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potential in the UK –  
Southern North Sea case study

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## **Summary**

This report discusses the potential for storing CO<sub>2</sub> in the Bunter Sandstone Formation (saline aquifer) and gas fields in the Southern North Sea Basin of the UK. The estimated storage potential in the closed structures of the Bunter Sandstone Formation and gas fields 2811 million tonnes and 14305 million tonnes of CO<sub>2</sub> respectively. Many of the Southern North Sea gas fields are produced by depletion drive with very little aquifer support during production. This makes them particularly favourable for CO<sub>2</sub> storage, as the reservoir pressure after production is low making CO<sub>2</sub> injection less costly. The gas fields also have proven gas seals over geological timescales. Most of the closed structures in the Bunter Sandstone Formation have not stored gas and the injectivity of the Bunter Sandstone Formation is largely unknown, as a result storage in this aquifer carries more uncertainties than in the gas fields. It is important that before CO<sub>2</sub> injection takes place at any geological storage site, a full site investigation, characterisation and testing should be carried out. The storage sites identified in this study were used to produce Tyndall Centre scenarios, outlined in this report (section 2). The purpose of the scenarios is to present stakeholders with a range of options for reducing CO<sub>2</sub> emissions using geological storage of CO<sub>2</sub>. This scenario work was presented to identified stakeholders as part of the Tyndall Centre Project 'An Integrated Assessment of Geological CO<sub>2</sub> Sequestration in the UK'.

## **1 Introduction**

The southern North Sea Basin lies to the east of England (Figure 1). It contains three major reservoir rocks; the Bunter Sandstone Formation, of Triassic age, the Leman Sandstone Formation, of early Permian age, and Carboniferous sandstones of Silesian age.

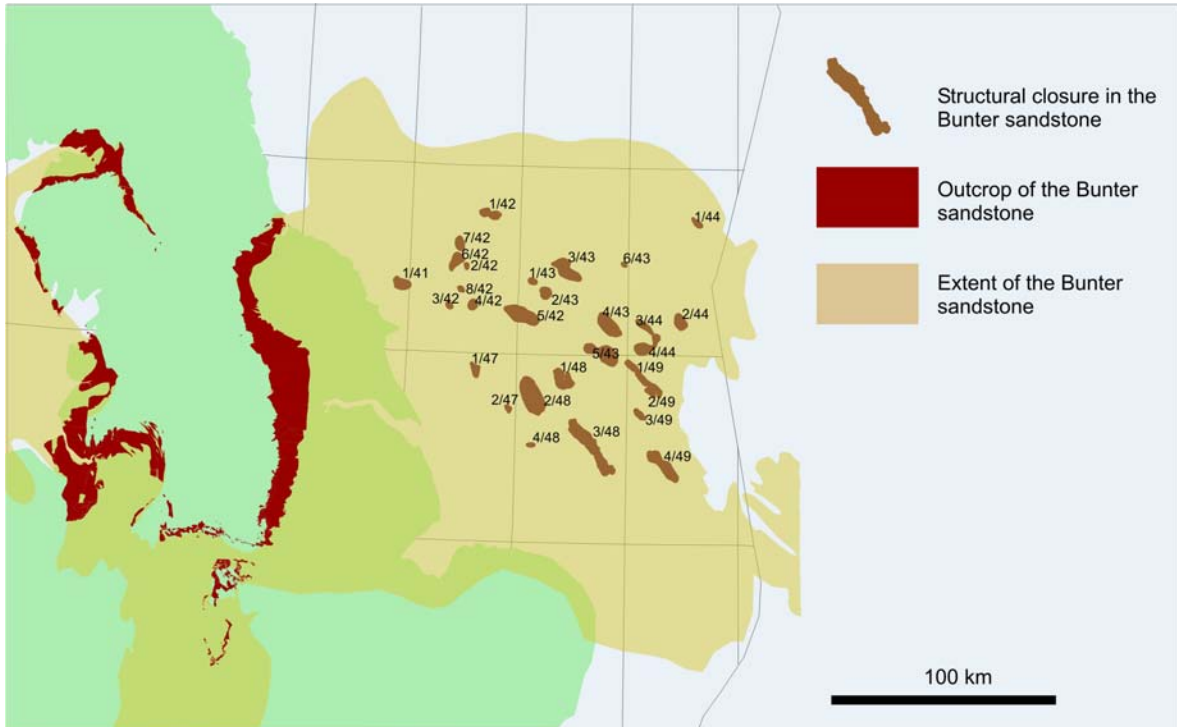
The CO<sub>2</sub> storage potential of the Bunter Sandstone is mainly aquifer potential. It contains some very large dome-shaped structures, the majority of which do not contain natural gas. The pore spaces in these structures are filled with highly saline water that could be displaced by CO<sub>2</sub>. There are a few gas fields in the Bunter Sandstone, but these do not represent the bulk of its potential storage capacity.

