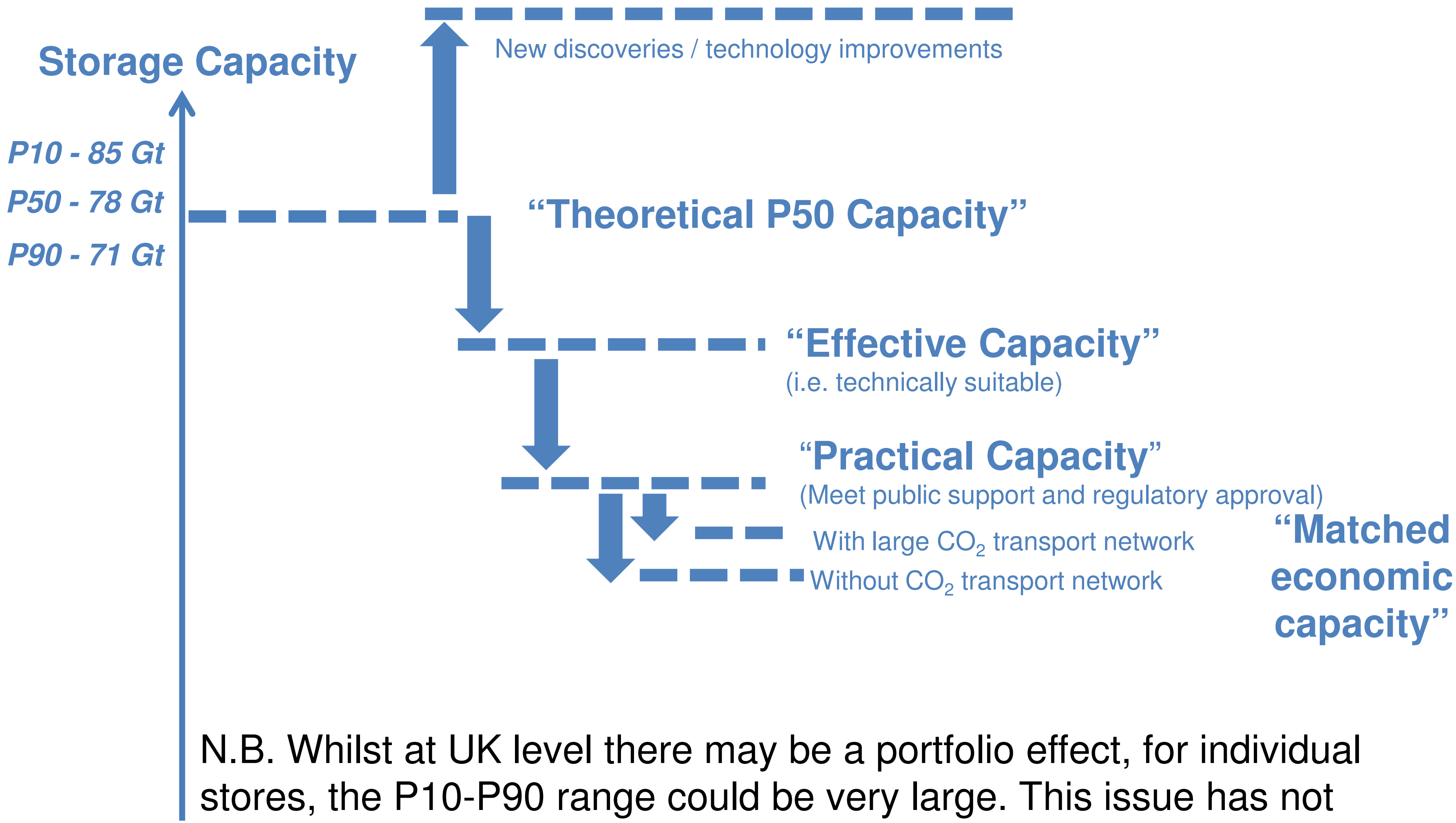
- Multiple approaches and sectors for capture can deliver comparable quantities of CO_2 for storage
- Scenarios without CCS can increase the costs of decarbonisation for 2050 significantly (e.g. by *ca*. 50%, equivalent to *ca*. 0.5% of GDP)
- Current candidates for the UK CCS commercialisation programme have capacities of 1-4 Mt/yr, so a *two* order-of-magnitude step change could be required to meet ESME scenarios

UKSAP shows storage distribution is complex and heterogeneous



- Nearly 600 potential storage units identified with P50 capacity over 70 Gt.
- Performance will be site specific but the types of storage are diverse and little information is available for many of them to predict performance reliably.
- Wide range of predicted well requirements and reservoir risks identified - realistic chance that many units will not actually be suitable on deep analysis.
- Storage is clustered. Most of the theoretical capacity in the Southern North Sea, Central North Sea and Northern North Sea, implying transport system will be an issue.
- Wide range of unit size and shape. Many aquifers are very much larger than traditional oil and gas fields. Some units are expected to be vertically stacked, although this has yet to be quantified and the implications assessed in depth.
- CO_2 storage costs can be estimated by understanding the requirements for appraisal, platforms, wells, pipelines etc. for which there are oil and gas analogues.
- Range of storage costs spans three orders of magnitude, depending on reservoir conditions, how the reservoir is developed, utilisation, financing, and prevailing market/regulatory conditions.
- Similar findings observed in GeoCapacities, a Europe-wide study

The matched economically accessible storage capacity may be significantly lower than the theoretical aggregate storage capacity identified in UKSAP upon detailed examination.



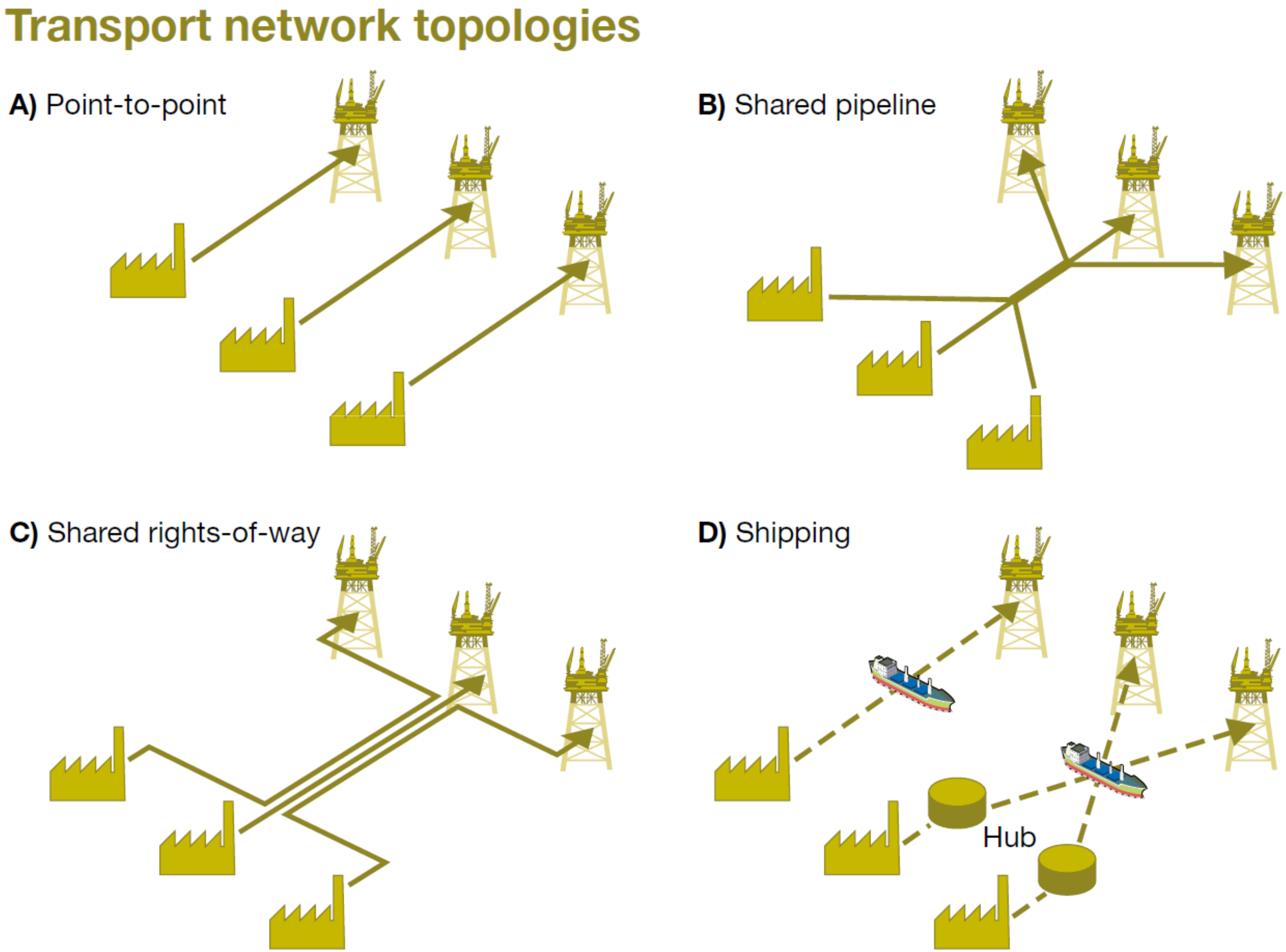
N.B. Whilst at UK level there may be a portfolio effect, for individual stores, the P10-P90 range could be very large. This issue has not been assessed in detail, and as CO_2 storage is relatively new, it is difficult to predict reliably today.

Key points from economic analysis of phased network development

Modelling of phased offshore transmission and storage networks identifies that, given perfect foresight,

- Small numbers of storage units (8-14) are most likely be able to deal with UK emissions for period up to 2050. May be necessary to appraise a larger number than actually used.
- Relatively simple offshore pipeline network topologies required - a mix of integrated pipelines and point-to-point pipelines.
- Below 10 Mt/yr there are very large economies of scale for sharing pipelines. Above this size, benefits from over-sized pipelines installed in 2020s are typically 10-20% of discounted costs in some scenarios, particularly for Yorkshire or Tees to distant Central North Sea sinks, but late arrival of higher CO_2 flows makes oversizing benefits marginal (esp. at industry discount rates).
- Net present cost of transport and storage configurations to meet ESME scenarios are in the range £5-10 billion up to 2050. ca. £2bn investment in 2020s in transmission pipeline; investment in storage grows gradually (potentially hundreds of injection wells although injection facilities can sometimes be shared).
- Wide range of individual network or system levelised costs for T&S between £4-£30/t+.
- Impacted by CO_2 supply, discount rate, choice of sink, requirements for appraisal, re-abandonment, wells, injection facilities, need for pressure boosting, re-use, EOR etc.
- NPV profile for overall T&S system is negative until 2030 in most scenarios – implying a huge investment challenge for transport only or storage only businesses.
- There are high stranded asset risks for poor infrastructure designs.

Multiple transport options are relevant for connecting UK sources with UKCS sinks, including new pipelines, re-used pipelines, shared pipelines and CO_2 shipping and hub concepts.



Element Energy *et al.* (2010) One North Sea

Each CO_2 transport solution has multiple advantages and disadvantages.

Topology	Advantages	Disadvantages
A point-to-point	• Low up-front capex • Does not require estimation of future demand • Does not require co-ordination between multiple stakeholders • Reduces risk of low pipeline utilisation	• Average cost per tonne across all networks is higher than with shared infrastructure. • Multiple pipelines across different routes means large planning hurdles and disruption to those affected. • No flexibility to accommodate additional sources at low cost. • Could be higher capex in long term.
B Shared pipeline	• Low transport cost when operating at full capacity. • Enables connection of marginal sources. Could attract new sources e.g. industry to the region. • Lower planning hurdles and disruption since multiple sources share one trunk pipeline.	• High initial cost. May require public sector funding initially. • Risk of low utilisation if demand is lower than forecast. • Requires common entry specifica-tion for CO_2. • Complex business models. • Requires higher up-front confidence in storage availability
C Shared rights of way	• Robust and flexible • Lower planning hurdles as new pipelines are built on shared rights of way. • Capacity matched to demand.	• Transport costs are higher than for shared pipelines with same throughput. • Does not significantly reduce costs for smaller, marginal sources.
D Shipping	• Lower upfront costs than pipelines. • Flexible in the event of sink failure CO_2 can be routed to other storage sites. • Suitable for projects where multiple, small sinks may be required, or where project lifetimes are small. • Capacity matched to demand	• Very high transport costs compared to mature pipelines. • Large number of ships required to meet high demand.

- It may be difficult for private CO_2 transport providers and their investors to capture all the system advantages and disadvantages from different investment strategies within their internal cost-benefit calculations.

Element Energy *et al.* (2010) One North Sea

Investments in shared CO_2 pipelines

- Analysis using CO_2NomicA of offshore North Sea CO_2 transport and storage networks required to deliver ESME scenarios of 100 Mt/yr highlights dramatic cost savings from shared pipeline and storage infrastructure relative to systems where each project has its own pipeline and store.
- The benefits of shared pipelines depend very much on discount rate, length of pipeline, capacity (i.e. diameter), and utilisation; they are most compelling when throughputs are below 10 Mt/yr, distances exceed 200 km, discount rates are below 5%, and if the pipeline is used at full capacity in early years.
- In contrast if the capacity is greater than 10 Mt/yr, offshore distances are below 100km, investors have a high cost of capital, and there is a risk that the pipeline will not achieve capacity for more than a decade, the benefits of a shared initially over-sized pipeline do not accrue to private investors but may be external e.g. in signalling intent, in reduced environmental disruption etc.
- At this stage of CCS technology development the system costs of meeting different CO_2 pipeline specifications (pressures, composition, temperature, flow-rate) is not well understood. There is a risk that pipeline CO_2 entry and exit specifications may unduly influence choices of CO_2 capture and storage.

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Summary of key market failures and challenges to large scale CO_2 transport and storage in the 2020s and 2030s

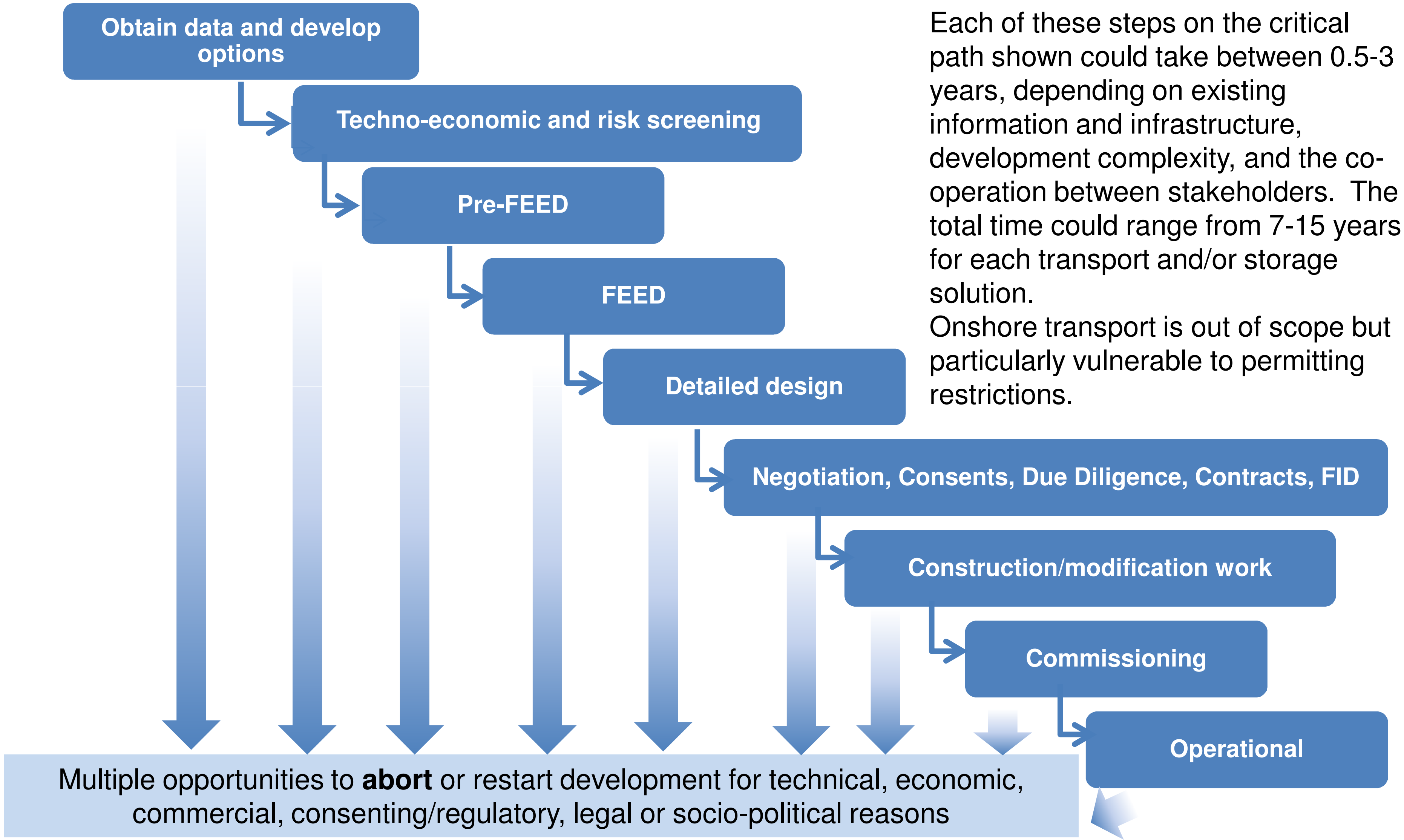
Failure to develop suitable transport and storage infrastructure threatens the viability of CCS as a decarbonisation option

Weak or uncertain financial incentives for CO_2 capture, and continued technology/market/ project-specific risks in the 2010s and 2020s before CCS is deemed commercially proven create systematic challenges for investments in all aspects of CCS.

Risk that CO_2 transport and storage capacity will not available at the right time, right place or right size because of high transaction costs and risks

- Offshore CO_2 transport and storage assets have high up-front and fixed costs, are long-lived and extremely specific in location, function, and capacity, have **very long** lead times.
- However there are large uncertainties today on 2030 requirements: uncertainty in capacities spanning two orders of magnitude, uncertainty in timing of utilisation spanning decades, uncertainties of hundreds of miles in the locations of plausible capture and storage sites, and uncertainty over future storage liabilities.
- Whilst the range makes sense within a UK-wide energy system perspective, it is unmanageable from more granular project engineering or commercial actor perspectives, particularly if financing is underpinned by Contract-for-Difference Feed-in Tariffs negotiated on project-by-project basis solely in the power market.
- Faced with a high risk of stranded assets and barriers to co-ordinated investment the private sector may not make economically efficient speculative anticipatory investments, particularly if there is a perception that returns will be low and comparable to those from waste disposal.

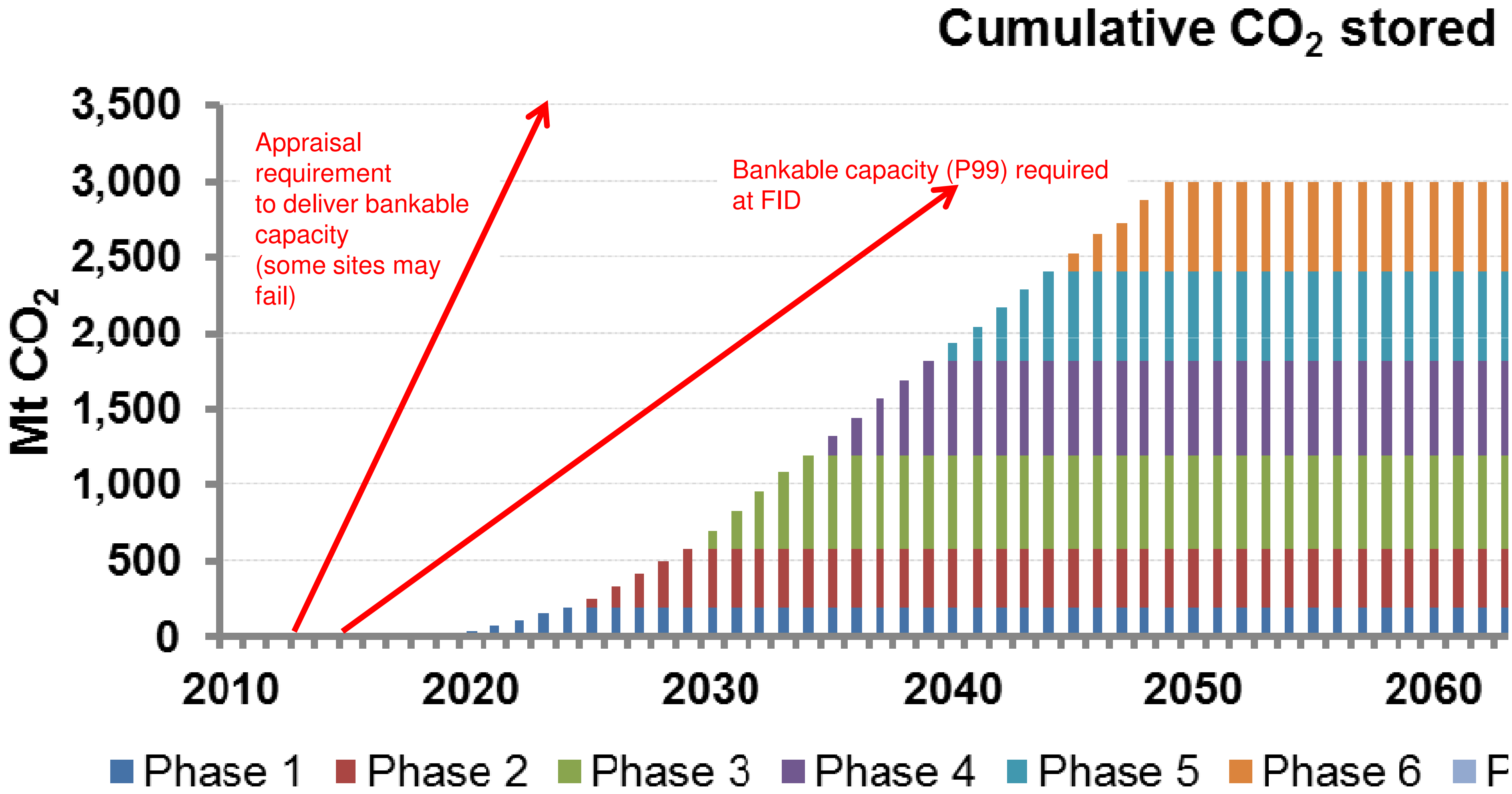
If the UK needs stores to be commercially operational by 2030, then site appraisal and route planning will need to commence several years earlier.



Each of these steps on the critical path shown could take between 0.5-3 years, depending on existing information and infrastructure, development complexity, and the co-operation between stakeholders. The total time could range from 7-15 years for each transport and/or storage solution.

Onshore transport is out of scope but particularly vulnerable to permitting restrictions.

An urgent challenge to developing the potential of CCS as modelled in ESME scenarios will be ensuring several years of "bankable" storage capacity ahead of final investment decisions.



Multi-billion pound investments in developing transport and storage solutions must begin while technologies, markets and regulations are still immature and evolving rapidly.

- Ramping up to a storage injection capacity of 100 Mt/yr in 2030 could imply *ca*. 5 “large”, 10 “medium-sized” or *ca*. 20 “independent point-to-point” offshore transport and/or storage solutions will need to have navigated successfully their critical paths from concept to operation.
- Given the novelty of CO_2 transport and storage, it is not possible to predict reliably if and how quickly projects will navigate the critical path from concept to operation.
- Several CO_2 transport and/or storage concepts could fail during development due to technical, economic, commercial, regulatory, socio-political or other reasons.
- To deliver the required 2030 infrastructure, therefore a larger number of transport and storage concepts will need to begin appraisal by in the late 2010s, recognising some may fail for diverse reasons.
- While a few full chain CCS projects may be operational worldwide by the late 2010s, CCS technology is unlikely to be regarded as “proven” as cost and risk-competitive with alternatives, and the energy, carbon and CCS markets are likely to continue to see substantial upheaval.
- Typically the private sector will only invest speculatively when potential returns are high; however the returns from transport and storage are likely to be modest reflecting their utility/waste aspects and the weak carbon market drivers.
- Therefore it is not credible to assume that in 2020 commercial actors will invest successfully in developing *either* a few large *or* a large number of smaller transport and/or storage solutions (including backup should any of these fail at any stage).

There are risks of incurring unnecessary costs, risks and delays.

- Storage development is data, resource, time and infrastructure intensive, but there are significant opportunities to limit time and costs by sharing data and infrastructure with the hydrocarbon production industry.
- However existing data that will inform estimates of reservoir cost and performance and the requirements for future proofing sites or infrastructure re-use is commercially held within the oil and gas industry.
- With weak CO_2 price signals, there is virtually no incentive for oil and gas companies and their supply chains to share these data.
- The information asymmetry could restrict market entry and limits the sharing of information which arguably has public good characteristics.
- It also limits the likelihood that choices will be made to future-proof physical assets or take advantage of infrastructure sharing opportunities.

