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Irish Sea Carbon Capture and Storage project, final report.

Energy and Marine Geoscience Programme
Commissioned Report

BRITISH GEOLOGICAL SURVEY

Energy and Marine Geoscience Programme
COMMISSIONED REPORT

Irish Sea Carbon Capture and Storage project, final report.

Michelle Bentham

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Foreword

This report is the product of a study by the British Geological Survey (BGS) as result of collaborative work with the Geological Survey of Ireland (GSI) in the Irish Sea Carbon Capture and Storage (CCS) project.

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In addition to the authors who contributed to the production of this report. A large number of individuals have contributed to the project. This assistance has been received at all stages of the study. In addition to the collection of data, many individuals have freely given their advice and provided local knowledge. Of the many individuals who have contributed to the project we would particularly like to thank the following: From GSI; Brian McConnell. From BGS; Karen Kirk, Ceri Vincent, Tim Pharaoh, Sam Holloway, John Williams and Caroline Graham. For the provision of data BGS would like to thank the Petroleum Affairs Division, Ireland (PAD) and Common Data Access Limited (CDA).

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Appendix 1 Irish Sea CCS ArcGIS user Guide

Appendix 2 An assessment of the potential for subsurface CO₂ storage in two regions of the Central Irish Sea Basin

Appendix 3 An assessment of the potential for subsurface CO₂ storage in the Celtic Sea Basin

Appendix 4 Transport and consolidation properties of the Mercia Mudstone

Summary

This report describes the BGS results of the Irish Sea Carbon Capture and Storage project. The Central Irish Sea Basin and the Celtic Sea were identified by Lewis et al (2008) as having potential to storage large volumes of CO₂. This project was designed assess the storage potential of the Irish Sea in more detail.

The Ormskirk Sandstone Formation of the Central Irish Sea Basin (CISB) was examined in two study areas using 2D and 3D seismic and well data provided by PAD and BGS. This study concludes that closures identified in the CISB have small storage capacity and are potentially compromised due to the high degree of faulting in the region.

The Celtic Sea region was examined using regional seismic and well data provided by BGS and PAD. Several potential reservoir horizons were identified in the Celtic Sea. From analysis of 2D seismic and well data, it is concluded that the best potential for CO₂ storage in the Celtic Sea lies in ‘open aquifers’ rather than closed structures.

The Mercia Mudstone Group is the primary caprock in the Irish Sea Basins. Work was undertaken to obtain a caprock sample from the Mercia Mudstone Group and experiments were undertaken to examine its CO₂ transport properties.

Element energy undertook an economic assessment of the storage options in the offshore Irish Sector and concluded the cheapest storage option involves capturing CO₂ from a 900 MWe IGCC located at Cork, with subsequent storage in Kinsale Head gas field.

Outputs of the project include multiple reports, a GSI 3D model of a study area in the CISB and a trans-border GIS of storage options in the Irish Sea region.

1 Introduction

The Irish Sea Carbon Capture and Storage (CCS) Project was a three year co-funded collaborative project between GSI and BGS. The project began in October 2011 and was completed in November 2014. The overall high-level aim of this work was to create a seamless integrated knowledge resource of Ireland-UK Irish Sea CCS opportunities to facilitate informed decision making. Work to achieve this included:

1. The development of a transnational GIS.
2. Evaluation of two regions in the Central Irish Sea Basin for CO₂ storage potential
3. Development of a GSI 3D model of the Central Irish Sea Basin
4. Acquiring access to further seismic and well data in the Celtic Sea region for interpretation
5. Regional interpretation of the Celtic Sea region
6. Evaluation of the Celtic Sea region for potential CO₂ storage sites
7. Interpretation of the Ormskirk Sandstone Formation in the Central Irish Sea Basin
8. Acquiring cap rock samples for cap rock experiments

This report aims to highlight the main results and conclusions of the project.

2 The development of a transnational GIS

An ArcView GIS (Figure 1) has been created to:

1. Act as the main data repository for the project.
2. Allow interrogation and manipulation of the data by both BGS and GSI staff
3. Act as a tool for quick visualisation of CO₂ storage options in the Irish Sea.
4. Be a 'living' project GIS which was updated throughout the project as work was completed.

The project GIS was updated as surfaces became available from other activities in the project.

