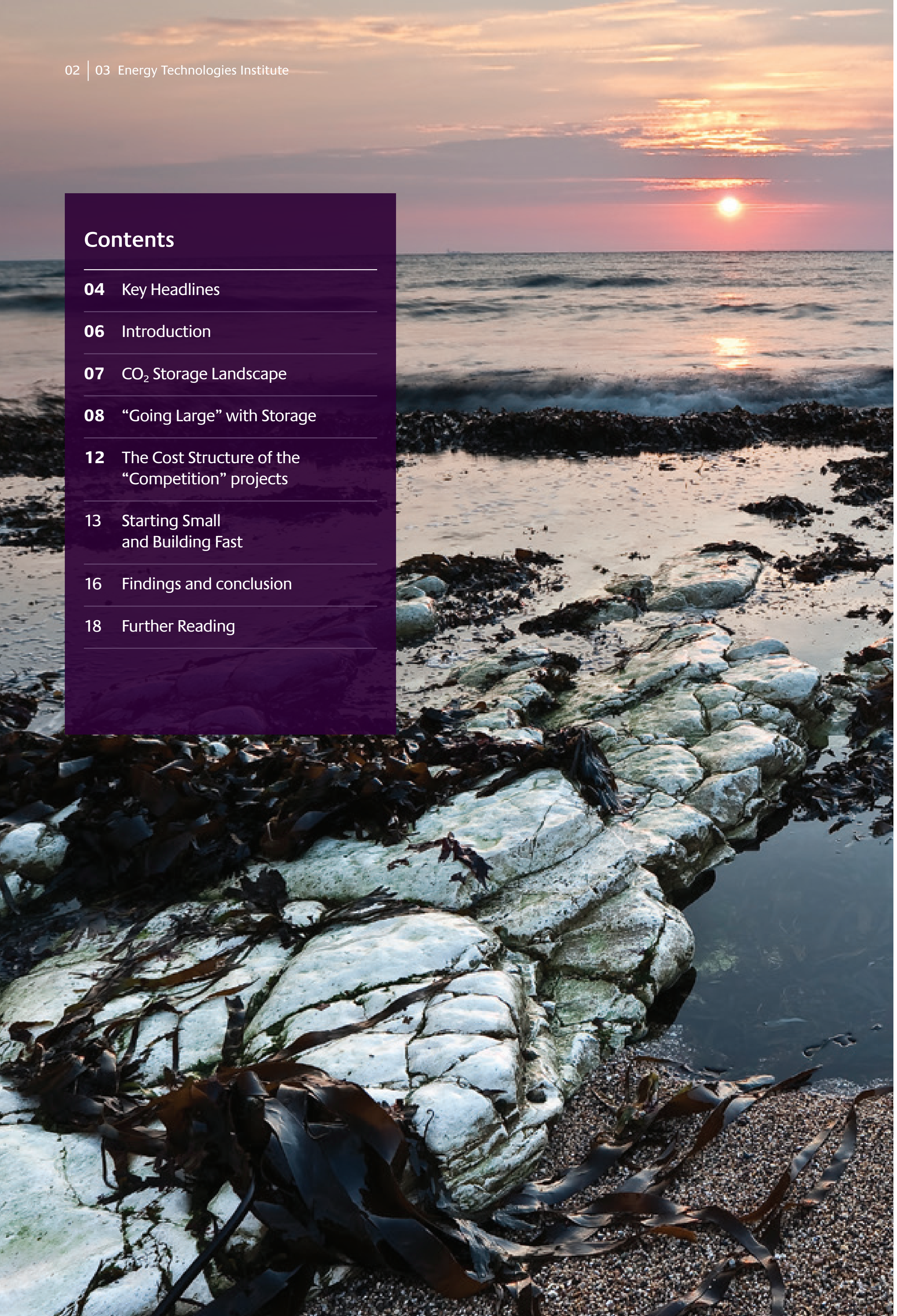
energy technologies institute

An ETI Insights report

TAKING STOCK OF UK CO_2 STORAGE

ETI10 TEN YEARS OF INNOVATION 2007—2017



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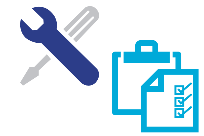
The UK has the CO_2 storage capacity to meet its needs out to

2050

and beyond

A substantial amount has already been fully or partially appraised

Storage appraisal to date shows there are no technical barriers to the storage of CO_2 in UK offshore sites



Lowest cost CCS can be achieved by combining large scale stores (over 3MT/a) with shared infrastructure and existing low risk technologies

TAKING STOCK OF UK CO2 STORAGE

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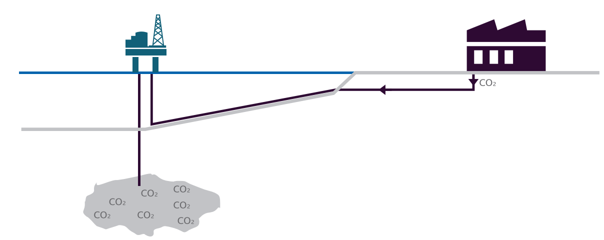
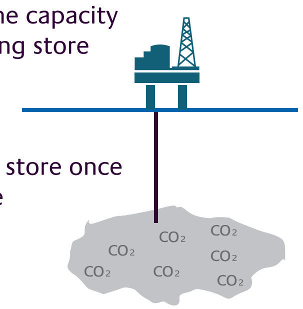
Some combinations of store and emission source offer an opportunity to “start CCS small, and build” as an alternative approach to market entry at scale