There are risks that economic capacity for CO_2 pipelines and storage will constrained by spatial competition / conflicts for the seabed or subsurface

- Anecdotal evidence indicates that potential CO_2 pipeline routes and CO_2 storage sites coincide with other UKCS activity, such as offshore wind-farms, hydrocarbon production, North Sea transmission grids, and navigation, military, SSSI areas etc. Without careful planning, congestion in some areas could limit the economic capacity available, increase planning risks, or delay installation of equipment. The extent of this issue has not yet been quantified.
- CO_2 storage sites are geographically complex, including a mix of stacked reservoirs, reservoirs that span more than 10,000 km^2, and reservoirs that are pressure connected or where long-range CO_2 migration may be an issue. Commercial actors are likely to cherry-pick or "land-grab" the best sites, potentially concentrating market power.
- Without a trusted regulatory framework this also adds risks to projects/investors, as there is a danger that the value of their investment in developing a particular store might be damaged by actions taken by those who control neighbouring stores. Put another way, a regulatory or compensation regime needs to reflect complex geological realities. If not, investors may factor this into higher risk premium.

Many storage units span much larger areas than hydrocarbon fields, are stacked above each other, and have very unusual shapes – creating licensing/ leasing difficulties in scenarios with multiple storage companies.

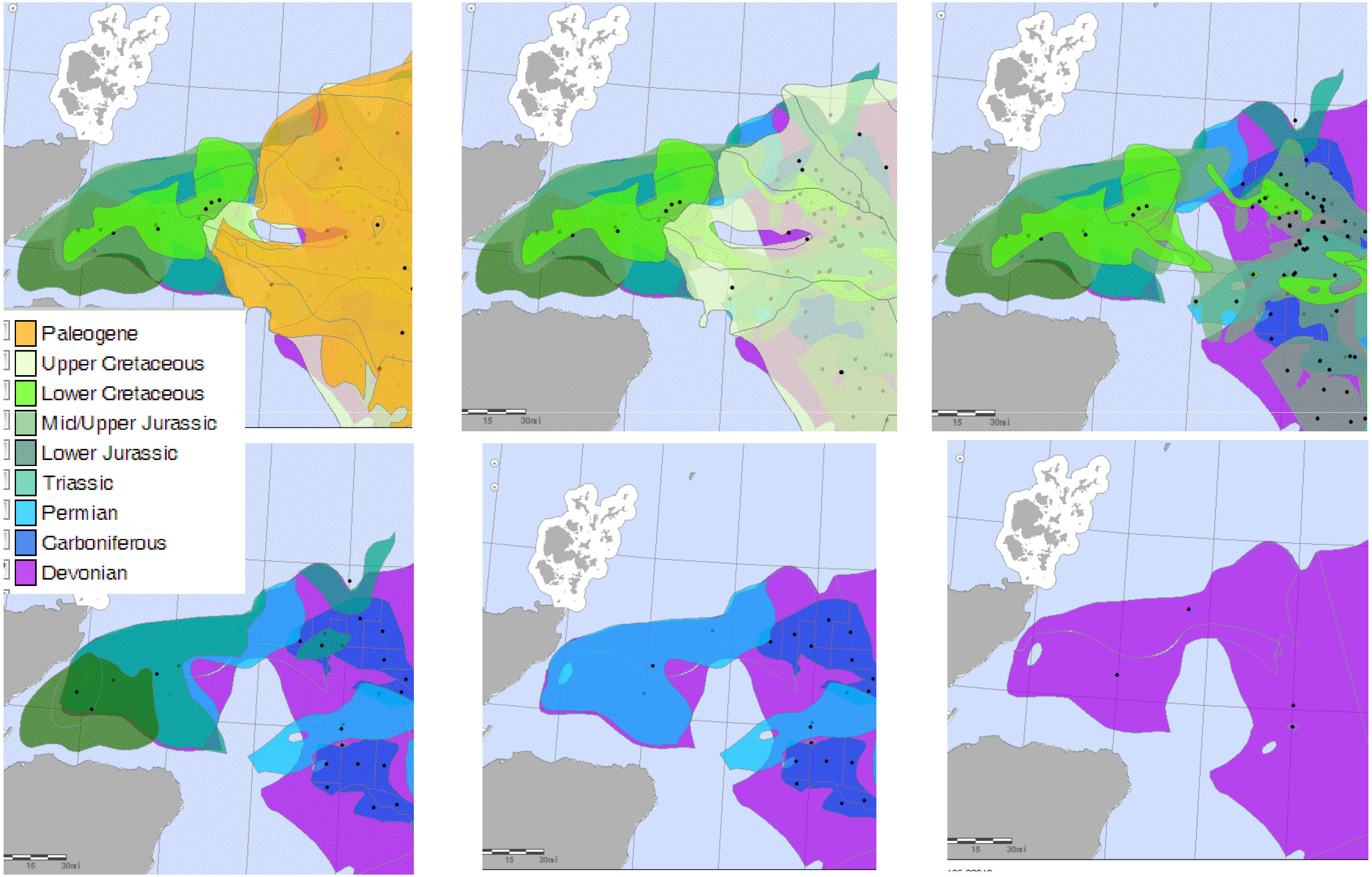


Diagram illustrates the complex stratigraphy of storage in the Moray Firth/Central North Sea

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High level options for infrastructure development

- Since the 1980s, there has been a strong preference for major new infrastructure investment in the UK to be privately financed and to some degree led by markets.
- The UK Government has frequently adopted “inform and enable”, “public-private partnership” or “regulatory” approaches, although at a more local or regional level the public sector has helped with planning locations and capacities.
- Fully national provision of new infrastructure is becoming rarer in the UK.
- There are also examples where industries appear to self-regulate and co-ordinate effectively (e.g. oil pipelines, internet domains).
- Where economies of scale imply monopoly service, “System Operators” are generally regulated at local, regional or national level (cf. water, wastewater, UK gas and electricity networks, trains, some ESCOs) by a designated Regulator or Authority. The system operator function clarifies incentives to run a complex network efficiently and provide open access for infrastructure.
- Even where there are regulated monopolies, competitive market pressures can be used at specific points within the value chain to encourage innovation and drive down costs. (cf. electricity generation plants and train operating compete on regulated networks).

Examples of public and private approaches for infrastructure development in analogous industries.

The review of analogous industries has identified a wide variety of business and regulatory models:

- Mostly public-driven, for example,
  - Gassnova, fully State-funded to represent State's interest in CCS.
  - Nuclear Decommissioning Authority is a public authority responsibility for nuclear liabilities (formed after the failure of industry consortium NIREX).
  - National oil companies seek to maximise resource developments for a nation.

- Mostly privately driven, for example, oil pipeline investments.
  - For oil and gas pipelines investments can be led by upstream, downstream or mid-stream partners (although mid-stream is the most fragile).
  - Vertical integration can reduce information asymmetries, transaction costs, counter-party risks and allow any economic rents to be captured.
  - Even with vertical integration however, a web of contractual ties between upstream suppliers and downstream users and performance guarantees are generally in place. This allows the asset to be run as a dedicated business, which can be sold if required to a third party. Contracts can be for capacity (e.g. annual throughput) and can be at the level of short timescales (e.g. hourly) or very long (e.g. 20 years commitment) or a mixture.

Analogous examples of mixed public-private investment or economic regulation.

The review of analogous industries has identified a variety of business and regulatory models where there is a mix of public and private involvement, for example:

- National Grid PLC, is the transmission network system operator for the UK gas and electricity networks, with investments and tariffs publicly regulated by OFGEM.
- Energy Service companies frequently involve equity partnerships between municipalities and commercial partners to support the phased growth of district heating infrastructure.
- In the UK, water is supplied through multiple regional regulated monopolies (previously publicly owned water boards).
- As part of the UK waste framework, regions are required to identify the types, locations, and capacities of waste management infrastructure.
- Sewerage infrastructure is mostly delivered through regional regulated monopolies, but sewage treatment facilities are often privately led.
- Investment for the London 2012 Olympics was delivered through a combination of LOCOG (private consortium) and the Olympic Delivery Authority.
- Though initially a private investment, the Channel Tunnel required strong political backing prior to launch and Governments have had to facilitate multiple rounds of restructuring, resulting from cost over-runs and overly optimistic uptake forecasts.
- The High Speed1 Rail network, originally a private development, was nationalised in the face of lower than required usage.

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Measures to support large scale CO_2 transport and storage in the 2020s and 2030s (1)

Managing spatial challenges and risks

- Zoning of CCS – identifying priority sites where permitting for CO_2 capture and/or storage will be expedited.
- Public sector masterplanning of CO_2 transport and infrastructure, with decisions on locations, capacities and other design specifications, and long-range forecasts.
- Masterplanning of offshore infrastructure, reserving critical sites or rights-of-way.
- A "one-stop shop" for permitting CCS, potentially across the UK and possibly extended to include nearby countries.
- Public programme for storage exploration and appraisal.

Managing infrastructure specification and access rules

- Industry council, technical body, self-regulation or designated regulator to raise awareness, share knowledge and assist with infrastructure specification and dispute resolution.
- System operator to set specs
- Publishing guidance for how third party access disputes would be resolved, how large storage units or complexes would be licensed and leased, particularly for systems covering large areas or with stacked reservoirs.
- Encourage availability of port/shipping infrastructure to increase flexibility

Measures to support large scale CO_2 transport and storage in the 2020s and 2030s (2)

Managing market power

- Industry council, self-regulation or designated regulator to raise awareness, share knowledge and assist with infrastructure specification and dispute resolution.
- Public monopoly company such as a National Carbon Storage Authority, responsible for delivery of storage capacity (and possibly capture or transport infrastructure), similar to a national oil company.
- Publishing guidance for how third party access disputes would be resolved, how large storage units or complexes would be licensed and leased, particularly for systems covering large areas or with stacked reservoirs.
- Economically regulated monopolies for CO_2 transport and/or storage (national or regional)
- Obligation for (selected?) hydrocarbon field owners to share data, provide access to infrastructure and obligation for storage developers to deposit data in a national repository. Some form of compensation may be available.
- Establish forward capacity market for CO_2 transport and storage infrastructure (i.e. combination of annual fixed U-o-S charge of £/Mt/yr and variable costs £/t).
- There could be specific tax incentives, e.g. enhanced capital allowances or tax reductions for CO_2-EOR projects.

Measures to support large scale CO_2 transport and storage in the 2020s and 2030s (3)

Bringing forward private capital, reducing private sector risks in investment and ensuring efficient capital allocation

- ❑ Public capital or operating funding in joint ventures for transport and storage, signalling policy intent
- ❑ Public monopoly company such as a National Carbon Storage Authority, responsible for delivery of storage capacity (and possibly capture or transport infrastructure), similar to a national oil company. Alternatives include regional companies, e.g. SNS, CNS, EIS – if so it may be difficult to join these up later. At the opposite extreme could be a joint North Sea storage authority.
- ❑ Establish a cross-industry fund or system for capped liabilities to deal with accidents, including payments for leaking CO_2.
- ❑ Clarifying requirements for transitions from hydrocarbon production to storage and from storage back to the state.
- ❑ Publish draft service contractual agreements between capture, transport and storage, to standardise these and reduce transaction costs.
- ❑ Capping or government sharing of liabilities connected to storage
- ❑ Facilitate anticipatory investment for funding, competitions, and in planning

General measures to underpin large scale CCS in the 2020s and 2030s

- Global "climate deal" with challenging and legally-binding CO_2 reduction targets.
- Europe-wide arrangements on funding CCS projects and infrastructure.
- Stronger carbon pricing/carbon taxes leading to a strong futures market for avoided CO_2 beyond Phase III of ETS.
- Legal and regulatory CO_2 emission constraints for large stationary sites.
- Comprehensive masterplanning of the UK energy system and decarbonisation transition, particularly identifying locations, capacities etc. for different forms of electricity generation rather than leaving generation entirely to the market.
- Co-operative, rather than competitive, approach to CCS roll-out in the UK to reduce counterparty risks, transaction costs /risks, share best practices, and increase potential for system optimisation.
- A "one-stop shop" for permitting CCS, potentially across the UK and possibly extended to include nearby countries. In this all permits would be granted simultaneously, so that capture projects aren't granted without stores and vice versa.
- Financing incentives tailored across the CCS challenges, exploration, appraisal, FEED, construction, operation, decommissioning, post-closure monitoring, including an appropriate mix of public tenders, auctions/competitions, bonds, feed-in tariff, soft loans, guarantees, etc.

Bundles of measures identified for the development of offshore CO_2 transport and storage infrastructure

Following the literature review which identified options for how industries could develop, five representative bundles of measured were identified for the development of offshore CO_2 transport and storage infrastructure.

These are summarised as:

1) UK Government informs and enables a competitive market for transport and storage
2) Industry leadership with Government informing and enabling
3) Regional private monopolies subject to light-touch regulation
4) Regional public-private joint venture monopolies subject to regulation
5) Government design, finance and build CO2 transport and storage infrastructure

Scenario 1: Govt informs and enables competitive market for CO_2 transport and storage infrastructure

This scenario assumes modest incremental changes to the current regime, with "organic" CCS project development. Also it assumes EU-ETS is extended beyond 2020, and that a combination of carbon price floor, long-range sufficient CO_2 price within ETS, CfD FiTs in the electricity market and CCS cost reduction, and stable policy environment is sufficient to encourage individual capture projects.

In this scenario, the UK Government could facilitate for example, by:

- ❑ Ensuring suitable incentives for CO_2 capture.
- ❑ Publishing guidance on licensing (and, for TCE, leasing) of complex or large stores.
- ❑ Publishing guidance on how third party access to transport and storage will be administered in practice, including tariffs.
- ❑ Providing framework with guidelines to facilitate the transfer of reservoir data, offshore infrastructure, and depleted fields between hydrocarbon production and CO_2 storage (including where necessary CO_2-enhanced oil recovery), and eventual handover of stores back to the state.
- ❑ Providing a support market framework to allow, where there is demand, for a forward capacity market for transport and storage infrastructure.
- ❑ Co-operating with nearby countries if cross-border infrastructure is required.
- ❑ Continuing to push internationally for policy agreements that underpin CO_2 reduction.

Scenario 2: Industry co-ordinates and provides leadership on CO_2 transport and storage infrastructure , with Government support

This scenario

- Assumes the CCS industry is able to co-ordinate and self-regulate, potentially through an industry body comprising key stakeholders.
- The UK government, EU and industry support high levels of information sharing that would be required for meaningful co-ordination and optimised decision-making, particularly around codes, standards, specifications, and information exchange.

This scenario potentially might involve the following:

- Industry stakeholders agree to set up and abide by decisions made by a CCS industry council.
- A process or Task Force involving industry, The Crown Estate and the UK Government could identifies preferred zones for CO_2 capture, transport and storage.
- Industry stakeholders co-operate on the designs of offshore CO_2 transport and storage infrastructure, including the locations, capacities, and specifications.
- High level of CCS industry co-investment in planning and delivery of transport and storage infrastructure, or advance purchase of capacity through open seasons, to share costs, risks and benefits.
- Industry agrees to self-regulate terms of third party access, notably tariffs.
- A cross-industry fund for storage liabilities is established, with rules on how this would be administered.

Scenario 3: Regional monopolies established to deliver transport and storage infrastructure

This scenario assumes

- Government, The Crown Estate, and industry share information and co-operate to establish preferred designs and financial model for CO_2 transport and storage infrastructure.
- The priority is attracting suitable investment, rather than considering economic regulation.

In this scenario, the role of Government and stakeholders might involve

- Enabling a private system operator to be developed
- Establishing priority zones where CCS can occur onshore and offshore, so that there is a presumption in planning (e.g. through National Planning Policy Statements) that CCS proposals can go ahead.
- Co-ordinating the various planning and consenting processes to provide a “one-stop” solution for CCS permitting.
- Providing an economic mechanism to support storage exploration and appraisal and private investment in transport and storage infrastructure, for example through economic regulation of a regional monopoly with pre-agreed IRR.
- Considering financing arrangements which draw on alternative regulated asset bases (for example a dedicated fund supported by electricity consumers). This would limit the risk to individual backers of assets that turn out to be under-utilised.

Scenario 4: Public-private Joint Venture(s) established to deliver transport and storage infrastructure

This scenario might involve:

- Government and industry establish JV(s) which provide a blueprint for the location, capacity and timing of CO2 transport and storage infrastructure.
- The JV has responsibility for delivery of CO_2 transport and storage infrastructure, including the exploitation of storage clusters.
- JV partners co-invest in storage exploration/appraisal and construction of CO_2 transport and storage infrastructure on the basis of a regulated returns model.
- Infrastructure designs and expansion plans should be subject to periodic reviews and consultation exercises.
- Govt. and industry enable creation of a regulated monopoly for transport and storage system operator.
- Govt and industry provide up-front funding for both storage exploration and appraisal and investment in transport and storage infrastructure, for example through economic regulation of a regional monopoly with pre-agreed IRR, with capped storage financial liabilities for commercial storage developers.
- Extensive data sharing, contractual agreements among stakeholders, and simplified permitting process de-risks and optimises investments, potentially via an independent body.
- A “one-stop solution” for CCS permitting, avoiding the risk that only parts of a CCS chain are permitted.

Scenario 5: Public authority established to deliver CO_2 transport and storage

This scenario might involve:

- The creation of a body which develops CO_2 transport and storage infrastructure in the national interest, charging agreed fixed and variable tariff to users, socialising the risks, costs and benefits in a manner among system users, the public and other industry stakeholders as agreed.
- This organisation has an incentive to maximise system efficiency in the national interest, using anticipatory investment where necessary.
- The organisation (potentially with support from industry, Government, and The Crown Estate), fully funds a national storage exploration and appraisal programme, putting data on the costs, performance, and risks of each storage site into the public domain.
- This is a monopoly public utility service arrangement, and so market competition is focussed exclusively around CO_2 capture.
- Economics improved through a national CO_2-EOR strategy.
- Co-ordination of the various planning and consenting processes to provide a "one-stop" solution for CCS permitting.
- Cross-border co-operation in place at Government<->Government level.

Outline

- The need for CO_2 transport and storage in 2030
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- Illustrative roles and responsibilities

Advantages and disadvantages of each bundle

	Advantages	Disadvantages
1. UK Govt informs and enables competitive market	Minor changes to regulatory regime means less uncertainty and less impact on existing developments. Market manages stranded asset and other risks. Market assumes standardisation challenge.	Development likely to be slow, waiting for CCS to be proven and for economic conditions to strengthen. High risk of inefficient T&S capacity as can be difficult to coordinate storage, transport and capture across long timescales and uncertainties. Commercial actors reponsible for all development risks, even when benefits accrue widely.
2. Industry leadership with Govt informing and enabling	Minor changes to regulatory regime means less uncertainty and less impact Industry manages stranded asset and other risks	No guarantee of efficient investment in short or long-term High risk of anti-competitive practices Lack of market pressures for innovation or reducing prices Could be difficult to ensure costs
3. Regulated regional private monopolies	Single regional provider aids coordination Modest need for standardisation at regional level. High potential for efficient T&S capacity over the longer term.	Monopoly excludes competition after initial round(s). Interest in anticipatory investment would suggest higher capital costs No precedent to bid for / evaluate any tenders for regional monopoly given uncertain capture and storage risks. Could limit innovative CCS systems Could disrupt existing CCS programme
4. Regulated regional public-private Joint Venture Monopolies	High potential for efficient T&S capacity over the longer term.	Would disrupt existing CCS programme Not clear how public investment would distort public or carbon markets
5. Govt design and build CO_2 transport and storage infrastructure	High potential for efficient T&S capacity over the longer term, due to anticipatory investment that maximises coordination. Potential for very high standardisation across network to maximise economic value Saves on time and expense in the future.	Central planning might reduce innovation and flexibility Costs Would disrupt existing CCS programme

Preliminary assessment of strengths and weaknesses of bundles of measures for CO_2 transport and storage infrastructure.

<table>
<tr><th></th><th>Inefficient T or S capacity within tight timescale (insufficient, stranded or sterilised assets)</th><th>Unnecessary costs or risks or delays (Data & infrastructure sharing, congestion)</th><th>Excess transmission or storage price</th><th>Ease of implementation</th></tr>
<tr><td>1. UK Govt informs and enables competitive market</td><td>Risk of insufficient capacity or stranded asset risk for over-sized pipelines or market power for stacked stores</td><td>Weak mechanisms for data and infrastructure sharing and to avoid congestion</td><td>Market pressures could reduce costs, but absence of market / market power could drive up cost</td><td>Current policy</td></tr>
<tr><td>2. Industry leadership and self-regulation (Govt. enabling)</td><td>Posssible to coordinate and thereby optimise design within commercial constraints</td><td>Need to co-operate with oil/gas and other stakeholders</td><td>Industry could critique and reduce costs, but also high risk of market abuse.</td><td>Will UK CCS industry self-regulate efficiently?</td></tr>
<tr><td>3. Regulated regional private monopolies</td><td>Likely to resolve spatial planning challenges and provide coordination, but absolute investment may still be difficult</td><td rowspan="3">Govt could create mechanisms to force data, infrastructure sharing and spatial planning</td><td>Regulation will limit prices. Co-ordination could reduce costs</td><td>How will Govt choose a T&S system operator between new entrants?</td></tr>
<tr><td>4. Regulated regional public-private Joint Venture Monopolies</td><td>Likely to resolve spatial planning challenges and provide anticipatory investment</td><td>Regulation will limit prices. Expect anticipatory investment in national interest.</td><td>Likely to be successful but planning and up-front public funding could be difficult.</td></tr>
<tr><td>5. Govt design and build CO_2 transport and storage infrastructure</td><td>Effective if Govt takes much larger control of energy and carbon reduction problem</td><td>Public infrastructure could be optimised, but it could also be inefficient.</td><td>Would require high spatial planning and up-front public investment, contrary to UK policy</td></tr>
</table>

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Illustrative anticipated roles in Scenario 1 (UK Govt informs and enables competitive market)

Stakeholder	Potential responsibilities
Each Capture provider	Secure financing, identify locations, develop capture options, co-ordinate and negotiate with CO_2 generation, transport and storage, win stakeholder support, obtain permits
Each Transport provider	Secure financing, identify locations, develop transport options, co-ordinate and negotiate with CO_2 generation, capture and storage, obtain permits, win stakeholder support
Each Storage provider	Secure financing, identify locations, develop transport options, co-ordinate and negotiate with CO_2 generation, capture and storage, obtain permits, win stakeholder support
DECC (OCCS)	Review each project, negotiate funding with project leader (through competitions for capex and CfD FiT);
DECC EDU	Review and negotiate each license agreement; manage conflicts
The Crown Estate	Negotiate each agreement-for-lease and lease
HSE regulators	Provide permits where projects meet HSE requirements
Other CCS industry	Build political support, optimise projects, stakeholder engagement, develop technology, assist commercial transactions, inform supply chain
European Commission	Tighten ETS CO_2 caps, Review and update CCS Directive in 2015.
North Sea Basin Task Force	Assist with cross-border projects, share best practice among North Sea countries.

Illustrative anticipated roles in Scenario 2 (Industry leadership, self-regulation with govt. enabling)

Stakeholder	Potential responsibilities
Each Capture provider	Financing, obtaining permits; develops and implements capture at sites and at capacity /spec agreed within industry CCS rollout plan; potentially work within JV
Each Transport provider	Financing, obtaining permits; develops and implements transport at sites and at capacity/ spec agreed within industry CCS rollout plan; potentially work within JV
Each Storage provider	Financing, obtaining permits; develops and implements storage at sites and at capacity/ spec agreed within industry CCS rollout plan; potentially work within JV
DECC (OCCS)	Assists creation of industry body (remove competition barriers)
DECC EDU	Review and negotiate each license agreement
The Crown Estate	Works pro-actively with industry and Government to ensure sensible roll-out plan
HSE regulators	Provide permits where projects meet HSE requirements
CCS industry body	Designs detailed rollout plan, facilitates negotiations between project partners and between project and other stakeholders, arbitrates in case of dispute
European Commission	Assists creation of industry body (remove competition barriers)
North Sea Basin Task Force	Assist with cross-border projects, share best practice among North Sea countries.

Illustrative anticipated roles in Scenario 3 (Regional private monopolies established to deliver transport and storage infrastructure)

Stakeholder	Potential responsibilities
Each Capture provider	Financing, obtaining permits; develops and implements capture at sites and at capacity /spec agreed with CO_2 transport and storage provider
Regional transport & storage private provider	System operator role - Develop regional plan for T&S and communicate this to potential generation and capture. Obtaining permits; develops and develop transport capacity at locations and spec agreed to regional plan. Raise funding
DECC (OCCS)	Review each project, negotiate funding for capture ; Policy support. Assists creation and business model of regional transport and storage provider
DECC EDU	Review and negotiate each license agreement
The Crown Estate	Works pro-actively with industry and Government to ensure sensible roll-out plan
HSE regulators	Provide permits where projects meet HSE requirements
CCS industry body	Facilitates negotiations between project partners and between project and other stakeholders
European Commission	Tighten ETS CO_2 caps, Review and update CCS Directive in 2015.
North Sea Basin Task Force	Assist with cross-border projects, share best practice among North Sea countries.