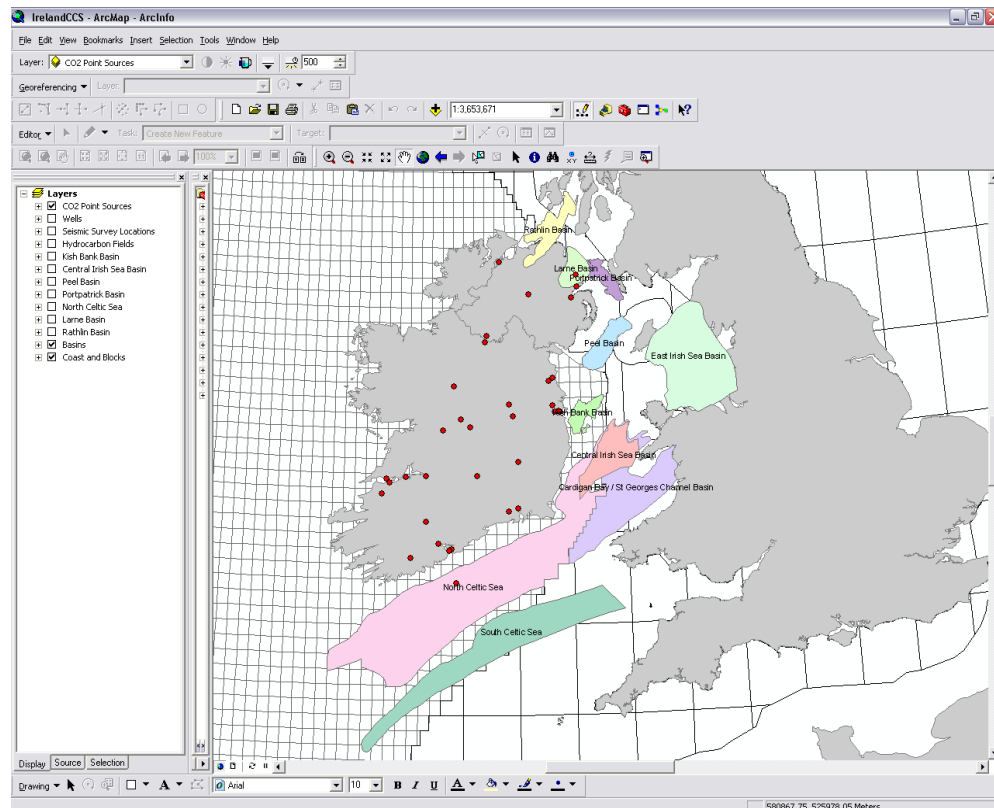


Figure 1. The project GIS

The project GIS is described in Appendix 1.

3 GSI3D Model

Results of work undertaken in 2012 in the Central Irish Sea Basin have been incorporated into a GSI3D model. The Two Way Travel Time (TWTT) and depth surfaces created in Petrel from the seismic interpretation of 2D and 3D data has been imported into GSI3D for visualisation purposes. The projection of the data is UTM (WGS1984) Zone 30N.

There are three formation surfaces:

- Top Sherwood Sandstone Group (SSG)
- Top St Bees Sandstone (SBS)
- Top Carboniferous (Carb)

The surfaces display some artefacts from the interpretation stage where there may be mis-ties in the interpretation or data. Most of these were smoothed out at the depth conversion stage.

There are 18 faults included in the model though a few faults make up one larger fault zone:

- Faults 1, 2, 3, 4 and 10
- Faults 9 and 16

Due to the geometry of some of these faults, the exported objects sometimes displayed with a jagged edge (Figure 2). This was an issue resolved by importing the objects into GOCAD first and remodelling them before importing into the fault planes GSI3D.

