# Delivering $CO_2$ storage at the lowest cost in time to support the UK decarbonisation goals

*UK Transport and Storage development group*

## Key Messages

1. Set up a spatial planning taskforce to identify the key locations of candidate sites that can form large scale storage hubs. This will leverage the work carried out by BGS (co2stored and derivative work, etc) and will link to pipeline trunk routes for transport to the major emissions clusters.
2. Fund an organisation, a coalition of bodies or a constituted taskforce (which could be led by BGS) to perform the early delivery steps in storage maturation[1].
3. Create a storage funding/loan mechanism to pay for the appraisal of storage – the relatively high cost steps of storage maturation[2].
4. Focus early work on stepping out from "current competition" stores and depleted fields. Turn these areas into storage hubs. Later work will plan to develop two new areas, bringing the total UK storage hubs to four.
5. Understanding of the impact of geological risk is key – this can be mitigated by a continuous development funnel of high graded candidate sites.

[1] these are lower relative cost steps but take significant time

[2] The combination needs to allow for public funding input plus the benefits to a company for spending its own money, e.g. expensing its costs against general income

# Contents

## Introduction

This report is an addendum to the May 2013 CCS Cost Reduction Task Force (CRTF) report; this paper focuses on two of the seven key steps recommended, but primarily on item (ii) below :

i. Ensure optimal UK CCS transport & storage network configuration; &
ii. Promote characterisation of $CO_2$ storage locations to create maximum benefit from the UK storage resource.

The CRTF recommended that the steps for bringing about cost reduction be delivered by examining the options for the general characterisation of storage areas and specific storage sites to recommend a way forward for industry and government. The aim was set out to reduce the 'subsurface risk' premium, making storage sites bankable both commercially and technically. The optimal network development was to take into account the likely future development of storage hubs and related infrastructure.

The target audience for this paper is UK policy makers, specifically DECC OCCS given that it set up the task force in 2012, who wish to incentivise the delivery of future UK CCS projects that will realise cost reductions identified in the CRTF report and thereby accelerate CCS commercialisation. DECC OCCS requires information on what are the key next steps to form its own policy decisions and inform other Government departments with an interest in CCS (e.g. HMT and BIS).

The DECC OCCS response (16/10/2013) to the CRTF anticipates 3 phases to CCS evolution over the next decade or so:

a) Commercial Demonstration phase (Phase 1) - with material (£1bn) government support, including R&D funding, to incentivise industry to participate and invest. This is the current phase which includes UK Commercialisation Programme projects and additional support from EU funding (EEPR, NER300);
b) Transition phase (Phase 2) – taking the sector through the first power generation CfD contacts and moving from point to point projects to part chain infrastructure capable of achieving independent FID; to a
c) Fully Commercial phase (Phase 3) – when power generation costs with CCS have been driven down to be affordable & competitive in a price driven electricity supply market.

The primary focus for this paper is how best to ensure storage characterisation is carried out at the appropriate time to ensure an optimal $CO_2$ transport and storage network configuration can be constructed, to enable the CCS industry to accelerate beyond the first phase Commercialisation Programme projects towards phase two and ultimately phase three, and to deliver a development trajectory consistent with aspirations for the 2030 and 2050 horizons.

The key levers identified in the CRTF report for cost reduction relating to storage are (a) achieving economy of scale through development of clusters and (b) reduction of project risk through a set of measures that reduce storage risk and improve investor confidence. $CO_2$EOR was flagged as a third storage related factor, but this is subject to separate analysis.

For the purpose of this work it is assumed that the Commercialisation Programme projects in the UK will succeed in establishing the first two trunk line routes and storage sites that have hub potential (Humberside to the Bunter Aquifer in the Southern North Sea; and NE Scotland to the Captain Aquifer in the Central North Sea). The potential and scale of the stores is backed up by storage assessments made from $CO_2$Stored[3] and academic work by SCCS, BGS et al.

It has been assumed by many in the "industry" that acceleration of CCS will be best achieved by promoting follow on projects that add to the Commercialisation Programme projects to realise their cluster potential. This assumption was tested with relevant industry practitioners at a workshop in May 2014.

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[3] www.$CO_2$Stored.co.uk

This paper draws on the experience from the Commercialisation Competition projects and insights from other industry studies and work groups / shops. In addition, it has drawn on other recent work attributed to ETI[4] & ZEP[5].

The recommendations can be revisited once the key learnings from the two Commercialisation Competition projects have been shared. Due to confidentiality it has not been possible to include the lessons from the project contract and CfD negotiation processes in this work.

[4] Optimizing the location of CCS in the UK & A picture of $CO_2$ storage in the UK– www.eti.co.uk

[5] ZEP June 2014 “Business models for commercial $CO_2$ transport and storage

# How much storage is needed and when? What is the lead time?

## The need for storage volumes to be available by 2030

Carbon capture and storage has the potential to help keep carbon emissions within the limits that are needed to avoid dangerous global temperature rises. As such it could be a game changer[6]; getting the first CCS power generation projects built will be key to reducing the cost of future CCS power projects and infrastructure, and the UK has unique characteristics in respect of promoting clustering, having excellent storage opportunities along with the option of developing $CO_2$-EOR.

A CCS project has high capital costs; each CCS-equipped power plant typically generates over 300MW of electricity. On a unit electricity generation capacity, the cost is competitive with other clean power sources as illustrated in Figure 1.