Illustrative anticipated roles in Scenario 4 (Regulated regional public-private Joint Venture Monopolies)

Stakeholder	Potential responsibilities
Each Capture provider	Financing, obtaining permits; develops and implements capture at sites and at capacity /spec agreed with CO_2 transport and storage provider
Regional transport & storage provider	System operator role - Develop regional plan. Obtaining permits; develops and develop transport capacity at locations and spec agreed to regional plan.
DECC (OCCS)	Review each project, negotiate funding for capture ; Assists creation and financing of regional transport and storage provider, provide co-investment
DECC EDU	Plan, review and negotiate license agreements
The Crown Estate	Works pro-actively with industry and Government on a Masterplanned approach
HSE regulators	Provide permits where projects meet HSE requirements
CCS industry body	Facilitates negotiations between project partners and between project and other stakeholders
European Commission	Tighten ETS CO_2 caps, Review and update CCS Directive in 2015.
North Sea Basin Task Force	Assist with cross-border projects, share best practice among North Sea countries.

Anticipated roles in Scenario 5 (Govt design and build CO_2 transport and storage infrastructure)

Stakeholder	Potential responsibilities
Each Capture provider	Financing, obtaining permits; develops and implements capture at sites and at capacity /spec agreed with CO_2 transport and storage provider
National transport & storage provider	System operator role - Develop national plan. Obtaining permits; design and develop transport and storage capacity at locations and spec agreed to national plan. Update in light of developments
DECC (OCCS)	Review each project, negotiate funding for capture ; Create and fund national transport and storage provider
DECC EDU	Masterplan, review and negotiate license agreements
The Crown Estate	Works pro-actively with industry and Government on a Masterplanned approach
HSE regulators	Provide permits where projects meet HSE requirements. Work pro-actively with system operator .
CCS industry body	Facilitates negotiations between project partners and between project and other stakeholders
European Commission	Tighten ETS CO_2 caps, Review and update CCS Directive in 2015.
North Sea Basin Task Force	Assist with cross-border projects, share best practice among North Sea countries.

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Opportunities for further ETI activities

- Work with DECC, The Crown Estate, CCSA, MMO and other industry partners to develop a coherent approach to meeting the challenge of offshore transport and storage provision.
- Quantify the costs and risks to the UK's decarbonisation trajectory as a function of different levels of CCS (and comparison with alternative investments).
- An option value-based assessment of levels of national vs. site based CCS readiness.
- Impacts from congestion on the seabed, implications for offshore routing constraints and the need for spatial planning.
- Entry specifications for pipelines and stores and the impacts these have on system costs (including generation and capture) and performance.
- Impacts from storage units being stacked or covering large areas on how the storage is best deployed.
- How the costs of capital for CO_2 transport and storage financing vary as a function of business model and regulatory environment.
- The impacts of existing pipeline, platform, well and power infrastructure on CCS deployment
- The underlying investment case for offshore hubs rests on an assumption that CO_2 transport onshore will be more challenging to implement than solutions involving the transport of fuels, hydrogen, and electricity; however these have yet to be analysed in depth for the UK.
- Systematic and comprehensive analysis of transport and storage configurations (considering infrastructure re-use, appraisal, risk reduction, EOR, monitoring and decommissioning in more detail).

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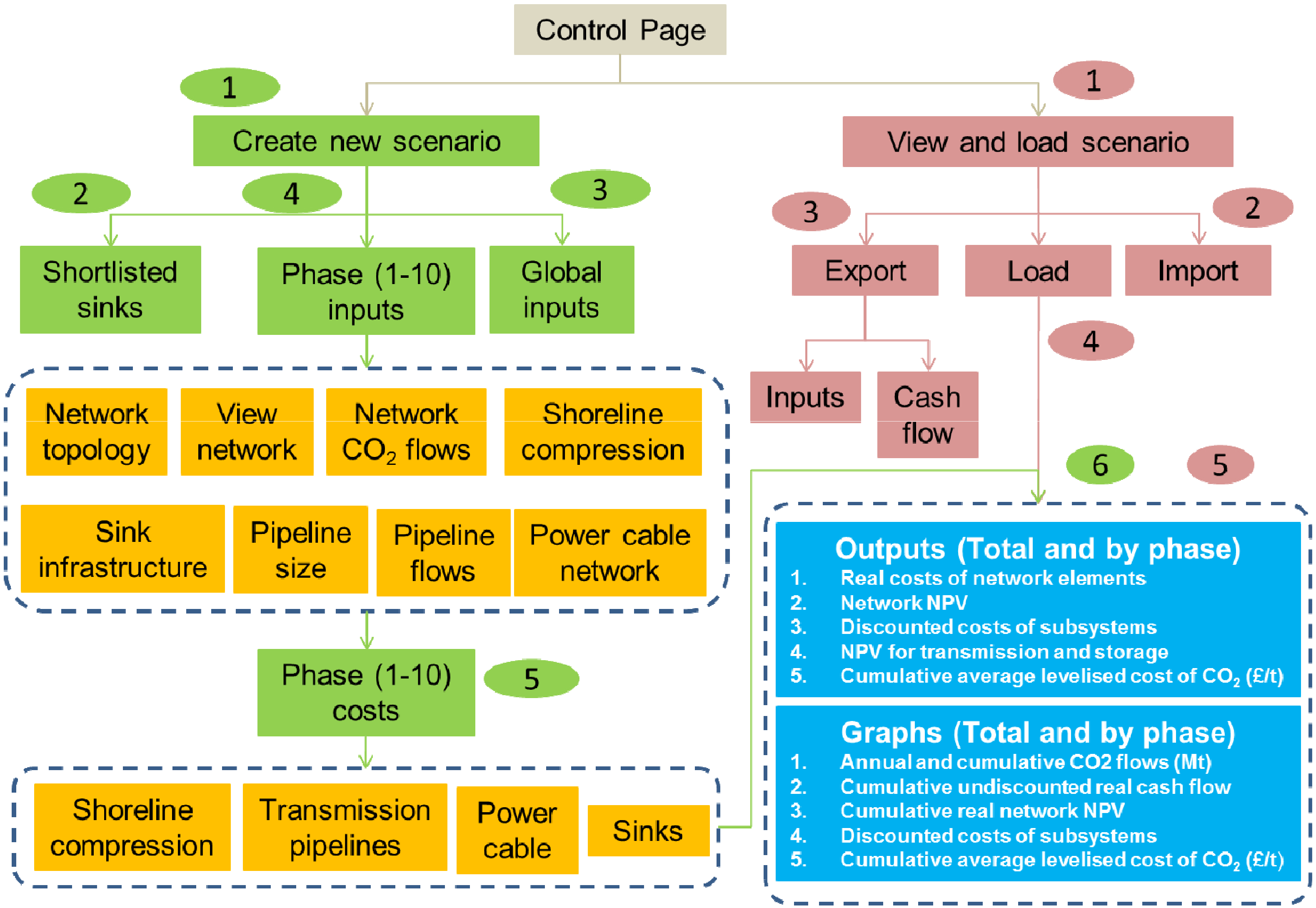
Appendix

- Illustrative results from network economic analysis
- UK and international CO_2 transport and storage review
- Experience in other major industries
- Potential market failures for CO_2 transport and storage

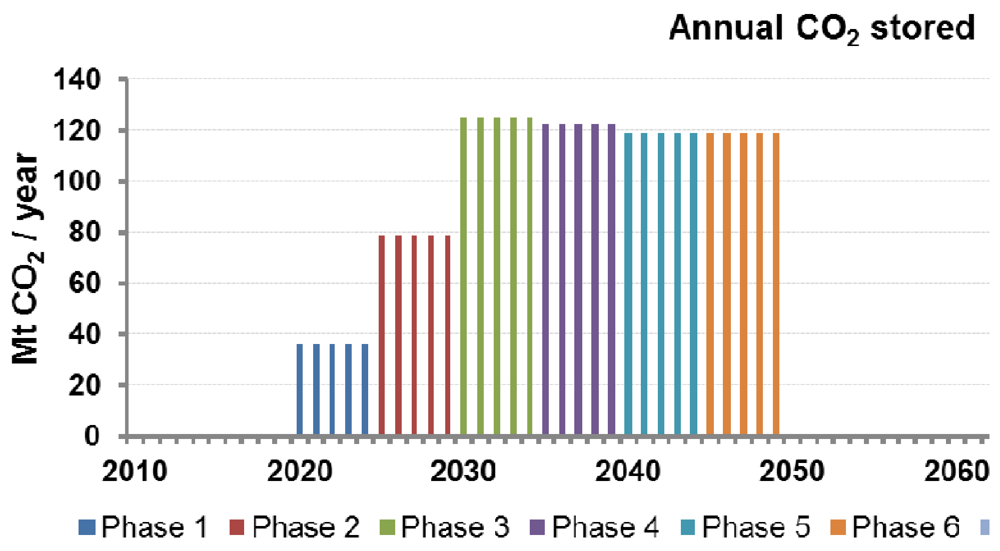
ETI has developed a tool to compare quantitatively the economics of different offshore transport and storage networks, phased over time.

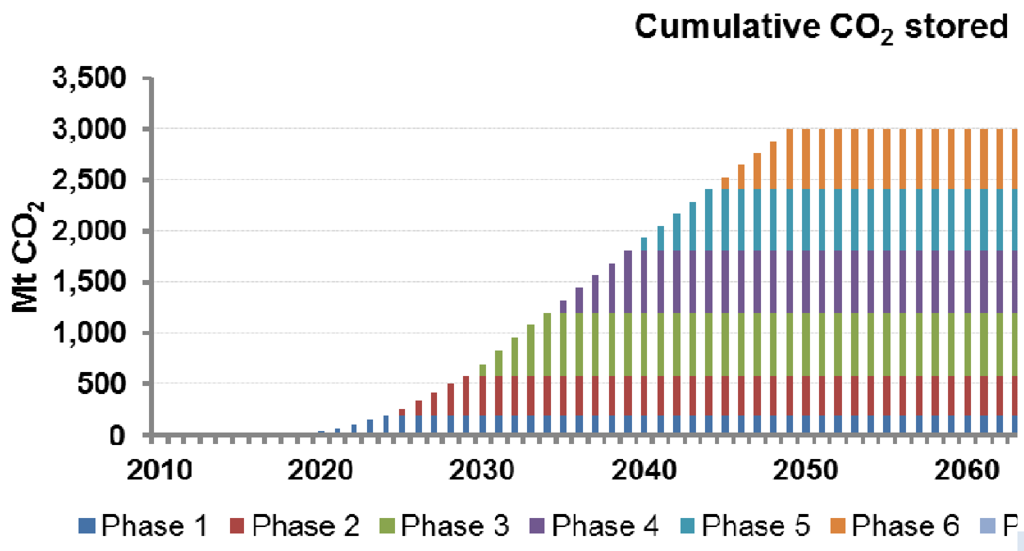
- In March 2012 ETI commissioned Element Energy to design and build a tool to quantify the economics of different configurations for offshore CO_2 transport and storage, phased over time.
- Importantly, the tool, CO_2NomicA - for CO_2 Network Economic Analysis - is flexible and users can select from multiple shoreline hubs, network topologies (linear, convergent, divergent), multiple sinks (each with phased appraisal, wells, platforms and distribution infrastructure) to grow over time, with CO_2 throughput changing in each phase, and a range of financial assumptions (e.g. tariffs, WACC, taxes, debt repayment schedules).
- The tool provides some basic internal consistency checks, and then allows key project performance metrics to be compared between networks, such as the NPV and levelised costs for offshore transmission and/or storage. Outputs are available in tabular and graphical formats at different levels of component resolution.
- So far the tool has been used to explore the impacts of needing redundancy (in wells or storage units), the phasing of wells over time, the benefits of shared pipelines and sinks, the relative economics of networks in the central and southern North Sea, the economically efficient levels of network future-proofing e.g. pipeline over-sizing.

CO_2NomicA model structure



Networks were developed to meet the most cost-effective CCS capacity scenarios within ESME.

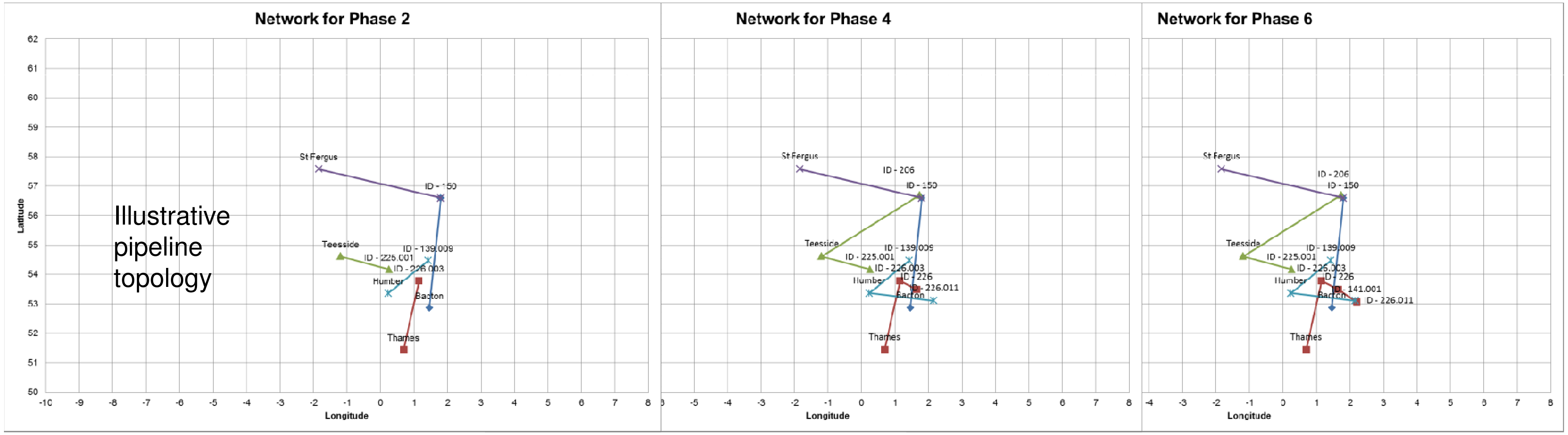




Illustrative offshore infrastructure requirements to meet >100 Mt/yr ESME scenario using North Sea aquifer storage supplied from five shoreline hubs.

Summary of Network Infrastructure

	Phase 1 2020-2024	Phase 2 2025-2029	Phase 3 2030-2034	Phase 4 2035-2039	Phase 5 2040-2044	Phase 6 2045-2064
Number of shoreline terminals in use	5	5	5	5	5	5
Total annual flow (Mt)	36	79	125	122	119	119
Number of sinks in use	4	4	7	7	8	8
Number of injection facilities	28	53	127	127	207	207
Number of wells	28	53	127	127	236	236
Number of transmission pipelines	5	10	13	13	14	14
Total transmission pipelines length (km)	1410	2820	3387	3387	3460	3460



Illustrative project technical and financial assumptions

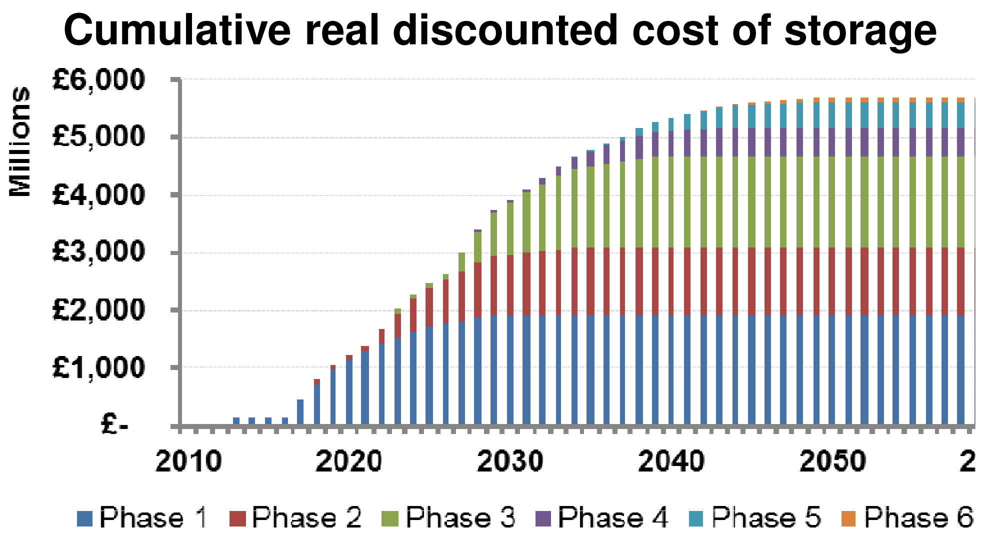
TIMELINE INPUTS

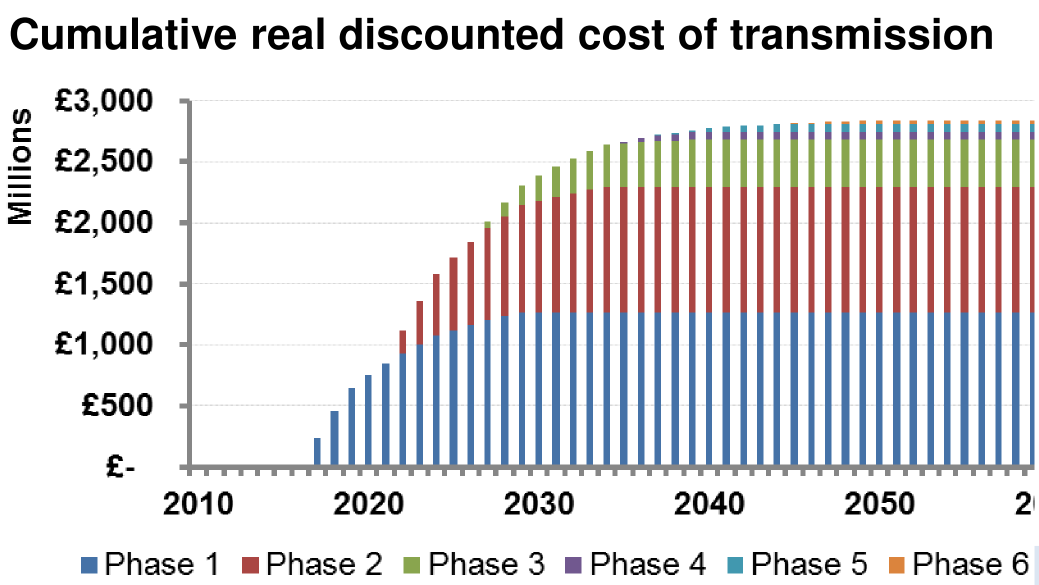
Project start year	2020		This is the start year for flows from Phase 1
Number of phases	6		The total number of phases included in the project
Start of last phase	2045		No more infrastructure development after this year, only CO_2 flows may carry forward
Duration of last phase	5	years	This is length of last phase only
Lifetime of pipeline	40	years	This is the lifetime after which pipeline need replacement
Lifetime of sink infrastructure	40	years	This is the lifetime after which sink infrastructure need replacement
Lifetime of shoreline compressors	40	years	This is the lifetime after which shoreline compressors need need replacement

FINANCIAL INPUTS

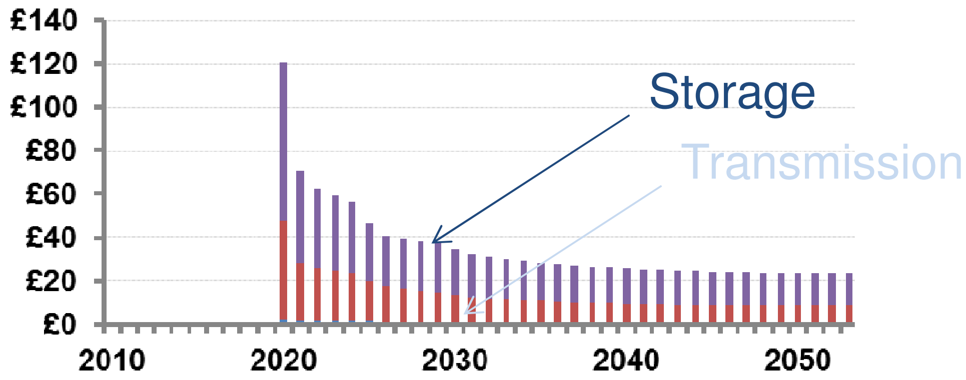
Repayment start year	0	years	This is the number of years after operation of a phase that loan repayments start
Repayment period	10	years	This is the duration over which the loan is repaid
Inflation rate	2%		This is rate at which real costs are inflated to obtain nominal costs
Interest rate	8%		This is rate at which loan repayments are made
Debt financing	50%		This is the ratio of capital investments which are incurred as debt
Depreciation	10%		This is the constant linear rate at which capital investments are assumed to depreciate over 10 years
Corporate tax	20%		This is the rate at which tax is paid on the net revenues after interest and depreciation
WACC (transmission)	10%		This is rate at which NPV is calculated for cash flows from onshore terminals, pipeline and power cable
WACC (storage)	10%		This is rate at which NPV is calculated for cash flows from offshore sinks
CO_2 tariff (pipeline)	£ 15	£/t	This is revenue generated for operating pipelines in real terms from storage of CO_2
CO_2 tariff (storage)	£ 20	£/t	This is revenue generated for operating sinks in real terms from storage of CO_2

Meeting the ESME 2030 capacity of ca. 120Mt/yr implies net present investment of £2.5bn in transmission pipelines and £4 bn in storage by 2030.





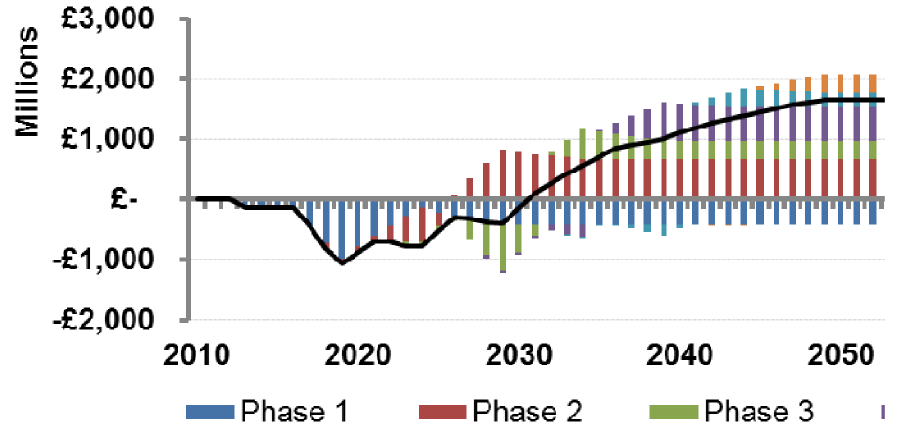
The system levelised transport and storage cost begins to stabilise after *ca*. 10 years.



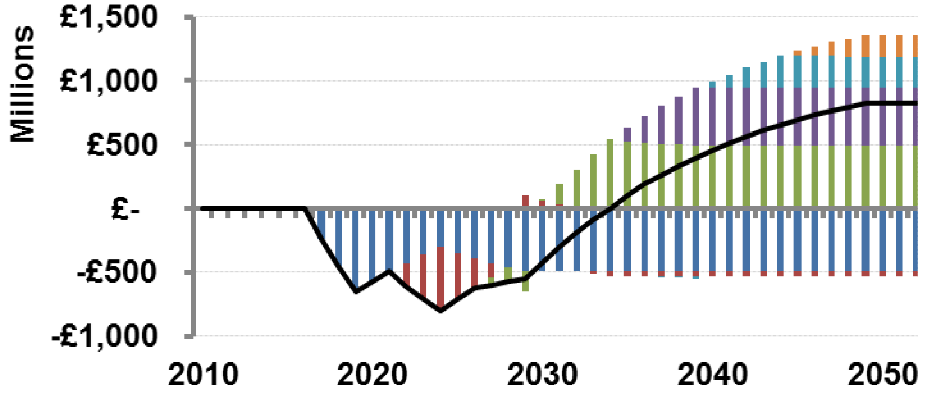
Key Performance Indicators for Transport and Storage Network	All Phases
Cumulative CO_2 storage (Mt)	3000
Levelised cost of transmission and storage within phase (£/t)	£ 24
System real NPV (transmission and storage) (millions)	£ 2,793
Real NPV of transmission pipeline (WACC= 10%, tariff= £15/tCO2) (millions)	£ 2,031
Real NPV of sinks (WACC= 10%, tariff= £20/tCO2) (millions)	£ 1,054
Discounted costs - Terminals (millions)	£ 292
Discounted costs - Transmission Pipelines (millions)	£ 2,838
Discounted costs - Cable (millions)	£ -
Discounted costs - Storage (millions)	£ 5,698
Discounted CO_2 storage (Mt)	372

The transport and storage system may not return positive NPV until at least until the 2030s.