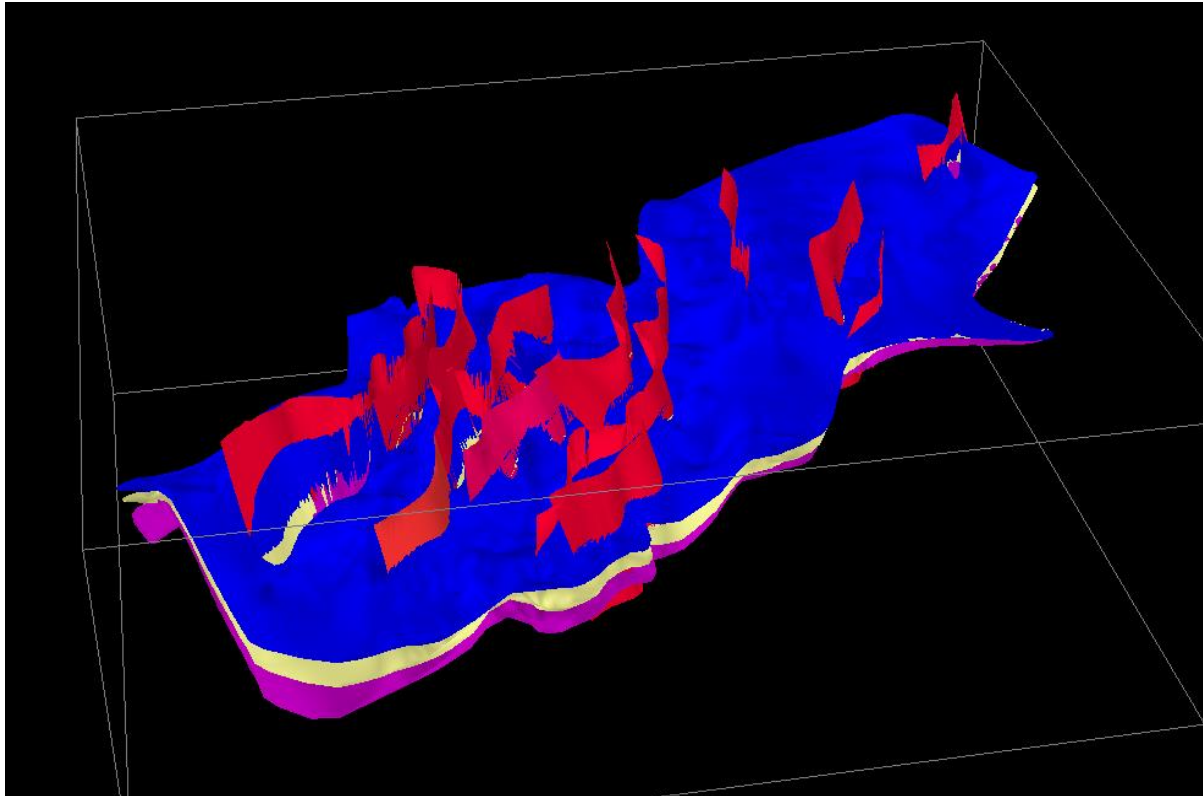


Figure 2 Modelled surfaces in GSI3D.

4 GoCAD surfaces

Surfaces and faults have been incorporated into GOCAD models for the Central Irish Sea Basin and the Celtic Sea Basin. These have been provided to the project separately.

5 The Central Irish Sea Basin

The Central Irish Sea Basin (CISB) was identified as having potential to store CO₂ by the All Ireland study (Lewis et al, 2008). The All Ireland study highlighted need for further investigation in the area and a number of risks associated with CO₂ storage in the CISB. Therefore this project focused on two study areas; one concentrating on a 2D seismic grid in the south-west region of the CISB basin the Irish Sector of the Irish Sea, the other area focused on a 3D seismic survey slightly to the east of the median line in the UK sector of the CISB. The two study areas are shown in Figure 3. The report giving details of the CISB study can be found in Appendix 3.