The CO<sub>2</sub> storage potential of the Leman Sandstone Formation lies principally in its gas fields. There is good reason to suppose that all closed structures in the Leman Sandstone Formation were originally full of gas, and thus its CO<sub>2</sub> storage capacity can be estimated with a high degree of confidence on the basis of its recoverable gas reserves.

The CO<sub>2</sub> storage potential of the Carboniferous sandstone aquifer has not been investigated in detail, as there is insufficient data available on the distribution and structure of these sandstones to make a meaningful analysis. It is the reservoir rock for several gas fields, which are discussed further.

## **2 Location of the Bunter Sandstone Formation**

The Bunter Sandstone Formation is a major sedimentary rock formation which is widely distributed in northern and central England (Figure 1). It is continuously present beneath a large area that stretches from its outcrop (the places where it comes to the surface) between Nottingham and Teesside, beneath the East Midlands and eastwards without interruption beneath the southern North Sea. This study focuses on the Bunter Sandstone in the UK sector of the southern North Sea.



**Figure 1 Extent and closures of the Bunter Sandstone Formation in the UK sector of the southern North Sea**

The Bunter Sandstone has many of the characteristics required for CO<sub>2</sub> storage, including large closed structures (domes), good average porosity and permeability, and a good seal in the overlying Haisborough Group, which consists of mudstones and evaporites (evaporites are rocks that have been formed by the evaporation of saline water, and those in the Haisborough Group include thick beds of rock salt). The Bunter Sandstone is a proven gas reservoir in the southern North Sea Basin and the Irish Sea Basin. Nonetheless, it is not possible to demonstrate conclusively that the large structures in the southern North Sea will not leak if filled with CO<sub>2</sub>; many of the structures are cut by faults and the sealing efficiency of these faults is not known.

A summary of the properties of the Bunter Sandstone Formation is given in Table 1.

**Table 1 Reservoir properties of the Bunter Sandstone Formation in the southern North Sea (Data from Brook et al 2003).**

Property	Value
Lithology (rock type)	Sandstone
Average porosity	18.7%
Porosity range	2.4 – 22.02 % (core porosity)
Depth range in the southern North Sea	200m – 3000m
Thickness range	0 – 350m (thicker in centre of the basin)
Average thickness	200m
Seal	Haisborough Group

Closures within the Bunter Sandstone Formation with the potential for CO<sub>2</sub> storage were identified using a combination of existing maps, offshore well data and 2D seismic data (Brook et al. 2003). The location of the closure sites is shown in Figure 1. The volumes of the closures and their CO<sub>2</sub> storage capacities shown in Table 2 were estimated using the equation below:

CO<sub>2</sub> storage potential (tonnes) = (Area x thickness x porosity x density of CO<sub>2</sub> at reservoir conditions) x 0.4

Where 0.4 is the estimated fraction of the pore space in the structure that could be filled with CO<sub>2</sub>. This factor was derived from reservoir simulation using the Esmond field reservoir model (Obdam et al. 2003).

**Table 2 Storage Capacities of the major structural closures in the southern North Sea. Refer to Figure 7 for location of individual structures.**

