Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 63 (2014) 5103 – 5113

Energy Procedia

GHGT-12

CO_2 STORage Evaluation Database (CO_2 Stored). The UK's online storage atlas.

Michelle Bentham[a]*. Tom Mallows[b], Jonathan Lowndes[a] and Andrew Green[c]

[a]British Geological Survey, Environmental Science Centre, Keyworth, Nottingham, NG12 5GG
[b]The Crown Estate, 6 Bell's Brae, London, EH4 3BJ
[c] Energy Technologies Institute, Holywell Building, Holywell Way, Loughborough, LE11 3UZ

Abstract

The CO_2 Storage Evaluation Database (CO_2 Stored) is the UK's offshore storage atlas. It provides online access to information for over 500 potential offshore storage units. CO_2 Stored is hosted and developed in partnership by The Crown Estate (TCE) and The British Geological Survey (BGS). CO_2 Stored provides access to some of the results of the UK Storage Appraisal Project (UKSAP; commissioned and funded by the Energy Technologies Institute). Through CO_2 Stored information can be delivered for a range of storage types including saline aquifers and oil and gas fields concerning the geological parameters of the storage units, potential geological risks and economic projections for cost of storage.

Peer-review under responsibility of the Organizing Committee of GHGT-12

Keywords: Storage Atlas; UK CO_2 stroage capacity; UK CO_2 storage.

1. Introduction

The CO_2 Storage Evaluation Database (CO_2 Stored) is an online web enabled database, which provides an overview of CO_2 storage opportunities around the UK. The database was initially developed as part of the UK Storage Appraisal Project (UKSAP), which was commissioned and funded by the Energy Technologies Institute (ETI). The aim of the

* Corresponding author. Tel.: ++ 44 (0)115 9363048; fax: ++ 44 (0)115 9363200.
E-mail address: mbrook@bgs.ac.uk

Peer-review under responsibility of the Organizing Committee of GHGT-12
doi:10.1016/j.egypro.2014.11.540

UKSAP project was to provide a comprehensive, auditable and defensible estimate of the UK CO_2 storage capacity.

In 2012, The Crown Estate and The British Geological Survey (BGS) entered a partnership to host and develop the database formed by UKSAP and thus CO_2 Stored in its current form was launched. The partnership's vision is to provide a living, user friendly and stable research tool for enabling cost effective access to a unique combination of CCS-focused geological storage data and spatial infrastructure and activity data on the UK continental shelf, facilitating the development of a sophisticated planning capability in addition to the dissemination of UK subsurface storage data and knowledge. In order to achieve this vision and working with stakeholders, over the planned five years developments will improve and add to both functionality and the underlying data.

Access to the CO_2 Stored database is available under licence through secure online web enabled database and Geographical Information System (GIS) (www.co2stored.co.uk). Users of the database will have access to information for over 500 potential UK CO_2 storage units collated as part of the UKSAP project and updated, validated and enhanced as part of The Crown Estate and BGS's ongoing development. The database provides information on storage units in saline water bearing reservoir formations (saline aquifers), oil fields and gas fields

This paper will discuss the data within the database and how the storage capacities are derived. It will also give an overview of CO_2 storage capacity around the UK. CO_2 Stored estimates that the UK has a total theoretical storage capacity of 78 Gigatonnes (billion tonnes, Gt) with 50% confidence (P50). The majority of this capacity resides in saline aquifers. This gives the UK one of the largest storage potentials in Europe.

2. Methodology

The database identifies all potential storage formations for the UK continental shelf (UKCS). These include saline aquifers and depleted and depleting hydrocarbon fields. The potential storage sites are classified within the database as storage units (individual geology-based units of assessment) and daughter units (mapped individual water-bearing or hydrocarbon bearing traps).

Regional saline aquifers are subdivided into either fully confined ‘closed’ pressure cells or ‘open’ units, based on geological understanding and/ or interpreted formation pressure data. Where identified, structural or stratigraphic traps (identified on published maps or seismic surfaces) within these units (daughter units) were also characterised and subsequently treated separately for capacity estimation purposes.