In the UK the east coast of England is a prime location for CCS deployment – it has a large emissions base, good sites for large new low carbon power stations and industry as well as good access to large, low cost offshore storage sites

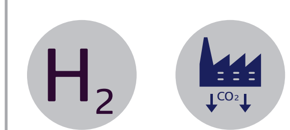


New ETI research shows brine production can increase storage capacity and injection rates cost effectively and could be used to restore the capacity of an underperforming store

It can depressurise a store once injection is complete



Once shared infrastructure is in operation – the decarbonisation of industry by CCS can be rolled out at an attractive cost and the generation of hydrogen and negative emissions developed



KEY HEADLINES

- In recent years Government funding has supported the initial appraisal of several offshore CO_2 storage options in the Southern and Central North Sea and East Irish Seas. Appraisal work completed to date is encouraging, and completion of this alone would present a sizeable, diverse and low cost CO_2 storage offering
- There is more than enough potential storage capacity to meet the UK's needs for CO_2 storage to 2050 and well beyond, even in high Carbon Capture and Storage (CCS) deployment scenarios
- Based on the appraisal work to date, there are no technical barriers to the storage of CO_2 in offshore stores that would limit the CCS industry developing at scale in the UK
- Large-scale stores (capable of storing over 3MT/a) are essential for low cost CO_2 storage, but some UK stores could allow an investment to "start small and build" to de-risk elements of the project, and then grow fast subsequently with low regret
- The contribution CCS can make to decarbonising the industrial sector is considerable, including a few opportunities with low capture costs (ammonia, H_2, biofuels). However, due to their scale, the unit costs of transport and storage from most industrial projects will be high, and these will not catalyse new CCS infrastructure. Conversely, when this infrastructure has been provided, industry can join storage networks at acceptable costs
- In spite of the demise of local coal-fired power stations, the Humber estuary (and to a lesser extent Tees and Thames) will still have a very large existing emission base, good sites for large new low carbon power stations and industry, and access to large, low cost, offshore storage sites.

There is more than enough potential storage capacity to meet the UK's needs for CO_2 storage to 2050 and well beyond, even in high CCS deployment scenarios

Introduction

Termination of the most recent Government CCS Commercialisation competition late in 2015 was a major setback for the decarbonisation of the fossil power and industrial sectors in the UK. Now the dust has settled, we review in this paper what we have learned about the CO_2 storage aspects of CCS in particular, and other aspects of CCS that have changed over the last few years, since we first published our analysis of the UK's CO_2 storage options in 2013[1]. At the point of cancellation, the two competing projects, Peterhead and White Rose, were advanced in terms of carrying out engineering and appraisal work, and some of the information gained by the projects has now been published by the government on its CCS website[2]. The UK government also funded the Strategic UK Storage Appraisal Project (S.SAP Project), via the ETI in 2015/16, in which a consortium led by Pale Blue Dot Energy (PBD) partially appraised several other potential CO_2 stores in UK waters, and this work has also been published[3]. We will step back from the "two-horse race" of two years ago and examine different issues affecting the starting point for the CCS projects we believe are necessary to deeper decarbonise our power, industrial and potentially domestic energy use.

Internationally, in the short period since the cancellation of the projects, confidence in the technical success of the industry has grown with successful operation of plants including Quest, Sask Power and recently Petra Nova, all in North America. However, key stakeholder confidence in the UK has been eroded by successive competition cancellations, and a clearer picture of risk allocation within the project chain and value recognition is needed to regain momentum.

The Oxburgh Report[4] called for urgent government action on CCS implementation, and emphasised the importance of the power sector in laying down infrastructure for industry.

The ETI's analysis[1,5] indicates that the lowest cost CCS can be achieved by combining large-scale storage (>3MT/a, equivalent to emissions from a 1.2GW gas power station) with shared infrastructure and low risk technology. Once this shared infrastructure has been provided, most probably by a large gas-fired power station, decarbonisation of industry by CCS can be rolled out at an attractive cost, and the generation of H_2 (via CCS) and negative emissions (bioenergy with CCS) can be developed.

1 ETI. CCS - A picture of CO_2 Storage (online). Loughborough. ETI (viewed 30/5/2017). Available at http://www.eti.co.uk/library/ccs-a-picture-of-co2-storage-in-the-uk

2 BEIS. Carbon Capture and Storage Knowledge Sharing (online). BEIS (viewed 30/5/2017). Available at https://www.gov.uk/government/collections/carbon-capture-and-storage-knowledge-sharing. Figure 5 uses data extracted and adapted from K11.133 and K11.043 for Peterhead and K.01 and K.38 for White Rose.