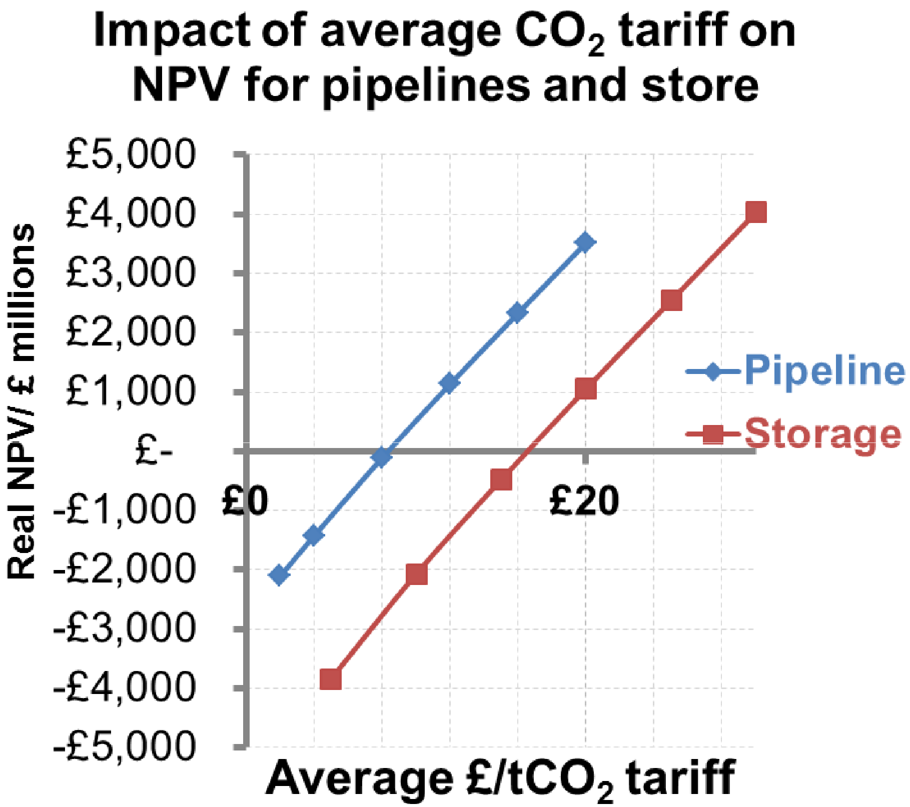
Real NPV(10%) for storage (assuming real revenue of £22/t)

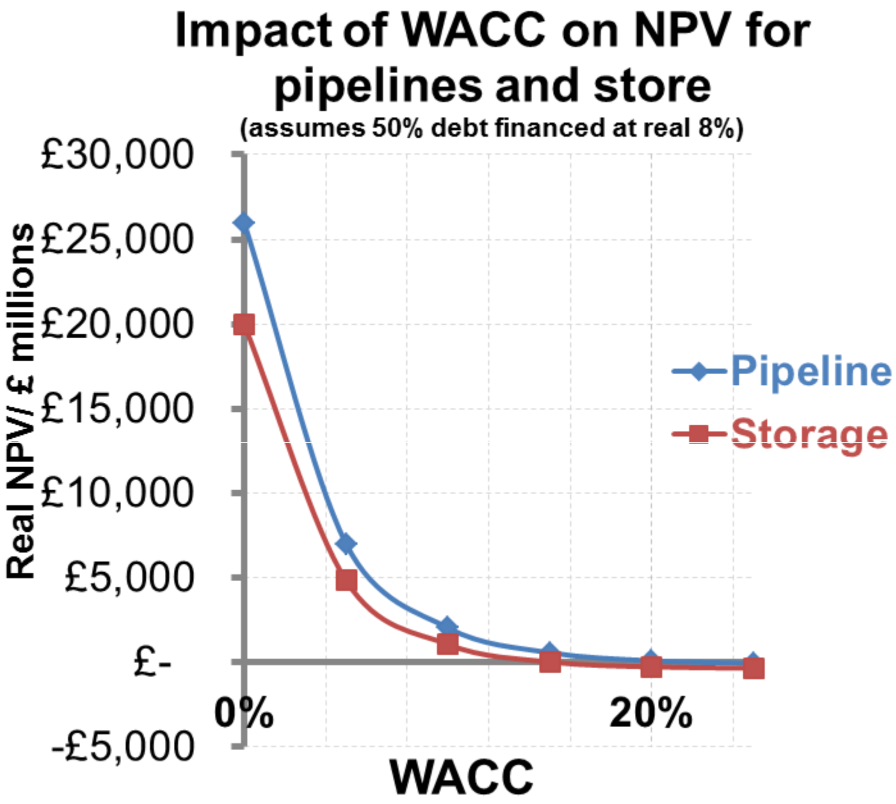


Real NPV(10%) for transmission (assuming real revenue of £11/t)



The NPV for transport and storage developers is highly sensitive to the average tariff charged and Weighted Average Cost of Capital (WACC).





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UK studies for CCS

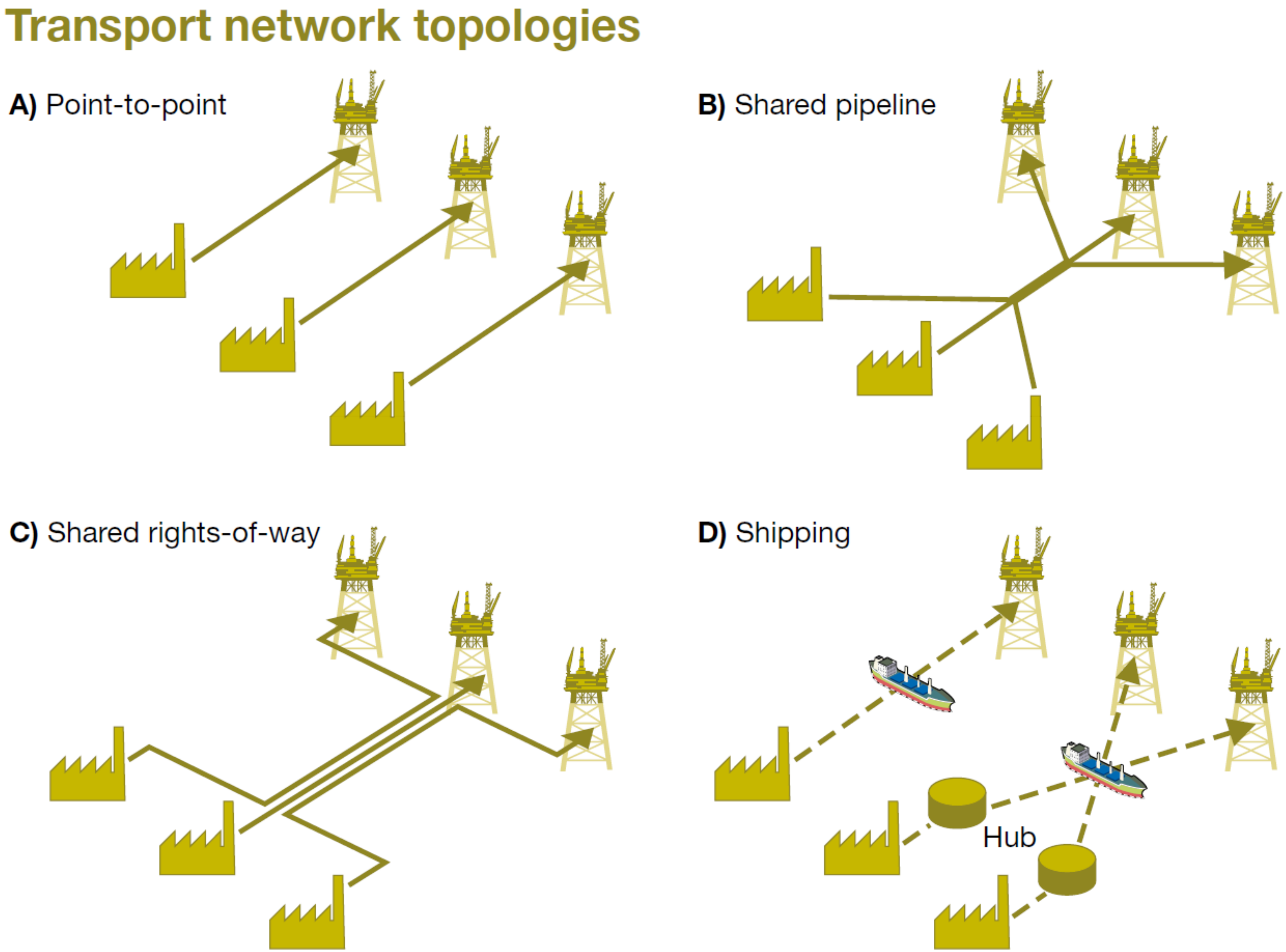
Element Energy's 2007 study for DTI quantified the economics of scenarios for CCS deployment over time for the UK and Norway:

- This identified the importance of central planning, or at least co-ordination, of development to allow shared CO_2 pipelines for clusters in the UK, particularly in the Thames, Yorkshire, North East, Forth Estuary, to give "least cost" infrastructure.
- Alternative scenarios, at high oil prices, included cross-border pipelines with UK CO_2 and Norwegian oilfields.
- Opportunities for existing oil and gas infrastructure re-use were also identified, albeit with a challenging need to match infrastructure with demand.

This work was followed up by several regional CCS studies:

- In Yorkshire this focussed on shared future-proof onshore pipeline infrastructure.
- In Scotland work has included characterising the storage opportunity, evaluating potentially shared transport infrastructure and hubs, and developing demonstration projects.
- In the Tees Valley, the focus has been on developing an anchor power CCS project with a future-proof pipeline network in the 2010s to allow high value industrial sources to connect in the 2020s.
- In the East of England, this considered supply-chain opportunities connected to the Southern North Sea storage basin.

UK stakeholders recognise that multiple transport options are relevant for connecting sources with sinks.



Element Energy *et al.* (2010) One North Sea

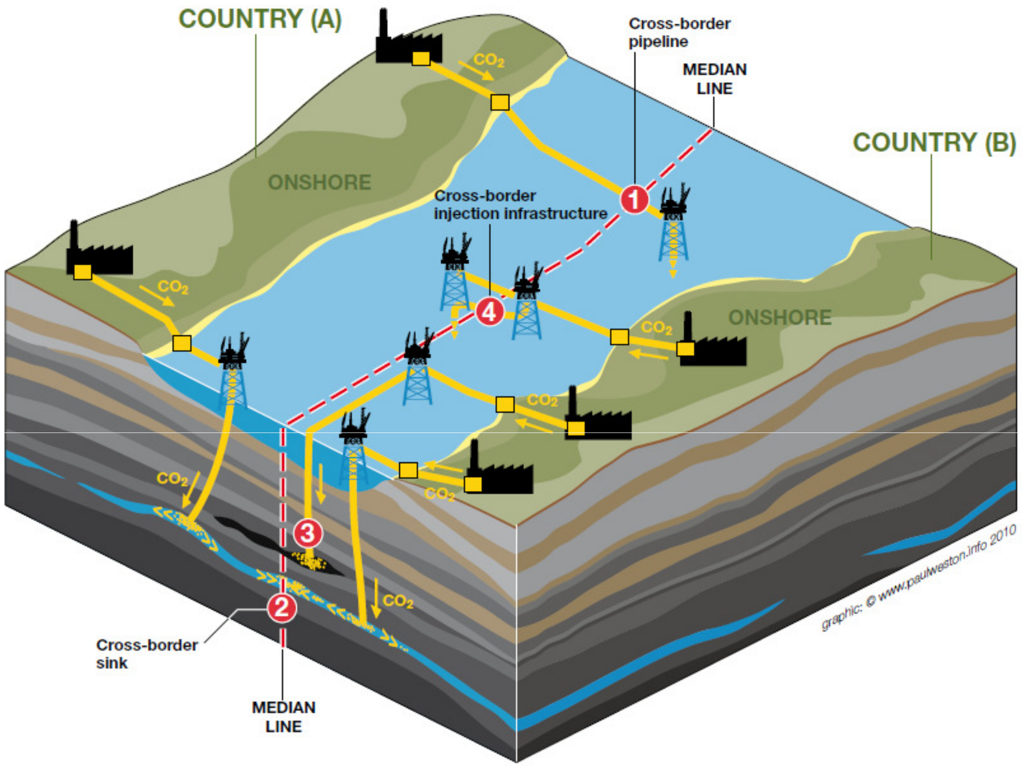
Each transport solution has multiple advantages and disadvantages.

Topology	Advantages	Disadvantages
A point-to-point	• Low up-front capex • Does not require estimation of future demand • Does not require co-ordination between multiple stakeholders • Reduces risk of low pipeline utilisation	• Average cost per tonne across all networks is higher than with shared infrastructure. • Multiple pipelines across different routes means large planning hurdles and disruption to those affected. • No flexibility to accommodate additional sources at low cost. • Could be higher capex in long term.
B Shared pipeline	• Low transport cost when operating at full capacity. • Enables connection of marginal sources. Could attract new sources e.g. industry to the region. • Lower planning hurdles and disruption since multiple sources share one trunk pipeline.	• High initial cost. May require public sector funding initially. • Risk of low utilisation if demand is lower than forecast. • Requires common entry specification for CO_2. • Complex business models. • Requires higher up-front confidence in storage availability
C Shared rights of way	• Robust and flexible • Lower planning hurdles as new pipelines are built on shared rights of way. • Capacity matched to demand.	• Transport costs are higher than for shared pipelines with same throughput. • Does not significantly reduce costs for smaller, marginal sources.
D Shipping	• Lower upfront costs than pipelines. • Flexible in the event of sink failure CO_2 can be routed to other storage sites. • Suitable for projects where multiple, small sinks may be required, or where project lifetimes are small. • Capacity matched to demand	• Very high transport costs compared to mature pipelines. • Large number of ships required to meet high demand.

It may be difficult for private transport providers and their investors to capture all the advantages and disadvantages from different investment strategies within their internal cost-benefit calculations.

Element Energy *et al.* (2010) One North Sea

Cross-border agreements – can be negotiated on a case-by-case basis or through a framework agreement.



1. Cross-border pipeline	2. Cross-border sink	3. Cross-border impacts	4. Cross-border injection infrastructure
ISSUES • Long term liability impact • Pipeline management	ISSUES • CO_2 migration • Pressure changes • Allocation rights	ISSUES • Possible compromise of nearby hydrocarbon reservoir	ISSUES • Infrastructure management

Study by NERA strongly influenced UK CO_2 transport infrastructure policy between 2008 and 2011.

- Government's role to internalise externalities, principally carbon price.
- Private sector can and does exploit economies of scale.
- Genuine uncertainties around CCS demand or performance mean anticipatory investment may not be efficient and there could be an excessive risk of asset stranding.
- If the Government publishes all policy information then it has no more information than the private sector, and risks are unchanged whoever invests.
- The regulatory regime for hydrocarbons within UKCS (with largely decentralised and market-driven), is a success. The Secretary of State is available to resolve disputes.
- Government could promote efficient investment by defining capacity on point-to-point basis to provide clear price signals, require open seasons, incorporate pipelines within planning rules and timescales.
- Government could promote efficient integration by an obligation to provide taps to ensure least cost network.
- Government could promote efficient use of existing capacity through unbundling of ownership and capacity (allowing a market price for capacity and perceived advantages for incumbents), setting tariffs so that variable usage charges should equal variable costs, and facilitate secondary capacity trading.
- Economies of scale in CCS weighed against diseconomies of scales in other parts of the energy system (fuel supply, electricity transmission).

Industry response to Government consultations on CO_2 transport and storage infrastructure

- In December 2010, the Government issued a consultation on CO_2 transport and storage infrastructure, in the context of transposing into UK law third party access requirements of the EU's CCS Directive.
- The UK planned to extend the legal framework which covers third party access to pipelines to include CO_2. This legislation prohibits the construction of a pipeline without consent, and allows a designated authority to modify the design, route or capacity, and determine the financial arrangements required. The onus is for parties to reach a voluntary agreement, but the authority can intervene if this is not possible.
- There was support for a negotiated access approach to capacity. However, there was concern that the storage capacity (i.e. maximum $MtCO_2$) should not be increased beyond the initially agreed value. DECC has modified the draft Regulations to clarify this, adding a requirement for operators to publish capacity information within one year of permit being granted and thereafter whenever the information changes.
- Some argued that that there was a risk that mandatory third party access regulation could discourage investment in the emerging industry. Perhaps more important, lack of clarity around the powers of any authority, e.g. how financial terms would be agreed with third parties creates significant uncertainties.

DECC Consultation on 3rd Party Access Agreements

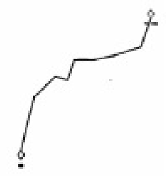
	Transport	Storage
Capacity	Easy to define (CO_2 per unit time)	Injection capacity (CO_2 per unit time) Accumulated reservoir capacity
Spare capacity	Easy to quantify with narrow uncertainty	Difficult to establish due to complex geological environment
Increasing capacity	Subject to meeting entry specification and physical constraints, CO_2 can be added up to the capacity.	Can be challenging
Third party volumes	Limited impact on other users.	Could alter the risk profile, limit future storage.
Liabilities	Once CO2 exits the pipeline, there is no expected ongoing liability or risk from third party CO_2.	Accepting third party CO2 will increase the magnitude and timescale of operator's liabilities.

Working party proposal to establish a National Carbon Storage Authority

- One concept is the establishment of a regulated monopoly, the National Carbon Storage Authority (NCSA).
- Could be a non-government body, similar to Nuclear Decommissioning Authority, or it could be a government-owned not-for-profit company.
- Prime function is to facilitate the movement of CO_2 from point sources to storage sites, and to ensure the availability of storage sites.
- Duties to include offering fair access and long-term contracts to installations wishing to dispose of CO_2.
- Organise tenders for provision of pipeline capacity, storage and monitoring services
- Commission survey work on stores
- Income initially from a power market levy or directly from Government.
- To date there has been no published analysis of this option (e.g. quantitative modelling of the impacts).
- In a recent DECC consultation, support for this mechanism was mixed.

In the Tees Valley, sources are densely clustered onshore and an integrated transport networks could be developed for a wide range of CCS scenarios.

Description	Metric	Anchor Only	Small	Medium	Large
Environmental effectiveness	$MtCO_2$/yr captured	5	14	22	26
Financeability	Combined capex for capture, transport and storage	£650 m	£1.8 bn	£3.0 bn	£4.2 bn
Cost effectiveness	Average capture cost £/tCO_2 abated	£18	£25	£29	£36
	Transport £/t CO_2	£12	£7.30	£7.40	£7.40
	Storage £/t CO_2	£14	£13	£12	£12
	Total £/tCO_2 abated	£44	£45	£48	£55
Flexibility and stability	Ratio of sites capturing CO_2: sites not capturing	1:35	5:30	8:27	35:0
	Ratio of CO_2 emissions captured: emissions not captured	5:21	14:12	22:4	26:0
Lead time / complexity	Number of sources connecting	1	5	8	35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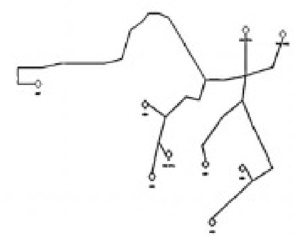
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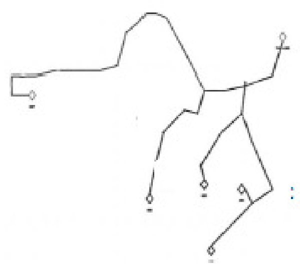
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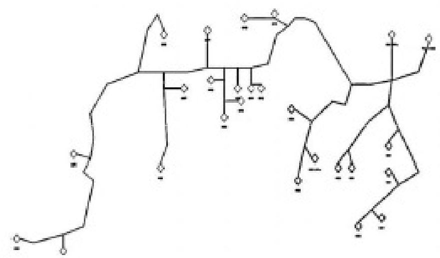
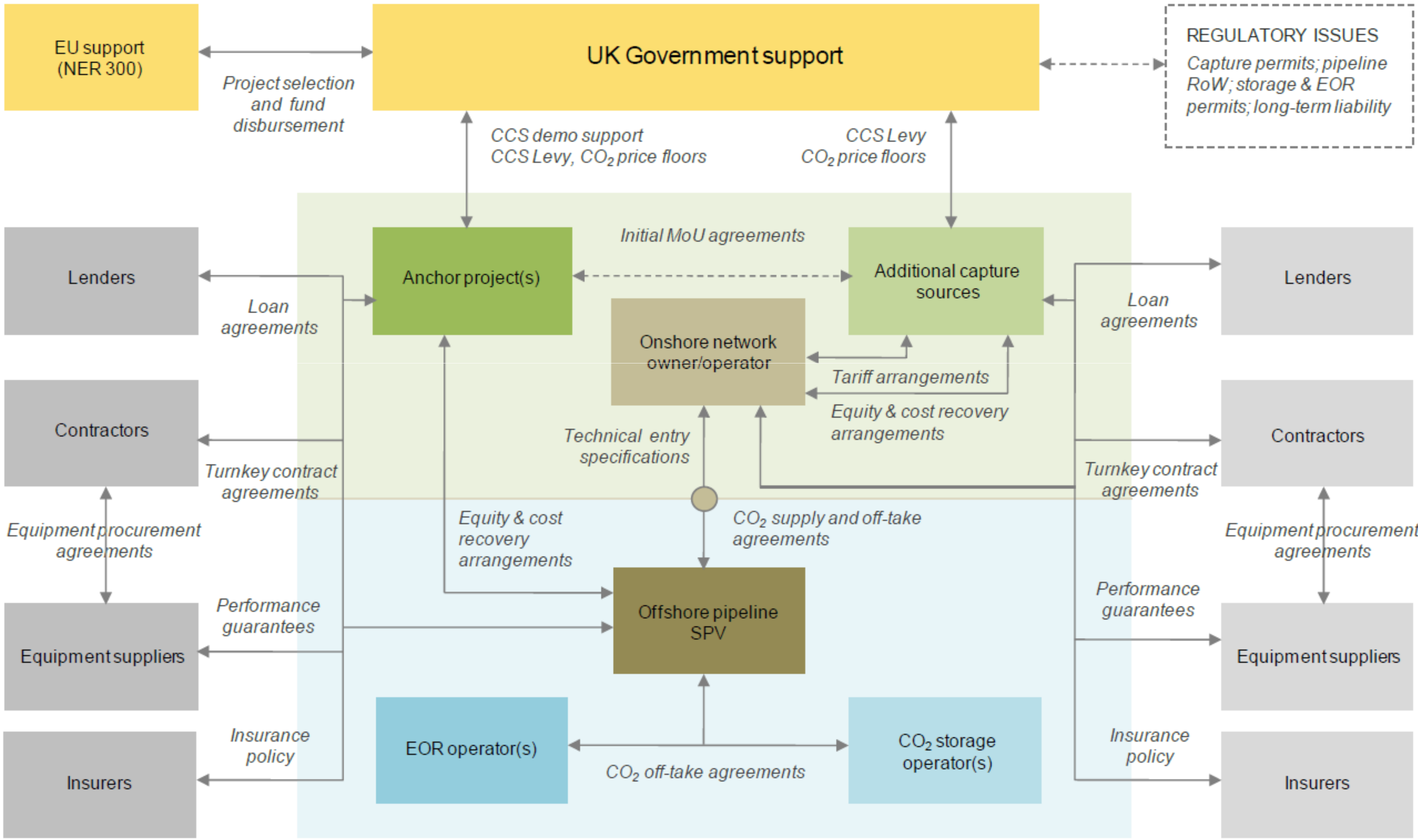

"Large"

Above, illustration of onshore network topologies.
Left, key performance indicators for the different networks, showing how the challenge of investment increases with network capacity.
Reproduced from Element Energy et al. (2010) The investment case for a CCS network in the Tees Valley.

Pipeline investors require firm arrangements with anchor and future suppliers and stores, under-pinned by credible performance guarantees, insurance and finance agreements .



For a CO_2 pipeline network supporting power and industrial sources, a Government -Industry Joint Venture aligns parties and mitigates multiple counter-party risks.

