Assessment of the potential for geological storage of carbon dioxide in Ireland and Northern Ireland

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Abstract

The project used a multi-disciplinary approach to assess the potential for carbon capture and storage (CCS) offshore and onshore Ireland and Northern Ireland. The project work flow has used internationally recognised methodology to produce an integrated capture to storage road map for the island of Ireland.

Using a basin-by-by basin approach, each sedimentary basin was individually assessed for carbon dioxide (CO_2) storage potential in hydrocarbon fields and saline aquifers. CSLF methodology was applied to calculate storage capacity for the identified sites; each potential storage site was categorised according to the CSLF techno-economic resource pyramid [1].

Identification and characterisation of point sources allowed hub scenarios to be developed between the major CO_2 point source emissions and the most promising geological storage sites. This allowed potential pipeline routes to be identified and engineering specification and costs to be addressed as well as consideration of planning, public safety and environmental issues. A range of capture transport and storage options were produced and subjected to rigorous economic assessment.

The major hubs identified are as follows:

- Moneypoint (Co. Clare) - Kinsale Head Gas Field, North Celtic Sea
- Kilroot (Co. Antrim) – Closed structures in the Portpatrick Basin
- Cork - Kinsale Head Gas Field, North Celtic Sea

The potential geological storage sites were subjected to FEP (Feature Event and Processes) and scenario analysis [2] with respect to the potential risks of geological storage.

Keywords: Ireland; Northern Ireland; Carbon Dioxide; Geological Storage; Aquifer; Hydrocarbon Fields

1. Introduction

The aim of this assessment was to identify geological storage sites for all of Ireland with the potential to store the emissions of large scale CO_2 point sources. The results of this study will feed into an economic assessment and risk assessment, with the final aim of the project to have several CO_2 sources to sink (storage) case studies.

Sedimentary basins often have suitable geology in which CO_2 may be stored. Storage potential may exist in depleted oil and gas fields or saline aquifers. This study concentrated on the major sedimentary basins of Ireland onshore and offshore where potential geological formations in which CO_2 could be stored (reservoirs) exist below 750 m and where suitable sealing formations are present.

For each basin, data were collected and interpreted and the basin was assessed according to its geological characteristics and available data. Carbon dioxide storage capacity was calculated in areas where sufficient data were available and potential CO_2 storage sites could be identified. The data available for each basin are highly variable in coverage, type, quality and source. To reflect this, each basin estimate was classified according to a techno-economic resource pyramid recommended by the Carbon Sequestration Leadership Forum [1].

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The major limitation when estimating CO_2 storage capacity for this study was the availability of data. Areas in which hydrocarbon exploration has taken place have the most available data. In basins where hydrocarbon exploration has been limited, data is often very sparse and therefore, there is more uncertainty. In such locations it may not be possible to make any estimate of potential CO_2 capacity. Sedimentary basins which fall into this category may still be suitable for CO_2 storage but have an unknown or unquantified CO_2 storage capacity. Similarly a large amount of data does not mean that particular basin will have good potential storage sites, but more information is available to analyse and provide conclusions.

2. Methodology

The work was undertaken using a basin-by-basin approach to analyse the geology and its suitability to store CO_2. Initial work focused on assessing the data provided by CSA and identifying gaps. The latter were addressed by an extensive review of the literature.

Each basin was examined in turn using digitised top depth structure maps (where available) in order to determine areas in which potential reservoir rocks exist below 750m. The geological structure maps were also used to identify closed structures, which may have the potential to store CO_2. Well data and published information were used to identify the geological characteristics of the potential storage reservoirs and seals. These data were utilised to calculate CO_2 storage capacity where possible.

2.1. Classification of storage capacity

Two main categories of issues complicate the assessment of CO_2 storage capacity:

- questions about the economic or practical availability of storage capacity
- difficulties caused by the lack, or sparsity of geological data and resources necessary to make realistic estimates of storage capacity

Estimates of the availability of many geological resources such as minerals and fossil fuels commonly divide them into at least two categories: *resources* (accumulations of anything that is useful and accessible to mankind) and *reserves* (that part of a resource that is available for production now, by being economically recoverable under current technological conditions).