Saline aquifer storage units have been identified and individually assessed by storage experts in the UKSAP using seismic, well data and published information. Important parameters essential for storage capacity assessment are recorded within the database. These include; location, storage unit type, lithology, water depths, porosity, permeability, formation thickness, formation depth, formation pressures, and salinity. Critical parameters are described by ranges (minimum, most likely and maximum). The calculation engine within the database undertakes Monte Carlo simulations to provide a probability based result for static capacity.

A number of storage capacity estimations are provided for the storage units. P10, P50 and P90 capacities are reported in the database for every storage unit. A dynamic utilisation capacity is provided for representative storage units. UKSAP also investigated dynamic behaviour of saline aquifer storage units in order to gauge the likely impact on static capacity estimates. Structurally simple, homogeneous flow simulation models were constructed in order to investigate generic effects of sensitivity of various key parameters (such as depth, thickness, horizontal and vertical permeability, dip etc) on storage in open aquifers, closed systems and structural traps. For these units a storage efficiency factor provided by representative numerical models of the storage unit was used in the capacity calculation. [1].

For depleted and depleting hydrocarbon fields, production and injection data was used to estimate the volume available for CO_2 storage on a fluid replacement basis.

Geological risk is presented for each storage unit. Risk to storage security, storage capacity and cost was assessed by a team of experts, using well, seismic and published data. Risk information includes geological information on faulting in the storage unit, cap rock, compartmentalisation of the storage unit, and likelihood of formation damage. The level of confidence in each criterion is also recorded. A cost estimate for each storage unit is provided based on a single CO_2 source to single storage unit infrastructure. Further information about the methodology used in the UKSAP project can be found in [1].

3. The database

The CO_2 Stored web interface is currently restricted by login to authorised users only. Licenced access can be obtained by emailing info@co2stored.org.uk. Within the site there are two methods of searching the dataset, an attribute based search and a map based search (Fig.1).

The Attribute search interface allows users to input a number of parameters on which to filter the data. The filtered result set displays a series of storage units in tabular form including basic information with a link to more detailed information about the unit. A table of overall capacity data is included in the filtered results. Selecting a specific storage unit from the results presents the users with a set of webpages containing detailed information on the chosen storage unit. The webpages display related information from general characteristics, risk and economics through to Monte Carlo Simulation results.

The Map search interface presents users with an interactive map of the UKCS displaying the location, extent and age of each storage unit. Users can filter the dataset based on a specified spatial extent and again the filtered result set is displayed in tabular form and includes overall capacity data. Users are also able to filter their spatial selection based on a set of attributes, highlight individual storage units on the map and link through to the detailed information pages for a specific unit.

The database is a relational system developed within Structured Query Language (SQL) Server. It makes use of a normalised table structure with values constrained by dictionaries where possible and a suite of history tables and triggers to maintain an audit record of all changes to the database. The database is versioned with only the current version available via the website. All earlier versions are archived.

The central data type within the database is a CO_2 Storage Unit and the database holds general information on each unit including its name, location, age and type. There are two groups of tables linked to the storage unit which hold computed values (derived and Monte Carlo) and measured values. There are further additional tables for administration purposes including storage of registered user details.

The user interface has been developed using PHP code and the design follows the Model-View-Controller methodology. The software modules developed are used to serve both the web search interface and a suite of background processes which run the Monte Carlo Simulation and update the computed values. The map interface has been developed using ESRI's Javascript API and queries a single ESRI web map service which is secured against 3rd party access.