3 ETI. Strategic UK CCS Storage Appraisal (online). Loughborough. ETI (viewed 30/5/2017). Available at http://www.eti.co.uk/programmes/carbon-capture-storage/strategic-uk-ccs-storage-appraisal

4 Oxburgh (2016). CCSA News and Events Lowest Cost Decarbonisation for the UK- The critical Role of CCS (online). London CCSA (viewed 31/5/2017). Available at http://www.ccsassociation.org/news-and-events/reports-and-publications/parliamentary-advisory-group-on-ccs-report/

5 ETI. Reducing the Cost of CCS – Advances in Capture Technology (online). Loughborough. ETI. Available at http://www.eti.co.uk/insights/reducing-the-cost-of-ccs-developments-in-capture-plant-technology

CO_2 Storage Landscape

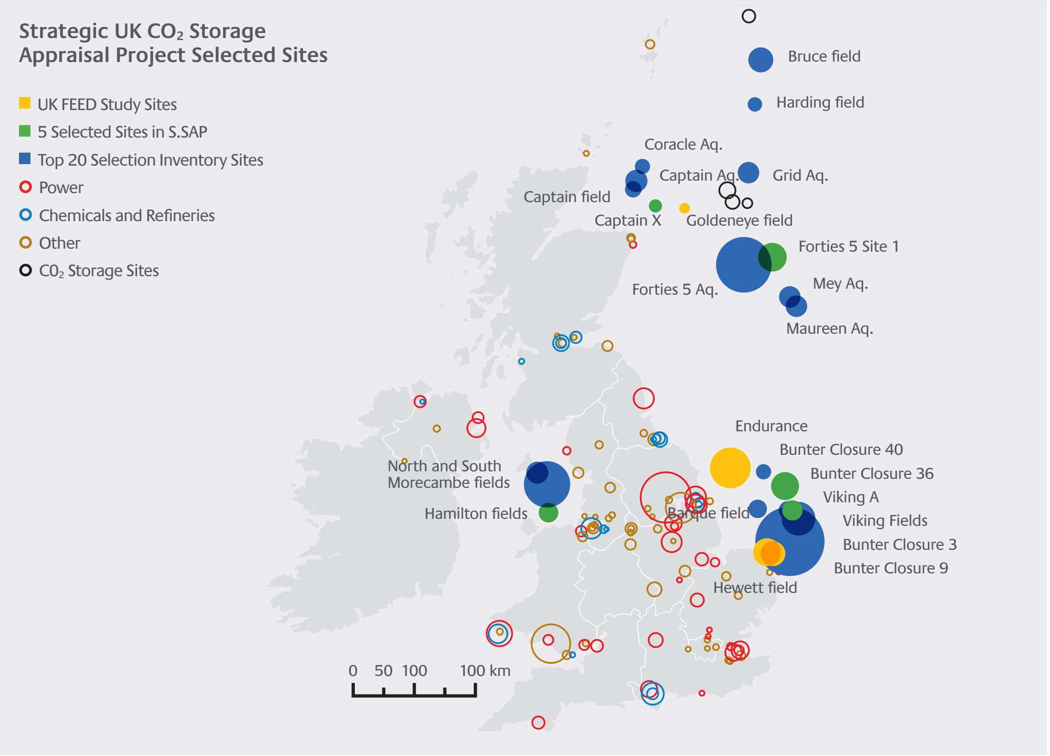
The UK Storage Potential

The two Government CCS Competitions appraised three CO_2 stores[6] with a capacity totalling c. 850MTs, of which about 200MT has completed detailed appraisal and is ready for final investment[3], and represents the most readily exploitable storage available in UK waters.

For the S.SAP project the PBD consortium started with the 574 potential stores in the CO_2 Stored[7] database, totalling 78,000MTs, from which they selected 20 geographically dispersed and geologically diverse sites for further assessment, all capable of development by 2030, and totalling 6,900MT of capacity. Five of these 20 were selected, peer reviewed for suitability, and further initial desktop appraisal work carried out. Together with the 3 "competition" stores, these could handle almost 50MT/a of CO_2 and store over 1600MT of CO_2 – approximately a quarter of the UK's 2014 power and industrial emissions for 30 years. These stores are shown colour coded in Figure 1.

Figure 1

Major UK CO_2 storage sites and point emitters[8] over 0.1MT/a, with coal and industrial plant closures removed.



6 The three stores appraised are Hewett, Goldeneye and Endurance

7 The Crown Estate /BGS. CO_2Stored (online). CO_2Stored (viewed 31/5/2017). Available at http://www.co2stored.co.uk/home/index

8 DEFRA. National Atmospheric Emissions Inventory (online). NAEI Point Source data 2014 (viewed 31/5/2017). Available at http://naei.defra.gov.uk/ ©Crown 2017 copyright Defra & BEIS via naei.defra.gov.uk, licensed under the Open Government Licence (OGL).

"Going Large" with Storage

The three stores appraised by the Government Competitions provide more than sufficient storage capacity for the Committee on Climate Change[9] recommendation of 4-7GW of power CCS and 3-5MT captured CO_2 from industrial plants by 2035 and so put the UK on track to meeting its carbon target commitments cost-effectively.