Potential CO_2 storage space in geological formations can be considered as a resource because it is potentially useful to man. However, very little of it appears to be economically exploitable under current technological conditions and thus qualifying as a reserve. Incentives are required to make geological CO_2 storage cost-effective, with the exception of some enhanced oil recovery projects. Hence some means of subdividing the resource is required. Bachu et al. [1] suggest classification into *theoretical, effective, practical or matched* capacity:

Theoretical capacity represents the physical limit of what the geological system can accept. It assumes that the entire volume is assessable and utilized to its full capacity to store CO_2 in the pore space at maximum saturation in formation fluids, or adsorbed at 100% saturation in the entire coal mass. This represents the maximum upper limit to a capacity estimate, however it is an unrealistic number, as in practice there will always be physical, technical, regulatory and economic limitations that prevent full utilization of this storage capacity.

Effective capacity (previously realistic capacity) represents a subset of theoretical capacity and is obtained by applying a range of technical (geological and engineering) cut-off limits to a storage capacity estimate, including consideration of that part of the theoretical storage capacity that can be physically accessed. This estimate usually changes with the acquisition of new data and knowledge.

Practical capacity (or viable capacity) is that subset of effective capacity that is obtained by considering technical, legal and regulatory, infrastructure and general economic barriers to CO_2 geological storage. As such, it is prone to rapid changes such as technology, policy, regulation and/or economic change. The practical storage capacity corresponds to the reserves used in the energy and mining industries.

Matched capacity is that subset of practical capacity that is obtained by detailed matching of large stationary CO_2 sources with geological sites that are adequate in terms of capacity, injectivity and supply rate. This capacity is at the top of the resource pyramid and corresponds to the proved marketable reserves used by the mining industry. The main difference between matched and practical storage capacity represents 'stranded storage capacity' that cannot be realised because of lack of infrastructure and/or CO_2 sources within an economic distance.

Bachu et al.[1] also recommend that all estimates of geological CO_2 storage capacity should (a) clearly state the limitations that existed (data, time, knowledge) at the time the assessment was made and (b) indicate the purpose and future use to which the estimates should be applied. Assessments that lack documentation of constraints (or justification for their use) cannot be easily compared with other assessments.

This is the approach that has been followed to classify the types of capacity estimates calculated in this study.

3. Potential storage sites

Figure 1 All-island Ireland sedimentary basins examined for this study

The basins assessed are shown in Figure 1. For each basin or hydrocarbon prospect assessed the storage capacity estimate is listed in Table 1. The storage capacity of all the sedimentary basins was assessed for both the onshore and offshore areas. Oil and gas fields and prospects were considered along with saline aquifer structures. Storage in caverns has not been calculated as they are too small to store the volumes of CO_2 captured from point sources.

3.1. Oil and Gas prospects

The East Irish Sea Basin (EISB) hydrocarbon fields all have reservoirs in the Ormskirk Sandstone Formation, which is of Triassic age and forms the uppermost part of the Sherwood Sandstone Group. Most of the hydrocarbon accumulations are in horsts or tilted fault blocks. They are sealed by the overlying Mercia Mudstone Group, which contains thick units of halite (rock salt) that provide an effective seal. The two largest fields, South Morecambe and North Morecambe are depletion drive fields. Total EISB storage capacity is estimated at 1034 Gt CO_2, of which 734 Mt (70%) is in the South Morecambe field and 139 Mt (13%) is in the North Morecambe field [3].

In the Celtic Sea Basin the main reservoir rocks lie within the Lower Cretaceous Greensands, with the Gault providing the seal. Hydrocarbons have been discovered in the ‘A’ and ‘B’ Sands of the Greensand Group and Upper Wealden in the Kinsale

Head, SW Kinsale, Ballycotton and Seven Heads gas fields. Other units with significant reservoir potential include an Upper Jurassic sandstone of Oxfordian-Early Kimmeridgian age and Liassic sandstone of Sinemurian age. Capacity estimates were only possible for Kinsale Head and Southwest Kinsale due to availability of data; these have been calculated at 330.9 Mt and 5.5 Mt respectively.

Prospects in the Porcupine Basin have been identified in Jurassic and Cretaceous reservoirs; there is limited data for the Burren and Connemara oil fields therefore storage capacities for these fields could not be calculated. However the storage capacity for the Spanish Point field which has accumulations in the Jurassic Voligian Sandstones has been estimated at 115 Mt.