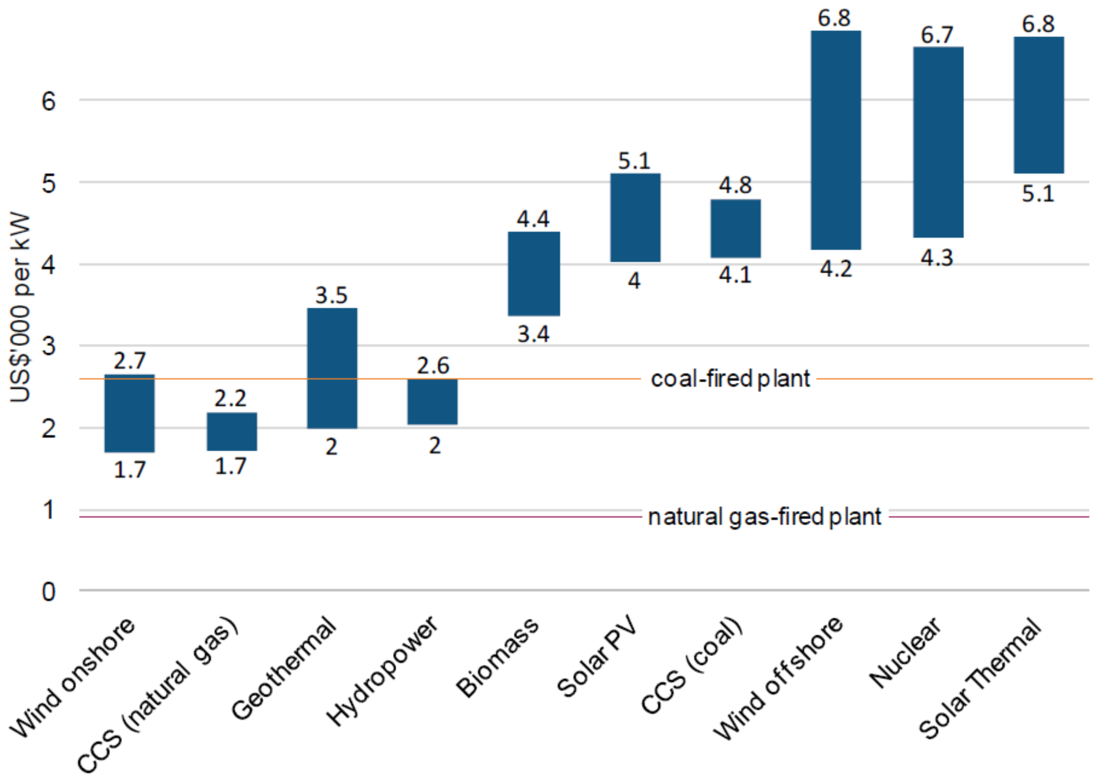


FIGURE 1: INSTALLED CAPITAL COST OF LOW-CARBON TECHNOLOGIES AND CONVENTIONAL POWER GENERATION, GCCSI 2011: THE COSTS OF CCS AND OTHER LOW-CARBON TECHNOLOGIES

It also has the advantage of generating power on demand; therefore, it compliments variable clean power sources, such as renewable energy. This is a unique feature and one that hasn't yet been "priced into" CCS power (as an added value) when the levelised cost of electricity is calculated. The pertinent point, often missed, when discussing CCS is that a single CCS electricity plant can provide low carbon energy **on demand** to over 600,000[7] homes.

There are currently no specific set CCS power generation targets for the industry[8] to point to but various scenarios (Climate Change Committee, DECC OCCS) show a range of 10-12GW of CCS generation capacity by 2030. This equates to building about 50Mtpa of storage injection capacity by 2030 and maintaining that 50Mt annually

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[6] Energy and climate change committee report 21 May 2014
[7] White Rose material http://www.whiteroseccs.co.uk/
[8] In this context industry covers power sources, industrial sources as well as transport and storage solutions; it is likely that all will be separate

thereafter. In order to achieve this build-out rate for power plants and storage injection facilities over the next 15 years the cumulative geological storage capacity will need to be proven on a timeline that makes a financial investment decision (FID) possible for both power station developers and storage facility developers consistent with their separate lead times. This gives a scale of the size of storage capacity required to be available to store $CO_2$ from power stations alone[9] of the order of 1200 - 1500 Mt by the mid-2020s. If you include the potential industrial sources then proven storage will need to be greater over the next 15-years.

In order to achieve these levels then options are required to overcome the barriers that were identified by the CRTF; these are necessary before the industry can skip directly to targeted scenarios.

The two projects in the current UK commercialisation competition, if both developed, will deliver approximately 750 MW power and around 3Mtpa $CO_2$ coming on stream by 2020. This is the foundation upon which the industry can build. Projects have been doing technical studies and design for around five years, both have received public subsidies to assist with appraisal, and both are in a publically part-supported FEED stage. Neither has made any final investment decision and the total available proven storage capacity for the Bunter Aquifer in the southern North Sea is not yet known.

[9] The focus has been on power given that industrial sources are seen to follow and the infrastructure will need to be in place first. The total assumes a mix of gas and coal.

## Timing of storage maturation efforts

Typically gas power stations have an operational life of 25-30 years (40 years for coal), but FID will be required 3-5 years prior to operations commencing. At FID the developers of a new CCS power station need to know that the infrastructure is in place so that it can store its $CO_2$ for the duration of its operation. For every 400MW of power generated between 1 (gas) and 2 (coal) Mtpa of $CO_2$ is produced: therefore the developers require an assurance that the station will be able to access 30 to 80Mt[10] of storage resource as well as the appropriate injection capacity. Typically a station is scaled at a little over 1GW, so it requires three times this resource: 90 to 240Mt of storage.

The pipeline infrastructure to be put in place in each of the two FEED projects is c18/19Mtpa in total so expanding or developing nearby stores would seem a logical cost and time effective option. When does transport investment and when does storage investment need to happen? The transport links and storage development are dependent on each other, making FID on either dependent on maturing storage capacities to a "proven" level.