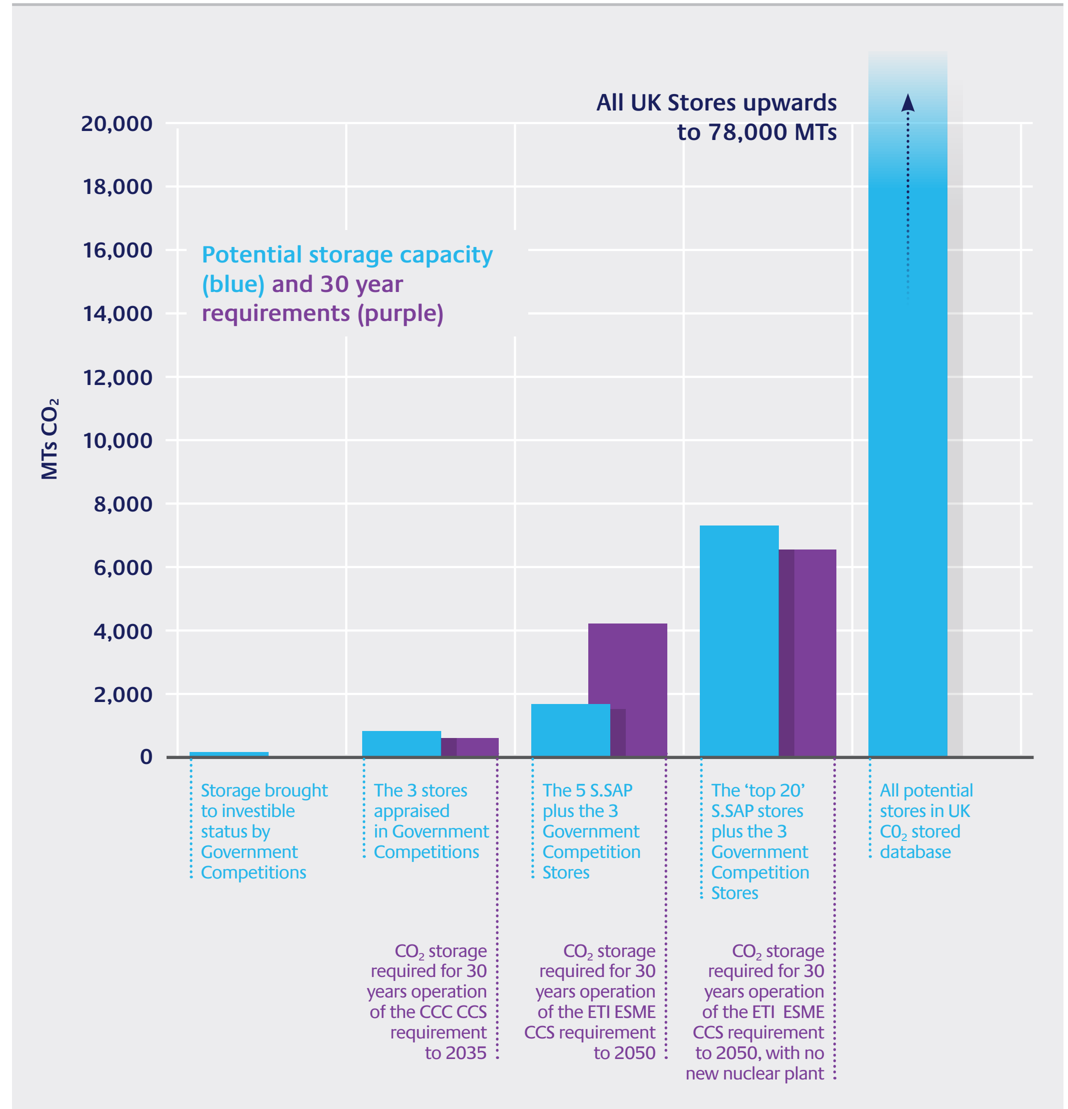
The ETI's Energy Systems Modelling Environment (ESME) tool consistently shows that a blend of renewables, nuclear and CCS technologies typically provide the lowest cost pathway to decarbonise the electricity supply, and CCS is also deployed in industry and to create hydrogen (including from biomass). This analysis suggests that the UK should be storing a total of c.110 – 130MT/a CO_2 by 2040 – 2050 from these various applications. Subject to further appraisal work, these storage rates could easily be accommodated by the "top 20" initial storage sites chosen by PBD in the S.SAP study.

Further, in a high CCS scenario, (such as one with no nuclear plants), the required CO_2 storage rate increased to 170 – 210MT/a in 2040 – 2050, which could also be sustained by the top 20 S.SAP sites for the 30-year life of typical power plants. However, this would require focused development of large, high injectivity stores or storage techniques. With regard to the decarbonisation of heat, recent work by Northern Gas Networks[10] showed that a city the size of Leeds (pop. 800,000) could have its commercial and domestic gas supply (for heating) decarbonised by substitution of natural gas with hydrogen. Leeds would require the storage of 1.5 MT/a of CO_2. The high CCS scenario rate described above would therefore accommodate a large number of UK cities (containing roughly half the UK population) being converted to hydrogen as long as new nuclear and renewables are deployed alongside CCS in the power sector.

The storage potential appraised to date is presented against these three potential requirement scenarios in Figure 2 (right). The blue blocks represent estimates of different subsets of stores identified by the Government Competitions and the S.SAP project. The purple blocks represent 30 years of storage capacity for the three CCS scenarios in the period 2020-2060, and is therefore a view of the absolute minimum requirement for storage appraisal to support these ambitions. The ETI scenarios require completion of all the appraisal work on the five stores examined by PBD (or equivalents) and further selections to be made and appraised from the "top 20".

Based on the appraisal work carried out to date, which covers a broad range of the types of stores available, there is no significant technical barrier that would limit the CCS industry developing at scale in the UK from a number of strategic shoreline hubs[3].