The Corrib gas field in the Slyne Basin has a Triassic fluvial sandstone reservoir (Sherwood Sandstone Group). The trap is a faulted NE-SW trending anticlinal structure, which retains a gas column of 310 m and is sealed by Triassic evaporites of the Mercia Mudstone Group. Total reserves in the fields are estimated to be 28.3 BCM (approximately 70% of Kinsale Head), however there is not enough data to provide a storage capacity estimate for this field.

3.2. Aquifers

The majority of Ireland's CO_2 storage capacity is in offshore and onshore saline aquifers. The Permo-Triassic basins located down the eastern flank of Ireland offer the most quantifiable CO_2 storage capacity for saline aquifers due to the data available from hydrocarbon exploration. The Triassic Sherwood Sandstone Group (including the Ormskirk Sandstone Formation) reservoir with a Mercia Mudstone seal is a prolific hydrocarbon reservoir in the East Irish Sea Basin. This reservoir-seal pair is present in several other Permo–Triassic Basins including the offshore Kish Bank, Central Irish Sea, Portpatrick and Peel Basins. Offshore the total effective storage capacity of the closed structures in the Kish Bank Basin, Portpatrick and Central Irish Sea Basins combined is 937 Mt.

Onshore prospective basins include the Larne, Lough Neagh and Rathlin Basins. Data and resources were not available to calculate the storage capacity of the Sherwood Sandstone Group for the onshore basins. In some areas the Sherwood Sandstone Group is not at sufficient depth for CO_2 storage. The Permian Enler Group offers some saline aquifer storage potential in the Larne and Lough Neagh Basins. Data were only available to calculate effective storage capacity for two identified closures in the Lough Beg area of the Lough Neagh Basin. The calculated combined effective storage capacity of the two closures is 1940 Mt. Sufficient data were only available to calculate the theoretical storage capacity of one other onshore sedimentary basin; the Northwest Carboniferous Basin. There are several potential reservoirs in the Carboniferous sediments of the basin, including the Dowra Sandstone Formation. The theoretical total basin storage capacity of the Dowra Sandstone formation has been calculated at 730 Mt. An important caveat is that this storage capacity may not be accessible due to expected difficulties injecting CO_2 into a tight gas reservoir.

Further saline aquifer potential may exist offshore in the Celtic Sea in the Cretaceous 'A' and 'B' Sands and the Jurassic Sinemurian Sandstone. Large but unquantified potential may exist in the Clare, Slyne, Erris, Porcupine and Rockall Basins.

3.3. Storage Capacity

Storage capacities have been calculated for basins and hydrocarbon prospects where sufficient data is available, the methods for calculating these estimates are explained in appendix A. These storage capacities have been classified according to the CSLF resource pyramid and are summarised in Table 1.

Table 1 Basins and the estimated storage capacity and storage capacity classification

Basin/hydrocarbon prospect	**Capacity classification**	**Quantified storage capacity Mt**
Kinsale Gas Field	Practical	330
South West Kinsale Gas Field	Practical	5
Spanish Point Gas field	Practical	120
East Irish Sea oil and Gas fields	Practical	1,050
Portpatrick Basin Sherwood Sandstone selected structures	Effective	37
Central Irish Sea Sherwood Sandstone structures	Effective	630
Lough Neagh Basin Enler Group selected structures	Effective	1940
East Irish Sea Basin Ormskirk structures	Effective	630
Kish Bank Basin Sherwood sandstone structures	Effective	270
Celtic Sea - 1 structure in the Cretaceous A sand	Theoretical	40

Portpatrick Basin/ Larne whole basin	Theoretical	2,700
Peel Basin Sherwood Sandstone whole basin	Theoretical	68,000
Northwest Carboniferous Dowra Basin whole basin	Theoretical	730
Central Irish Sea whole basin	Theoretical	17,300
Kish Bank Basin Carboniferous sandstone and coal	Theoretical / un-quantified	
Rathlin Basin Sherwood Sandstone, Permian and Carboniferous	Theoretical / un-quantified	
Celtic Sea Cretaceous A sand	Theoretical / un-quantified	
Porcupine Basin	Theoretical / un-quantified	
Slyne/Erris Basins	Theoretical / un-quantified	
Clare Basin	Theoretical / un-quantified	
Rockall Trough	Theoretical / un-quantified	
Gas prospects	Theoretical / un-quantified	
Other onshore basins	Theoretical / un-quantified	
Total storage capacity (million tonnes CO_2)		**93,782**