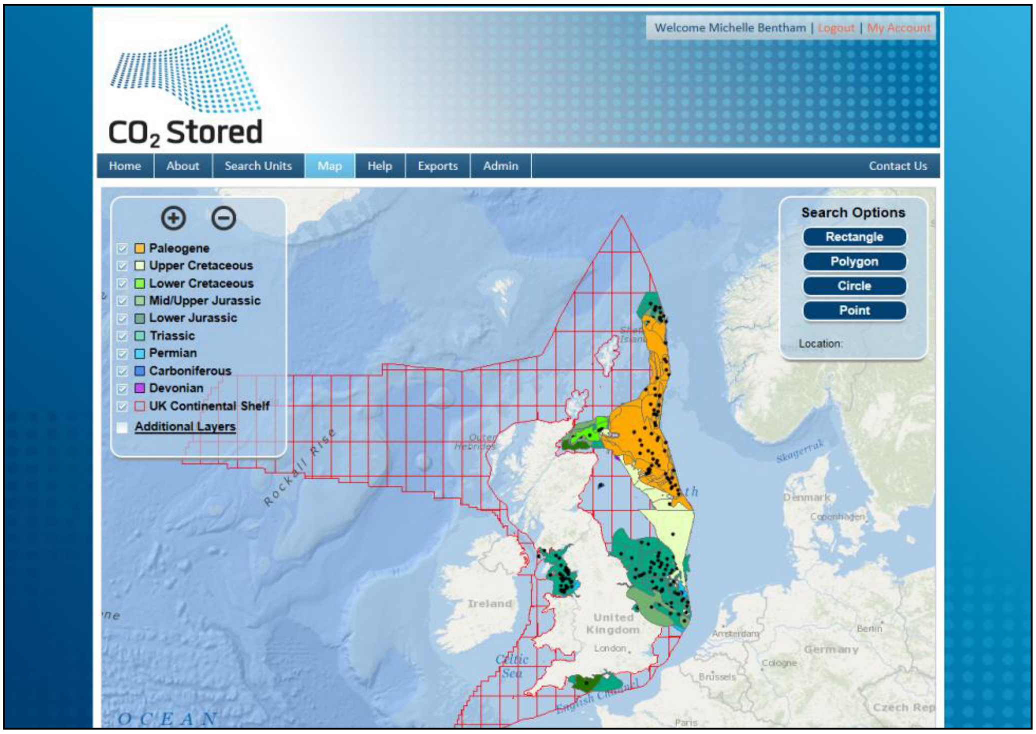

Fig. 1. Map search interface in CO_2 Stored (www.co2stored.co.uk)

4. UK Storage Capacity

The CO_2 Stored database contains over 500 storage units with the potential for CO_2 storage. The total estimated P50 theoretical storage capacity for the UKCS is 78 Gt (Fig. 2). Storage can be divided into four major storage regions based on major offshore sedimentary basins; the Southern, Central and Northern North Sea and the East Irish Sea.

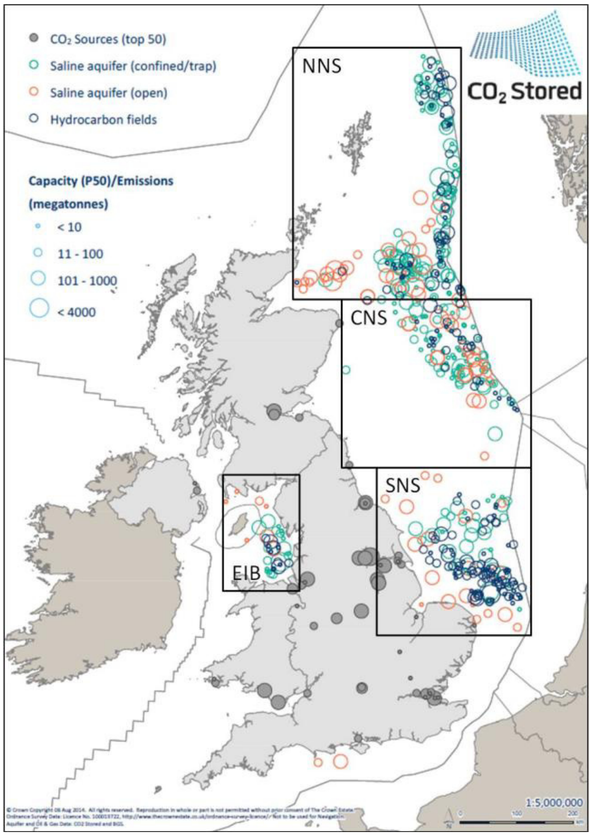

Fig. 2 Location of UK storage units and largest 50 point source CO_2 emitters, storage unit type and P50 theoretical storage capacity (data source CO_2 Stored). Major CO_2 storage regions are shown; Southern North Sea (SNS), Central North Sea (CNS). Northern North Sea (NNS) and the East Irish Sea (EIS)