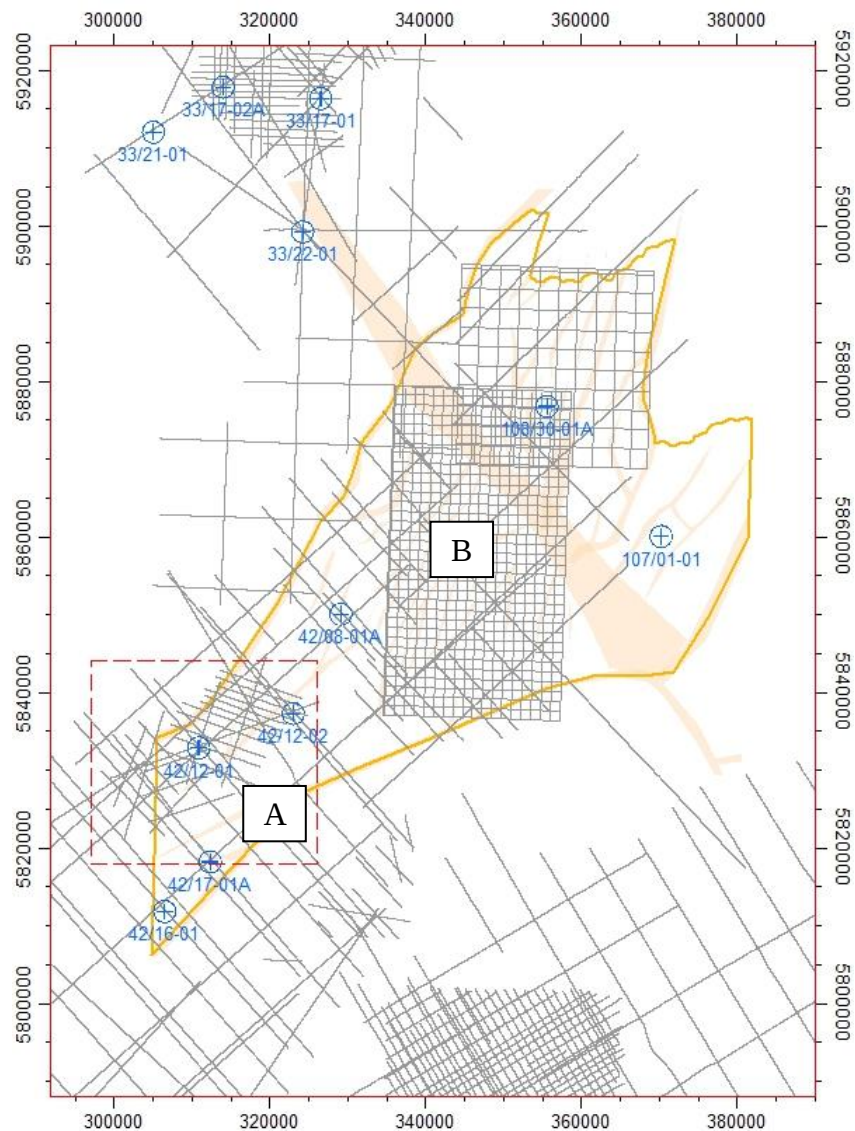


Figure 3 Location of seismic and well data in the CISB used in study area A and B.

The study concluded that the Ormskirk Sandstone Formation has fair to good reservoir properties over the whole of the south-eastern part of the Central Irish Sea Basin. Overlying mudstones, siltstones and halites of the Mercia Mudstone Group act as an effective seal to hydrocarbon accumulations in the East Irish Sea Basin and thus this succession in the Central Irish Sea Basin would also be expected to act as an effective seal for CO₂ storage schemes. The study area however is structurally complex with closely spaced normal faults dissecting the Ormskirk Sandstone Formation and these may challenge storage security. Evidence of gas seepage on the Codling fault in the Kish Bank Basin adds further uncertainty to the sealing capacity of similar faults in the CISB. Some faults detach along assumed evaporitic horizons at several levels, adding complexity to the area.

Structural closures have been identified (Figure 4) and the CO₂ static storage capacities have been calculated based on a range of storage efficiency factors from published research. The static storage capacities of the individual closures are estimated to range from 1.26 to 61.50 Mt of CO₂. To achieve specific storage efficiency factors for the Central Irish Sea Basin, numerical flow simulations would be required.