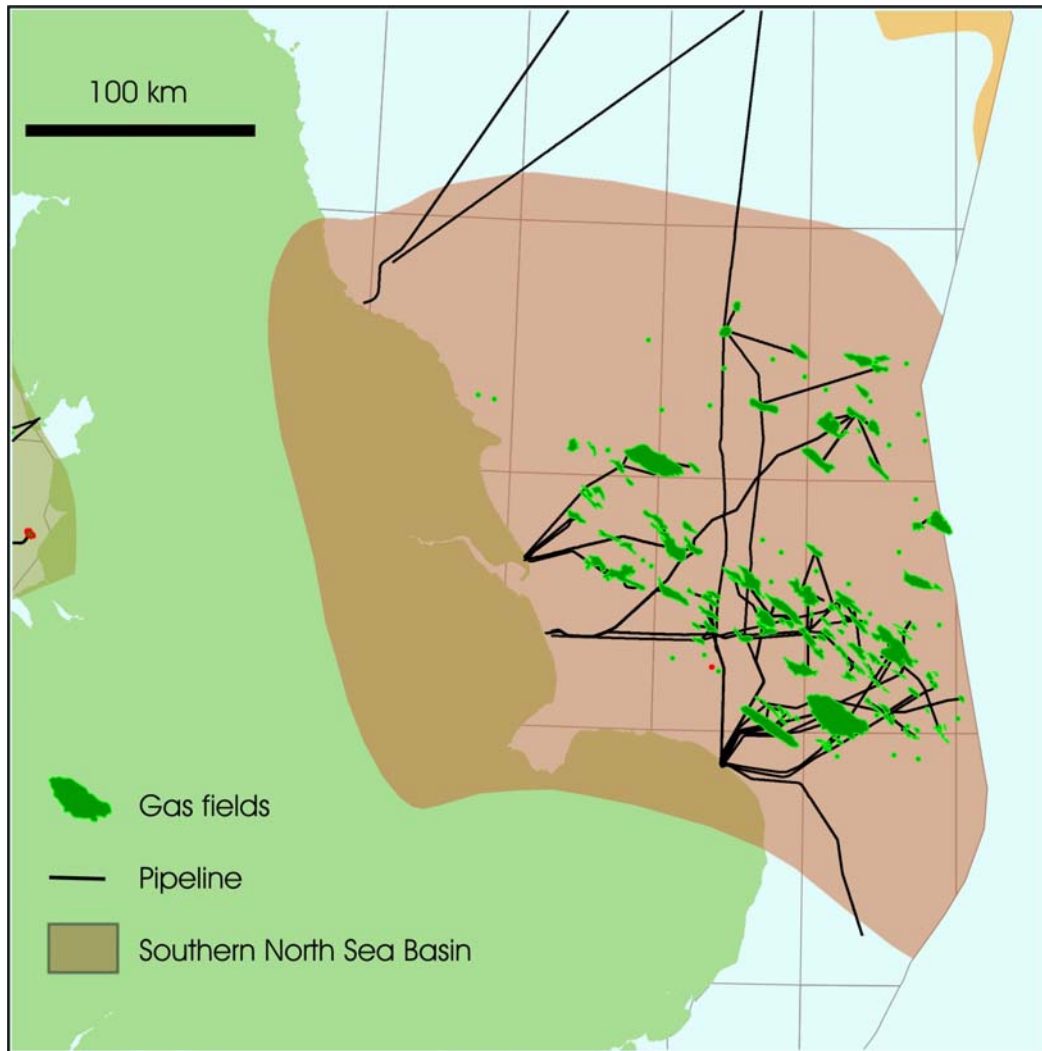
Closure Name	Area (m <sup>2</sup> )	Depth (m)	Thickness (m)	Average Core Porosity	Pressure (Mpa)	Density of CO <sub>2</sub>	Total Pore Volume (m <sup>3</sup> )	CO <sub>2</sub> stored (MT) 40% pore space saturation
5/43	106604196	1600	262.5	0.18	162.6688	0.6624376	5037048283	1335
4/43	87874997.8	1800	250	0.18	182.8774	0.6641573	3954374902	1051
1/43	8218386.06	1200	150	0.18	122.2516	0.6541464	221896423.5	58
1/48	62737184.5	800	300	0.18	81.8344	0.6009652	3387807962	814
2/48	180678309	1100	375	0.18	112.1473	0.6497103	12195785838	3169
3/48	177715633	1200	275	0.18	122.2516	0.6541464	8796923844	2302
2/44	36634215.9	1400	175	0.18	142.4602	0.6594876	1153977800	304
4/44	54592459.3	1400	225	0.18	142.4602	0.6594876	2210994603	583
3/44	19519238.7	1600	212.5	0.18	162.6688	0.6624376	746610881.6	198
3/43	87325385.9	1400	150	0.18	142.4602	0.6594876	2357785419	622
1/41	38389372.8	400	175	0.18	41.4172	0.1007283	1209265245	49
4/49	94649284.8	1200	250	0.18	122.2516	0.6541464	4259217814	1114
4/48	3315938.42	1600	175	0.18	162.6688	0.6624376	104452060.1	28
2/42	2853850.66	1000	137.5	0.18	102.043	0.6428487	70632803.74	18
4/42	17254618.1	1400	187.5	0.18	142.4602	0.6594876	582343361.4	154
3/42	6145169.83	1200	237.5	0.18	122.2516	0.6541464	262706010.4	69
1/42	32248591.7	1200	37.5	0.18	122.2516	0.6541465	217677994.1	57
3/49	13079112.4	1400	212.5	0.18	142.4602	0.6594876	500276050	132
5/42	117520230	1400	150	0.18	142.1602	0.6594876	3173046221	837
6/42	34269721.3	1300	162.5	0.18	132.3559	0.6572377	1002389348	264
7/42	22673167	1100	112.5	0.18	112.1473	0.6497103	459131632.3	119
2/43	25473682.6	1000	200	0.18	102.043	0.6428487	917052572.2	236
1/44	8638407.32	1600	25	0.18	162.6688	0.6624376	38872832.94	10
1/47	17747806.7	1700	112.5	0.18	172.7731	0.6634092	359393085.3	95
2/47	4751521.89	1600	225	0.18	162.6688	0.6624376	192436636.4	51
1/49	48444370.1	800	225	0.18	81.8344	0.6009652	1961996988	472
2/49	10610630	1400	225	0.18	142.4602	0.6594876	429730513.3	113
8/42	4176487.53	1200	187.5	0.18	122.2516	0.6541464	140956454.2	37
6/43	1930226.57	1600	150	0.18	162.6688	0.6624376	52116117.26	14
<b>Total Storage Capacity of the Bunter Closed Structures</b>								<b>14305</b>