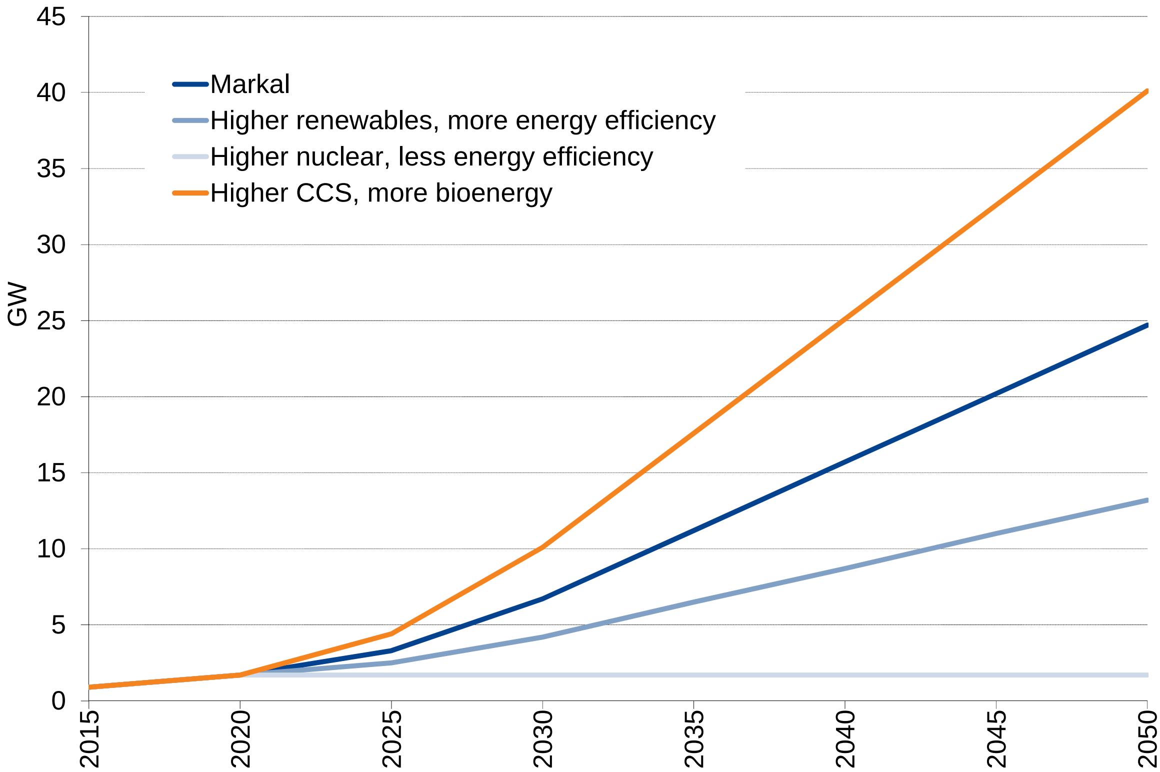
***The cumulative availability of proven storage required for taking FID on CCS power stations to ramp up to 10+ GW over the next 15 years is approx. 1.5GT of storage capacity by about 2025. The UK also requires transport and storage injection capacity of at least 50Mt each year to be on stream from the year 2030 onwards. If the North Sea is to make a disproportionate contribution to storage capacity for Europe as a whole then you might need to multiply the UK contribution by 3 or 4 times to make a useful impact on behalf of Europe***

The first projects in the UK commercialisation competition will start injecting in the 2018-2020 timeframe. Realistically these need to be rapidly followed by an additional 5Mtpa of storage injection capacity a few years later, then ramping up to the 30/40/50Mtpa in 2030. Further pipeline capacity will need to be built during this same time period to meet annual throughputs. Given the proven scale of the two FEED projects then this would represent a significant scale up of current proven storage capacity. Early work from the SCCS MultiStore project indicates that the Captain store can accept up to 12Mtpa as a step out but the total proven storage capacity (less than 200Mt) will create a constraint on investment decisions and actual size of injection facilities. So it is important to know how many projects annually will be required.

The above figures are based on the scenario of 10+ GW of CCS power generation flagged for 2030 and the need to scale up new regional power projects. Naturally the speed of scale up will depend on the amount of "proven" storage available.

The Figure below shows different CCS power deployment rates under three DECC scenarios. The discussion above demonstrates the scale of the transport and storage infrastructure required to deliver these, and the challenge facing the sector.

[10] The higher tonnage range is for coal stations




*CONTEXT: CCS RECOGNIZED AS AN IMPORTANT COMPONENT OF DECARBONISATION*

**DECC CARBON PLAN SCENARIOS FOR CCS DEPLOYMENT ARE SHOWN ABOVE; MANY OTHERS WOULD LIKE TO SEE FASTER AND GREATER GROWTH**

SOURCE: DECC CARBON PLAN

This steering group / taskforce has identified that the time to mature a new storage resource of 50-100Mt requires a lead time of between at least 2-4 years of appraisal and 2-3 years of construction for a step out or enlargement of a current store or depleted field, and 4-10 years + construction for a new area development. Working backwards from 2030, we assume power development requires certainty of the storage resource 5 years before a power generator commences development to allow planning and FID, so storage appraisal must start around 2015 (new area) and 2021 (step out) for an early phase 2 project.

The Crown Estate had commissioned a report by Poyry in 2013[11] which concluded that, in the absence of further interventions to incentivize exploration and appraisal of storage sites independent of power station projects, significant risks to CCS deployment would exist that could lead to:

- Development of smaller stand-alone projects;
- Only roll out CCS projects at a slow rate, so sub optimal;
- Realise extremely slow growth of industrial non-power CCS projects.

Hence, the conclusion of the steering group, based upon the workshop input, is that without further bespoke policies for $CO_2$storage appraisal, the aspiration of having CCS power as a competitive alternative in the UK generation mix is at risk and therefore the cost to energy consumers of meeting low carbon targets would be 40% higher. This leads to

[11] Market barriers to Carbon transport & storage infrastructure development in the UK and how to incentivize future build out, May 2013

a wider issue of which way does UK energy policy point e.g. more wind, more investment in nuclear or restrict growth of new hydrocarbon based electricity.

# Storage development process

## Background: What is a bankable or proven storage resource? Why is it not simple?

In order for $CO_2$ not to be emitted it must be injected into rocks one or two miles under the ground [P18-4 is over 2 miles[12]]. If the injection stops or slows down the $CO_2$ either has to be emitted to the atmosphere or the power export (or manufacturing process) may have to stop until the problem is rectified. The generator will cease to be paid for the clean power and return on capital invested could be affected. As a result, before an investment is made, the ability to inject into the subsurface at a predictable and reliable rate and price for the service must be guaranteed.

Over the last 50 years we have built up a good understanding of the subsurface in the North Sea; the areal extent of the permeable layers where the $CO_2$ can be stored; the compartmentalization of the layers, with reservoirs bounded by faults and discontinuities which dictate the volume that individual wells can access, but our knowledge is not complete, which means we will continue to invest in seismic surveys and wells to reduce uncertainty and to access new storage volumes. For example, a depleted pressure gas field might be very well understood and the storage volume reliably calculated, but an aquifer storage layer might stretch for many miles before a barrier is reached and we will learn more about the size of the usable storage volume in the aquifer reservoir as we inject. Examples of this would be the large scale storage capacity of the Sleipner aquifer in Norway compared to the disappointing size of the compartment selected in the Snøhvit reservoir.