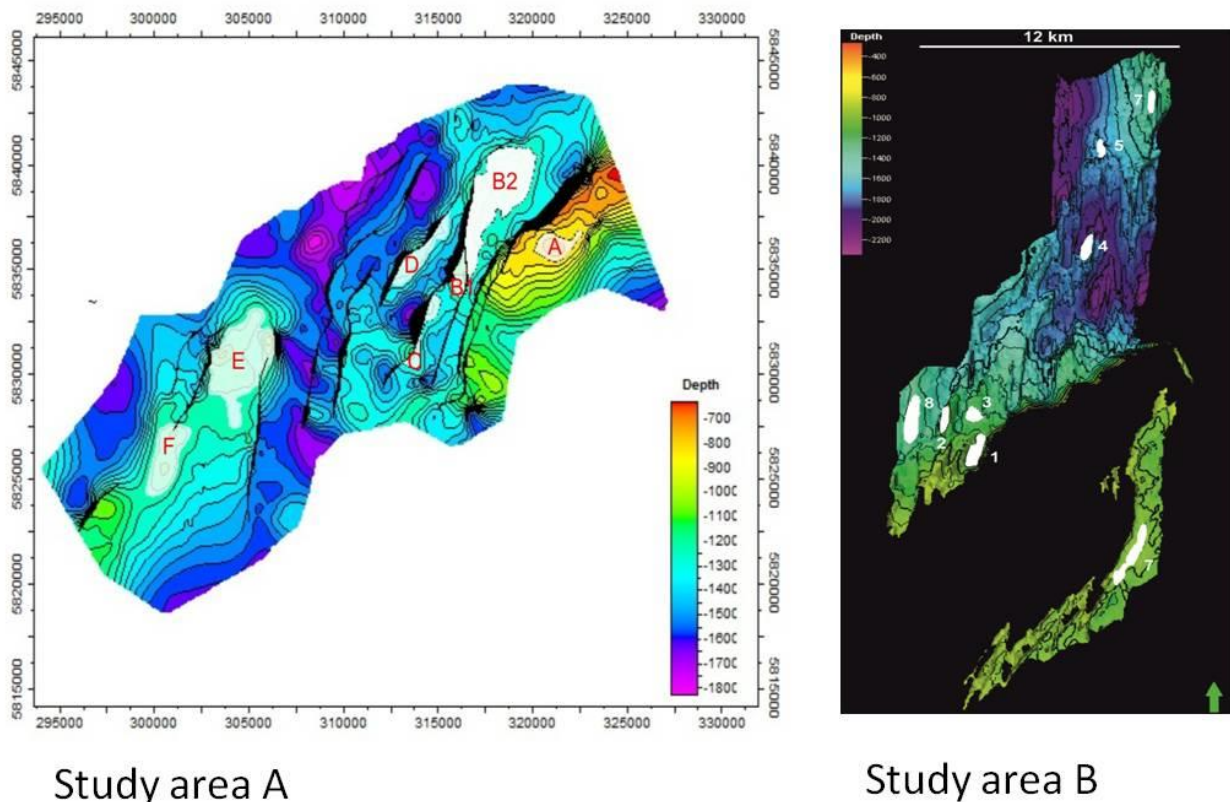


Figure 4 Location of closures in study area A and B

Many of the closures in the study areas may be too small for large-scale storage of CO₂ from industrial point sources. If the higher storage efficiency factors of 0.25 could be achieved in the larger closures, B and E (Figure 4) could potentially achieve 10 years worth of CO₂ storage from a large point source such as the Moneypoint Power station which emits approximately 5 Mt of CO₂ per year. It may be that smaller sources of CO₂ could find niche storage in the area covered by this study.

A major source of uncertainty in the analysis is the accuracy of the depth conversion. Inaccuracies in depth conversion will affect the calculated dip of the Top Ormskirk Sandstone, this in turn will affect the geometries of the closures and ultimately the closure volumes. These inaccuracies will have been carried forward into the static capacity calculations.

Proving storage security in the CISB would be a major challenge. All the closures identified (with the exception of closure A) are affected in some way by faulting. They define the closure in for example, closures E, B 7 and 6 and are present within the other closures. The faults are closely spaced and could potentially provide migration pathways for CO₂ out of the storage closures. Due to the known distribution pattern of faults identified in study area A it is likely that faults exist ‘between’ the 2D seismic grid and will not therefore have been mapped in this study. The analysis of the 3D seismic survey in study area B demonstrated that the faulting in this region is densely spaced; in some areas faults are separated by less than 500 m. As a result, structural closures are small. It is unlikely that large scale secure storage could be implemented in the CISB.

6 The Celtic Sea Basin

Following the initial seismic interpretation across the whole of the Celtic Basin, a region covering the north region of the North and South Celtic basins adjacent to the Central Irish Sea

Basin was selected for detailed study to avoid potential conflicts with ongoing oil and gas exploitation when identifying potential storage opportunities.

The main horizons of interest were the Sherwood Sandstone Group, the Sinemurian sandstone, the Lower and Upper Bajocian sandstones and the Bathonian sandstone. The Carboniferous strata was also considered during the assessment as this is a potential hydrocarbon reservoir and contains sandstone layers.