Figure 2
Storage Capacity Estimation vs 30 years storage for three scenarios/time periods



9 Committee on Climate Change. A balanced response to the risks of dangerous climate change (online). CCC (viewed 31/5/2017). Available at https://www.theccc.org.uk/wp-content/uploads/2016/07/Letter-to-Rt-Hon-Amber-Rudd-CCS.pdf

10 Northern Gas Networks. Delivering gas to the North of England (online). H21 Leeds City Gate (viewed 31/5/2017). Available at http://www.northerngasnetworks.co.uk/wp-content/uploads/2016/07/H21-Report-Interactive-PDF-July-2016.pdf

"Going Large" with Storage

Continued ›

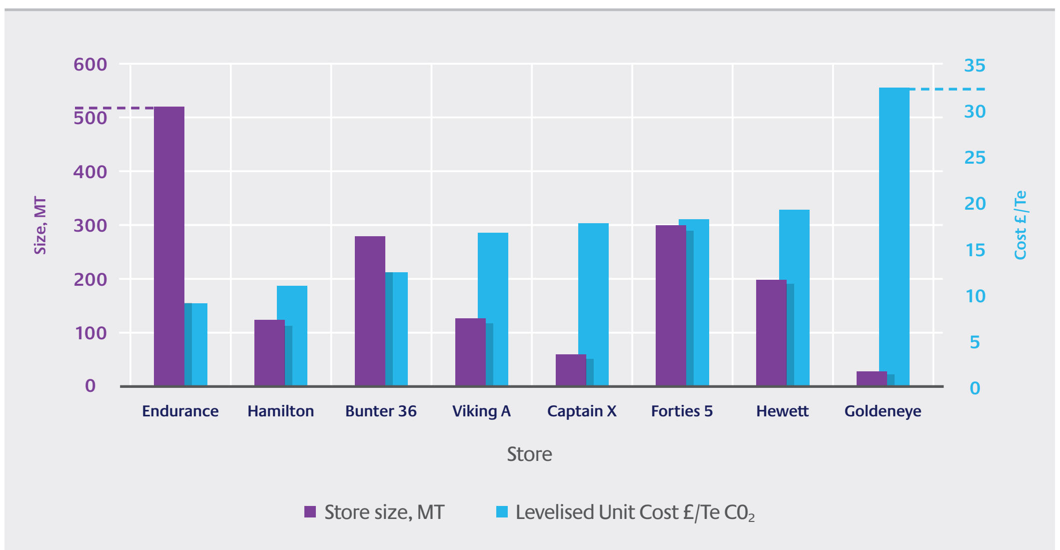
Similar to any oil and gas field development, even after full appraisal, uncertainty will remain in the capacity and injection rate achievable in any store. For more than half of the 78,000MTs of potential storage in CO_2Stored, capacity is provided by available pore space in the rock (gas reservoirs), or by the ability for aquifer water to be displaced elsewhere in the formation as CO_2 is injected. However, the balance of the 78,000 MTs is "confined" in that as CO_2 is pumped in, aquifer water is not free to move out of the way. This aggravates pressurisation issues and may restrict CO_2 injection. Many of these stores are large, but deep and relatively remote, and so are not on our radar for early development, although there are several notable exceptions in the Central North Sea and East Irish Sea. To increase confidence in both near-term and longer-term storage capacity estimation the ETI commissioned Heriot Watt University and Element Energy to examine any benefits a technique called "brine production" might have on storage efficiency. In this technique, pressurisation of the store caused by the CO_2 injection is mitigated by releasing saline water from the store through separate water production wells. The project is currently preparing to report its results, which show that brine production:

- Increases storage capacity and injection rates in a cost-effective manner – by a factor of three at high injection rates for the specific confined stores examined in detail
- Restores the utility of a store which underperforms because of unexpected barriers to pressure dissipation. This may have nearer term application as a risk reduction strategy, for all storage types represented in the "top 20", not just the "confined" ones, of which there are only four
- Depressurises a store once injection is complete, putting the store in a more quiescent state before it is handed over to a competent authority for long-term monitoring.

The work serves to show us that there should be "room to manoeuvre" in managing the risks that expected or unexpected confinement may pose to the success of a storage project development, and certainly scope to substantially increase overall storage capacity should this be necessary.

Figure 3

Offshore storage and transportation costs[3]



As can be seen in Figure 3 (left), the cost profile for different storage options have different features. Larger stores tend to offer the cheapest levelised cost of storage, assuming a strategic approach is taken to the CCS investment, capable of offering storage at about £10/Te, which for a gas power station works out about £5/MWh. Endurance offers the cheapest storage on a levelised cost basis and is a strategic play, in that there are several other large stores of this type such as Bunter Closure 36 in the area, as well as geologically diverse options in the UK's Southern North Sea gas fields such as Viking A and Hewett.

Additionally, in spite of the recent demise of many coal plants, Endurance, and its neighbours, are located closest to the largest accessible group of onshore CO_2 sources in the UK. As shown in Figure 4 (below), the Humber (in particular the south bank) has an unrivalled number of economically sized industrial and power sources upon which an extended CO_2 network could be built. It has a pipeline gas supply from Norway and onshore sites for the development of new power stations. The North Eastern and South Eastern emitters can also reach such stores, and the North East has published a network plan which, if supported by a large offshore infrastructure investment, provides industrial CCS projects at an affordable cost[11].