The total storage capacity given in Table 2 is best regarded as a theoretical estimate of the maximum as some of the structures would likely prove to be unsuitable for CO<sub>2</sub> storage, for a variety of geological reasons, e.g. they might leak through faults. Nonetheless, UK power plants currently emit in the order of 176 Mt CO<sub>2</sub> per year, so it is likely that a very large proportion of CO<sub>2</sub> emissions from UK power plants could be stored within closures in the Bunter Sandstone Formation for several decades and possibly hundreds of years. The individual structures are discussed in more detail in Chapter 2.2.

### **3 Southern North Sea Gas Fields**

The first gas to come ashore from the UK sector of the southern North Sea was from the West Sole gas field, in 1967. Most of the major gas discoveries have been in the Lower Permian, Upper Carboniferous and Triassic sandstone reservoirs. Gas has also been found in the Upper Permian carbonate reservoir, e.g. in the Hewett field (Cameron et al. 1992). The major source

of the gas in the southern North Sea is coal seams in the Upper Carboniferous Coal Measures. The Permian Leman Sandstone Formation contains the majority of the gas in the southern North Sea and as a result has the greatest potential for CO<sub>2</sub> storage.



**Figure 2 Location of gas fields in the southern North Sea.**

The storage capacities of the southern North Sea gas fields were calculated in the GESTCO study. The calculation assumes all the gas produced from the field can be replaced by CO<sub>2</sub> (Table 3).

$$V_{CO_2} = (V_{GAS} (stp) / Bg) \times \rho_{CO_2} \text{ (Equation 1)}$$

Where:

$V_{CO_2}$  = CO<sub>2</sub> storage capacity (10<sup>6</sup> tonnes)

Stp = standard temperature and pressure

$V_{GAS} (stp)$  = volume of ultimately recoverable gas at stp (10<sup>9</sup> m<sup>3</sup>)

Bg = gas expansion factor (from reservoir conditions to stp)

$\rho_{CO_2}$  = density of CO<sub>2</sub> at reservoir conditions (kg m<sup>-3</sup>)

The factor of water invasion into the reservoir after gas production will affect the amount of CO<sub>2</sub> that can be injected back into the gas field. This was not factored into the GESTCO calculations. The effect of this can be most accurately calculated by using reservoir simulation. But for this study no reservoir simulations are available. In the absence of simulation the following factors have been used to adapt Equation 1 (from studies by Bachu & Shaw (2003) on oil and gas fields in Alberta):

1. In gas fields with depletion drive, i.e. those where the wells are opened up and the pressure in the gas field simply depletes, as it would if the gas were being produced from a sealed tank, it is assumed that 90% of the pore space could be occupied by CO<sub>2</sub>.
2. In gas fields with water drive, i.e. those where water encroaches into the pore space formerly occupied by the produced natural gas reserves, it is assumed that 65% of the pore space could be occupied by CO<sub>2</sub>.
3. In gas fields where the drive mechanism is both pressure depletion and water drive it has been assumed that each mechanism is acting equally on the reservoir, it is assumed that 77.5% of the pore space could be occupied by CO<sub>2</sub>.