Table 8 Assessment of CCS network project structure options

	Commercial risk profile			Likelihood of funding	Likelihood of success
Structure option	Policy & regulatory	Technical & operating	Economic & market		
Laissez-faire	Significant without government support and intervention	Significant, and compounded by multiple parties and interests ('project on project' risk unmanageable). Structure very unstable.	Significant, and compounded by multiple parties and interests ('project on project' risk unmanageable)	Extremely unlikely	Extremely unlikely
Centrally planned	Effectively addressed due to government acting as project sponsor as well as primary policy-maker / regulator	Technical risks remain but can be underwritten by government; key operating risks can also be managed through use of government supply and demand guarantees	Effectively addressed as government has capacity to create new regulation and economic framework to support objectives, and enforce payments in cash-flow model	Extremely high, due to government involvement and commitment (subject to incentives and project terms)	Contingent on the development of new government policy and regulation; approach at odds with current UK policy approach
Single entity led	Significant without government involvement, project guarantees and support.	'First of kind' technical risk remains overriding barrier to attracting commercial debt. Non-supply and demand risks can be addressed through design of suitable contractual arrangements.	Significant, exposed to all non-supply and demand risk due to limited involvement of underlying users of network ("midstream issues").	Challenging, and likely based on project sponsor's credit-worthiness and access to capital (corporate finance). Few corporate sponsors likely to have sufficient profile.	Unclear, and dependent on profile and track records of project sponsor in addition to level of government support
JV consortium	Significant without government involvement, project guarantees and support.	'First of kind' technical risk remains overriding barrier to attracting commercial debt. Non-supply and demand risks can be addressed through design of suitable contractual arrangements	Effectively addressed, as equity involvement ensures commitment of partners with interest in underlying assets i.e. direct link to network users.	Likely to be promising, subject to developing a strong corporate 'coalition of the willing' with good track records and credit ratings	Dependent on level of equity involvement and ability to de-risk counterparty commercial linkages. Proven track record on Teesside in building investment consortia and facilities-sharing.

One issue identified is the need to reconcile diverse business models and capacities

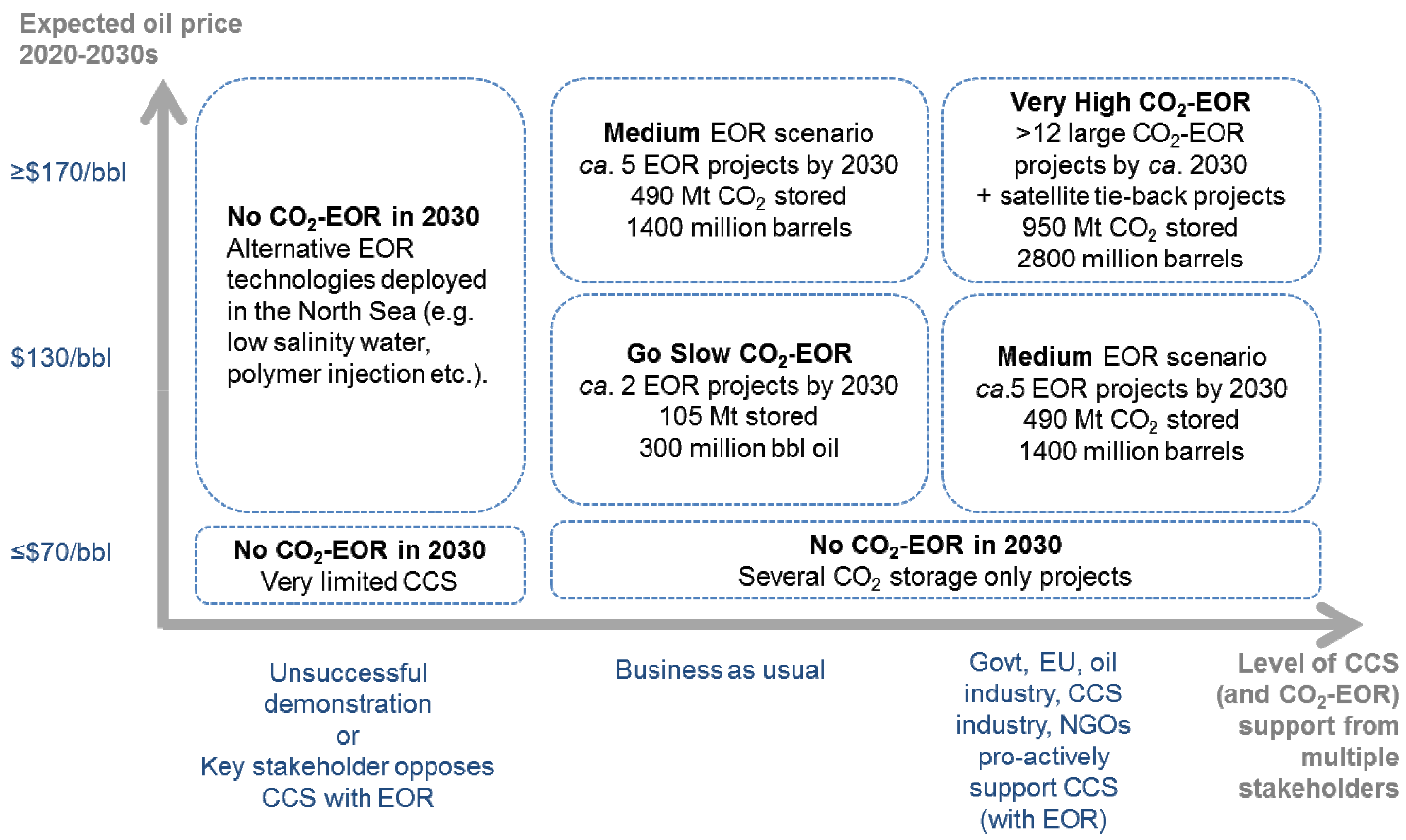
Key risks identified in the SCCS 2008 study are revenue risk, costs, and technical/operating risks:

- Revenue risks arise from the power market, government policy, carbon market and, in the case of EOR, oil price.
- Cost risks include financing rates, capex increases, opex increases, and need to replace equipment.
- Technical risks include site availability, flexible running, system integration, supply chain, and operational performance (i.e. efficiencies)
- Co-ordinated action by Government, Regulators, Industry and companies developing CCS project are required to mitigate these risks.

Within a given CCS project,

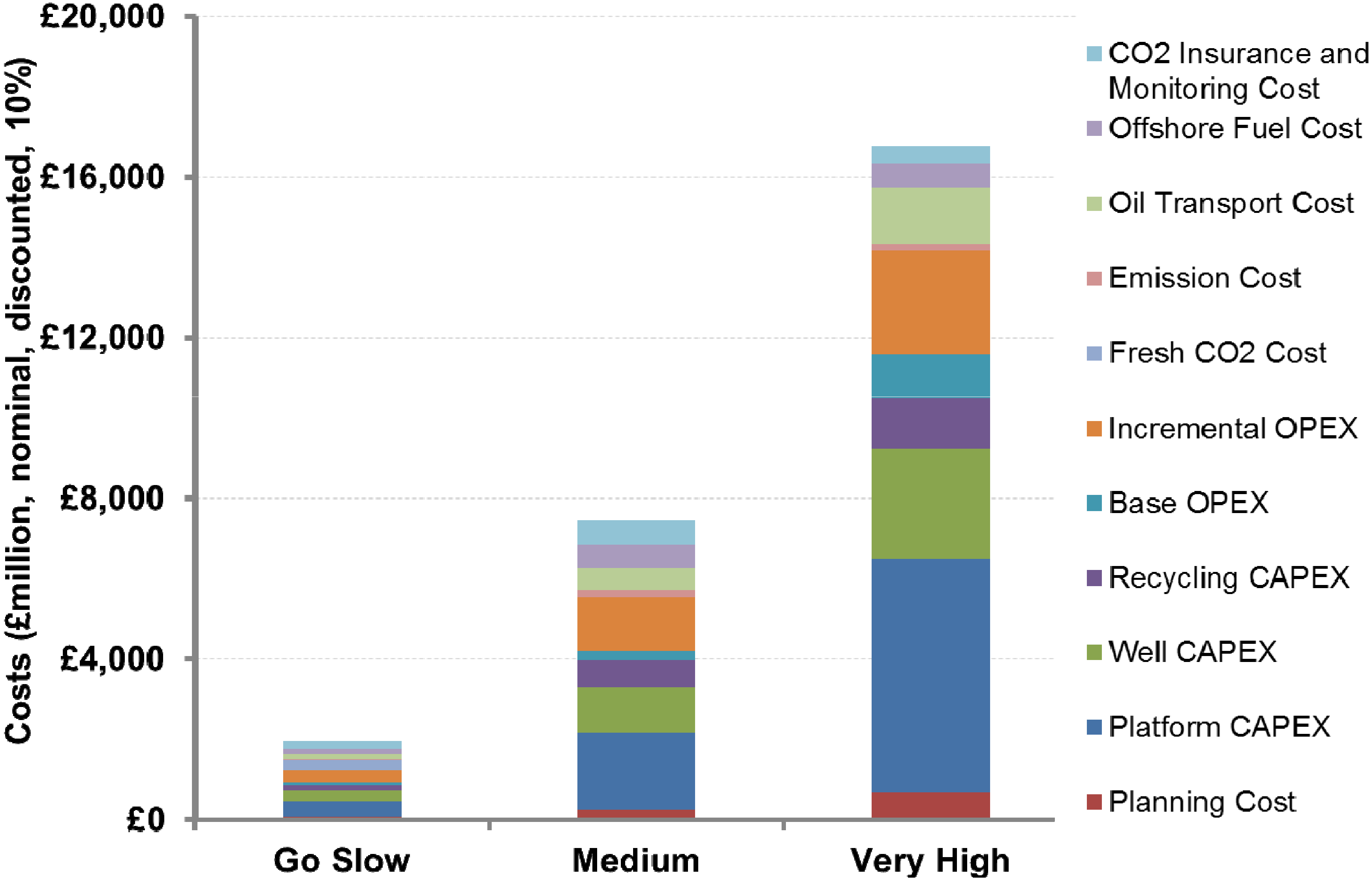
- Fully-integrated models help share risks and information. However financing structures, hurdle rates, risk-taking and ownership models for the power, industrial, pipeline and offshore hydrocarbon production/storage industries are very different.
- Take-or-pay or supply-or-pay or fixed+variable contracts can provide maximum certainty to components within the chain, but these structures fails to align risks fully across the chain. However, the penalty for non-supply or non-acceptance may need to be different (higher) than the average tariff in some scenarios, e.g. payment of the carbon price.

Interest in CCS combined with CO_2-Enhanced Oil Recovery is dependent on oil price. The highest scenarios could see *ca*. 1Gt CO_2 permanently stored.



Potential scenarios for CO_2-EOR investment in the North Sea Basin (includes UK, Norway and Denmark oilfields) as described in Element Energy *et al.* (2012) The impacts of CO_2-EOR on Scotland.

The requirement for additional platform infrastructure for CO_2 recycling facilities is a major feature in the costs of CO_2-EOR projects.



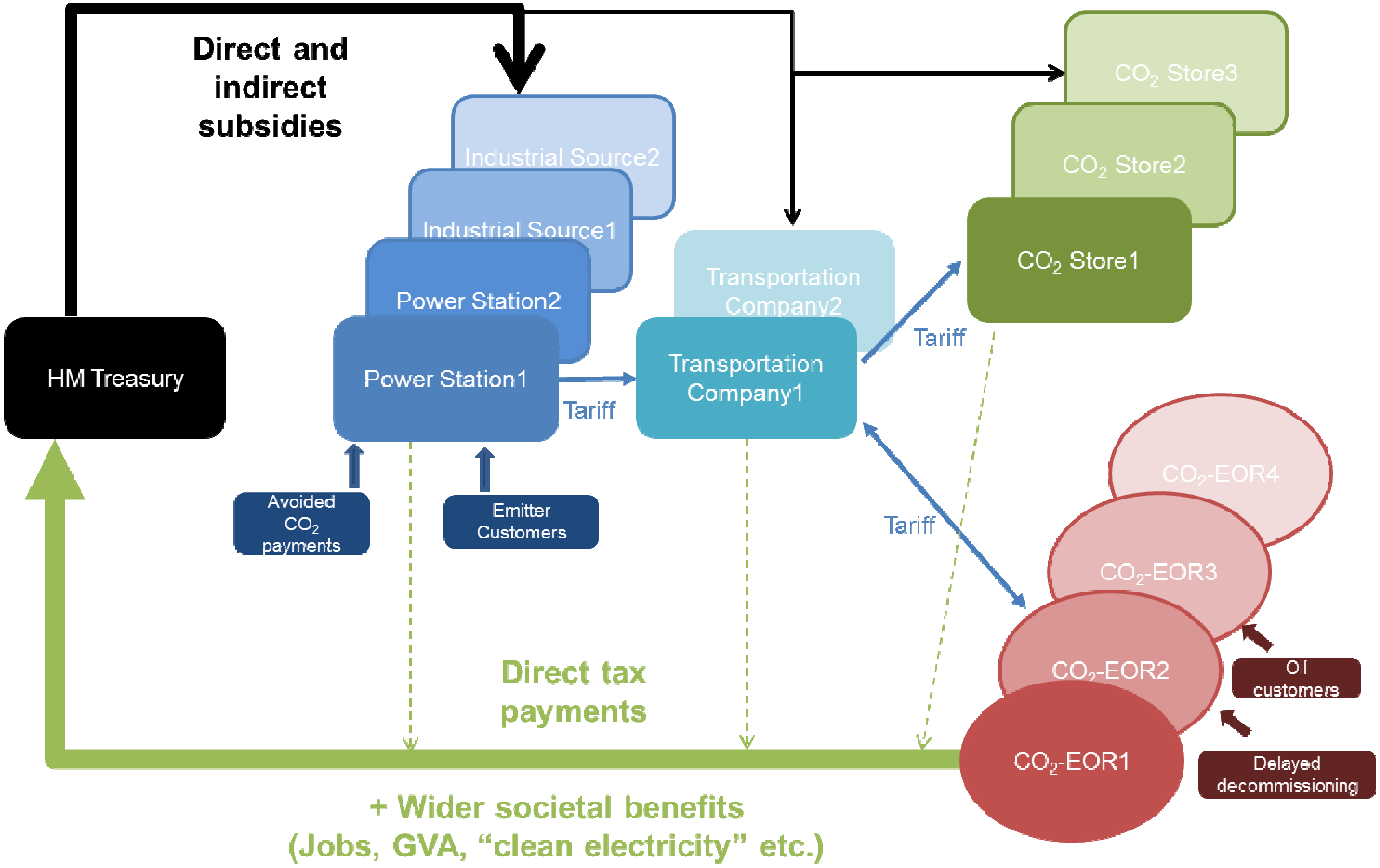
Cost breakdowns corresponding to the potential scenarios for CO_2-EOR investment in the North Sea Basin (includes UK, Norway and Denmark oilfields) as described in Element Energy *et al.* (2012) The impacts of CO_2-EOR on Scotland. N.B. excludes capture and transport.

The majority of the benefit from CO_2-EOR deployment accrues to national Governments, through increased tax receipts.

Scenario	Country	Cumulative EBIT (discounted at nominal 10%, excl. decomm.)	Cumulative Developers NPV (discounted at nominal 10%, post-tax and incl. decomm.)	PV of capex (discounted at nominal 10%)	Average discounted profitability	Average Unit Development Cost £/bbl	Incremental production / million barrels	Cumulative National Tax receipts (discounted at nominal 10%)
Very High	**UK**	**£13 bn**	**£ 4.7 bn**	**£5.6 bn**	**0.84**	**£11**	**1,085**	**£ 8.9 bn**
	NO	£11 bn	£ 1.5 bn	£4.8 bn	0.32	£14	1,397	£9.9 bn
	DK	£24 bn	£ 1.5 bn	£1.2 bn	1.24	£9	325	£3.2 bn
	UK+NO+DK	£48 bn	£7.7 bn	£11.5 bn	0.67	£12	2,807	£22 bn
Medium	**UK**	**£3.2 bn**	**£0.94 bn**	**£2.11 bn**	**0.45**	**£11**	**420**	**£2.5 bn**
	NO	£3.1 bn	£0.33 bn	£1.16 bn	0.29	£8	608	£2.8 bn
	DK	£6.3 bn	£0.61 bn	£1.08 bn	0.56	£10	328	£1.8 bn
	UK+NO+DK	£12.5 bn	£1.88 bn	£4.35 bn	0.43	£9	1,356	£7.1 bn
Go Slow	**UK**	**£0.71 bn**	**£0.22 bn**	**£0.45 bn**	**0.5**	**£10**	**137**	**£0.56 bn**
	NO	£0.00 bn	£0.00 bn	£0.00 bn	0	£0	0	£0.0 bn
	DK	£0.71 bn	£0.15 bn	£0.50 bn	0.3	£9	163	£ 0.67 bn
	UK+NO+DK	£1.42 bn	£0.38 bn	£0.95 bn	0.4	£10	300	£1.2 bn

The table shows nominal developer post-tax NPV and national Government receipts from a CO_2-EOR network for the UK, Norway and Denmark when oil prices are $90/bbl. Taken from Element Energy *et al.* (2012) The impacts of CO_2-EOR for Scotland

CO_2-EOR developers argue that the tax receipts from EOR should be used to fund wider investments in CCS.

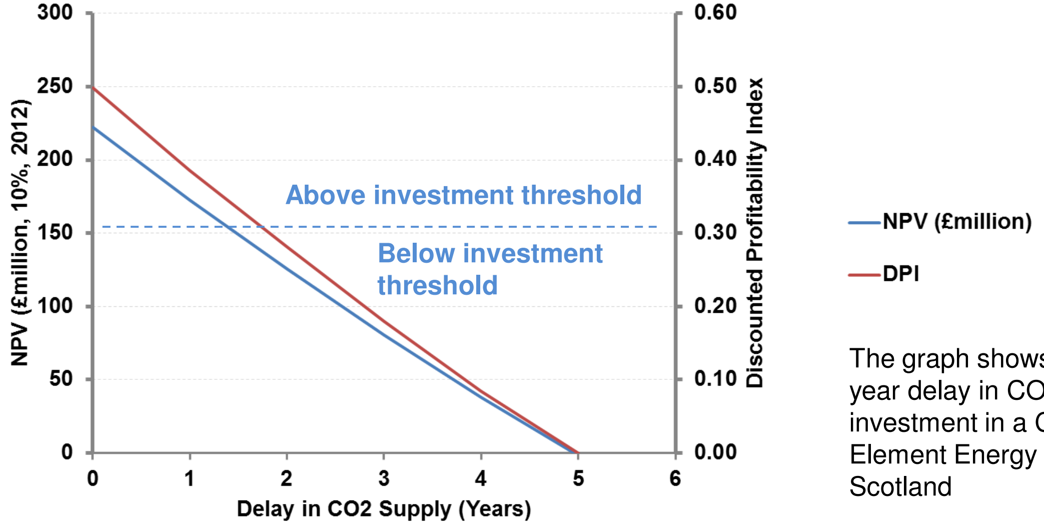


The scheme suggests that, under favourable scenarios, tax receipts should support investment across CCS. Image taken from Element Energy *et al.* (2012) The impacts of CO_2-EOR for Scotland

CO_2-EOR investments may struggle to compete with alternative oil industry investments, as there are significant downside commercial risks.

Revenues can fall below “acceptable” levels if any of the following occur

- Oil price falls
- Reservoir performance with CO_2 is below expected (i.e. lower or slower oil recovery, low CO2 storage capacity)
- Need for more wells or for more widely spaced wells
- High tax rates
- Offshore costs increase
- Oil companies have to pay for CO_2
- The cost of financing increases
- There is a delay in CO_2 supply e.g. due to problems onshore or with pipeline.

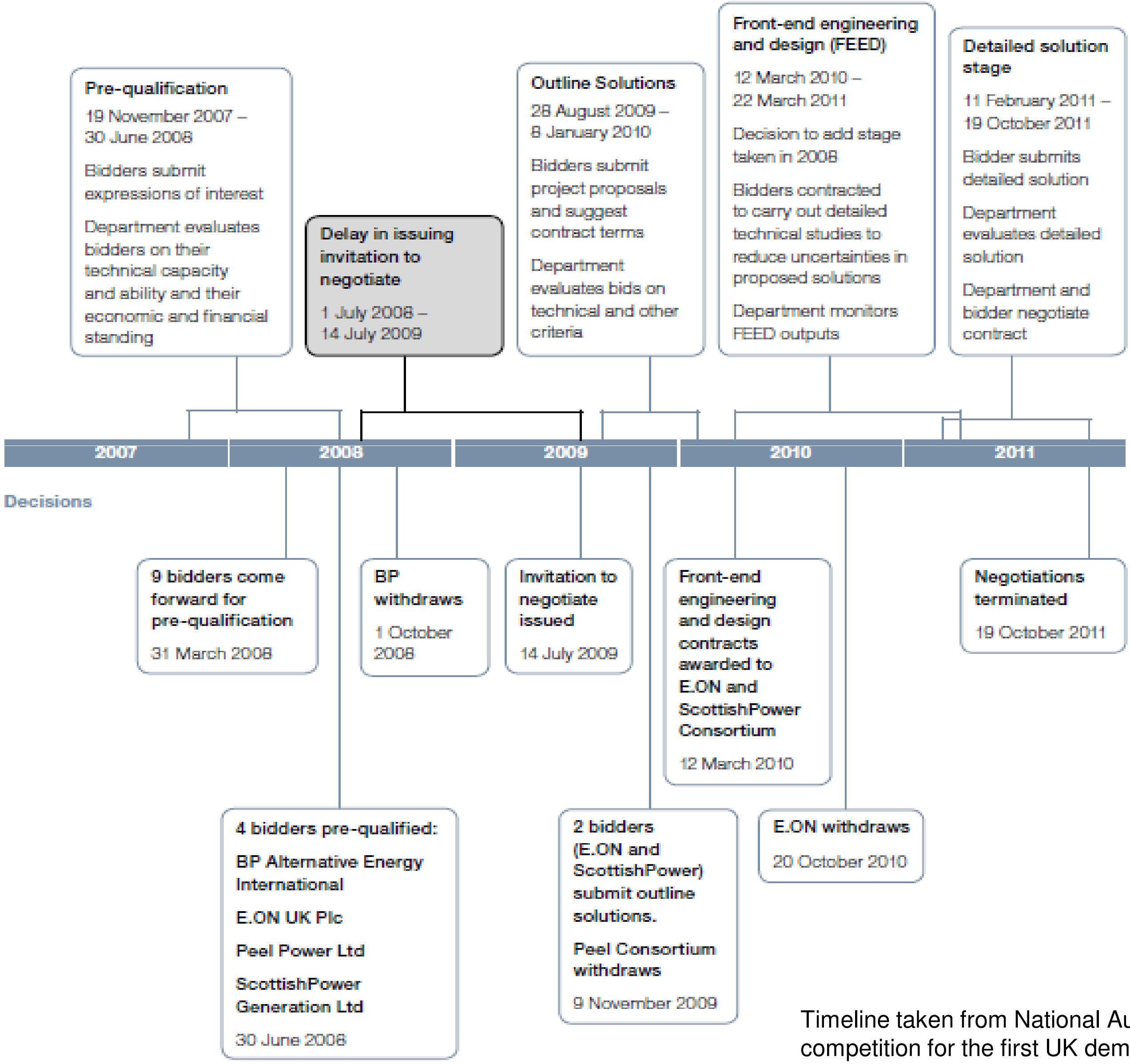


The graph shows that a plausible threat of more than a two year delay in CO_2 supply could scupper oil company investment in a CO_2-EOR project.
Element Energy *et al.* (2012) The impacts of CO_2-EOR for Scotland

The Department for Business, Enterprise and Regulatory Reform launched the UK's first CCS competition in 2007.

- In the early 2000s, BP was looking for opportunities to limit their decommissioning liabilities for the Miller oilfield. The BP/SSE DF1 proposal emerged, for a pre-combustion gas power station at Peterhead, with CO_2 transported through an existing offshore gas pipeline to the Miller oilfield for CO_2-enhanced oil recovery. The project went as far as FEED and Environmental Impact Assessment in 2006.
- However this industry-led proposal did not fit in with the UK's energy policies at the time, and it was not possible to agree subsidy with DTI before the Miller oilfield had to be abandoned as it was no longer economic to operate.
- Following the 2007 Energy White Paper, the potential need for CCS was formalised. BERR introduced its first CCS competition in November 2007 for a project to be operational by 2014.
- At the time, market analyses of the for CCS pointed to the largest potential global opportunities as coming from retrofitting capture ready coal plants. Therefore, the competition was limited to post-combustion capture from coal power stations. A size limit of 300 MW was chosen as the most efficient in demonstrating the new technology, so that the next step could be commercial roll-out. No support was explicit for "over-sized infrastructure".
- By 2011, the only remaining bid was for a retrofit capture at Scottish Power's Longannet power station, re-use of an existing onshore gas pipeline by National Grid with low pressure CO_2 to St. Fergus. The CO_2 would then be compressed and pumped offshore by pipeline to Shell's depleted Goldeneye gas condensate field for permanent storage.

9 bidders submitted EOIs to BERR, 5 were disqualified. By 2010, 3 of the 4 qualified bidders had withdrawn.