Data from boreholes were used to assess reservoir quality; lithology, net to gross and porosity of the potential reservoir formations. Although the Carboniferous strata contain sandstones, the permeability of these layers was generally very low and therefore overall these strata have limited potential for storage. The Sherwood Sandstone Group generally has the most consistent lithology across the study region and generally contains sandstone layers. The Sherwood Sandstone Group porosity and permeability data from cores was disappointingly low, it may be possible to target promising sandstone layers within it however. The Sinemurian strata has very variable lithology; in the St Georges Channel Basin strata mainly comprise mudstone and claystone, however, in the rest of the study area, there are some more porous and permeable sandstones noted, particularly around 41/30-01 (Figure 5) in the North Celtic Basin.

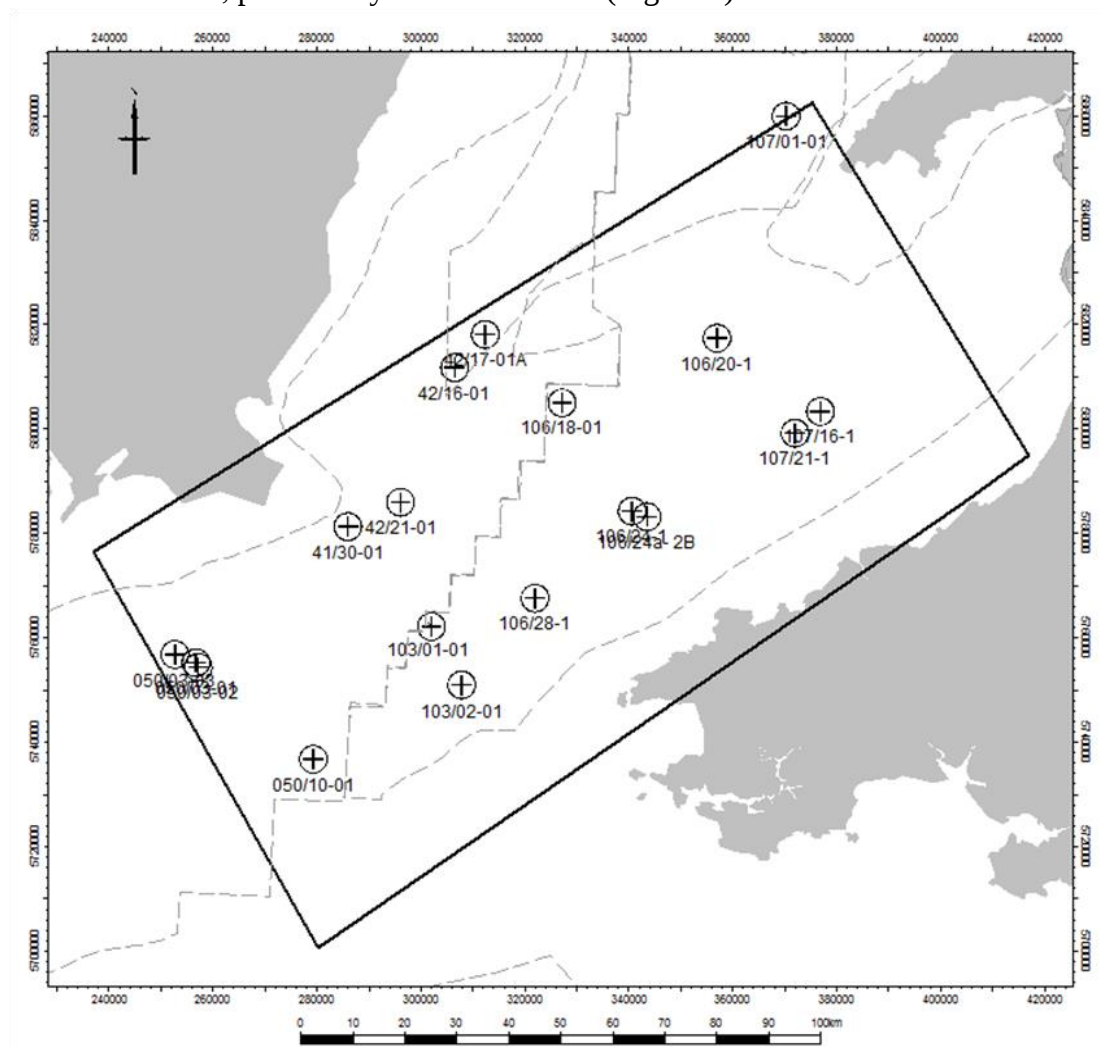


Figure 5 Location of wells in the study area

The Bajocian and Bathonian strata have potential reservoir layers in sandstones and/or limestones and porosity generally appears to be reasonable. The lithology of these strata are variable and in many cases the whole Bajocian-Bathonian sequence would have to be considered

as one storage reservoir where there are no apparent seals separating potential reservoir rocks. The main issue with these strata is the need to confirm the overlying seal is of sufficient quality.