4. Economic analysis of carbon capture and storage

An assessment of the technologies and costs involved in building a complete carbon capture and storage (CCS) chain was carried out using internationally accepted methodology and taking into account the recommended approach by the International Energy Agency (IEA). The following case studies where CO_2 is captured from both IGCC and pulverised coal power plants were analysed:

1. Moneypoint power station to Kinsale Head gas field
2. Cork power station to Kinsale Head gas field
3. Kilroot power station to Portpatrick Basin

The costs of CCS have been estimated at €28 to over €56 per tonne CO_2 avoided, and are highly dependent on the source of CO_2 and the conditions and location of the storage reservoirs. The costs of CCS for IGCC power plants are approximately €15 per tonne less than that of pulverised coal power plants.

The study is a preliminary analysis based on limited process and cost data. Rules of thumb and simple equations were used to model the cases and detailed process or reservoir simulations were not carried out.

5. FEP analysis

Based on the case studies in the economic analysis of CCS, a FEP analysis was carried out for the Kinsale Head gas field and for the Larne/Portpatrick basins.

5.1. Kinsale Head field

The Kinsale Head gas field poses an attractive option for gas storage. Capacity is more than adequate and injectivity, constrained by gas production performance, appears to be satisfactory at expected injection rates. The field is quite shallow however and because of this careful attention should be paid to the possible containment risks. The geological seals, in intact form, appear to be satisfactory, but the possibility of their recent modification during pressure depletion should be evaluated. As a small number of faults cut the top of the reservoir and are perceived to present significant containment risks, fault geometry, linkage and sealing properties should be evaluated. Wells pose the clearest containment risk, and a suitable risk management, monitoring and remediation strategy must be developed.

5.2. Larne Basin/Portpatrick Basin

The Larne Basin may have some theoretical CO_2 storage potential, but major risks include the shallow depth of the Sherwood Sandstone across the basin, the possible lack of suitable closed structures and possible interference of injected CO_2 with potential potable water supplies. In addition, key monitoring datasets (4D seismic) may be severely compromised by geological conditions. Further major data acquisition and analysis would have to be undertaken to reduce uncertainty before onshore storage could be contemplated.

On the basis of currently available data in the Portpatrick Basin closed structures filled in the Sherwood Sandstone Group may have potential theoretical storage capacity, but economic storage is likely to be limited by the restricted dimensions of the structures. The Mercia Mudstone caprock, where intact, is likely to form an effective seal to stored CO_2. If injectivity can be successfully demonstrated, CO_2 storage may be viable. Individual storage sites in the basin would have to be studied more closely via a detailed site characterisation, with particular reference to fault seal capacity and injectivity.

6. Conclusions

Ireland has a good potential to store its point source CO_2 emissions in geological formations in its sedimentary basins. The greatest potential exists offshore in saline aquifer formations. The most accessible geological storage may be in the depleted gas fields of the Kinsale gas field in the Celtic Sea Basin, where geological conditions are well understood. The field could potentially store 330 Mt of CO_2 and is nearing the end of its producing lifetime offering a window of opportunity for CO_2 storage before infrastructure is removed. The offshore Permo-Triassic basins of the eastern shore of the Ireland have a similar geological expression as the prolific hydrocarbon basin of the East Irish Sea. These basins could potentially store up to 937 Mt in identified closed structures. The hydrocarbon prospective areas of Slyne, Erris, Porcupine, Clare and Rockall basins potentially offer a large CO_2 storage capacity in their saline aquifers but due to a lack of data this is an un-quantified resource. The Celtic Sea which is the location of the Kinsale gas complex may also offer saline aquifer storage in the Cretaceous 'A' and 'B' Sands reservoir. Onshore the Northwest Carboniferous Basin has a total basin storage capacity of 730 Mt in the Dowra formation. To access the potential in the Dowra formation may be technically challenging due to the low permeability of this tight gas reservoir. Storage of CO_2 in the East Irish Sea basin may offer the potential to store large amounts of CO_2 in its oil and gas fields (1050 Mt) and allow access of the storage potential of the Ormskirk Sandstone Formation (630 Mt).