The region with the biggest contribution to the UK storage potential is the Central North Sea (CNS) with a estimated P50 theoretical storage capacity of 40 Gt, followed by the Southern North Sea (SNS), Northern North Sea (NNS) and the East Irish Sea (EIS) with 15 Gt, 14 Gt and 6 Gt with of storage capacity respectively (storage units with less than 20 Mt of storage capacity are not included in these figures).

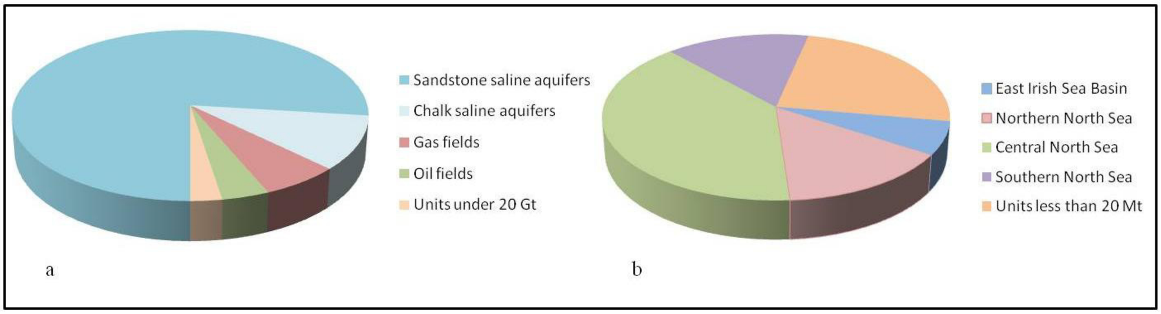

Fig. 3. Distribution of storage capacity in the UKCS. a) Shows the UK CO_2 storage capacity by unit designation (saline aquifer, oil and gas fields). b) Shows UK CO_2 storage capacity by region (storage units with less than 20 Mt of storage have been removed). Data source CO_2 Stored.

4.1 Storage in saline aquifers

Saline aquifer storage units provide the majority of potential storage in the UKCS. When chalk reservoirs are excluded (due to poorly understood injectivity and storage security) 60 Gt could potentially be stored in saline aquifer formations. Saline aquifers account for over 300 storage units in the database with over 52 storage units estimated to have the potential to store a total of over 200 Mt of CO_2. The majority of the storage units in the UKCS are co-located within the same geological basin, geological formation or vertically stacked [2].

The saline aquifers with large storage potential are often aerially extensive, covering large areas of the UKCS and are estimated to have the potential to store many Gigatonnes of CO_2. Some of these units, such as the Bunter Sandstone Formation in the SNS [3], have defined closures which are expected to be attractive targets for CO_2 storage. If stored in a well defined closure, the CO_2 will be confined within a known area, increasing confidence in future containment and reducing the plume footprint, potentially reducing the cost of site assessment and subsequent monitoring costs.

However, much of the storage identified in CO_2 Stored is in large, open, dipping, saline aquifer formations with little or no defined closure. Examples of such formations in the CNS and NNS include the Forties Sandstone Member and the Maureen Formation. When CO_2 is injected into such a formation the migration of CO_2 will be driven by gravity and buoyancy trapping, in which circumstances CO_2 could migrate over several kilometres [1].

This is particularly notable in the CNS and NNS where many of the potential saline aquifer storage units are classified as 'open' (i.e. the storage unit is not laterally confined). For example, three such units are shown in Fig. 4 and have a combined estimated P50 theoretical storage capacity of 10 Gt. Utilising laterally open aquifers may require the storage complex to be significantly bigger than in the case of a site with defined structure. It is not clear at this stage how such open units would be managed to balance exploitation of the available storage potential while ensuring costs and risks are minimised. This has implications for operating several CO_2 storage projects within the same storage unit.