Where the drive mechanism is unknown, the following assumptions have been made. If the reservoir rock for the gas field is the Lemman Sandstone the drive mechanism is depletion drive. This assumption has been made on the basis that most of the Lemman Sandstone fields are depletion-produced fields. If the reservoir is in the Triassic or Carboniferous it has been conservatively assumed that the field is acting under water drive, as are most of the fields within these reservoirs. The drive mechanism and resulting estimated capacity are detailed in Table 3.

**Table 3 Storage capacities in southern North Sea gas fields. Adapted from Brook et al 2003.**

FIELD NAME	Status	Age	Startup	Storage capacity GESTCO(Mt)	Drive mechanism	Storage Capacity (MT)
Leman	Producing	Permian	1966	966.17	Depletion	869.55
Indefatigable & Indefatigable SW	Producing	Permian	1983	246.17	Depletion	221.55
Viking	Producing	Permian	1965	238.32	Depletion	214.49
West Sole	Producing	Permian	1965	150.92	Depletion	135.83
Galleon	Producing	Permian	1985	142.96	Depletion*	128.66
Hewett	Producing	Triassic and Permian	1966	139.66	Depletion & water drive	108.24
Indefatigable	Producing	Permian	1966	122.99	Depletion	110.69
Barque & Barque S	Producing	Permian	1966	98.54	Depletion	88.69
Victor	Producing	Permian	1972	81.63	Depletion	73.47
Ravenspurn N.	Producing	Permian	1984	66.13	Depletion	59.52
Vulcan	Producing	Permian	1983	59.06	Depletion	53.15
Audrey	Producing	Permian	1976	54.99	Depletion*	49.49
Clipper N	Producing	Permian	1983	51.22	Depletion	46.10
Amethyst E & W	Producing	Permian	1970	51.08	Depletion	45.97
Sean N. & S.	Producing	Permian	1969	49.25	Depletion	44.33
Schooner	Producing	Carboniferous	1996	45.48	Depletion	40.93
Pickerill	Producing	Permian	1984	43.02	Depletion*	38.72
Ravenspurn S.	Producing	Permian	1983	40.63	Depletion	36.57
Thames, Yare, Bure & Wensum	Producing	Permian	1973	34.28	Depletion	30.85
Murdoch	Producing	Carboniferous	1993	25.54	Water drive*	16.60
Rough	Producing	Permian	1968	25.13	Depletion	22.62
Skiff	Producing	Permian	1995	23.85	Depletion*	21.47
Neptune	Producing	Permian	1986	23.28	Depletion*	20.95
Ganymede	Producing	Permian	1989	23.24	Depletion*	20.92
Welland	Producing	Permian	1984	22.22	Depletion*	20.00
Excalibur	Producing	Permian	1988	21.50	Depletion*	19.35
Cleeton	Depleted	Permian	1983	21.01	Depletion & water drive	16.28

Anglia	Producing	Permian	1985	20.04	Depletion*	18.04
Lancelot	Producing	Permian	1986	19.26	Depletion*	17.33
Markham	Producing	Permian	1984	19.07	Depletion*	17.16
Camelot N, C&S	Producing	Permian	1967	18.82	Water Drive	12.23
Gawain	Producing	Permian	1988	18.19	Depletion*	16.37
Johnstone	Producing	Permian	1985	17.81	Depletion	16.03
Corvette	Producing	Permian	1996	17.20	Depletion	15.48
Boulton	Producing	Carboniferous	1997	14.93	Water drive*	9.70
Valliant S.	Producing	Permian	1970	13.81	Depletion	12.43
Bell	Producing	Permian	1994	12.49	Depletion*	11.24
Galahad	Producing	Permian	1975	12.49	Depletion*	11.24
Esmond	Depleted	Triassic	1985	12.12	Depletion & water drive	9.39
Vixen	Producing	Permian	1999	12.00	Depletion*	10.80
Sean E	Producing	Permian	1983	10.11	Water drive	6.57
Orwell	Producing	Triassic	1990	9.61	Depletion*	8.65
Trent	Producing	Carboniferous	1996	8.92	Depletion*	8.03
Valiant N.	Producing	Permian	1971	8.78	Depletion	7.90
Bessemer	Producing	Permian	1989	8.66	Volumetric depletion	7.80
Europa	Producing	Permian	1972	8.42	Depletion*	7.58
Hyde	Producing	Permian	1966	7.90	Depletion*	7.11
Baird	Producing	Permian	1993	7.38	Depletion*	6.64
Ann	Producing	Permian	1966	7.29	Depletion*	6.56
Guinevere	Producing	Permian	1988	7.26	Pressure depletion	6.53
Vanguard	Producing	Permian	1982	5.51	Depletion	4.96
Gordon	Depleted	Triassic	1985	5.25	Depletion & water drive	4.07
Forbes	Depleted	Triassic	1985	2.24	Depletion & water drive	1.74
<b>Total Carboniferous</b>				<b>94.87</b>		<b>75.27</b>
<b>Total Triassic</b>				<b>175.93</b>		<b>116.89</b>
<b>Total Leman</b>				<b>2910.07</b>		<b>2618.61</b>
<b>Grand Total</b>				<b>3180.87</b>		<b>2810.76</b>