- The total cost of the competition was £64m.
- Of this, £40 m was spent on FEED studies.
- The National Audit Office recognises that the overall sum spent is relatively small compared to the project scale and potential benefits.

Timeline taken from National Audit Office (2012) CCS: Lessons from the competition for the first UK demonstration

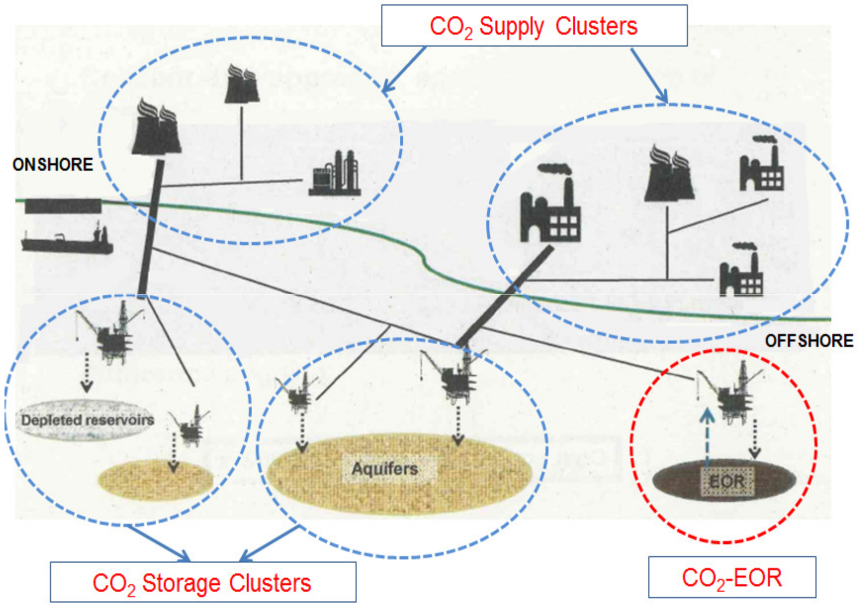
Analysis by the National Audit Office provided insights into why the CCS competition failed

- Procuring individual CCS projects is a challenging high-risk undertaking, particularly in the context of wider energy and carbon market reforms.
- Alternatives to a single demonstration competition were not reviewed carefully, and the criteria for assessing outcomes were not clear.
- With a requirement for Government capital funding, there would be a need for early engagement by BERR/DECC (i) on the commercial risks involved and their impacts on costs and (ii) the source and amounts of funding available from Treasury for capital and operating costs.
- The procurement approach restricted negotiations to the project specifications that were set at the outset, which were set very narrowly (i.e. 300 MW post-combustion coal). This limited the number of bidders and the competitive tension.
- Early threats to value-for-money were identified but opportunities to change strategy were not taken.
- The industry trade association (CCSA) agreed with the NAO's conclusions. In particular they have consistently argued that a compelling commercial case must involve clear support for both capital and operating costs, and should be forward looking, i.e. paving the way for wide scale roll-out.

Latest UK CCS policy

- The Climate Change Act commits the UK to an 80% reduction in annual CO_2 emissions by 2050 compared to 1990.
- In the UK, the Department for Energy and Climate Change has committed to support the commercialisation of CCS with the objective this is cost competitive by the 2020s. DECC's vision for CCS in the 2020s includes the use of shared pipeline infrastructure connecting depleted fields, aquifers and CO_2-EOR projects.
- The latest competition is backed by up to £1bn of capital support, performance incentive for decarbonised electricity generation from contract-for-difference feed-in tariff for CCS, and CO_2 emissions penalised through Carbon Price Floor if not sufficient through the ETS.
- Regulatory measures are also in place on new coal plant, with emissions performance standards included in the draft energy bill.
- Thrust is for private ownership and financing of CCS, although public finance, economic regulation, regional infrastructure and potential to assist through the Green Investment Bank are under review. Government does not support detailed planning of electricity generation.
- 3rd party transport and storage access arrangements in place.
- Regulation in place for storage licensing and leasing from Crown Estate; one permit granted so far (GoldenEye).

DECC OCCS Vision for CCS in the 2020s



UK Govt also supports a wide range of academic research connected to CCS, and international activities such as the North Sea Basin Task Force.

Shortlisted projects within the UK CCS commercialisation programme

Four projects have been shortlisted to progress through to the next phase of the UK's CCS commercialisation programme. These are:

- Captain Clean Energy Project: A proposal for a new 570MW, fully abated coal Integrated Gasification Combined Cycle (pre-combustion) project in Grangemouth, Scotland with storage in offshore depleted gas fields or aquifer. Led by Summit Power, involving Petrofac (CO_2 Deepstore), National Grid and Siemens.
- Peterhead: A 340MW Post-combustion capture retrofitted to part of an existing 1180MW Combined Cycle Gas Turbine power station at Peterhead, Scotland. Led by Shell and SSE. Storage at the Goldeneye field in the central North Sea
- Teesside Low Carbon Project: A Pre-combustion coal gasification project (linked to c330MWe net power generating capacity fuelled by syngas with 90% of CO_2 abated) on Teesside, North East England with storage in a depleted oil field (potentially with EOR) and saline aquifer in the central North Sea. A consortium led by Progressive Energy and involving GDF SUEZ, Premier Oil, and BOC.
- White Rose Project: An Oxyfuel capture project at a proposed new 304MW fully abated supercritical coal-fired power station on the Drax site in North Yorkshire. Led by Alstom and involving Drax, BOC and National Grid. Storage probably in an aquifer or depleted gasfield in the Southern North Sea.

The Crown Estate is the owner for storage capacity in the UKCS and Agreement-for-Lease and Lease structures have been drawn up assuming a landlord/tenant arrangement

Agreement-for-lease
(Covers exploration phase)

THE CROWN ESTATE

DATED 201●

HER MAJESTY THE QUEEN (1)

and

THE CROWN ESTATE COMMISSIONERS (2)

and

[ ] (3)

and

[ ] (4)

AGREEMENT FOR LEASE

relating to a Carbon Dioxide storage site upon and under the bed of the sea

Estates Ref: ●
Legal Ref: ●

CONTENTS

Lease
(Covers operational phase)

THE CROWN ESTATE

DATED 201●

HER MAJESTY THE QUEEN (1)

and

THE CROWN ESTATE COMMISSIONERS (2)

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LEASE

relating to the right to store Carbon Dioxide under the bed of the sea

Estates Ref: ●
Legal Ref: ●

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Norway – first CCS mover, through a CO_2 tax. Future CCS growth directed by the State.

- Offshore CO_2 tax led to commercially viable CCS investment by Statoil resulting in Sleipner and Snohvit projects based around injecting CO_2 separated from natural gas.
- These are “simple” independent systems with a single capture and single store.
- During mid-2000s there was considerable interest in offshore CO_2-EOR, but without CO_2 available, these projects collapsed. Recent attention has been focussed on offshore aquifer storage instead.
- Gassnova has been established as a fully-funded organisation that manages the State’s interest in CCS. Currently this is paying for capture test centre at Mongstad, and design work for a full scale post-combustion gas power CCS project linked to storage in aquifers.
- Long-term Norway may profit from providing CO_2 storage for Germany etc.
- Gassnova has been working with the Norwegian Petroleum Directorate to characterise Norway’s storage potential in detail. A challenge is a large amount of undiscovered or discovered-but-not-yet-exploited hydrocarbon fields, creating exclusion areas where no CCS investment can occur.
- State Aid clearances have been granted for specific CCS projects, on the grounds that these would not have been viable without the aid and it helps meet Europe-wide objectives. One allowed mechanism is for Gassnova to be paid the prevailing ETS price by emitters, and for Gassnova (i.e. the State) to pay the incremental CCS cost relative to the carbon price.

Netherlands – emphasis on masterplanning and co-ordination of stakeholders.

- Strong academic and industry interest in CCS in the Netherlands.
- EBN is charged with developing energy resources and oversees the exploitation of the deep sub-surface in a manner that is profitable for Dutch society. It is involved in storage deployment, but actual investments to date are unclear.
- Gasunie as the gas grid system operator is interested in developing CO_2 pipeline infrastructure. Actual investments to date are unclear.
- First steps have been made towards an "integrated national masterplan" for storage.
- Expectation that Government will act as an instigator, supervisor or owner.
- Existing efforts (Rotterdam Climate Initiative, Nord Nederlands group) involve public sector coordination of industry stakeholders to carry out feasibility studies, develop a vision, and factor in the regional economic impacts within the investment case.
- Some concerns over the transitions between hydrocarbon production and storage, liabilities around abandonment, and to date few E&P operators are interested.
- Emphasised need for timely assessment of storage reservoirs.
- Experience of local hostility to onshore storage (Shell's Barendrecht project) means public acceptance is now a key risk to deployment of those sites, even with strong industry and political support. Alternative offshore sites are more expensive for transport and storage but are now the main candidates.
- Progress has been mixed, and there appears little progress since 2011, possibly linked to Euro crisis, change in Government etc.

North America - “market-led” approach, driven by strong contribution of EOR.

USA

- Multiple strands of existing activity related to CCS and EOR.
- Considerable public grant-based support for demonstration administered by DoE, with a few full chain projects passing Final Investment Decision.
- Key driver (in the absence of controls on CO_2 emissions or incentives for decarbonised electricity) is CO_2-EOR, which is regarded as a mature technology.
- Conventional CO_2-EOR uses “naturally occurring CO_2” and was supported by federal and state tax breaks.
- Regional partnerships (industry, politicians, NGOs, geologists) produce updated maps of storage potential annually.
- No serious policy attempts at integrated pipeline infrastructure although several studies have identified opportunities for this.

Canada

- CCS expected to play major role in Canada, with significant role for EOR.
- Future oil sands likely to generate new CO_2
- Existing Boundary Dam project (pipeline and wells) driven by EOR
- Alberta and Saskatchewan have provincial legislation for carbon sequestration and expanding regulatory frameworks for CCS.
- Alberta Energy Research Institute is drilling test wells to understand local geology.
- Onshore infrastructure in sparsely populated areas.
- Potential for extensive co-operation with US.

Middle East and Brazil have different experience of developing CCS coupled to EOR

Middle East experience

- Limited "climate" drivers although "trophy" projects are interesting.
- However significant EOR potential, well understood geology, and growing demand for power and energy-intensive industries.
- Three driving countries are Qatar, UAE and Saudi Arabia. In these three countries, the decision makers are highly aligned (i.e. Royal Families own organisations which own, plan, operate, and regulate activities of oil companies, pipelines, subsurface, refineries, power generators etc. and collect revenues). Even still, no project has passed FID.
- Inclusion of CCS within CDM brings extra finance.
- No evidence of any CCS masterplanning within countries and no interest seen in cross-border projects.

Brazil

- Force developers of CO_2-rich oil and gas fields to implement CCS as a condition of license.
- Petrobras (with BG Group) is carrying out trial CO_2 injections of produced CO_2 into an aquifer or for EOR at the Lula field.
- Difficult to mandate CCS, as this might make it ineligible for Clean Development Mechanism funding, which is only for additional projects.

Asia CCS policies to stimulate domestic industry with a view to export potential as well as hedging industrial sector against future emissions regulation

Japan

- Ministry of Economy, Trade and Industry currently funding a demonstration project capturing 100,000tCO2/yr and injecting into an offshore aquifer and has a target of 100 Mt/yr from 2020.
- Japan CCS Company Ltd is undertaking storage evaluations. Comprises 29 major Japanese power and energy-related companies to jointly develop carbon capture and storage technologies to overcome technological difficulties for commercialization.
- Mitsubishi Heavy industries developing capture technology
- Closure of nuclear likely to increase use of fossil fuels but is it credible that "risk aversion" to nuclear would lead to support for CCS…?

Korea

- New law on low carbon growth
- Aims to have commercial CCS by 2020
- Two fully integrated projects under development.
- Government has commenced storage assessment
- Government exploring shipping CO_2 concept.
- Strategic interest in supporting engineering firms such as Samsung in developing CCS through export credit agency.

China

- Apparent current support for CCS demonstration activity.
- Opaque as to long-term infrastructure strategy
- Support for exports through export credit agency finance.

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  - Large oil transmission pipelines
  - Gas transmission pipelines and systems
  - Onshore electricity transmission
  - Offshore electricity transmission (for offshore wind)
  - Water and sewerage infrastructure
  - Waste Regulations
  - District Heating Networks
  - Major transport projects
  - Nuclear Decommissioning Authority
  - Telecommunications (Mobile and Broadband)
- ❑ Potential market failures for CO_2 transport and storage

Extensive CO_2 pipeline network in the US, driven by private sector exploitation of EOR potential

- Started in 1970s, currently, 3900 miles of CO_2 pipeline network exists transporting 30-65 MtCO_2/yr, producing 6% of US crude oil production
- Private, contract or common carriage regulatory regime
- CO_2 owned by pipeline owner or third party
- No tariff oversight or regulation although some dispute resolution (this is rare)
- Siting determined by state or local governments
- Unregulated entry or exit
- No federal regulations on CO_2 quality, subject to HSE. Over four decades of operation there have been no serious accidents or injuries reported.
- CO_2-EOR has been encouraged by federal and state tax breaks. The costs of CO_2-EOR are much lower onshore than offshore and the technology is considered mature.

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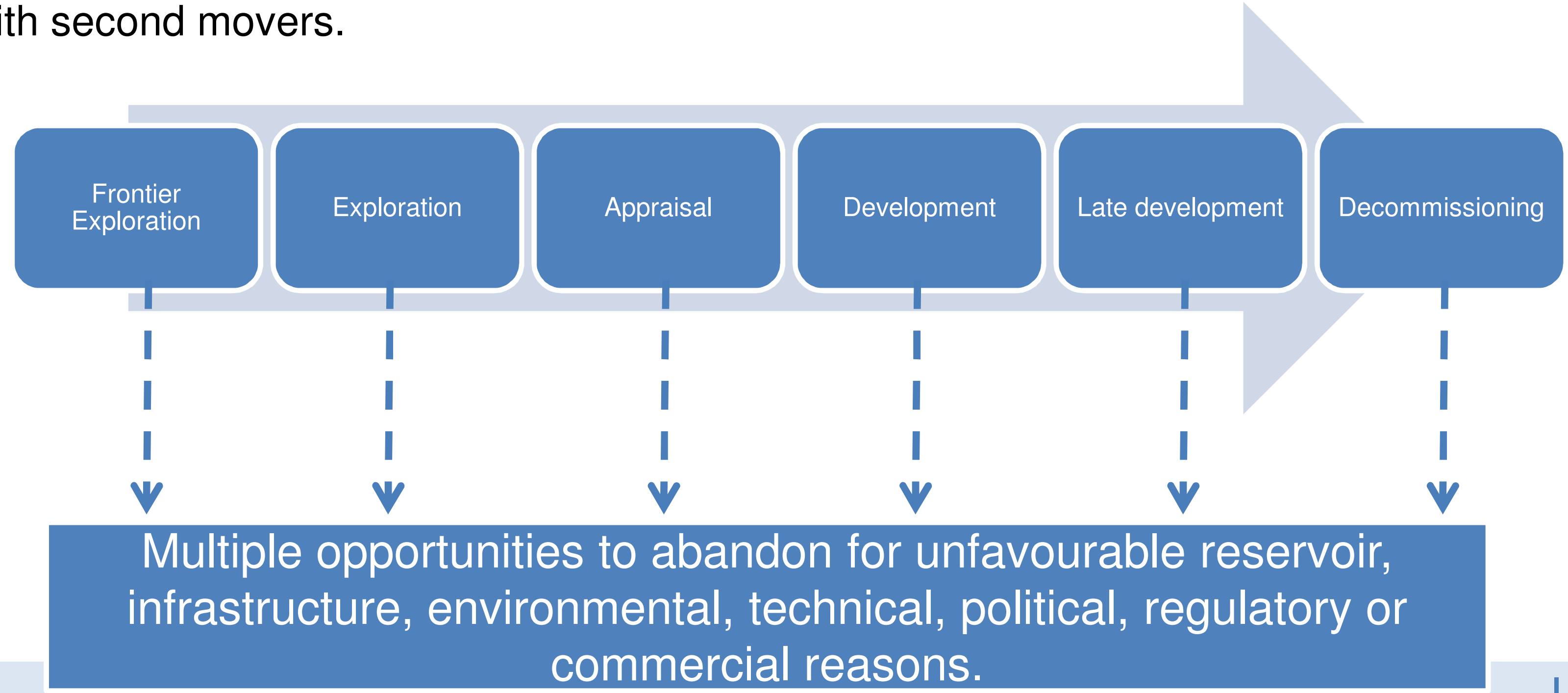
Upstream oil and gas exploration, appraisal and production

- First episode of basin exploration is controlled by technical and political factors.
- Technical factors include size and access, and potentially need for new technologies.
- Weak political drivers (or political conflicts) can lead to oil and gas basins languishing for decades without being exploited.
- Key challenge is for oil and gas companies to obtain "acreage", i.e. the rights to explore and subsequently produce petroleum from an area. States can sequester this.
- Strong first mover advantages, e.g. able to derive revenue from sharing infrastructure with second movers.



Oil and gas industries operate with different economics.

- For the oil industry, there are deep, liquid spot and future markets in a wide range of oil blends and downstream products, worldwide. A wide range of options for oil storage and transport exist. Therefore it is possible to determine the value of any specific amount, blend at any current or future location or time with high accuracy.
- In contrast, for gas, although the costs of production and distribution can be established, the value can usually only be established at the point of consumption. It can be difficult to establish intermediate prices, unless there is a very mature market (e.g. the UK has a National Balancing Point).
- It is likely to be difficult to establish distinct "values" for CO_2 at different points of a network. Within an integrated network, CO_2 used for oil recovery could have a "positive" value, whereas CO_2 for storage would always have a negative value. Although "vented" CO_2 would have the same climate impact wherever it occurs, accounting principles may result in distinct penalties (e.g. onshore vs. offshore may be counted differently within carbon price floor).
- The economic driver for oil production is much larger than is likely to be ever the case for CO_2 storage. For example, an oil price $100/bbl corresponds to $700/tonne of oil produced before expenses and taxes. Even in "worst case scenarios" of low oil prices, high costs of production and high oil taxes, the commercial driver for oil production could still be an order of magnitude higher than potential CO_2 storage revenues on a per tonne basis. This would allow for a high level of risk taking while still providing returns to oil shareholders. [Crude oil and dense/supercritical phase CO_2 have similar densities, implying broadly similarly sized infrastructure.]

The importance of licensing rounds in oil and gas field development

- Ministries for energy or State oil companies organise licensing rounds. Approaches include a simple cost for a given acreage, or a technical bid requiring the company to collect seismic and well data. In the UK, DECC is responsible for licensing, exploration and regulation of oil and gas, although HSE must approve every well before it is drilled.
- Terms of a license include length of time before the bid reverts to Government or other owners, or if a discovery is made, the process by which it is appraised and developed. The licensing terms will change from round to round vary across the world.
- License will include escalating annual fees to encourage early exploitation.
- It is in the interest of the licensing authority and company to exploit the finite resource to maximise delivery of energy and income, therefore there is a fine balance. Typically there is a trade-off for equity ownership by the State, taxes or royalties on petroleum produced, and tax reliefs for investment.
- License areas can come in all shapes and sizes – they can be bounded by geographic features, infrastructure, or tied to an arbitrary grid (creating quadrants which are in turn divided into blocks).
- Ownership changes throughout the life of a field, driven by commercial considerations, but is often a JV consortium– to spread risk and reward, and also to maximise technical capacity. The valuation at each transfer is developed through extensive due diligence activity.
- A few large area fields that straddle blocks are “unitised” . In some cases vertically stacked reservoirs can have different ownerships (e.g. Britannia). Mostly however responsibilities for a given area are well defined.

Reference: Gluyas and Swarbrick (2004) Petroleum Geoscience, Blackwell Publishing

Taxation plays a much larger role in oil and gas economics than for most commercial businesses.

- Current investment in the North Sea is measured in £10s of billions each year (capex and opex).
- Profits from oil and gas production are considered "super-normal" because the revenues from successful fields usually outweigh the costs of production, even when the costs and uncertainties of exploration are factored in. To avoid excessive economic rents, and the fact that petroleum is considered a finite national asset, taxes for oil and gas production are often very high.
- As an example, in the UK, petroleum taxes are 50%-81% depending on field age. However this is offset by a 100% first year depreciation, the ability to carry forward losses, and arrangements to include the cost of decommissioning or brownfield development. There are also field allowances for "difficult" projects. Some of the allowances are "ring-fenced" to apply only to specific fields or only for companies' investments in the UKCS.
- This compares to conventional corporation taxes in the region 20-25% (although the slower depreciation complicates direct comparison).
- Oil and gas investors operate in a world of substantial risks (sub-surface performance, oil price, political risks which translate into changes in legal, regulatory and commercial risks), currency risks, supply chain costs, and the need to anticipate low probability high impact events (e.g. oil spills). These companies frequently apply tougher investment criteria (e.g. high hurdle rates) than adopted in the utility sector.

Reference: Gluyas and Swarbrick (2004) Petroleum Geoscience, Blackwell Publishing

The UK Government intervenes regularly in the economics for oil and gas production.

Earlier years

1975	1979	1980	1983	1993	2002	2003	2004
• PRT introduced at 45%	• PRT increased to 60%	• PRT increased to 70%	• PRT increased to 75%	• PRT reduced to 50% and abolished for new oil fields	• Introduction of 10% Supplementary Charge Tax • Introduction of 100% first year allowance	• Abolition of Royalty payments	• Introduction of Exploration Expenditure Supplement (EES)

Recent years

2006	2008	2009	2010	2011	2012
• Supplementary Charge increased to 20% • Introduction of Ring Fence Expenditure Supplement, which replaced EES	• Carry back of decommissioning losses to 2002	• Introduction of New Field Allowance for small fields, HPHT and heavy oil fields	• Extension of field allowance to remote deep water gas fields	• Supplementary Charge increased to 32% • Decommissioning cost tax relief for SC is restricted to 20%	• Ring Fence Expenditure Supplement increased from 6% to 10%. • Introduction of “Brown field allowance” • Government announced a Fair Fuel Stabiliser (FFS)*

- **FFS**: if the oil price falls below a set trigger price (i.e. $75/bbl) on a sustained basis, the Supplementary Charge will be reduced to 20% on a staged and affordable basis while prices remain low.

Role of National Oil Companies

- National Oil Companies come in various guises. Typically NOCs have the powers of Government but the flexibility and initiative of a private enterprise. They can be formed as part of socialism-style control over a key part of the economy, as a rejection of exploitative or environmentally disinterested multinational oil companies, to realise sovereignty over a national asset, to foster national pride, to provide hands-on information, experience and training, or to ensure security of energy supply.
- A NOC provides an opportunity for the State to acquire more information and thereby provide more efficient control of private companies. This is particularly important when companies are multi-national and underlying value structures are opaque. A NOC allows the State to capture rents that are sub-optimally captured by taxes or production-sharing contracts.
- However, NOCs face many political and economic challenges that mean that in practice these benefits are difficult to realise. Norway's Statoil is sometimes held as a model NOC, but in some countries there have been allegations of inefficiency, incompetence or corruption, and sub-optimal investment decisions. Some of the arguments and counter-arguments to NOCs are of direct relevance to CO_2 storage businesses.
- Alternative state interventions through a mixture of taxes, subsidies, regulation, price controls, planning are well established in the developed world and increasingly prevalent in developing economies.

Based on Stevens, National Oil Companies: Good or Bad? A Literature Survey
Available at http://www.dundee.ac.uk/cepmlp/journal/html/Vol14/Vol14_10.pdf

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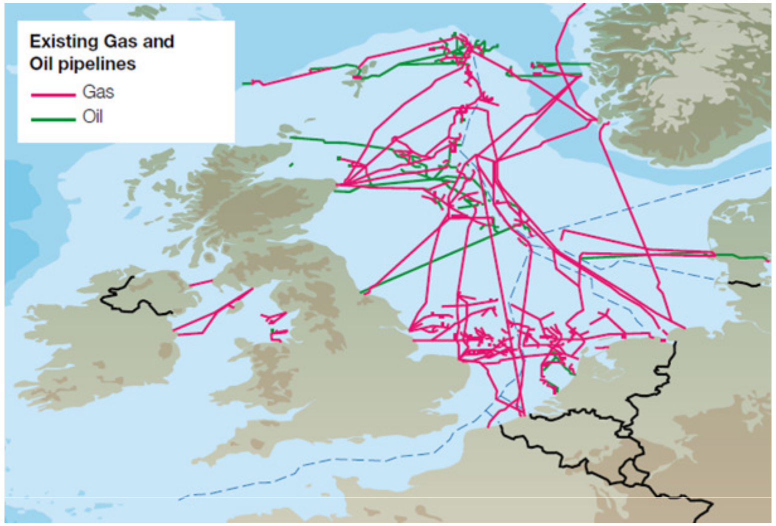
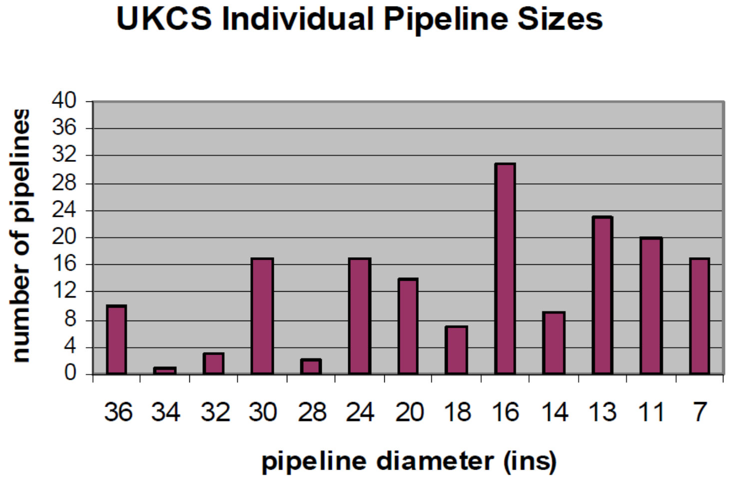
Oil and gas pipeline investments are made around anchor fields.