Although most of the UK's storage capacity is locked up in saline aquifers, these are the geological formations that we know least about as they often have no economic value so few data have been acquired. The quality of the cap rocks, presence or absence of internal barriers or access to any dynamic data makes assessment of such units for CO_2 storage difficult. It is therefore essential that these units are appraised in more detail before CO_2 storage investment decisions are made.

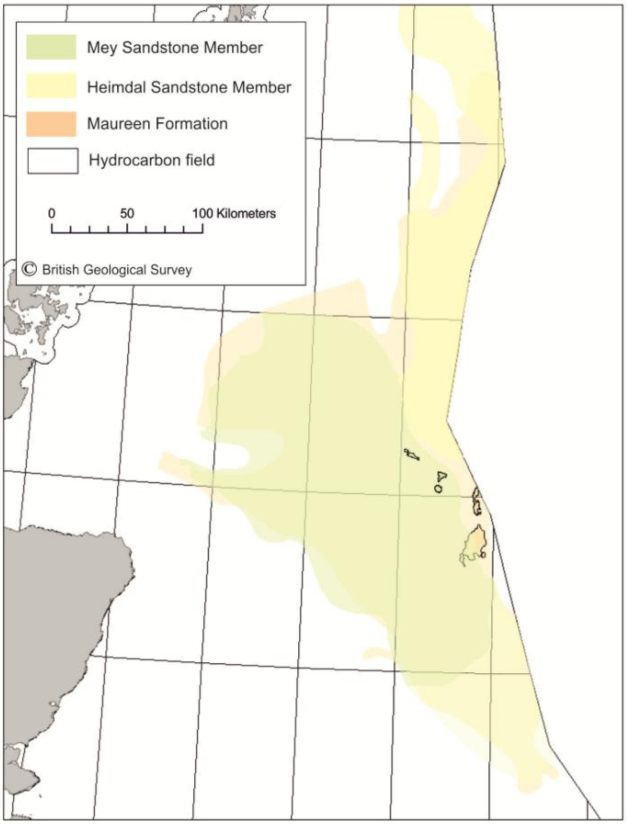

Fig 4. Map of the UKCS Central and Northern North Sea showing and example of storage units which are both stacked and aerially extensive [TCCS-7].

4.2 Storage in hydrocarbon fields

The UK North Sea is a mature hydrocarbon basin. The maturity of the fields is indicated in CO_2 Stored, the expected recoverable reserves and the produced volumes are displayed. There is the potential to store 8 Gt (P50 theoretical storage capacity) in the UKCS in depleted and depleting oil and gas fields. This does not include the extra storage potential which may be available through Enhanced Oil Recovery using CO_2. Timing of availability of hydrocarbon fields will be key when making storage decisions.

5. Case study

This case study looks at the data associated with one storage unit located in the Bunter Sandstone Formation of the Southern North Sea.

5.1 Map interface

Unit 139.016 is located in the UK sector of the Southern North Sea shown in Fig. 5. CO_2 Stored provides the location of the storage unit based on a centroid (latitude and longitude data) and the areal extent of the unit is shown in the map interface (Fig. 5).