\* Assumption of the drive mechanism.

#### **4 Tyndall Stakeholder Scenarios**

Future energy supply scenarios including CO<sub>2</sub> capture and geological storage were produced as part of the integrated assessment process examining the potential role for geological storage of CO<sub>2</sub> as a mitigation option in the decarbonisation of UK energy supply. The Scenarios presented here are named Fossilwise, Capture as a Bridge and Spreading the Load. Within each scenario an amount of CO<sub>2</sub>, derived from power plants in Yorkshire and Humberside, is made available for storage in geological formations beneath the southern North Sea. The amount of CO<sub>2</sub> available for storage is detailed at the beginning of each scenario and the emissions for each scenario from the included power plants are given in Appendix 1. The potential storage sites for these emissions are those described in Chapter 1, i.e. the aquifer potential in the Bunter Sandstone Formation and the southern North Sea gas fields. Only gas fields which could store over 40 MT were considered. The available gas fields with 40 MT of CO<sub>2</sub> storage and over are listed in Table 4.

**Table 4 Gas fields with the potential to store over 40 MT of CO<sub>2</sub>**

<b>Field Name</b>	<b>CO<sub>2</sub> storage capacity in Million Tonnes (MT) GESTCO</b>	<b>CO<sub>2</sub> storage capacity in Million Tonnes (MT) New figures</b>
Schooner	46	40.93
South & North Sean	49	44.32
Amethyst west & east	51	45.97
Audrey	55	49.49
Clipper North	55	46.10

Vulcan	59	53.15
Victor	82	73.47
Barque & Barque south	99	88.69
Raven spurn	107	69.55
Galleon	143	128.66
West Sole	151	135.83
Viking	238	214.49
Indefatigable	246	221.55
Leman	966	869.55
<b>Total Storage Capacity</b>	<b>2437</b>	<b>2081.75</b>

All of the Bunter Sandstone Formation closures shown in Figure 1 and Table 2 were considered and a selection was made based on their storage capacities and proximity to the gas fields.

It should be noted that insufficient geological data was available to properly characterise the individual potential CO<sub>2</sub> storage sites presented here. They were chosen solely because of their potential storage capacity and location, and their actual geological suitability is not known. Enhanced gas recovery and gas field abandonment dates were not considered in this study.

## **5 Basic Information about the Gas Fields used In The Scenarios**

### **Barque (Sarginson 2003)**

The Barque field lies in blocks 48/13a and 48/14, 45 km off the Norfolk coast in the southern North Sea. Water depths in the area vary between 27m and 45m. It was one of earliest gas discoveries in the southern North Sea and the Sole Pit Basin, discovered in 1971. It produces to the Bacton terminal. The trap is a dip closure against a NW-SE trending major fault. The main reservoir is the Rotliegend Group Leman Sandstone Formation and is sealed by Zechstein Evaporites. The Rotliegend is 215 – 250m thick and consists of mainly aeolian sandstones. Diagenesis has lowered the porosity and permeability of the rock in some areas of the field. Matrix permeability averages less than 1 mD with porosities less than 10%. The field still produces in these low permeability areas due to the presence of natural fractures. Fractures occur throughout the field and are both open and closed. In the west of the field the fractures are cemented, compartmentalising the reservoir, resulting in production being more difficult in this area. In some wells acid hydraulic fracturing has enhanced production. The best areas of reservoir have porosities of 15 – 20 % and permeabilities in tens of mD. Horizontal drilling after 1990 has allowed the whole field to be produced. Barque is produced in conjunction with the Clipper Field.

No encroachment of water is expected throughout the field production. There has only been minor water production from two wells; this was as a result of an open fracture reaching into the aquifer beneath. Gas production has been by pressure depletion. Expected recoverable reserves are estimated at 1366 BCF (10<sup>9</sup> cubic feet).