The more information that is gathered, and the more appraisal wells drilled, the lower the risk of the storage resource turning out to be smaller than expected. Sometimes an appraisal well can be drilled after injection has started a few miles away. If this well sees a change in pressure caused by injection it proves connectivity and helps to prove the size of the storage resource.

Once an area of geology has been shown to work for $CO_2$ injection, it becomes reasonable to assume that a similar area will also work.

In the long run aquifer storage will provide the main contribution to storage volume, but certain depleted fields, selected for their size and definition will provide early capacity and help kickstart the industry. Part of the solution to managing the inherent geological uncertainty in storage volumes is to have alternatives accessible from each transport network. For example if it is discovered that a particular storage reservoir is compartmentalised and smaller than ideal, a new well can be drilled into another compartment , or water can be extracted from the existing compartment making more room. These contingency plans come at a cost and will increase the unit cost of storage for a development – but, as illustrated by Snøhvit and backed up by a century of oil and gas development experience, this is an inherent part of working with the subsurface.

It is therefore key that development and appraisal activities maintain fallback options – often termed the development funnel – in order, both to provide for continued expansion of storage resources and also to mitigate the geological uncertainty risk. Developers and operators will need to include a reward for maintaining such options in their income streams and business models. A corollary to this is that the underlying cost of storage is difficult to predict until the actual injection performance is known. In oil and gas development the operators always use probabilistic ranges, P90, P50 and P10, to describe the range of subsurface outcomes and the impact on unit cost.

The P50 is termed the expectation case. While the P90 is the case where 90% of the time the storage volumes will be larger than this number – it is a high certainty case. This case is related to the proven or bankable storage volume which is the volume that the developer can effectively guarantee is available. We should add that there is a technical P90 capacity and also a project P90 that is influenced by economic and commercial factors. This is the case with

[12] This is the TAQA store for ROAD

natural gas reserves reporting and for project financing decisions. For example a P90 gas resource means you have a market for that volume of gas. We may need a similar approach to a storage resource and this will require further dialogue with financing institutions.

So there is a "technical" P90 which then gets turned into an "economic or project" P90 for the banks. Even this proven/bankable volume is not absolute as geology that is miles underground can still spring surprises, but it is much less likely. If the range of outcomes is thought of as a bell curve (or statistical distribution), then the greater the level of investment in appraisal the narrower the range between the P90, P50 and P10. Also, as injection continues, the increase in knowledge gained by monitoring the conformance (pressure and distribution of $CO_2$) of the project reduces the spread in values. At the end of the injection project when the store is full, then all three numbers become the same and the size of the store is known, though there will be no more available storage resource.

**In summary:**

A funnel of developments is vital, with a continuous stream of storage resources being matured: both to provide for new projects and also to insulate against the effects of geological uncertainty.

Project developers and policy makers need to understand the range of potential geological outcomes and not simply state one number for storage, but use probabilistic ranges. This is the case for both injectivity (the rate of storing $CO_2$) and the volumetric capacity of the geological formation.

The more information that is gathered about a rock formation, the higher the confidence that a certain volume can be injected at the required rates.

There is an economic cut-off where it stops being feasible to appraise. As a result, in a new area, it is unlikely that huge storage volumes (e.g. 200Mt) can be guaranteed from the start. The exception is where existing hydrocarbon production has done much of the de-risking – but these sites are limited, may need actions and expense to remediate wells, and are not likely to be the whole solution.

Once injection starts, more information is forthcoming about the size of the store, however, it is often necessary to invest more in appraisal to "prove up" these larger volumes.

Once an area has been shown to work other similar areas are deemed more likely to work as well. Hence stepping out from a known store often carries less risk than developing a completely new area.

## The cost components of a $CO_2$ storage project

The cost of a storage project can be divided into five elements

1. Finding & de-risking cost
2. Cost of design (FEED) leading to a final project cost estimate
3. Development/construction cost
4. Operating cost including post injection stewardship
5. Decommissioning and transfer cost

The economies of scale operate on costs 3-5 while the finding cost can be reduced by stepping out from existing developments.

Finding and de-risking cost deserves special attention as the investment must precede any CfD negotiation, yet the magnitude of the investment is inherently unknown owing to the nature of geological uncertainty. In the hydrocarbon industry much of the income from existing developments is invested in finding new oil and gas, which is inherently risky and requires multiple opportunities to cover the uncertainty of success. This potential source of funding does not yet exist in CCS as there is no existing industry.

The most cost effective manner in which to develop storage is to grow a small number of large storage hubs. This implies that spatial planning is needed. Fortuitously many emissions in the UK are clustered onshore adjacent to high potential offshore storage areas. Pipeline transport also benefits strongly from economies of scale. However, poorly planned power station developments, in a low carbon context, which are a significant distance away from a storage solution, or unable to access pipeline infrastructure economically, will prevent optimal CCS deployment. Some CCR consented sites already have demonstrated this (policy) failure.

Special mention must be made of the potential for $CO_2$-EOR to lower the cost of storage. This comes about because storage of $CO_2$ left behind during the EOR process is a “by product” of the operations. Again fortuitously the $CO_2$-EOR potential is clustered in two regions of the central North Sea not too far from one of the current demonstration projects.  It should be pointed out, however, that co-located or nearby storage formations that allow a first step of investment decisions by emissions sources leading to sufficient volume aggregation is essential to enable $CO_2$-EOR investment decisions to be made in parallel.

## What effort is required to de-risk and develop a storage site?

Many claims have been made and papers published on the effort and cost to develop a store. Most, if not all, of these have been based on theoretical studies and analogy with oil and gas projects. The Transport & Storage development group wanted to validate these claims. In order to do this, in May 2014, they gathered together experienced storage experts from companies[13] that ***have developed or are developing storage solutions***, and ran a structured workshop.

The workshop concentrated on the following three areas:-

- Time and effort required to de-risk a new store & how to step out from the current stores (in the UK Commercialisation programme): what barriers existed & what effort is required.
- Funding mechanisms for de-risking of storage.
- How to make the characterisation process work.