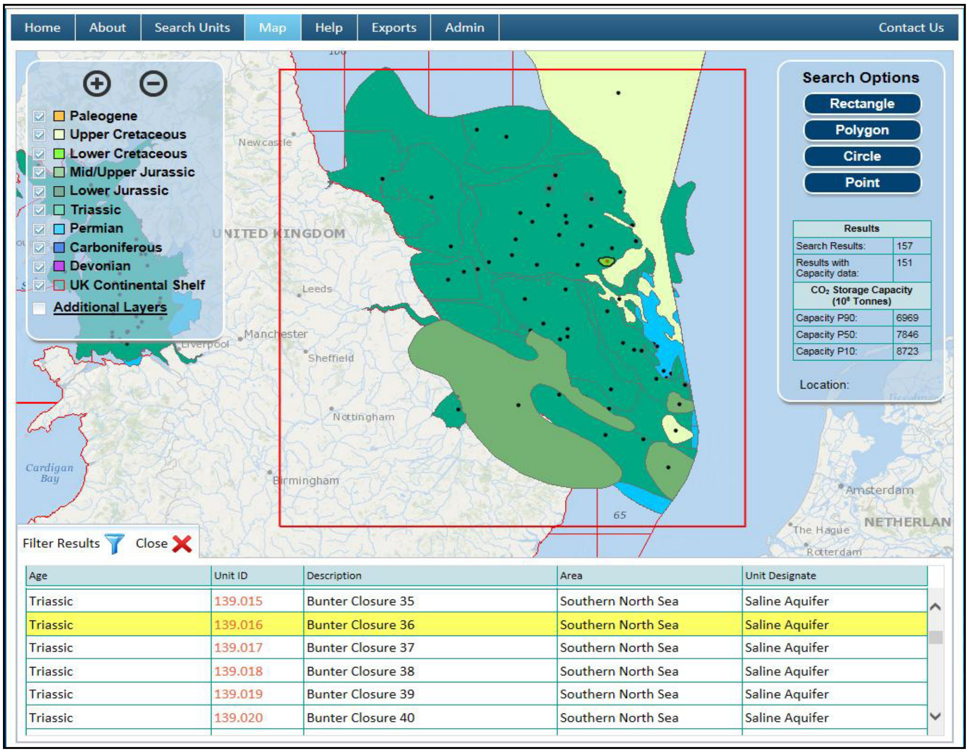

Fig. 5. Map generated by CO_2 Stored showing the location of storage unit 139.016 in the UK sector of the Southern North Sea

5.2 General Page

The General page of the database provides the unit designation and a description of the unit characteristics; in this case the unit is a saline aquifer. The geological age and the Group and Formation are described (storage unit 139.016 lies in the Triassic Bunter Sandstone Formation which is a member of the Bacton Group). The General page also gives the predominant lithology as sandstone and records that the unit is located in the Southern North Sea and that the water depth in this area is typically 60 m deep. The 'storage unit type' describing the architecture of the storage unit is also listed, here it is described as a structural trap.

5.3 Pore Volume Page

The Pore Volume of the unit is calculated using a number of inputted parameters including; area of the storage unit, average gross thickness, estimated relief of the structure, average areal net sand, average vertical net to gross ratio, and average porosity. Each of the field parameters provides a minimum, most likely and maximum value. Using these data the gross rock volume and pore volume of the storage unit are derived using an automatic calculation. In this case the 'most likely' pore volume for storage unit 139.015 is 2.4 x 10^9 m^3.

5.4 Static Capacity Page

The Static capacity page provides the remaining data required to make the static capacity calculation. This includes efficiency factors, which are dependent on the storage unit type (in this case 0.10 is used as the minimum, 2.00 as the most likely and 6.00 for the maximum percentage of the pore volume which will be occupied by CO_2). The shallowest depth at which there is closure is used in calculating the maximum allowable pressure rise before the expected fracture pressure is reached. The depth to the centroid of the unit is used in calculating the density of CO_2 in combination with the formation temperature and calculated pressure for the capacity calculation. Rock compressibility, formation water salinity and sweep efficiency are also inputted parameters for the static capacity calculation. Computed or set parameters used in the static capacity estimate include; formation water compressibility, aquifer seal capacity, rock compressibility, CO_2 density, CO_2 viscosity, hydrostatic pressure at shallowest depth and CO_2 column height. Different calculation methodologies are used depending on the storage unit type and trap type. The methods of calculation of capacity are described in [1].

The static capacity estimate is reported as a pressure capacity (capacity limited by the fracture pressure threshold and as a buoyant trapping capacity not limited by pressure). For storage unit 139.016 the most likely pressure capacity is 13 Mt of CO_2 and the buoyant trapping capacity is 388 Mt of CO_2.