### **The Clipper Field (Sarginson 2003)**

The Clipper Gas Field is located in blocks 48/19a, 48/19c and 48/20a within the Sole Pit area. It is 65km off the Norfolk coast, and lies in water depths of 25m. First gas was produced in 1990. The reservoir is formed by the Rotliegend Group Leman Sandstone Formation and is sealed by Zechstein Evaporites. Reservoir permeability and porosity are both low, due to compaction and diagenesis. The average porosity for the field is 11.1%. On average, matrix permeability is less than 1 mD. Well production relies on intersecting natural fractures and enhancement by acid hydraulic fracturing; horizontal wells help to maximise the production. The trap is a broad faulted anticline. The reservoir consists of mainly quartzose aeolian sandstone. Most of the gas occurs between 2290m– 2440m below the sea bed. No water

encroachment has been observed or is expected during the field life. The recovery mechanism is by natural depletion. Expected recoverable reserves are 753 BCF.

**Indefatigable (McCrone 2003)**

The Indefatigable field lies in blocks 49/18, 49/19, 49/23 and 49/24 on the northern side of the Sole Pit Trough. Water depth is 30m. The field is 90km from the Bacton gas terminal on the coast. The primary reservoir is the Rotliegend Group Lemn Sandstone Formation, consisting of 45m – 120m of stacked dune sand, with a good porosity and permeability of 15% and 100 – 1000 mD respectively. The trap is a major NW-SE trending horst and a series of lower relief blocks and satellite structures. The field is complex with 11 gas/water contacts and 15 reservoir compartments. As the reservoir is depleted some of the faults between compartments stop acting as complete lateral seals allowing some communication between compartments. Only a very small number of wells exhibit water production, these are located on the flanks of the field. There is no evidence of an active aquifer. The expected recoverable reserves are 4.7 TCF (10<sup>12</sup> cubic feet).

**Leman field (Hillier 1990 & 2003)**

The giant Leman Gas Field lies across Blocks 49/26, 49/27, 49/28, 53/1 and 53/2 at the southern side of the Sole Pit Trough between two major fault zones. It is located 50 km NE of the Bacton terminal on the Norfolk coast. The field is nearing the end of its lifetime with originally an estimated 360 BCM of recoverable reserves with 298.8 BCM produced by 2000. The trap is a faulted elongated dip closed periclinal structure orientated NW – SE. Faults within the reservoir, which partially compartmentalise it, have broken down during the depletion of the field. The main reservoir is the dune sands of the Rotliegend Group Lemn Sandstone Formation, there is also an additional gas accumulation in the Carboniferous beneath the Rotliegend Leman accumulation. It is 170m to 280m thick and lies at a depth of 1800m. The Leman reservoir has a porosity and permeability of 12% and 0.55mD - 15.60mD respectively. The reservoir is well sealed by the Zechstein evaporites. Fractures in the NW of the field raise productivity by approximately 50%. The main drive mechanism for the field is depletion drive. There are over 192 development wells in the field originating from six platforms. Estimated recoverable reserves are 360.3 BCM.

**Schooner (Moscariello 2003)**

The Schooner Field lies in blocks 44/26a and 43/30a. It is located approximately 150 km from the South Yorkshire coast in the Silver Pit Basin. Gas production began in 1966. It is an Upper Carboniferous field. The reservoir, formed from Barren Red Measures Group fluvial sandstones, is 390m thick and lies at a depth of 3600m. The reservoir is compartmentalised by both faults and lateral discontinuities. The porosity ranges in the reservoir are 11 –13% with permeability measurements between 1 and 100 mD. The reservoir is sealed by the Silver Pit Formation, which is formed of lacustrine evaporites and shales. The trap is a NW-SE trending anticlinal closure bounded to the SW by oblique-slip faults. The recovery mechanism is by natural depletion.

**Ravenspur North (Ketter 1991)**

Ravenspur North is located 80 km east of Scarborough. The field covers an area of 19 km by 3 km in blocks 42/30 and 43/26a. Production began in 1990 and the estimated recoverable reserves are 1.4 TCF. The trap is a structural trap with elements of stratigraphic trapping in the northwest of the field. The reservoir rock is the Lemn Sandstone Formation, which is sealed by 120 m of claystones of the Silverpit Formation. The depth of the reservoir is 3040 m and it is 83 m thick. The field is mostly produced by depletion drive with a small amount of water drive in some compartments of the field.