Three scenarios were explored – these related to the development of a new large aquifer, the development of a new depleted hydrocarbon field, and a step out from either option.

### The development phases for $CO_2$ storage

In deciding how to develop a storage option any developer will need to go through various stages. They are well understood and are:

(i) identify a potential storage region (a play) and a best area within it (a lead);
(ii) collect remote sensing [seismic] data over a number of leads, and chose the best one: termed the prospect;
(iii) drill a well into the prospect and determine if there is a suitable storage rock formation: termed the discovery;
(iv) once the right type of rock formation has been discovered then the size (connectivity, lateral variation in properties) has be to determined: appraisal;
(v) de-risking: this is key to $CO_2$ storage as the storage containment needs to be shown and the ability to monitor must be shown;
(vi) At this point the project is ready to work out the best way to develop the storage resource: how many injection wells and where to put them. A certain core storage resource and injection capacity has been de-risked to a high confidence, while a larger volume has been identified as potentially available. The developers finally have the evidence required and confidence to commit to investing in a storage, transport and capture FEED. At the same time the application for a storage permit can be made (an exploration permit would be applied for in step (ii)).

Cost elements (i) to (iv) are termed the finding cost. They serve to establish the capacity and sustained injectivity of the store.

Cost element (v): de-risking establishes the containment and monitorabilty of the store. Experience in projects has shown that the de-risking element is common to all storage projects and takes up to 2 years, costing in the order of £10 million. This element is driven in part by policy and regulatory requirements linked to securitization of risk and does not exist in hydrocarbon development to such an extent.

Only after step (vi) is the cost of the whole end-to-end development known. Eventually, at this point, a CfD price could be set with a power generation source.

[13] For example: Shell; BP; Statoil; Gassnova; Taqa

## Developing a saline formation store in a new area

The most costly and time consuming evaluation is when entering a new area. This will be explored first, then differences between this and stepping out from a field or existing store will be highlighted.

(i) *Identify*. Much of the ground work for this phase has been successfully delivered by the UK Storage Appraisal Project (ETI) and the follow on $CO_2$Stored project (The Crown Estate and BGS). These publically and privately funded projects have analysed the majority of the UK continental shelf and have identified the storage plays – the large areas where rock formations are thought to be located that will be suited to storage.
A prospective storage operator will need to work with this valuable knowledge resource to identify the best play for their $CO_2$ needs, and then identify the most promising areas within each play, termed a lead. The $CO_2$Stored and UK SAP projects have not had the funding to take plays down to leads.

The process of maturing a play into a lead requires the deepening of the work that underpins $CO_2$Stored, including the purchase and analysis of new data – and in some cases the acquisition of new remote sensing datasets. Time estimates range from 3 months to 2 years depending on the availability of specialist geoscience staff and data. The cost, assuming that no new remote sensing data is required, is expected to be up to £3 million per play.

(ii) *Prospect*. The lead still defines a region within a larger play. It is expected that there would be a number of leads. This has next to be refined into a set of prospects – a prospect is an actual candidate store. In order to identify prospects it is likely that new remote sensing data [3D seismic survey] will be required. In the UK many areas are covered by existing surveys so cost and time might be reduced by purchasing an old survey. Once this data has been received, processed or re-processed and then interpreted, a drilling location within the prospect can be chosen. The maturation of prospects from leads, and the identification of appraisal drilling locations has cost various CCS projects between £7 million and £20 million, with a work duration ranging from 1 year (the developer already has the data) to 5 years (new data is needed).

(iii) *Discovery*. Once a drill location has been chosen a drilling rig needs to be leased, the well designed, materials need to be ordered, and the well must be drilled, cored, logged and tested. If the well discovers that the properties of the target rock formation underground are suitable for storage then a discovery has been made. If not, then another prospect needs to be chosen and the drilling process starts all over again. In the success case this is estimated to cost between £15 million and £50 million (depending on water depth and target storage formation depth) and will take between 1 and 2 years.

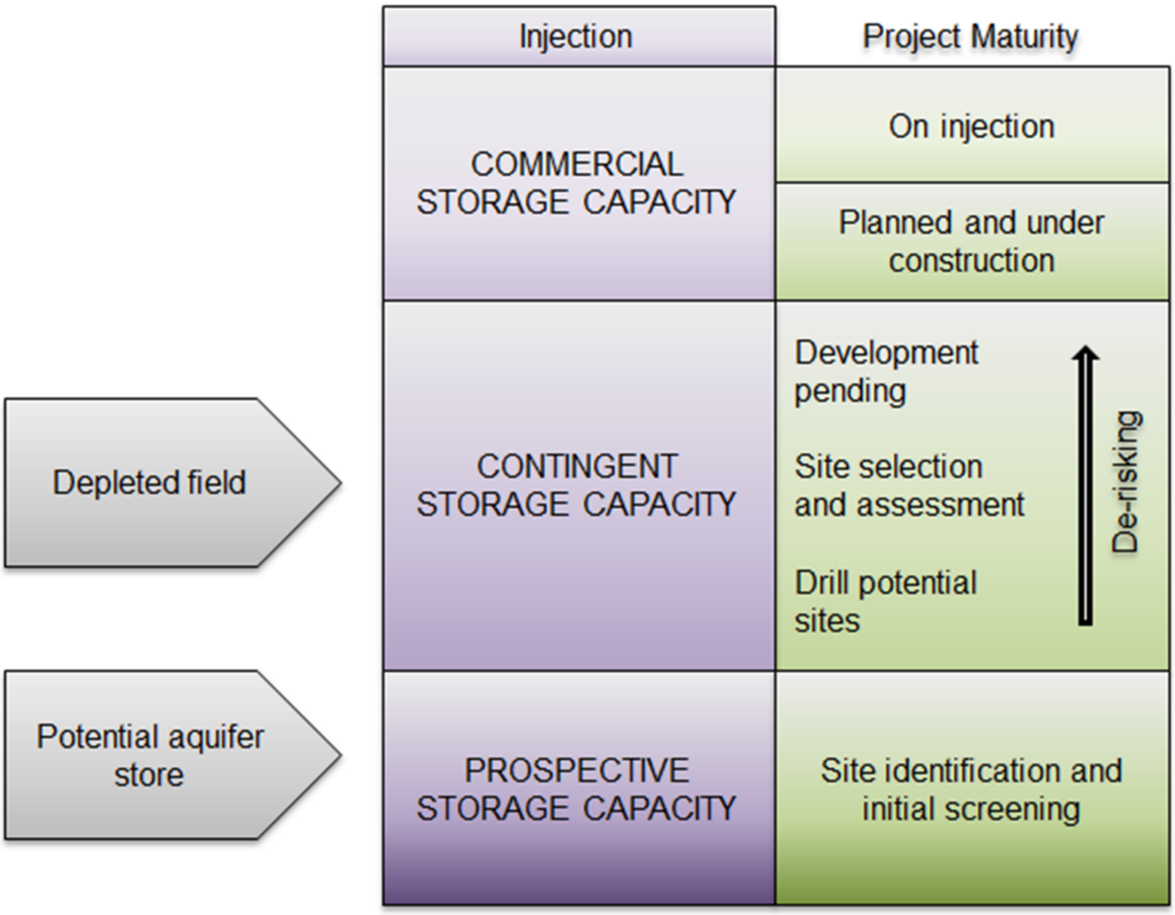
(iv) *Appraisal*. Assuming success then only a small portion of the potential storage resource will have been tested (a small proved volume). Appraisal is often required which will likely mean the drilling of an additional well or running an extended well test. This will validate the lateral continuity of the good rock properties and look to de-risk small compartment sizes. This cost of this phase is variable depending on the exact conditions. The Shell Quest project drilled an exploration and an appraisal well, while the White Rose project benefited from an old oil/gas exploration well but still needed to drill an appraisal well. The cost of this phase can range from £2 million to £50 million, with time from 1 to 4 years.