5.5 Injectivity Page

Injectivity of the formation is calculated within CO_2 Stored and the results are presented as P10, P50 and P90 representation of CO_2 injection rate versus the number of well required and bottom-hole pressure at different CO_2 injection rates and injection durations. These results are used in the economic analysis module. Inputted parameters for the calculation include the permeability of the storage unit, the irreducible water saturation, the maximum allowable pressure and the CO_2 end point relative permeability. The injectivity is calculated using a method developed by the University of Durham [4].

5.6 Theoretical Capacity Page

The results of the calculations are presented in the Theoretical Capacity Page. For some units several capacities are reported depending on the storage unit type (open, closed pressure cell, trap type etc). For storage units which are representative the UK's offshore storage dynamic simulations have been performed to estimate the storage efficiency factors, the estimated storage capacity of such units is reported in the dynamic utilisation field. Each parameter (calculated and inputted) on this page has been subject to Monte Carlo simulations and the parameters are reported as P10, P50 and P90 fields. Results for storage unit 139.016 are shown in Table 1. The lower capacity figure represent the move from a static capacity estimate to a theoretical capacity estimate as more information about the storage unit is used in the estimate, for example the use of efficiency factor produced by dynamic modelling.

Table 1. Theoretical capacity estimates for storage unit 139.016

	P90	P50	P10
Theoretical capacity of unit (Mt of CO_2)	299	232	459
Dynamic utilisation (Mt of CO_2)	80	200	350

5.7 Risk and security of storage Pages

The risk and security of storage were assessed qualitatively using a Features Events and Processes approach [1]. The security of storage risks are split within the CO_2 Stored database into containment and operational risks (Table 2). For all risks, a level of confidence in the data, severity of the risk on capacity and cost is given.

Table 2. Security of storage fields within CO_2 Stored. Adapted from [1]

Containment risks				Operational risks	
Seal	Faults	Lateral Migration	Wells	Formation Damage	Compartmentalisation
Fracture pressure	Density	Structural trend	Density	Mineralogy	Vertical
Chemical reactivity	Throw seal	Depositional trend	Vintage	Mechanical integrity	Lateral
Lateral degradation	Vertical extent	Dip direction	-	Salinity	Faults
-	-	Dip magnitude	-	-	Diagenesis
-	-	Rugosity	-	-	-
-	-	Hydrodynamics	-	-	-
-	-	Pressure sinks	-	-	-
-	-	National boundary	-	-	-

Risk data for storage unit 139.016 identifies the seal formations as the Rot Halite Member of the Haisborough Group Formation, this means the risk of migration of CO_2 through the seal is low. The density, throw and vertical extent of faults for storage unit 139.016 is classed as low which means there are no recorded faults (note this is limited by seismic resolution). The number of wells which penetrate the storage unit is recorded as medium risk i.e. therefore there could be wells that penetrate the storage unit. The unit has low score on compartmentalisation, suggesting there would be no formational barriers to CO_2 injection.

The risks are brought together into risk profiles relevant to cost, capacity and are presented in the database in the Boston Squares format. For storage unit 139.016 the highest risks to storage security which have an effect on capacity are depositional and dip related, these have a medium severity of impact versus a high likelihood of occurring (Fig. 6).