- A vast network of oil and gas pipelines has developed since the 1960s. This includes long transmission pipelines and even cross-border pipelines, as well as point-to-point pipelines, and complex integrated networks.
- Pipeline investments are made around major oil and gasfields, i.e. anchoring. These fields are then able to support satellite fields which share infrastructure (e.g. power, pipelines, hydrocarbon processing facilities, accommodation).
- As an example, the Forties Pipeline system connects 70 fields. Its tariffs are published and relate to future, current and historic costs.
- As the Forties field reaches end of life, the pipeline owners' income derives mostly from capacity from the satellite fields.
- The offshore industry was largely able to self-organise investment in the 1970s and 1980s.
- Nowadays, as the major fields deplete, the need for offshore coordination is more valuable but more challenging. New focus is the use of government-industry working groups, such as DECC's PILOT Task Force.





EEEGR (2006), N.B. excludes the 42" Langeled pipeline

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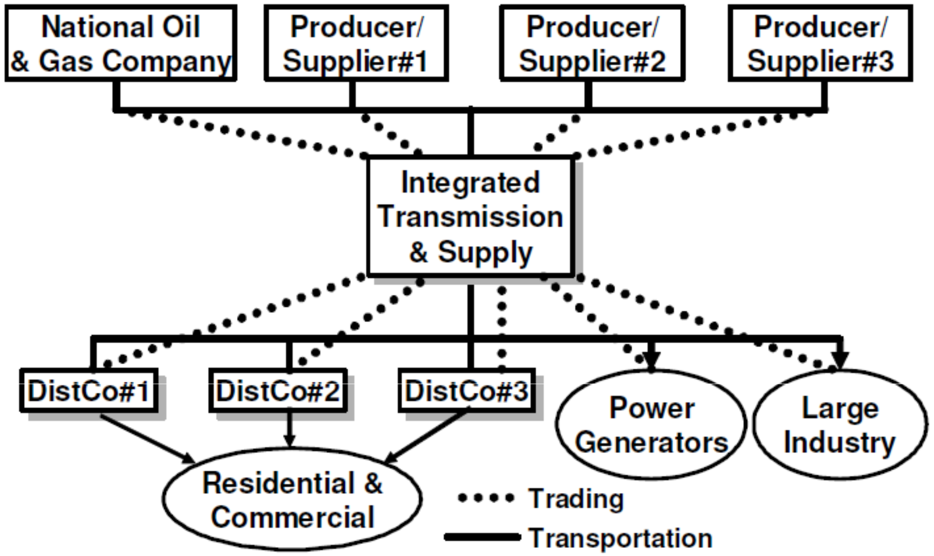
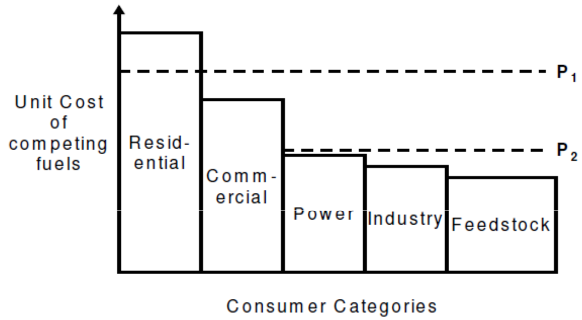
European onshore gas pipeline markets use integrated transmission system operators to aggregate supply and demand. Prices developed through regulated markets.



Box 1: The Economics underpinning long-distance natural gas transmission

The gas price formation under the Integrated Transmission & Supply model is described as Market Value/Netback pricing. The first step is to establish the Market Value of gas and this and is illustrated in the following figure.



Regulated monopoly, such as National Grid, is the system operator. This was for a long time under public ownership, but was since privatised.

Significant differences in the organisation of gas pipeline investment between the USA and EU.

	Crude Oil & Petroleum Product + Upstream Gas	US & EU Gas Pre Deregulation/ Liberalisation	US Gas Post Deregulation	EU Gas Post Liberalisation
Organisation of Investment	Vertical Integration or coalitions/JVs of market participants	Pipeline companies linking producers & buyers (US); exclusive rights to transmit & supply (EU)	Unbundled pipeline companies, independent interconnections, competitive provision of capacity	Centralised control of investment subject to (not very effective) regulation
Assurance of Investment Recovery	Contractual framework	Regulated cost recovery (US); granted monopoly (EU)	Long-term, tradable, clearly-defined capacity contracts	Primarily via regulation but uncertainty exists
Capture of Economies of Scale	Incentives to form coalitions	"Rolled-in" incremental costs (US); building in advance (EU)	Mandatory "open seasons" and incremental pricing of capacity	Hindered by regulatory uncertainty and lack of long term contracts
Efficiency of investment & operation	Common interest in cost reduction and performance	Potential to capture consumer surplus	Users decide investment in, and use and trade of, capacity	Entry-Exit pricing suppresses price signals
Role of Government	Regulated "common carriage" (US); mandatory requirement to serve new users; limited regulatory oversight (EU)	Cost-of-service regulation (US); grant of exclusive rights (EU)	Reduced primary regulation as pipe-to-pipe competition emerges and pipeline capacity is traded in liquid markets	Regulatory dominance, but investment policy concerns exist

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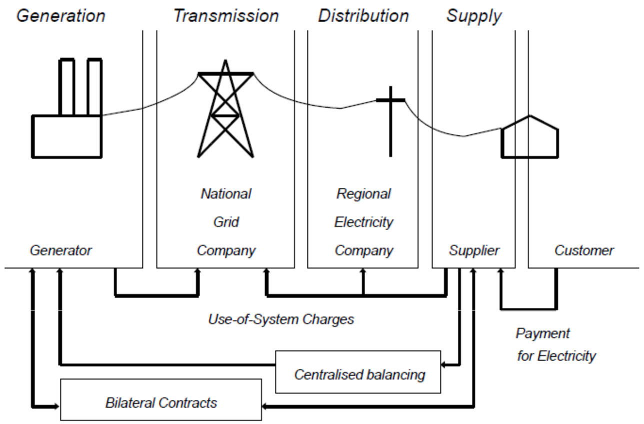
Early development of the UK electricity transmission grid involved considerable State intervention.

- In the 1920s, the Central Electricity Board was created to link efficient power stations with consumers.
- In the 1930s National Grid schemes were developed across the UK, and started to join up. Inefficient power stations closed and electricity metering becomes regulated.
- During WWII, the priority is to manage operation during bombing and limited coal supply.
- In the late 1940s, legislation is introduced to resolve the problem of extensive power cuts by nationalising the supply. The Central Electricity Board is replaced by the British Electricity Authority which generates and sells electricity to regional electricity boards who buy in bulk and sell to consumers.
- The 1950s sees a period of expanding the grid, including development of a 400 kV transmission line network, a 2GW interconnector with France, electrification of railways, rural electrification. Tariffs are standardised, including cheap night-time rates to flatten the load curve. The Electricity Authority is replaced with the Electricity Council and the Central Electricity Generating Board.
- In the 1960s there is significant investment in nuclear and coal generation plants.
- In the 1980s, policies encourage a shift away from coal and towards gas generation.
- At the start of the 1990s there is extensive privatisation of the electricity and gas sectors.
- In 2001, New Electricity Trading Arrangements (NETA) to increase competition.
- In 2005, single wholesale market for electricity, with British Electricity Trading and Transmission Arrangements (BETTA), with National Grid as GB System Operator.

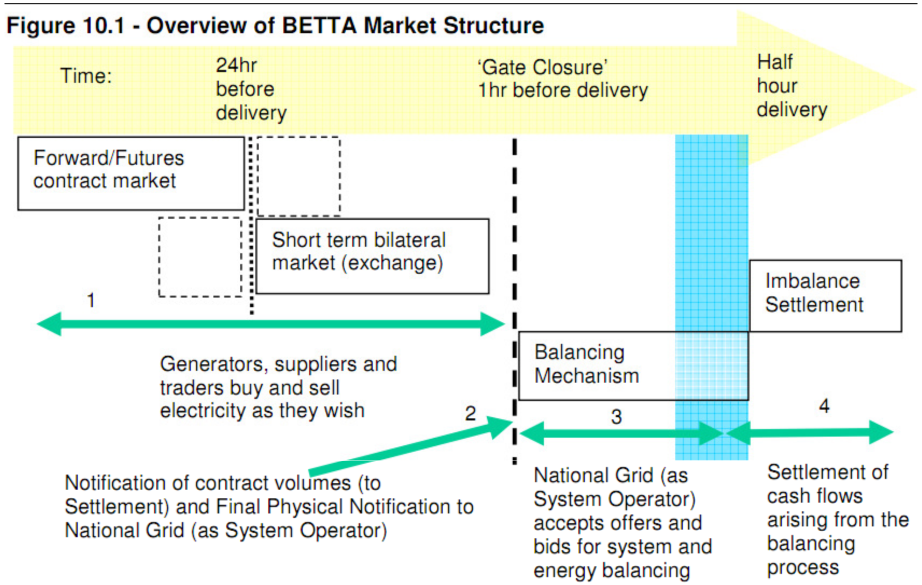
The UK electricity and gas markets are regulated by the Office for Generation and Markets (OFGEM)

- In the UK market, large Generators receive income through bilateral contracts with Suppliers and through the balancing market. They pay Use-of-System charges to the Grid.
- National Grid, as the regulated Transmission Network System Operator, receives income from Generators and regional electricity companies through use-of-system charging, typically based on £/MW/yr. This reflects the low variable costs of operation.
- Distribution companies are paid by Suppliers.
- Suppliers receive their income from domestic and non-domestic customers for electricity. They also participate in the balancing market.
- The Office of the Gas and Electricity Markets (OFGEM) protects current and future consumers, by promoting competition, facilitating security of supply, helping the industry meet environmental challenges efficiently. Priorities include protecting vulnerable customers.
- The regulator is governed by the Gas and Electricity Markets Authority, whose powers and duties are provided for in statute. The regulator is funded from the licensed companies that are regulated.



Balancing electricity demand and supply at all timescales is achieved through a mix of short and long-term contracts.

- The existing market (BETTA, see right) is dominated by short and long-term payments based on throughput, i.e. £ per MWh.
- Renewable generators also receive Renewable Obligation Certificates, the value of which depends on the market.
- Generators can offer additional services, including black-start (starting from scratch) and frequency response (maintaining the 50 Hz requirement).
- If approved, the latest electricity market reforms will create "capacity payments", i.e. £/MW/yr to support power stations with low load factor that are available to maintain security of supply.
- Contracts-for-difference Feed-in Tariffs will also be created for innovative low carbon generators, such as wind and CCS (based on a pre-agreed "strike price" £/MWh).
- The counterparty for CfD FiTs will influence financing, but is still under debate.



National Grid (2011) NETS Seven Year Statement

“Batch” approach for investment in onshore electricity transmission in Ireland.

- Ireland provides an example of where periodic planning and coordination should help minimise the cost of transmission investment to connect new onshore generation. Renewable developments with a maximum export capacity of at least 0.5 MW must proceed through a group process application.
- Applications for connection to the transmission and distribution systems that are deemed to be completed by a set date or “Gate” are processed as a batch, although applications can also be divided by the TSO or DSO based on geographic location and level of interconnectivity.
- Once connected, capacity is then allocated on a first-come-first-served principle.

Texas provided anticipatory investment in onshore electricity transmission networks ahead of generation in selected zones.

- In early 2000s, a renewable portfolio standard in Texas obliged electricity providers to obtain new renewable energy capacity based on their market shares. Wind investment followed existing transmission lines, and this led to congestion and in some cases curtailment.
- In 2005 the Competitive Renewable Energy Zone scheme was put in place to overcome these issues.
- Top 25 potential wind generation zones were identified by the Electricity Reliability Council of Texas, and then connected to the grid prior to any wind farms being developed.
- Structured to avoid connection to the wider electricity grid, so that other states do not free ride on Texas' investments (even if this would have reduced costs).
- Model deemed successful and was replicated in other US states.
- Note however that Australia consulted on the potential for over-sizing transmission capacity for new wind farms, and the decision was not to maintain a status quo investment, with the risk that this penalises future customers.

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Offshore electricity transmission market

- Offshore transmission is critical to UK meeting EU targets for renewable energy.
- Government and OFGEM worked together, reviewed impacts and consulted on approaches to delivering infrastructure for offshore wind farms.
- Consultation considered a variety of approaches, considering potential benefits from co-ordination.
- Although generators can build infrastructure, there is a key role for an offshore transmission owner (OFTO), separating ownership of transmission from generation.

Redpoint has recently assessed the benefits and risks of coordinated investment in offshore transmission networks for DECC.

- Benefits identified included reductions in total capex and opex, local environmental impacts, planning and consenting issues, connection timing risk once the network is established.
- Other benefits identified included increased transmission system flexibilitiy and security of supply and greater consistency with European developments.
- Risks identified included stranding risks associated with anticipatory investment, technological challenges, increased project complexity and potential temporary reduction in flexibility and security of supply in early phases.

Redpoint (2011) Coordination in offshore transmission – an assessment of regulatory, commercial and economic issues and options

Redpoint considered a number of options for network development corresponding to different levels of Government intervention

	Inform and Enable	Market-led evolution	Regional monopoly	Blueprint and build
Theme	Incremental reforms	Sharing of risks with between consumers and generators	Facilitated regional monopolies with coordinated build. Risks shared between investors and consumers	Central direction coordinated, with consumers bearing risk and reward
Role of central body in coordination	Provides information	Light touch, help for no-regrets investments	Light touch with regional focus	Complete blueprint
Who decides whether coordination is beneficial	Generators and or NETSO	Generators and/or NETSO	Regional OFTO	Central body
Anticipatory investment process	Guidance	Pre-approval of specific anticipatory investments	Regulatory approval	Anticipatory investment allowed as per blueprint
Degree of competition	Tender based competition for build	Tender based competition for build	Competition for regional monopoly	Tender based competition for component of network
Technology innovation and investment	Generator or OFTO responsible	Sharing of risks through mechanisms	Sharing through support mechanism	Sharing through support mechanism
Consistency with broader developments	High flexibility		Regional OFTO	Blueprint to incorporate North Sea Grid

Redpoint (2011) Coordination in offshore transmission – an assessment of regulatory, commercial and economic issues and options

Conclusions from Redpoint assessment of offshore transmission network regime

- Inform and enable or market-led evolution of networks will likely deliver less stranded asset risk, involve very limited changes to the current regime.
- The regional monopoly or blueprint approaches offer higher potential for future benefits being achieved but these place the risk (mainly stranded asset risk) on consumers. They involve significant intervention and therefore disruption to the status quo. They also provide greater certainty for supply chains and generators. Authorities will need to plan infrastructure to a higher level and there is a loss of flexibility if these plans are incorrect.
- The lower the expected future capacity, the more that the light-touch approaches will be relevant. In contrast, the higher the expected future capacity of the network the more co-ordination will be required.

Redpoint (2011) Coordination in offshore transmission – an assessment of regulatory, commercial and economic issues and options

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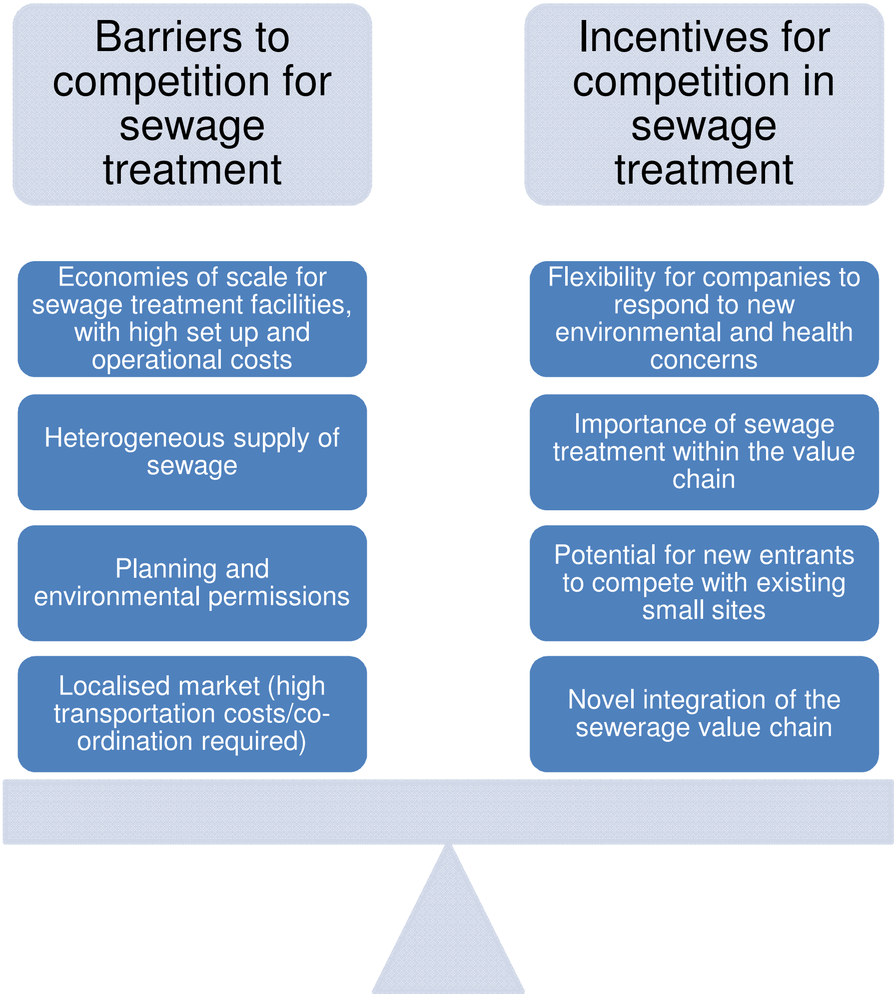
Water and Wastewater markets

- Initial UK investment was public-led in the Victorian era, recognising the public good of investment. Once in place, alternatives are never going to be competitive, i.e. the investment is irreversible.
- Pre-1989, the UK system comprised 10 water authorities. These had received little public investment in the 1970s and 1980s, but were frequently subject to Government interventions. The result was poor infrastructure and poor water quality.
- These were subsequently converted into independent regulated water companies with regional monopolies. (Regulator is OFWAT). The benefits identified were to limit government intervention for the day-to-day management of private companies, provide access to the capital markets to fund infrastructure investment, diversify, improve accountability, and provide value to Treasury from the sale.
- Companies have been able to manage operational and maintenance costs (e.g. within RPI-X tariff controls), but have been criticised for under-investment in major new infrastructure projects.
- Protection of the environment and response to climate change are emerging priorities for these businesses.

Sewage treatment plants were identified as an opportunity within the sewerage value chain to increase competition.



- Analysis for OFWAT identified opportunities for competition within the sewerage value chain based on the economies of scale, nature of sewage supply, difficulty in obtaining regulatory consents, geographic distribution of existing facilities and opportunities for novel integration.
- All of these drivers may be relevant for CO_2 transport and storage networks, albeit to different degrees.

Based on London Economics (2010) Competition in upstream sewage and sludge markets, Report for OFWAT. Available at http://www.ofwat.gov.uk/competition/rpt_com_le_upstream.pdf

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UK Waste Regulatory Model

- DEFRA has produced guidance for implementing the Waste Framework Directive.
- Government policy on waste is to protect health and environment, by producing less waste, by using it as a resource where possible.
- Planning is seen as the key to the adequate and timely provision of the right type of waste management facilities in the right place.
- Regional spatial strategies and local authorities should provide sufficient opportunities to meet the identified waste needs, looking forward for 15-20 yrs, considering the distribution of tonnage and identifying strategically important waste facilities.
- Waste management should be considered alongside wider spatial and economic objectives, and should be based on clear policy objectives, robust analysis of data available, and an appraisal of options.
- The pattern of waste management should prove attractive to investment without constraining movement up the waste hierarchy (i.e. reduction or reuse of waste).
- A broadly-based regional technical advisory body should be convened to provide advice on the preparation of the strategy for waste management and its implementation. The body should consider national policies, data, Environment Agency and local authority information. The body could comprise waste collection and disposal authorities, central/regional/local Government representatives, the waste management industry and NGOs.
- Expect expeditious and sympathetic handling of planning applications for sites identified in planning documents.

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Energy Service companies are often used to deliver district heating networks.

Deployment of low carbon solutions, such as district heating, in the built environment, suffers from barriers including:

- Need to balance supply and demand precisely over short and long timescales and in space.
- Market and social barriers – price distortion, hassle factors, split incentives, low priority of energy issues, fragmentation of the building chain, short-term outlook
- Regulatory barriers – narrow procurement practices, cumbersome permitting processes
- Information failures – lack of information, knowledge, competence, awareness
- Financial barriers – very low returns on investment, high up-front costs, difficult access to capital, high (real or perceived) technology risk, high transaction costs.

Diverse solutions have been developed, including use of an Energy Service Company (ESCo):

- These can reduce the hassle-factor and information failures by providing a complete heat and power solution for a neighbourhood.
- Economies of scale can allow cost reduction.
- Performance-based payments to align incentives between the ESCo and customer.
- Diverse models but ownership frequently includes municipalities and residents' associations.
- Can provide access to finance for high up-front expenditure.
- Limited to cost-effective measures, long contract periods, minimum number of customers, including an "anchor" project such as a swimming pool, hospital etc.

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Rail privatisation highlights the potential for technical specifications to reduce compatibility between different parts of a network.

- In the early 1830s, private investors created individual routes, which competed with horse (for people) and canal (for freight) transport.
- However, there was a wide range of gauges (although legacy issues led to a particular gauge); within a few years a standardised approach developed for the UK.
- Industry grew rapidly with private investment, peaking in 1920 in terms of total network length. Freight customers could reap value of investment due to different prices for goods in different parts of the country.
- The UK rail industry was nationalised in 1948 (except for brief national control during WWI and WWII). British Railways (later British Rail) was created to own and manage.
- In the 1990s, the UK privatised and adopted a fragmented approach to rail infrastructure planning, with the aim of enhancing transparency and efficiency. Each stakeholder feels that they are acting in the best interests of the industry, but lack a cohesive approach, e.g. to new technologies and standardisation. Government has had to step in to rescue services that were not deemed sufficiently commercially attractive.
- The multiplicity of organisations has led to a plethora of technical and operational standards. This has reduced compatibility of equipment (e.g. rolling stock) across the network.
- It also makes it difficult to trial and plan the phased roll out of new technologies (e.g. regenerative braking).

Eurotunnel investors suffered from overly optimistic projections of revenue.

- Concepts for a physical link between England and France were developed in the 1800s, but failed to win political support for many years for a variety of reasons.
- In 1985, promoters of privately-funded projects were invited to submit proposals to the UK and French Governments.
- Existing ferry operators protested strongly against the proposed service which includes Eurostar trains to city centres, passenger/vehicle services from port to port, and freight transport. They cut prices and improved service to compete, in a period that has also seen the advent of low cost air travel.
- The Channel Tunnel was a build-own-operate-transfer (BOOT) project with Transmanche Link responsible for design and construction, followed by transfer to Eurotunnel.
- The total investment costs were expected £2.6 bn at 1985 prices, but actual costs were £4.7 bn, due to enhanced safety, security and environmental demands, as well as higher financing costs.
- The British and French Governments gave Eurotunnel a 55 year operating concession to repay loans and investors – later extended to 65 years.
- However original estimates of usage were extremely optimistic; actual revenues have been considerably below forecast.
- Despite Eurotunnel's share price originally rising after launch, the company has been largely a terrible investment for its original investors – the company has been close to bankruptcy and has had to undergo a number of financial restructuring attempts. It took 22 years to post its first dividend.

High Speed 1 also experienced multiple rounds of financial restructuring.