| Phase | Duration, years | £ million |
|---|---|---|
| **(i) Identify Leads** | 0.3 to 2 | 3 |
| **(ii) Prospect** | 1 to 5 | 7 to 20 |
| **(iii) Discovery** | 1 to 2 | 15 to 50 |
| **(iv) Appraisal** | 1 to 4 | 2 to 50 |
| **Total Finding Cost** | 3.3 to 13 | 27 to 123 [£0.27 to £1.23 / tonne] |

TABLE 1 GREEN FIELD DEVELOPMENT, ESTIMATES FROM DEVELOPER EXPERIENCE FOR A 100MT STORE

**The sum total of the exploration and appraisal cost is termed the Finding Cost**.

Another way of viewing the development phases of storage can be seen in the below maturation table:




**POSSIBLE VIEW OF STORAGE MATURATION**

ADAPTED FROM: ILLUSTRATING THE ESTIMATION OF CO2 STORAGE CAPACITY FOR HYPOTHETICAL INJECTION SITE. (ALLINSON ET AL, GHGT11, NOV 2012 AND GUIDELINES FOR THE EVALUATION OF PETROLEUM RESERVES AND RESOURCES, SPE 2001)

## Developing a step out: re-using a depleted field or extending near a current store

### Existing fields

The re-use of depleted fields is instinctively an attractive proposition. The field has already been discovered and its size is known. There is, however, a stage similar to the appraisal stage where the suitability for re-use has to be assessed. This involves a detailed analysis of the status of the legacy well penetrations and an examination of the production data. The key for any storage developer is to gain access to high quality legacy data from the original operator. This can take time and cost money both for the original operator and the developer. It can be estimated that data collection will take approximately 1 year, followed by ½ to 1 year of analysis, with a cost of £0.5 million to £1 million (assuming minimal charge for the data). It is possible, but not guaranteed, that other finding costs could reduce to almost zero.

If the depleted field is connected to an aquifer that is suited to storage, the field production will have significantly de-risked the aquifer – all the way to the end of phase (iv). The size of the proved capacity will also be significantly larger in this case, reducing the range of capacity estimates and increasing confidence in future performance.

### Stepping out from an existing store

Extending or stepping out from an existing store is attractive because again phase (i) has been skipped, and phase (ii) shortened. The de-risking phase (v) will also be reduced in cost as it will be able to draw upon work from the previous store.

The expert workshop found that 1 to 5 years could be removed from the duration of the exploration activity, while cost could also reduce, but the magnitude of the reduction would depend on the exact geological structures in the area. Referring to Table 1 (greenfield development), the cost could potentially reduce by £10 million to £20 million.

# Delivery mechanisms for funding and developing storage resources.

The workshop was made up of experts from developers with experience in $CO_2$ storage projects. This experience was both technical and commercial and spanned multiple countries. As a result the opportunity was taken to explore potential avenues for delivering the required storage resource in time for the UK's needs.

The first fact to note is that very little storage exploration has taken place without external support. However, where support has been forthcoming, from the ETI in the case of UK SAP, and from the EEPR mechanism, significant progress has been made.

As noted above the UK SAP project and now $CO_2$ Stored have together reduced the lead time for storage delivery by 6 to 12 months.

Table 1 (page 15) shows that the expenditure is not linear. Turning plays into leads can be delivered at a low relative cost, as can the conversion of leads into prospects. If this is done for the whole UK continental shelf (UKCS) the cost would be prohibitive, but combined with effective spatial planning to select the best areas for future giant hubs the funding cost becomes manageable from government funding schemes.

The Australian government realised this and in 2009 the Carbon Storage Taskforce published the National Carbon Mapping and Infrastructure Plan. In this they identified key areas for the development of $CO_2$ storage offshore. The Australian Government, through the Department of Industry, then supported Geoscience Australia in undertaking a series of regional-scale, geological studies to assess the $CO_2$ storage potential of the key storage areas. The funding covered study work using existing data and the collection of new seismic data. The work was delivered by Geoscience Australia, academic partners, and specialist consultancy companies. It has significantly reduced the uncertainty in the areas studied, effectively taking some of them through to the end of phase (ii).

It is worthwhile noting that progressing this work to the next level of detail in the Gippsland Basin offshore Victoria, has taken a $5 million Victorian Geological Carbon Storage (VICGCS) initiative. In early-2010, a 2D, 8,000 km line seismic survey was completed over the southern flank of the Gippsland Basin to create a 3D model to study storage potential and develop prospects ready for drilling.