Some risks to CO_2 stored in these locations have been identified in this study and should be fully assessed before considering CO_2 storage. Kinsale Head poses some potential containment risks e.g. modification of the geological seal, leakage from wells. In the Larne and Portpatrick basins the risks include shallow reservoir depths and structure limitations. Basins should not be disqualified purely on the basis of a perceived geological risk. It is fair to conclude that CCS will only be permitted where the environmental integrity can be assured before, during and after injection.

The costs of CCS have been estimated at €28 to over €56 per tonne CO_2 avoided, and are highly dependent on the source of CO_2 and the conditions and location of the storage reservoirs. The costs of CCS for IGCC power plants are approximately €15 per tonne less than that of pulverised coal power plants.

The estimated storage capacities in this study have been classified according to the CSLF methodology of a techno-economic resource pyramid. The total quantified (total theoretical CO_2 storage capacity) but unproven CO_2 storage capacity of the Island of Ireland is approximately 94000 Mt.

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Appendix A.

7.1. Calculating CO_2 storage capacity

7.1.1. Gas Fields

The methodology used to estimate the storage capacity of the gas fields is based on the principle that a variable proportion of the pore space occupied by the recoverable reserves will be available for CO_2 storage, depending mainly on the reservoir drive mechanism [4]. The mass of CO_2 that would occupy the pore space in each field formerly occupied by its recoverable reserves of natural gas is calculated according to the following formula:

$$M_{CO2} = (V_{GAS}\ (stp) / Bg).\ \rho CO_2 \qquad \text{(Equation 1)}$$

Where:
M_{CO2} = CO_2 storage capacity (10^6 tonnes)
Stp = standard temperature and pressure
V_{GAS} (stp) = volume of ultimately recoverable gas at stp (10^9 m^3)
Bg = gas expansion factor (from reservoir conditions to stp)
ρCO_2 = density of CO_2 at reservoir conditions (kg m^{-3})
The density of CO_2 at reservoir conditions was calculated from an equation-of-state [5].

The above figure should be reduced (discounted) to allow for factors that may reduce the amount of pore space in the reservoir that could be filled with CO_2. Water invasion into the reservoir during (and after) gas production is considered to be the main factor that will affect the amount of CO_2 that can be injected back into the gas field. This can most accurately be estimated by numerical reservoir simulation. Unfortunately, no reservoir simulations were available for this study, so the following empirical factors were used to discount the CO_2 storage capacity calculated in Equation 1:

1. In gas fields with depletion drive, i.e. those where, during production the pressure in the gas field simply decreases as it would if the gas were being produced from a pressurised sealed tank, it is assumed that 90% of the pore space could be occupied by CO_2.
2. In gas fields with water drive, i.e. those where water encroaches into the pore space formerly occupied by the produced natural gas, it is assumed that 65% of the pore space could be occupied by CO_2.
3. In gas fields where weak water drive or water drive in one or more compartments of a field has been observed it has been assumed that 65% of the pore space could be occupied by CO_2.

In the absence of any specific data, the discounts used are similar to those used by Bachu & Shaw [4] in their study of the CO_2 storage capacity of the oil and gas fields of Alberta.

7.1.2. Aquifers

CO_2 storage capacity (tonnes) = [1]total pore volume x [2]density of CO_2 x 0.4[3] (Equation 2)

[1] As water has to be displaced from the pore space in aquifers, and the reservoir is heterogeneous, much of the pore space can be bypassed by migrating CO_2 when it is injected into such structures as it follows the path of least resistance. This results in a less than perfect sweep of CO_2 through the pore space and relatively low CO_2 saturation of the reservoir rock. Based on reservoir simulation of closed structures in the Bunter sandstone (Obdam et al. 2003), it is expected that the maximum regional CO_2 saturation of the pore space that could be achieved is approximately 40%.

[2] Calculated from experimental equations of state (Eric Lindeberg pers comm.)

[3] Calculated using the gross rock volume (thickness and area), multiplied by the net to gross ratio (where available) multiplied by the average porosity.

This method does not take into account the adverse pressure effects of injecting into low permeability reservoirs.