- The 1987 Channel Tunnel Act made Government funding for a Channel tunnel rail link unlawful. Since initially a fast link from Kent to central London was insufficiently profitable, no proposals were developed, and the only service was on existing tracks shared with other commuter services.
- Originally London and Continental Railways was formed as a private consortium to build and operate the Channel Tunnel Rail Link, offering a fast direct connection. Following an Act of Parliament in 1996, compulsory purchase powers were granted to allow a high speed rail service to be built.
- In 1998 the British Government produced a rescue plan to address serious financial difficulties. This was partly because revenues from Eurostar were much lower than expected. The rescue included phasing of the network to reduce risks and restructuring of ownership and finances. The UK Government offered to guarantee bonds issued by LCR, in exchange for a percentage of profits and a "golden share".
- Repeated financial difficulties among participants (including shareholders such as Railtrack) forced multiple restructuring rounds between 1998 and 2010, including full national ownership in 2009.
- The most recent of these restructuring involved the Government awarding a 30-year concession to a consortium of private investors to sell access to the track and stations on a commercial basis, regulated by the Office of Rail Regulation. After 30 years the ownership reverts to Government.

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  - District Heating Networks
  - Major transport projects
  - Nuclear Decommissioning Authority
  - Telecommunications (Mobile and Broadband)
- ❑ Potential market failures for CO_2 transport and storage

Case study: The Nuclear Decommissioning Authority (NDA)

- Lit review did not identify successful commercial models in the long-term liabilities for nuclear waste in the UK (a commercial industry consortium NIREX failed), although there is an example in Finland.
- The Nuclear Decommissioning Authority (NDA) is a non-departmental public body created through the Energy Act 2004.
- Strategic authority that owns 19 sites and the associated civil nuclear liabilities and assets of the public sector, previously under the control of UKAEA and BNFL.

Responsible for

- decommissioning and cleaning up these civil nuclear facilities
- ensuring that all the waste products, both radioactive and non-radioactive, are safely managed
- implementing Government policy on the long-term management of nuclear waste
- developing UK-wide nuclear Low Level Waste (LLW) strategy and plans
- scrutinising decommissioning plans of British Energy
- deliver the decommissioning and clean-up of the UK's civil nuclear legacy in a safe and cost-effective manner, and where possible to accelerate programmes of work that reduce hazard. Introduce innovation and contractor expertise through a series of competitions.
- NDA reports to the Department of Energy and Climate Change (in some cases Scottish Ministers).

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Market failures exist when the outcome supply or demand of a good or service is not efficient from the point of view of the economy of a whole.

- If there is a market failure, then the market is away from demand and supply equilibrium and it is possible to find an alternative configuration that improves net welfare without leaving some actors worse off.
- At equilibrium, the capacity is efficiently used i.e. the marginal costs of delivering additional capacity match the marginal benefits.
- This does not mean that there will always spare capacity to meet any future demand. If building the capacity requires high up-front expenditure at risk, the most efficient solution is often not to invest in the building the spare capacity.
- There are multiple overlapping causes of market failure.
- A key question for UK policymakers and the CCS industry is whether the existing market arrangements are likely to lead towards economically optimal or efficient CO_2 transport and storage capacity.
- In the first part of this slidepack, we review the dimensions of market failure that may pertain to the CO_2 transport and storage industry.
- We note that (i) some industries form inherently difficult markets for commercial operations, even when market failures are corrected; (ii) in some sectors there are multiple opportunities for "Government failure" as well as market failure; and (iii) there are multiple examples where the costs and risks of intervention to address the market failures outweigh the benefits.

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The economics literature reveals multiple, overlapping categories of market failure

- Monopoly power – one firm controls market, sets higher prices or excludes some buyers or sellers
- Imperfect competition – buyers or sellers are able to influence price.
- Missing markets – market fails to form to meet demand, e.g. street cleaning
- Public goods – non-rival and non-excludable, e.g. defence, where there is a free-rider problem.
- Incomplete markets – markets fail to produce enough goods
- Merit goods – purchaser under-estimates benefits, e.g. job centres
- De-merit goods – purchaser under-estimates costs, e.g. junk food
- Negative externalities – price fails to recognise cost imposed on third parties, e.g. pollution
- Positive externalities – price fails to recognise the benefits to third parties, e.g. education
- Property rights – failure to assign property rights may limit the ability of markets to form, e.g. clean air
- Information failure – one or both partners have insufficient information during a market transaction
- Unstable markets – volatility as there are extreme and rapid responses e.g. in some commodities, foreign exchange and credit markets
- Inequality – unfair distribution of resources in free market
- Asymmetric information – prices do not reflect all the benefits, costs and opportunity costs, because either buyer, seller or both have insufficient information.
- Moral hazard – excessive risk taking if consequences are not felt by the party taking the risk.
- Transaction costs – the internal and external costs of search, information, bargaining, policing and enforcement are too high to allow parties make a transaction, even when this would be beneficial.
- Factor immobility – e.g. geographic/occupational immobility

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Information failure:
What will be the value of future CO_2 reduction?

- With continued uncertainty in climate predictions, and following decades of discussion, there remains limited consensus globally on the extent, timing and distribution of reductions of greenhouse gas emissions to atmosphere, how these should be paid for, and the appropriate roles of different solutions. The absence of a "comprehensive deal" on climate policies, makes it particularly difficult for smaller countries, such as the UK, to "go it alone" and remain economically competitive.
- Even if legislation enshrines transparent targets (e.g. the Climate Act 2008 commits the UK to carbon budgets towards an 80% cut by 2050 in CO_2), policymakers will need to balance this with electoral preferences, such as energy affordability, energy security as well as economic competitiveness. Further, even where climate impacts are internalised through a cap-and-trade system or carbon price floor, there is limited visibility as to the long-term e.g. the EU ETS after 2020, it is not obvious the price reflects the extent of the externalities, and carbon prices could remain extremely volatile.
- The market is constantly likely to remain vulnerable to policy shift. In the last ten years there have been substantial policy shifts in relation to nuclear, wind, PV, coal, gas, CCS technologies and the structure of the electricity markets in the UK, the EU and many countries. The repeated interventions create a very real threat that policy assumptions upon which business cases might be based are fragile.
- Therefore in the UK, as elsewhere, the likely value for any given level of future CO_2 reduction are likely to remain extremely uncertain for many years. This is a systemic issue facing all investors in long-lived assets, including CCS infrastructure.

Information failure:

What will be the most economically efficient capacity for offshore CO_2 transport and storage infrastructure for the 2020s and 2030s?

- Even with a given CO_2 target, the high variability of the costs, performance, risks, growth rates of many energy technologies, commodity prices and exchange rates suggest very wide ranges of "economically efficient" CCS capacity in the future energy mix.
- For example, ETI's own ESME scenarios identify scenarios with capacities between 0 and 200 $MtCO_2$/yr, and specific capacity levels also show variations in the number, nature, and location of capture.
- This range is unlikely to narrow significantly during the 2010s: With few CCS projects in the UK or worldwide, CCS cost and performance uncertainty could remain high. Uncertainties in commodity prices and exchange rates will always be a challenge. Finally, socio-political attitudes to specific technologies can be impacted by events (e.g. nuclear phase-out in Germany triggered by events in Japan, CCS demand in the UK could similarly be impacted by events in analogous industries).
- The implication is that private investors may need to factor in two orders-of-magnitude uncertainty in the capacity of transport and storage infrastructure required.
- There is a requirement of synchronisation and agreement between diverse actors in CO_2 generation, capture, transport, storage, and plausibly more than a hundred consents and contractual agreements in place.
- First movers are particularly disadvantaged because of high transaction costs, diverse first-of-a-kind risks and need to assemble and educate diverse stakeholders.

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Information asymmetries:
A fair price of CO_2 storage?

- Realistic estimates of the costs, performance and risks of potential storage sites can only be carried out site-by-site with resource- and data-intensive models. Further the price of storage will need to reflect expected risk-weighted returns, recognising that many sites may prove non-viable for diverse reasons.
- Although globally the subsurface industry is large, there could be a shortage of data and suitably qualified individuals with the experience to assess independently the costs, performance and risk profile for CO_2 storage in the North Sea in the period to 2020. The transaction costs for them to carry out independent assessments could be prohibitive for power/capture investors.
- The potential storage providers, and particularly existing incumbent oil and gasfield operators, having the most information, will therefore have the most bargaining power.
- Attempts to force owners to share their data and models with potential future competitors could dissuade CO_2 storage developers from carrying out exploration and appraisal, if it is unlikely they will be able to retain the advantage that arises. This is an example of where investment leads to a "public good", which the investor finds it difficult to protect value.
- Anecdotally, current oil and gas operators have also suggested that they would resist transferring data and models, or would require significant compensation, including indemnities.

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Property rights and concentration of market power:
How should ownership for storage be allocated efficiently?

- The EC CCS Directive and UK storage regulations create property rights for storage through a system of licensing (by DECC) and leasing (by Crown Estate).
- UKSAP reveals that most of the UK's storage is clustered in a few areas which have a high number of storage sites in close proximity. This includes sites which are stacked on top of each other, where there is a risk that some licensing approaches could make it difficult to expand capacity in the future. It also includes sites which are in pressure communication, so that injection in one location impacts the costs, performance and capacity of injecting into a neighbouring location.
- It also includes some units with areas spanning many thousands of square kilometres, for which it is unlikely that full appraisal followed by full utilisation seem unlikely in the near future. However any geographic division of these units into smaller license blocks is likely to be arbitrary. For the aquifers, the boundaries of suitable CO_2 storage zones are poorly defined, especially in advance of detailed reservoir simulation.
- Commercial developers will cherry pick the cheapest/least risk sites, including those where redundancy is high. However, there is a risk that in awarding of storage licenses, market power could be concentrated into a limited number of actors, who could withhold capacity from the market, which could drive up costs. Secondary markets, including forward markets, to allow trading in storage capacity would reduce ties to "anchor" projects and may result in more efficient storage allocation.
- The permitting processes for power generation, capture, transport and storage are not co-ordinated at present, which puts each component at high risk.

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Moral hazard

Shared or public liabilities could lead to excessive risk- taking

- The EC CCS Directive and UK storage regulations place the onus firmly on storage license holders for managing the liabilities from CO_2 leakage.
- With virtually no past experience, it is very difficult to calibrate the possibility and impacts of downside risks.
- One approach to mitigate risks is for partners to share risks across the chain, e.g. through sources owning equity in transport and stores or vice versa.
- For storage, some catastrophic failure scenarios, though very low probability could see significant local impacts to health, property or the environment. This could include release of CO2 for which payments are required.
- If insurance companies are unable or unwilling to price this risk, the industry may try to develop shared funds or ask Government to own the low probability high impact risks, capping the liabilities for commercial storage developers or their partners.
- However, these approaches to risk sharing or capping liabilities could lead to inexperienced organisations responsible for decisions outside their core business or for moral hazard, where decision-makers do not accept responsibility for their decisions.

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High transaction costs, risks and timescales could result in limited competition

Should Government encourage competition in the storage industry?

- To date site-specific storage analysis has largely been tied to specific CCS projects, reflecting the nature of Government CCS demonstration competitions. These competitions have shown that it can take many years with costs in the region of millions of pounds to put together a suitable project proposal that may ultimately be rejected anyway.
- Further investors in transport and storage must have a strong expertise additionally in the current and potential future markets for capture, and provide input for lengthy consultation and contractual negotiation periods with subsurface licensor (DECC), the landowner (Crown Estate), relevant CO_2 sources, and other stakeholders which may have very little interest in supporting any CCS development.
- These high transaction costs could act as an entry barrier to the market, limiting entry to a few well resourced organisations. This could result in limited competition.
- Transaction costs, risks and timescales will be particularly large for trans-boundary projects, creating a risk that these opportunities will not be exploited.
- Whereas in highly competitive markets, all organisations are price-takers, with limited competition, some organisations could set the price of storage above an economically efficient price. Any policy imperative to deliver a CCS target could then see these organisations collecting economic rents.

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Positive externalities

Information from any CO_2 transport and storage projects (including unsuccessful ones) will be useful for the market.

- As CCS technology seeks to cross the "technology valley of death", information on costs, performance and risks will be extremely useful to the global CCS industry and its stakeholders. In particular, since many of the concerns relate to CO_2 storage, having a library of case studies will improve decision making worldwide. This is a positive externality that storage developers will only be able to "internalise" if policy makers develop suitable incentive schemes for knowledge transfer, including for those projects which fail to reach the market.
- However there will be a trade off between information sharing, maintaining leadership, and enjoying the benefits from intellectual property protection for "know-how". In the examples of CCS at Sleipner and Snohvit, Statoil appears to have limited dissemination on engineering designs and costs. This allows Statoil to maintain a leading position on CCS. In contrast the UK has stipulated that FEED studies from the Longannet-Goldeneye and Hewett-Kingsnorth studies are published to maximise global learning.

Positive externality

Future-proofed infrastructure provides external benefits

- With climate ambitions subject to a degree of scepticism, the design of transport and storage infrastructure designed for future demand has the potential to generate additional value that may not be possible for developers to capture through tariffs.
- In the case of over-sized pipelines running close to large stationary emitters, the risks of these emitters becoming stranded in a carbon-constrained world decreases. Indeed these emitters now gain the option value of being able to plug into a network at a time of their choosing.
- Transport and storage solutions that provide higher capacity than initially needed can also signal to the wider industry a strong commitment to CCS development over the long-term, (recognising that policymakers can often be guided by sunk costs), and help solving the "chicken or egg first" dilemma. Conversely failure to "over-size" may be (mis)interpreted as not trusting the technology, or the need for it in the future.
- These signals will only be valuable if clear and low-hurdle entry specifications for third-party access are available. There is however a risk that the excessive entry specifications that may be needed for an integrated transport infrastructure may discourage system-wide innovation that reduces costs (particularly in capture, where most of the costs lie, or storage, where most of the risks lie).
- However, pipeline and storage investments are highly specific, both in location and use, and the lack of certainty over utilisation creates a significant stranded asset risk. In contrast most pipeline investments are considered "low risk, low return", and therefore shareholder expectations will need to be managed appropriately.

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Monopoly tendencies

- Pipeline investments exhibit natural economies of scale, as the incremental costs of increasing diameter or pressure to accommodate increases in capacity are small relative to the costs of a bespoke end-to-end solution.
- For two small sources that share a common but distant sink, there are significant benefits for sharing a common pipeline, especially at low discount rates, and even if there is a delay between the sources connecting.
- In the absence of a secondary market for capacity trading, there is a risk that the transport provider may exploit this advantage and sell capacity at a price equal to the marginal price of alternative solutions, rather than reflecting the cost of provision.
- Although the third party access requirements are enshrined in regulations, it is not clear how an appropriate tariff for capacity would be agreed if this was developed by Secretary of State intervention. Unlike gas, oil or telecommunications infrastructure, the prospects of excessive rent-seeking seem low and there is no evidence for assuming that monopoly providers of CO_2 transport or storage infrastructure would ever seek to restrict throughput. Under these conditions excessive economic regulation may be seen as trying to solve a problem that would never occur in practice.
- If the distances are much shorter, if both volumes are each larger, if there is a long gap between first and second source connecting, or if discount rates are high, then the most economically efficient solution is to develop multiple pipelines.
- If only one store or one storage company is available, there is potential for monopolistic behaviour, given the long lead times for storage development.

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Environmental externalities, price volatility and inequalities

- The dominant market failure, systemic for all decarbonisation solutions, is an inadequate market framework for valuing (penalising) current and future CO_2 emissions to atmosphere.
- In providing rules for CCS within Phase III of the EU ETS, there will be a market for avoided emissions by implementing CCS.
- The price of allowances within the EU ETS price has to date been extremely volatile, responding to fossil fuel prices, economic growth/recession, technology development, and multiple disparate policy interventions at European level or within Member States.
- Even with tightening of the CO_2 cap, the price is likely to remain extremely volatile and vulnerable to decisions (e.g. expansion of the cap-and-trade scheme globally).
- The UK Government is implementing a carbon price floor that provides a greater degree of price certainty for investors.
- However even with a large carbon price, it may be difficult to reach economically efficient scenarios as the market is crowded with a myriad of existing and planned subsidies, regulations and penalties that directly or indirectly influence the demand for CCS. These inequalities include scenarios where Government has tried to remedy other examples of market failures, including through the use of feed-in tariffs and regulations.
- Feed-in tariffs which reward “clean MWh” do not match the risk profile of CO_2 pipeline and storage infrastructure which has high fixed and low variable costs.

Environmental externalities

Weak price signals, and lack of location signalling, may lower the potential for infrastructure re-use or optimised planning.

- Some of the data required to assess storage sites can be obtained from seismic scans which can have negative environmental impacts, from exploration or appraisal wells, which could also have negative environmental impacts and potentially form a pathway for CO_2 or hydrocarbons, to leak to the sea. There could therefore be some value in limiting the extent of seismic and well drilling, although the amount could be small compared to the oil and gas industry.
- Construction of new platforms, wells and pipelines is resource intensive, disruptive and creates health, safety and environmental risks. With low visibility on the value of storage at specific sites, there is little incentive to future-proof new infrastructure or phase decommissioning of hydrocarbon infrastructure in a way that minimises overall health, safety and environmental impact, which could involve re-using the facility in whole or part for CO_2 transport or storage. However owners of existing facilities may struggle to capture any appropriate economic value for future-proofing.
- Congestion at the beach and at the seabed is increasing rapidly in the context of multiple users of the seabed, including potentially tens of GW of offshore wind in planning or under construction. It would be extremely challenging, and probably unrealistic that CO_2 pipelines and storage platforms could be constructed within dense wind farms which have grids of multiple sub-sea cables. Currently however, there is no formal pricing system for congestion offshore – and location signals onshore are often also weak.
- Pro-active planning of beach crossings, the routes of pipelines and offshore cables, and the locations of wind turbines and storage infrastructure could minimise the routing difficulties, allowing more rapid implementation.

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Tackling information and environmental externalities

- The future economics for making sunk costs in long-lived specific assets for CO_2 abatement are weak, with weak CO_2 price signals and very weak locational price signals.
- Our literature review finds no relevant examples of commercial multi-billion pound up-front investment in specific assets for a new technology in a competitive unregulated market, when the uncertainties on timing, capacity, location, political support, and future regulatory environment are comparable as for those facing CCS.
- Instead Governments have sought to internalise externalities or regulated these for example, imposed pollution standards (e.g. for CFCs, road vehicles), SOx cap-and-trade, abstraction licenses for water, European legally binding targets for technology (e.g. renewables targets, biofuel obligations).
- In some cases national or regulated monopolies have been able to provide speculative investments to test new solutions.
- In contrast, the literature shows numerous examples of multi-billion pound investments in specific assets in markets where there are deep, liquid, strong (i.e. profitable) forward prices and stable markets.

Tackling information asymmetries

There are multiple information asymmetries around CO_2 storage:

- Commercially sensitive existing data of the UKCS - the current value for existing oil and gas production license holders of keeping their data secret is greater than the commercial value from sharing this. Public investors, and capture and transport developers, licensor and leaseholder need to trust store for information on risks (or carry out expensive due diligence) but the storage company understands true cost, performance and risk profile for store.
- Threat of making data public in the future may deter knowledge creation and encourage free rider behaviour.
- General public and NGOs are apprehensive about storage risks

In other industries, information asymmetries are tackled through:

- Data sharing with an independent regulator, different levels of access for data
- National oil and gas companies
- Economic regulation, e.g. limit returns to cost + X%
- Nuclear Decommissioning Authority develops transparent site screening assessment to reassure wider stakeholders about safety
- Pharmaceutical industry have intellectual property protection for 20 yrs to cover high costs and risks of drug development
- Transport and storage spatial planning

Securing economies of scale

There are challenges in benefitting from economies of scale if the market only sees one project at a time (or simultaneous competitions), e.g. project-by-project CfD FiT, and multiple permits (each at risk) including storage agreements-for-lease, lease and licenses.

Previous examples of measures to manage this include:

- ❑ OFTO regime implemented to increase co-ordination in offshore wind transmission infrastructure.
- ❑ Statutory monopoly provisions for regional monopolies e.g. in rail, water – allows a single organisation to manage extensive spatial planning, consultations, enquiries etc. Government sanctions route. These systems can develop with a high degree of foresight.
- ❑ Masterplanning, e.g. Olympics Delivery Authority
- ❑ Stakeholders are informed by monopolies of future investment e.g. NG's 7-year plans and water industry has 25 year resources plans.

Note that the oil and gas pipeline and production investments faces similar risks and interdependencies. However historically, economies of scale were easy to capture as projects are built around large anchor fields and then satellites grow organically. For CO_2 storage we start with small projects and need to scale upwards.

Limiting the scope for free riding

The complexity, challenges and third party access arrangements for CCS disincentivise first movers and instead encourage late adoption. It is not clear what price should late adopters pay for infrastructure, and it can be especially tricky to determine a fair price for access to parts of otherwise vertically integrated CCS systems. Ex-post estimate of risks and costs of CCS may be very different from ex ante.

In other industries, options to bring early investment include:

- Direct public grant or joint-venture equity funding, soft loans, under-writing, guarantees etc. for infrastructure investment.
- Managing third party access through appropriate tariff structure (based on fully allocated costs, or marginal cost if the first project is a publicly funded demonstration).
- Regulate access, e.g. by OFGEM, OFWAT, EU telephone markets or for use of airports, and publish guidance could be given by arbiter/regulator as to how they would reach a decision on third party access arrangements.
- Ensure appropriate accounting systems to be in place from the start to help judge fair costs in the event of a backstop price intervention.

Ambiguity of property rights and liabilities

At high CCS deployment, ownership of CO_2, ownership of the incentives for avoided CO_2, and liabilities for storage complexes will need to be clear, especially in a network with multiple sources and sinks.

- ❑ Who is responsible for the liabilities for CO_2 and pressure impacts in a “storage complex” extending beyond the actual storage site?
- ❑ Ability for storage developers to impact proximal developments (other CO_2 stores, but also hydrocarbon, offshore wind and other marine users)

The lesson from other industries is that generally it has proved much harder to tackle diffuse pollution cf. point sources, e.g. radioactivity, water from farms. As these large areas are difficult to police, disentangle background effects and prove causation, problems are left unsolved.

Avoiding concentrating market power

In the event of high CCS rollout, there are theoretical risks of market power becoming concentrated, as realistically the combination of a few pipelines and few stores would provide the most economically efficient system.

However, it is not clear if a market would deliver (i) rational exploitation of the storage, as there are real challenges to licensing complex storage clusters, which cover a large area of interlinked sites; (ii) "fair", low prices for CO_2 transport and storage.

In other industries, market power has been constrained through:

- ❑ Development local, regional or national monopolies that where the system operator investments and returns are regulated, e.g. water, DNOs, OFTOs, National Grid, Telephone market, landfill.
- ❑ Business models based on £/t transported or stored are unlikely to turn away customers except for technical incompatibility or capacity constraints, so disputes over third party access may never materialise.
- ❑ Industry self-regulation to agree technical specification, define the basis for technical interactions.
- ❑ Companies could share technical and commercial information with the Government or independent authority who could quantify the level of market abuse.
- ❑ Fixed period concessions

Managing moral hazards for CO_2 transport and storage

Current balance of liabilities eliminates moral hazard by placing most responsibilities with storage permit holder. However financial markets cannot yet price CCS risks especially storage risks, and it is far from clear how accidents would be managed in practice. Ultimately the risks are socialised as state may need to step in, stores are handed over to the state in perpetuity.

Market can handle financial compensation for transient interruptions to service. A single pipeline or storage site or CCS project will never be "too big to fail", in terms of catastrophic impact on the UK economy, but it is possible to imagine a company going bankrupt, and this having a knock-on impact on the economics of linked power stations and industries, which then could have an impact on the UK economy.

Examples of planning for negative eventualities from other industries:

- Oil and gas operators in some jurisdictions have capped liabilities.
- Ensuring all users have lifetime responsibilities for managing stores, even post-sale.
- Electricity networks are regulated to ensure "the lights stay on".
- Utilities, trains, banks have special administration regime to continue operations in the event of bankruptcy etc.
- Could have a cross-industry fund or body for managing liabilities.

Capturing positive externalities

Data on all aspects of CO_2 transport and storage will be valuable to CCS projects elsewhere in the UK and worldwide. The European Commission and UK Government have highlighted that knowledge transfer is a criterion for funding CCS demonstration projects, but this information could be valuable beyond a first demonstration project, particularly for storage where expertise and supply chains could be limited to a few individuals and organisations.

Because of its specificity and high sunk costs, investment in CO_2 transport and storage infrastructure will signal the direction and scale of future policy commitment to CCS.

If CO_2 transport and storage is available, then sources in the appropriate location can implement CCS at a time of their choosing. But it is hard for an emitter to price this fairly and for the transport/storage developer to receive this value, even in an open season, as the source knows they can benefit from third party access arrangements later.

Ideally externalities are internalised through appropriate price signals. Where this is not realistic, direct public investment is often employed e.g. in the transport sector.