The UK could or should think of adopting a similar approach, setting up a focused group with the remit of spatial planning to, in a structured manner, formally identify the key storage areas, and then tasking an organisation such as the British Geological Survey with coordinating a programme to mature these areas to "drill ready prospects" and to de-risk monitoring & containment. This can build on work already underway by BGS for The Crown Estate to create a portfolio of higher ranked storage prospects. This is also applicable for the step outs from existing stores and the re-use of fields and connected aquifers. Funding to a level that already exists in the UK CCS R&D budget can significantly de-risk the areas.

Phase (iii) discovery requires much larger expenditure and would require a different funding mechanism. It is not suited to delivery via the current CfD mechanism owing to issues related to the CfD contract structure[14], lead times, market confidence and price signals that are outside the scope of this document.

As a result a mechanism for pre-investment funding needs to be developed. This could include a loan scheme to be reclaimed via the CFD mechanism once projects are developed. Ideas suggested on this are included in the "Britstore" box below.

Suggestions for funding of the finding costs from the workshop, which could / should be taken up by a separate group, included:

I. 10% of the ETS income goes into an appraisal fund for pre-investment on storage;
II. Link the development of storage to carbon capture readiness;
III. As suggested by ZEP, capitalise a market maker/hub developer which will drill the first wells then put out to tender & money is reused for the next phase.

A fuller list of the workshop suggestions can be found in Annex A. Significant support was generated for state supported appraisal. The key message from the workshop was that industry won't be able to do this activity unless:

- Policy clarity is in place that $CO_2$ will be captured;
- Subsurface risk-taking is rewarded; and that getting confidence in these things might not happen straightaway in which case an alternative is needed.

**The "BritStore" Model (government agency prospect) & generic thoughts & structure on appraisal funding**

There are layers. Simplest is that the government funds additional appraisal – probably through a 3rd party agency, like BGS.

Additional appraisal can take place:

1) Review public data (done by $CO_2$Stored);
2) Purchase access to additional data – wells and seismic – plus detailed analysis;
3) Perform appraisal activities – seismic ;
4) Perform appraisal activities – wells;

The question is how and where to capture value? What about a model of cost recovery [student loan] – when a

[14] By this we mean the components making up the contract terms do not cope with the timing issue for upfront storage expenditure, and then for subsequent potential re-baselining as a result of ongoing storage appraisal costs, plus a number of other things. The problem is analogous to the CfD issues around how to deal with variability in input fuel costs and loss of income due to variability in dispatch in the merit order.

developer takes on a store with a payback clause when injection starts.

The Britstore model, in simple terms, is about a government agency model which centrally buys the storage data and even drills the first wells to de-risk the store and then tenders / sells on the proven storage site, but at a lower return on capital than say the rate that an oil company would require.

## Annex A - Funding options section from the workshop

Storage business model:

The current model envisaged by government is that the storage activity can and should be undertaken by the private sector without risk being shared by the government [apart from storage liability risk]. The CRTF was unsure this is a credible business model proposition at this stage of offshore storage development.

Points from the workshop session, which could / should be explored in more detail by a focused storage & commercial group, were:

i) A government agency could do the storage appraisal work. This could be similar to (iv) below,

This takes away the need for $CO_2$ delivery / full chain risk; the Government takes the risk and the "agency" will be the entity that has to mobilise skills & capability, whereas the private sector may have issues with delivering this.

ii) Tax breaks

The feeling was that for this to be relevant then the storage entity needs to be a very big player to benefit. In this case a company can try to overcome this issue with cross-sector expensing of costs against any income.

iii) Loan

This is akin to a student loan model. So if there is no revenue to repay the loan then the loan remains unpaid; plus the loan would need to be a low percentage interest.

iv) The BGS [for example] option or "Britstore" model:

At its simplest the government funds additional appraisal – probably through a 3rd party agency, like BGS.

The Britstore model, in simple terms, is about a government agency model which centrally buys the storage data and even drills the first wells to derisk the store and then tenders / sells on the proven storage site, but at a lower return on capital than say the rate that an oil company would require.

This option could require 20 exploration & production (E&P) people, c£150M from government & 4 years at a minimum to:

Aggregate all the data;

- Complete & publish a relevant atlas;
- Screen & publish sites;
- Select 3 suitable prospects;
- Plan & drill the first 3 wells & publish the data from them; and
- Then tender for (say) £50M each site [or more].

Other thoughts & comments raised at the session were:

v) Capital grants would be required for FEED & for appraisal: say £2/te. Storage operators need a return on their capital of at least 20%, once the opportunity cost is taken into account;
vi) Loans: there is no income pre-FID, so the need for 0% interest on the loan and a guaranteed income in the FID range of £100-200/Mwh;
vii) Tax breaks – only relevant to the O&G sector as it can look at offsetting tax and skills;
viii) UK context: Prioritise storage regions; grant funding to support pre-FEED & FEED work OR

Government could take a stake & get investment paid back later; this could be split 75% grant / 25% private.

OCCS "Phase 2" will need capital grants and CfDs.

ix) $CO_2$-EOR: would not (necessarily) need special funding, but possibly a separate petroleum tax regime. Could try to bring storage and EOR together rather than treat them as separate or sequential businesses.
x) Incentives for decommissioning of hydrocarbon fields – what does this do & how does it deliver proven storage?
xi) Could build on past projects & FEED e.g. Longannet work & Hewett work? How to do this cost effectively?
xii) Emitter support / incentives / drivers: force them to buy options for storage to demonstrate options [as part of CCR?]. This would reflect a policy change.
xiii) State geology to prove up some storage & a central agency to be a portfolio owner.
xiv) Redo the Miller project idea with CfDs & $CO_2$EOR structure?

Therefore many options were flagged[15], and except for the government agency one, they require guaranteed $CO_2$, so a policy direction is needed. As with all new sectors, clarity and confidence on an enduring framework in which to make investment decisions and undertake risky activities is required. These various options can provide useful steps along the way for storage appraisal and development, but will still need the underlying market failures to be addressed through policies providing certainty over an extended period beyond the first projects.

*The next two pages show tables which capture data from the workshop, as the attendees were split into different work 'tables'.*

[15] The above is aimed at capturing all the points made by the attendees, rather than ranking them.