A small number of closures have been identified in the model top horizon surfaces for the Bathonian, Bajocian, Sinemurian, and Carboniferous strata and the Sherwood Sandstone Group. These closures are based on seismic interpretation of 2D data across the detailed study region. Overall the closures identified have a low total estimated storage capacity of 4 – 25 MtCO₂ depending on the storage efficiency factor used. . Not all these closures lie at optimum depth for storage using the recommendations of Chadwick et al (2008). If reservoir quality porosity expected to be greater than 10% based on the recommendations of Chadwick et al., (2008) is also considered, only closures in the Sinemurian, Bajocian and Bathonian strata are suitable for storage. In addition, the security of the identified closures is not confirmed, seal quality over these closures needs careful study through collection of additional data. Faults cut through/form one or more of the boundaries of several of the closures and the sealing ability of these faults is not proven. There are examples in this region where it seems faults have allowed hydrocarbons to migrate to the sea bed though there are other examples (in the East Irish Sea Basin) where faults have formed an effective seal trapping hydrocarbons. Taking all these factors into consideration, none of the closures seem suitable for storage. However, a small pilot scale test could be considered, in particular, a study considering the sealing ability of faults would be beneficial to understanding security of storage and would contribute to the body of knowledge on one of the current topics of interest for CCS.

As closure volume is so low and has so many uncertainties relating to security of storage, the potential for open aquifer scenarios was also considered in the Sherwood Sandstone Group and in the Bathonian and Bajocian strata. In order for these scenarios to be considered, more data would be needed on the sealing properties of faults, the completion of boreholes and particularly in the case of the Bathonian/Bajocian option, in the quality of the stratigraphical seal. Flow simulations would be required to assess the likelihood of CO₂ migrating in an open aquifer to reach the potential manmade/natural pathways in the Celtic Sea Basin. The regions which could be considered for an open aquifer storage scenario are in the Sherwood Sandstone Group (around 103/01-01, 106/18-01 and 42/16-01, Figure 5) and Bathonian/Bajocian strata (around boreholes 107/21-01 and 103/01-01, Figure 5). The main disadvantage of open aquifer storage is the potentially large monitoring area required which would increase the cost of any project, particularly considering the need for financial security to meet the requirements of the EU Storage Directive.

The main uncertainties in the study of the Celtic Sea Basin arise from lack of data; most the region is only covered by 2D seismic data, boreholes do not always penetrate the reservoir/seal horizons, porosity and permeability data are not always available. In addition, various assumptions were made during depth conversion and well log interpretation which also increase uncertainty. The lack of 3D seismic data and assumptions made during depth conversion will affect accuracy of closure delineation. Assumptions made during well log interpretation will impact assessment of reservoir quality and capacity assessment for the closures. In addition, injection testing has not been carried out in this region which increases general uncertainty of the injectivity of the potential reservoir horizons. Overall, more primary data would be required before any of the storage options outlined in this report could be recommended; ideally, 3D seismic data over areas of interest, sampling cores to confirm reservoir and seal quality and drilling of new boreholes with the specific aim of confirming injectivity potential and seal quality.

The full report is provided as a separate file (Appendix 3)

7 Economic assessment

Element Energy provided an economic study of storage options in the Irish Sea region and the full report was provided to GSI. The main conclusions and recommendations of this report are as follows:

The source to sink combination with the lowest cost (€28 per tonne CO₂ avoided) involves capturing CO₂ from a 900 MWe IGCC located at Cork, with subsequent storage in Kinsale Head. CCS from an IGCC power plant located at Moneypoint with storage in Kinsale Head has a slightly higher cost (€31 per tonne CO₂ avoided). The costs of capturing CO₂ from pulverised coal power plants at the same location is approximately €16 per tonne CO₂ avoided higher. It would cost an estimated €56 per tonne CO₂ avoided for capturing CO₂ from at Kilroot with storage in the Portpatrick Basin.