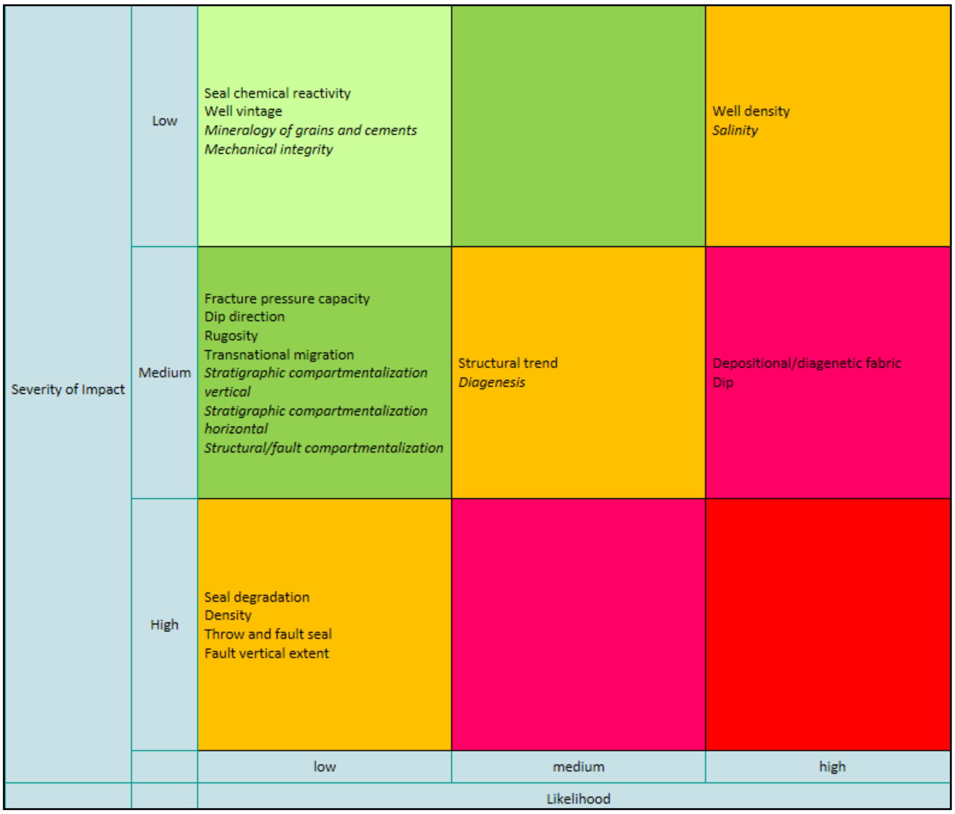

Fig. 6. Containment and operational risk factors with an effect on storage capacity for storage unit 139.016 (operational risks in italics).

However, the confidence in the data associated with the risk of the depositional and diagenetic fabric affecting storage capacity is low indicating that further investigation characterisation would be needed.

5.8 Economics

The database contains the results of calculations that estimate the cost of storage for a point to point transport system. These ‘economics’ are based capacity estimates and assessment of the security of storage. This information underpins the economic analyses provided for each identified unit and considers costs associated with site appraisal and development, injection facilities, number of new wells required, remediation of existing wells and CO_2 transport by pipeline. The results are presented in Pounds Sterling (£) for a projected injection duration and transport rate and are separated into;

- Storage capex and opex
- Transmission capex and opex
- Undiscounted lifetime cost of storage £/tCO_2 stored
- Undiscounted lifetime cost of transmission and storage £/tCO_2 stored

Currently the economic module is static and is not updated automatically when other parameters are changed.

6. Discussion

The CO_2 Stored (www.co2stored.co.uk) database offers a unique tool to help identify potential storage options around the UK Continental Shelf with geological storage data, risk profiles and economic assessments available for each storage unit. It is easily accessible online under licence and is maintained and updated by experts periodically.

The UK has a plentiful and diverse range of storage options including saline aquifers and hydrocarbon fields. CO_2 Stored estimates the UK has an estimated P50 theoretical static capacity of 78 Gt, with the majority of storage in saline aquifer units.

Under the stewardship of TCE and the BGS, CO_2 Stored will be continually developed, improving the user interface and data as well as adding the information and analyses needed to help build the UK’s CCS industry.

References

[1] Gammer D, Green A, Holloway S, Smith G. The Energy Technologies Institute’s UK CO_2 Storage Appraisal Project (UKSAP). SPE paper 148426, presented at the SPE Offshore Europe Oil and Gas Conference, Aberdeen; 2011.
[2] Bentham M, Pearce J. Leasing and regulatory issues for large scale CO_2 storage in the UK; (*In Press*) Energy Procedia.
[3] Bentham M. An assessment of carbon sequestration potential in the UK – Southern North Sea case study. Tyndall Centre for Climate Change Research; 2006 Working Paper 85.
[4] Mathias SA, de Miguel GJGM, Thatcher K E, Zimmerman RW. Pressure buildup during CO_2 injection into a closed brine aquifer. Transport in porous media; 2011. 89(3), 383-397.