South Wales and South England have good anchor CO_2 emitting plants, but are challenged by a lack of convenient pipe-linked storage potential. Based on published economics of ship-based systems[12], networked pipeline opportunities are likely to be more cost-effective, and avoid onshore liquefied CO_2 storage.

The North West and North Wales, like Scotland, have sizeable overall emissions but from fewer and smaller power and industrial sources than the east of England offers.

Figure 4

Size and Geographical Distribution of Emitters over 0.1MT/a[8] with all coal plants except Drax removed

Regional Emissions over 0.1MT/a 2014[8]	Area total	Plants over	Avg. Emitter Size	Non Power
	MT/a	1MT/a	MT/a	MT/a
Humber, less Drax	17.1	7	1.1	10.1
- Drax , 50% Bio	11	1	-	-
South Wales/Seabank	18	4	1.5	11.7
South and South East, less Fawley, Marchwood	6.6	2	0.5	1.6
- Fawley/Marchwood	5	2	1.6	3.3
North West/N Wales	6.5	1	0.5	5.1
Scotland	6.2	1	0.4	5.9
North East	5.3	2	0.6	3.9
Northern Ireland	2	0	0.4	0.5
Isolated inland sources	18	-	-	-

11 Teesside Collective. A new industrial future for the UK (online). Available at http://www.teessidecollective.co.uk/wp-content/uploads/2015/06/Teesside-Collective-Business-Case1.pdf

12 Zero Emissions Platform. Carbon dioxide capture and storage (online). ZEP (viewed 31/5/2017). Available at http://www.zeroemissionsplatform.eu/library/publication/167-zep-cost-report-transport.

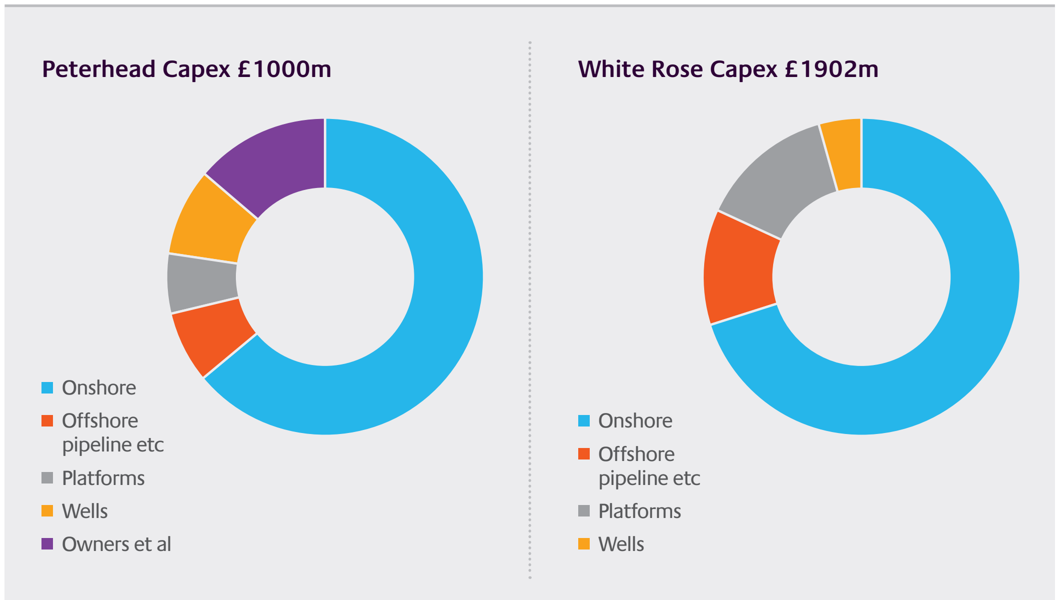
The Cost Structure of the "Competition" projects

Both of the Government Commercialisation competition projects were stopped in 2015 as they were considered too expensive, in part caused by the fact that they are sub-optimally sized, being essentially demonstration projects. The two had very different offerings. The Peterhead Project offered a lower capex option for a project of limited duration, as the store is small, and some of the equipment "lifetime" has been used up on previous activity. On the other hand, the White Rose Project offered all-new infrastructure strategically placed and sized to offer cheap additions to several other future large projects in the region. It therefore required further substantial commitment to CCS (increased volume) to reach the very low unit costs of transport and storage shown in Figure 3. In spite of these differences, the distribution of capital needed to build these projects, in terms of onshore and offshore splits are broadly similar, and are dominated by the onshore portions as seen in Figure 5 below[2].

All the ETI's (and others') work[1,5] concludes that CCS benefits from economies of scale, with the levelised cost of large (>3MT/a), long-lived (30 year), compact stores (e.g. Endurance, Bunter Closure 36) combined with large CO_2 emitter hubs each with a sizeable anchor project[1] comfortably outperforming the levelised costs of smaller stores of short duration – as shown in Figure 3.

However, the Peterhead project succeeded in keeping initial costs down, in spite of being small, by reusing existing infrastructure and so we were interested in examining the economics of other potential options storing say 1- 2MT/a, such as a combination of a small power and industrial CCS project, and if projects using only industrial sources looked feasible.

Figure 5
Distribution of Capex needed to build Peterhead and White Rose Projects.
Note total sums are not on a strictly comparable financial basis.