# UK T&S working group, 100Mt store

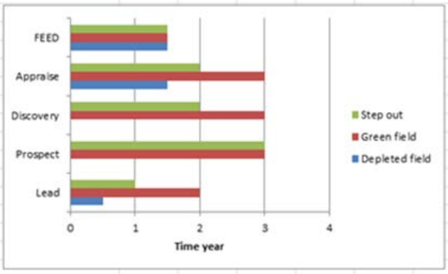
The play is the North Sea, we assuem that the UK SAP project helps to pick the lead

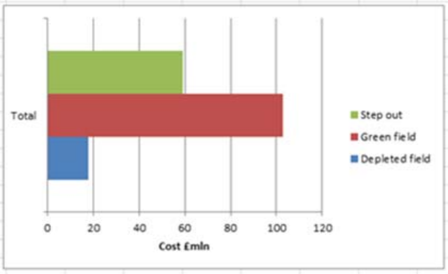
| Type of appraisal | Lead Cost £mln | Lead Team FTE | Lead Time year | Prospect Cost £mln | Prospect Team FTE | Prospect Time year | Discovery Cost £mln | Discovery Team FTE | Discovery Time year | Appraise Cost £mln | Appraise Team FTE | Appraise Time year | FEED Cost £mln | FEED Team FTE | FEED Time year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depleted field | 1 | 5 | 0.5 | #N/A | #N/A | #N/A | #N/A | #N/A | #N/A | 7 | 15 | 1.5 | 10 | 20 | 1.5 |
| Green field | 3 | 10 | 2 | 15 | 10 | 3 | 50 | 15 | 3 | 20 | 15 | 3 | 15 | 20 | 1.5 |
| Step out | 2 | 10 | 1 | 15 | 10 | 3 | 25 | 15 | 2 | 5 | 15 | 2 | 12 | 20 | 1.5 |

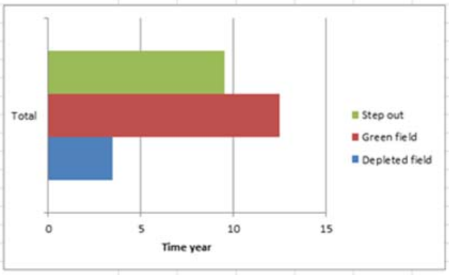
| Cost £mln | Lead | Prospect | Discovery | Appraise | FEED | Total |
|---|---|---|---|---|---|---|
| Depleted field | 1 | #N/A | #N/A | 7 | 10 | 18 |
| Green field | 3 | 15 | 50 | 20 | 15 | 103 |
| Step out | 2 | 15 | 25 | 5 | 12 | 59 |

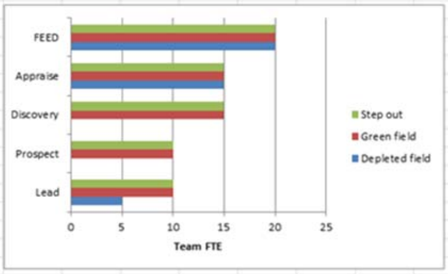
| Team FTE | Lead | Prospect | Discovery | Appraise | FEED | Total |
|---|---|---|---|---|---|---|
| Depleted field | 5 | #N/A | #N/A | 15 | 20 | 40 |
| Green field | 10 | 10 | 15 | 15 | 20 | 70 |
| Step out | 10 | 10 | 15 | 15 | 20 | 70 |

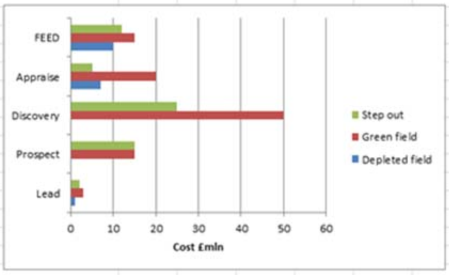
| Time year | Lead | Prospect | Discovery | Appraise | FEED | Total |
|---|---|---|---|---|---|---|
| Depleted field | 0.5 | #N/A | #N/A | 1.5 | 1.5 | 3.5 |
| Green field | 2 | 3 | 3 | 3 | 1.5 | 12.5 |
| Step out | 1 | 3 | 2 | 2 | 1.5 | 9.5 |



Below table shows ranges and "table differences" from the workshop audience

| **Activity** | | | | **Cost** | **Team** | **Time** |
|---|---|---|---|---|---|---|
| **Identify** | | Done → UK SAP (cap rock) | | £1m depleted field | 1-3 depleted field | 3-6 months for depleted field |
| **Lead** | | Screening | | <£1m | Small 2-3 people | <1 year |
| | | Prospect | Lots of data<br>Buy | £100k+ | 10+ | <1 year |
| | | | Little data<br>Acquire | £10 – 15m<br>3D seismic £7m+<br>£5-20m dep field | 10+<br>2-5 + contractors<br>20<br>10+ dep field | 2 – 5 years+<br>planning Challenges;<br>Access to kit/rigs<br>2-3 yrs |
| Permit (↕) | **Discovery** | Design<br>Drill | | £15m<br>£20-25M + 1 well<br>£50m aquifer for a P50 | Drillers<br>3- 5 people FTE<br>10+ [aquifer] | 2 Years<br>Need a storage licence |
| | **Appraise** | Might need 2nd well | | £20m<br>1 in 3 failure? | Analysis<br>If well up to 6 (contracted) | 2 years |
| | **FEED Permit** | Concept & Refinement<br>Tenders | | £3-4m<br>£10m+ | 12 FTE<br>20 | 6 months (ish) |

## List of May 14 2014 Workshop attendees:

| | |
|---|---|
| Jason Golder | The Crown Estate |
| Tom Mallows | The Crown Estate |
| Peter Edmonds | The Crown Estate |
| Owain Tucker | Shell |
| Michelle Bentham | BGS |
| Jonathan Pearce | BGS |
| Stephen Cawley | BP |
| Mervyn Wright | National Grid |
| David Hanstock | Progressive Energy |
| Lamberto Eldering | Statoil |
| Chris Gittins | TAQA Global |
| James Lorsong | 2COEnergy |
| Patrick Dixon | DECC (OCCS Expert Chair) |
| Brian Allison | DECC (OCCS) |
| George Day | ETI |
| Praveen Gopalan | Ecofin Research Foundation |
| Hallvard Høydalsvik | Gassonova |
| Luke Warren | CCSA |