The sensitivity analysis shows that cost estimates are strongly affected by capital cost estimates. Doubling the capital costs increases the specific cost of CCS by €30 to €40 per tonne CO₂ avoided. The CCS costs are also affected by reservoir and fluid behaviour uncertainties, which in turn affect the number of wells required. The cost estimates increase by up to €30 per tonne CO₂ avoided if the number of wells increase from 1 to 65. Changes in the US dollar to Euro exchange rate and the coal price have a smaller impact increasing the costs of CCS by up to €20 per tonne CO₂ avoided. Site evaluation costs have a small effect on the total costs. The Element Energy report is a preliminary analysis based on limited process and cost data, which uses rules of thumb and simple equations to model the cases. Detailed Commercial-in-Confidence process or reservoir simulations have not been undertaken. As such, the results of this evaluation are indicative with a margin of error of ±50%. Furthermore, the effect of tax and any effects of the European Emissions Trading Scheme have been excluded. Recommendation from the economic analysis are that:

- More reservoir data is acquired to assist in characterising the storage sites;
- The geological modelling of the Kinsale and Portpatrick Basin formations is expanded;
- Detailed and comprehensive reservoir simulations are carried out for each storage site;
- The behaviour of the CO₂ injected at Kinsale Head over time is modelled in detail;
- Local vendor quotes for capital and operating expenses be obtained; and
- Process simulation of the power plant cycle is carried out, in particular for the IGCC power plant.

An economic feasibility assessment, including full engineering design and costing should be undertaken to address the uncertainties identified in the Element Energy report.

8 Cap rock Experiments

As part of the cost sharing basis of the project, BGS have aligned National Capability funding to match the cash funding provided by GSI. The aligned work included examination of the transport properties of the Mercia Mudstone Group. This unit represents one of a number of potential sealing lithologies of particular interest for carbon dioxide storage in both the Irish Sea and the southern North Sea. Observations presented are the initial findings of the study and additional analyses and testing will be reported later.

Appendix 4 describes project rationale, the sample recovery process, the experimental approach and preliminary observations from consolidation and hydraulic testing. Finally the expected future direction of the test programme is described.

The work so far includes:

Whilst the multi-phase transport characteristics of Mercia Mudstone Group have been indirectly inferred in a limited number of studies (e.g. Seedhouse and Racey, 1997; Armitage et al., 2013), the authors of this report are unaware of any direct measurement of CO₂ transport properties for this material, under realistic *in situ* conditions. It was the intention of this study to address this by conducting the first direct measurement of transport properties in the Mercia Mudstone Group and to expand the highly limited data-set of reactive flow tests in caprock currently available in literature (e.g. Hildenbrand et al. 2004; Angeli et al. 2009). The emphasis of the test programme was on improving process understanding, the results of which can be applied to performance assessment of long-term caprock sealing capability.

There is also a paucity of data available in relation to the hydraulic properties of the Mercia Mudstone Group. Initial findings from this ongoing study indicate that there may be significant variation in the hydraulic response of this material, though good sealing properties (sub- 1×10^{-21} m²) do occur in some material. However, the question of natural variability cannot be addressed without additional testing. The influence of burial depth on physical properties has also been investigated and further analysis will provide data on the influence of such changes on the hydraulic flow properties of the Mercia Mudstone Group. Consolidation data will also allow the construction of the yield envelope for the Mercia Mudstone Group from the Larne Basin, providing insight into the influence of stress conditions on the potential for yield and, the likely associated failure mode (brittle/ductile) for a given stress path. Such data can be used to select suitable injection strategies to maximise capacity, whilst maintaining seal integrity.

The full report can be found in Appendix 4.

9 Conclusions

This project has provided insight into the realistic storage potential of the Central Irish Sea Basin and the Celtic Sea basin. The CISB is unlikely to be suitable for CO₂ storage due to the small estimated closure storage capacities and the high risk of CO₂ leakage from faults. The Celtic Sea Basin offers limited CO₂ storage potential in closed structures which are also small in capacity and frequently directly affected by faulting. There may be some opportunity for storage in ‘unconfined aquifers’, but further work would be needed to assess the integrity of the caprock and the risk of unwanted migration of CO₂ due to faults and leakage pathways. The project has allowed pioneering work into the sealing properties of the Mercia Mudstone Group, which will provide vital data about the transport properties of the Mercia Mudstone Group and enhance our understanding of seals in general. The project has produced a transnational GIS of potential storage opportunities in the Irish Sea which can form the information base for future work in this region.

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