Starting Small and Building Fast

With Peterhead in mind and also seeking solutions for the North West and Wales, the ETI commissioned PBD and Costain in 2016 to examine "low cost" design concepts for offshore projects which "start small and build" using the cost databases they recently published for the five potential UK stores in the S.SAP Project. Several of these stores, shown in green in Figure 1, are large enough to be rapidly expanded into strategic ones. Initial cost reduction was achieved by:

- Temporary reuse of existing infrastructure such as pipelines and platforms
- Using subsea templates rather than platforms for the deeper stores
- Reducing the size of pipelines, platforms and well counts to closer match the initial filling rate.

These projects have higher unit storage rates but incur less regret expenditure if no follow-up project materialises, or worse, if the offshore project experiences difficulties. On the positive side, if a large follow-up project does materialise, it benefits financially from having lower chain risks because a "seasoned" store operator is in place, and from having higher tier "bankable" storage in place due to operational experience.

The Hamilton store in the East Irish Sea has several features which made it a good candidate for a "start small and build" project:

- The geology is understood. It has a proven cap rock and a functioning pipeline and platform (but the ability to re-use these is currently unknown)
- It is close to shore, the water and field depths are shallow, reducing the cost of new pipelines and platforms when these become necessary
- The huge, geologically similar Morecambe gas fields lie to the north, and will become available for additional storage in future decades
- The reservoir formation has high injectivity, keeping the well count low and the platform small. Up to 5MT/a of CO_2 (equivalent to 2GWe) can be injected for 25 years, capturing most economies of scale. Although smaller, its overall cost structure is similar to Endurance.

Finally, it could serve the industrial and populous North West and North Wales areas as can be seen in Figure 6 (page 14):

Starting Small and Building Fast

Continued ›

Figure 6

Hamilton Store and surrounding area

An outline economic analysis of the costs involved in different approaches to development is shown in Figure 7 (right). We start with a BASE CASE, for comparison purposes, which consists of a large gas-fired power station storing CO_2 at Endurance, yielding the best levelised costs of any considered, and ample opportunity for industrial sources to tie in later. Then we test CASE A, which uses a small industrial CO_2 source (assumed to be the ammonia plant at Ince in the North West), and provides a new gas phase CO_2 pipeline across to the Point of Ayr. From there another new CO_2 pipeline feeds the existing platform and new wells at Hamilton. This scheme is intended to cut the onshore capture costs (the large blue segment in Figure 5), by starting with an ammonia plant which generates a CO_2 stream without much expenditure on capture equipment, thus keeping overall costs down. However, for the chosen option, we find the cost of the new pipelines, combined with the low capture rate and limited lifetime of the plant considered, makes the unit costs of transport and storage (T&S) very high.

In CASE B the first train of a large CCGT/CCS unit is built at a site at Connah's Quay in North Wales. A new gas phase pipeline to Hamilton feeds the existing platform and new wells. The CCGT produces 5 times more CO_2 than the industrial unit, so a higher capital spend on capture up front is required, but better positioning and economies of scale keep the unit costs down. CASE C completes the multiple train unit, seven years after the first unit, giving the owners two years of injection at commercial rates before the decision to complete the investment. A new platform and wells are provided which are suitable for dense phase operation, and the existing platform abandoned at the project's expense. CASE D adds the CASE A plant to the CASE B/C infrastructure, requiring a short, liquid phase pipeline.

In practice, CASE C would benefit from lower costs of capital – a 1% reduction in the discount rate reduces the levelised cost by about £3/MWh. Less than half the ultimate capital cost and support funding for the CASE C capture and storage needs to be committed in CASE B to get the project going.

Once CASE B and C have built the infrastructure, the small industrial emitter can join the network (CASE D) at much better terms with a shorter, liquid phase pipeline.

Figure 7

Example of key economic indices for different development options.

CASE	Source	CO_2 Flow	Duration	Store	Up Front T&S Capex	Levelised T&S	Levelised Capture +T&S	Levelised Power Cost
		MT/a	Years		£M	£/Te	£/Te	£/MWh
Base Case – 2.6 GWe	Power	7.5	25	Endurance	592	11	58	78
Case A Ammonia Unit	Industrial	0.33	8	Hamilton	324	256	300	
Case B Single GT	Power	1.5	25	Hamilton	255	33	63	95
Case C Expansion of Case B	Power	4.5	25	Hamilton	390	17	62	82
Case D Add Ammonia Unit to Case C	Industrial	0.33	20	Hamilton	56	37	80	

Assumption used in Figure 7:

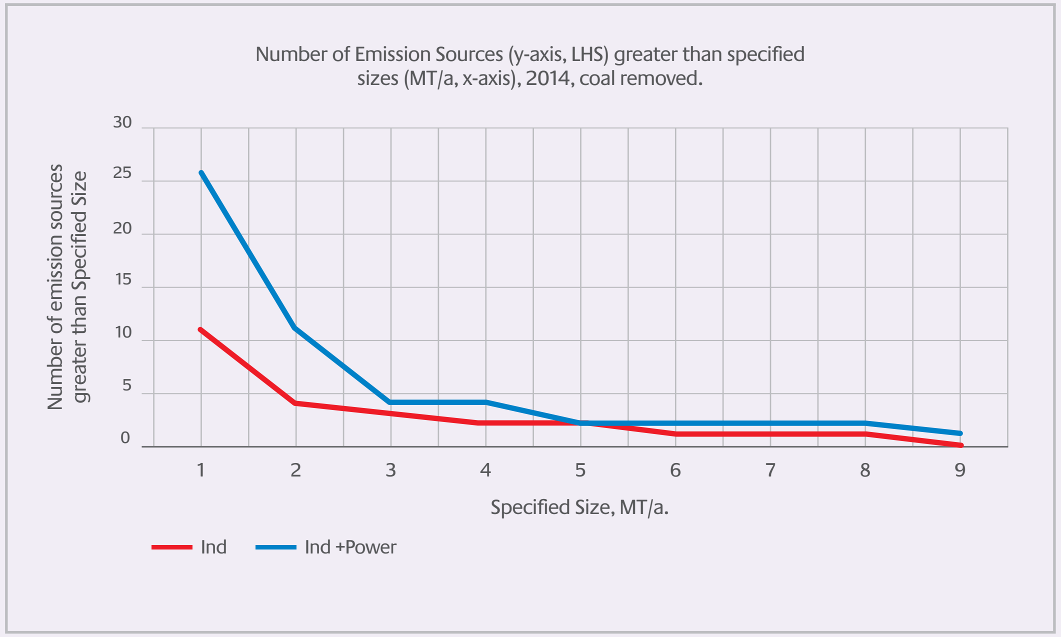
1. All projects are costed in 2015, with the a final investment decision to proceed in 2015
2. A simple 10% discount factor is applied, with no additional finance costs, and no inflation
3. Gas 2p/kW-h
4. Class F turbines are deployed
5. Case A is costed with an 8 year lifetime as after 8 years significant expenditure will be required to switch operation from gas phase to dense phase CO_2, and provide new replacement infrastructure

Findings

- In the case of "starting small" at the Hamilton store, the local industrial options look too small to get CCS started
- However, a phased power station build has benefits for reducing initial exposure without causing regret spend. Whereas the levelised power costs (basic costs) are higher than the BASE CASE at Endurance, the total initial investment is less than half, assuming that the existing offshore platform can be reused. Even when expanded in CASE C, the economics cannot match the BASE CASE; however, CASE C should have considerable lower costs of capital than the BASE CASE due to de-risking. More sophisticated financial modelling at the ETI suggests that a 1% reduction in the discount rate reduces the levelised cost by about £3/MWh
- Since CASE B only produced 1.5MT/a CO_2, it would be reasonable to assume large industrial emitters were worthy of investigation as starting points, but very few are conveniently placed for a "start small and build" approach
- The proximity of several emitters does not on its own make a convenient cluster, as issues with pipeline routing can make some connections extremely expensive. Outline planning studies of candidate areas (such as published for Teesside[12]) are needed before selecting strategic areas to ensure smaller industrial emitters can be realistically included in a hub
- In CASE D, the industrial unit was able to tie in to the existing T&S infrastructure at a far more competitive cost than was achievable as a standalone project in CASE A
- In CASE A, the captured emissions are small – 0.33MT/a. Referring to Figure 8 (right), we can appreciate that the overall opportunity for industrial capture from sources over 3MT/a is low. In addition, there are clearly more large gas power station emitters (>1MT/a) than industrial ones
- Like Hamilton, the Hewett, Captain, N&S Morecambe, and other fields (including aquifers which overlie or are near existing hydrocarbon fields) may have "start small and build" options using existing infrastructure. Any CCS development company would benefit from a register of existing infrastructure assets (onshore and offshore), and awareness of when they are due for decommissioning to inform future feasibility studies.

Figure 8

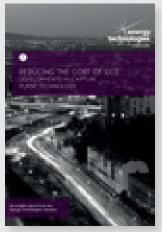
Size Distribution of 2014 Emitters over 1MT/a[8] with all coal plants except Drax removed.



Conclusion

Following the closure of the Government CCS Commercialisation competition, we have reassessed options for developing the UK CCS Transport & Storage infrastructure. There is no shortage of potential storage, either fully or partially appraised. Attractive projects to the developer and government will need to realise economies of scale at, or relatively shortly after start-up. Well positioned, large new emitters are most likely to be large gas power stations delivering strategic infrastructure to enable the later tie-in of industrial emissions. For some potential stores, options to start small and build may reduce the size of initial commitment at risk and so offer an alternative approach to building a regional CCS network.

Further Reading

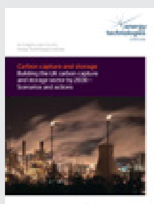


Reducing the cost of CCS - Developments in Capture Plant technology

http://www.eti.co.uk/insights/reducing-the-cost-of-ccs-developments-in-capture-plant-technology

The role of hydrogen storage in a clean responsive power system

http://www.eti.co.uk/insights/carbon-capture-and-storage-the-role-of-hydrogen-storage-in-a-clean-responsive-power-system



Building the UK carbon capture and storage sector by 2030

http://www.eti.co.uk/insights/carbon-capture-and-storage-building-the-uk-carbon-capture-and-storage-sector-by-2030

The evidence for deploying bioenergy with CCS (BECCS) in the UK

http://www.eti.co.uk/insights/the-evidence-for-deploying-bioenergy-with-ccs-beccs-in-the-uk

A picture of CO_2 Storage in the UK – Learnings from the ETI's UKSAP and derived projects

http://www.eti.co.uk/library/ccs-a-picture-of-co2-storage-in-the-uk

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