**Ravenspur South (Heidrich 1991)**

Ravenspur South field is located 65 km east of Flamborough Head. The field lies in blocks 42/29, 42/30 and 43/26, it covers an area of 36 km<sup>2</sup>. The water depth in this area is

approximately 45 m. Production began in 1989, the expected recoverable reserves are 700 BCF. The reservoir rock is the Leman sandstone Formation. The average porosity and permeability of the reservoir is 13% and 90 mD respectively. The quality of the reservoir does vary greatly across the field. The depth of the reservoir is 2760 m and it is 80 m thick. The trap is a NW-SE striking anticline seal by the clays of the Siverpit Formation. The recovery mechanism is by pressure depletion and aquifer influence is thought to be negligible. All wells are hydraulically fractured to stimulate flow.

#### **Sean (Hillier 2003)**

The Sean North, South and Sean East fields are small gas fields located in block 49/25a. They are situated 100 km of the coast of Norfolk in 30m of water. The reservoir is in the Rotliegend and is sealed by Zechstein evaporites. The reservoir is at a depth of 2560m. The reserves for the fields are 234 BCF (North), 488 BCF (South) and 127 BCF (East). The trap for all of the fields is a dip closure. The drive mechanism for South Sean is both gas and water; i.e. there is water influx into the field. The drive for North and East Sean is volumetric depletion.

#### **Vulcan (Courtier et al 2003)**

The Vulcan field is part of a group of fields collectively known as the V-Fields fields that are located in blocks 49/16, 48/20a and 48/25b. They lie on the eastern side of the Sole Pit Basin. The reservoir is within the Leman Sandstone Formation and it is sealed by the Zechstein Salt. The reservoir is 2200m deep and approximately 30m thick. The average porosity is 13.5% and the average permeability is 5.4 mD. The field is a dip-closed trap bounded by faults, it is made up of a series of blocks bounded to the NE by a major fault. The gas is piped to the Theddlethorpe gas terminal.

#### **Victor (Lambert 1991)**

The Victor gas field is located on the eastern flank of the Sole Pit Basin 140 km east of Mablethorpe. It lies in blocks 49/17 and 49/22 in 38 m of water. The field is an elongated fault bound structure 11 km by 3 km. Production began in 1984 and the estimated recoverable reserves are 920 BCF. The trap is an elongated tilted fault block trending NW-SE, large faults bound the field to the northwest and southeast, sealed by Zechstein evaporites. The reservoir is in the Leman Sandstone Formation the crest of the field is 2530 m deep. The reservoir has a porosity and permeability of 16% and 52 mD respectively.

#### **Viking (Riches 2003)**

The Viking field is located 138 km east of the Lincolnshire coast of England in blocks 49/12, 49/16 and 49/17 where the water depth is approximately 30m. It produces from 11 separate gas-bearing compartments in 7 separate gas pools, from the Early Permian Leman Sandstone Formation. The crest of the main field is at 2743m below the seabed. Recoverable reserves were originally estimated at 2.89 trillion cubic feet (tcf). The total production to date is approximately 2.815 tcf, and the newly identified Viking Phoenix resources are estimated at a further 3.5 tcf. The traps consist of a series of tilted fault blocks separated by major normal faults trending E-W. Some of the faults act as permeability barriers and divide some of the pools into individual compartments. However, other faults in the north of the field are permeable and the individual fault blocks are connected forming a stair of connected pools. The Zechstein Group evaporites overlie the Rotliegend and form the caprock/seal.

#### **West Sole (Winter et al 1991)**

West Sole is located in the Sole Pit area of the Southern North Sea Permian Basin in block 48/6, approximately 60km east of Humberside. The gas is piped to the Easington terminal. The field was discovered in 1965. Production commenced in 1967. Initial reserves were 1.873 TCF. Gas is trapped in aeolian sandstones of the Permian Lower Leman Sandstone Formation. Productivity is enhanced in the southern part of the field by open gas filled fractures. Permeability is reduced due to illite cementation, it averages 3Md in the dune sandstones.

West Sole trap is a SE-plunging inversion anticline trending NW-SE. The anticline is cut by NW-SE trending reactivated Carboniferous faults. NE-SW trending cross faults break the structure into compartments. The crest of the structure at the top Lower Leman is 2700m. The gas water contact is at 2949m giving a 250m gas column. The structure is full to spill point. A partial seal to the main reservoir is provided by the playa mudstones and siltstones of the Silverpit Formation. Above this however, the Upper Leman Sandstone is gas bearing and was productive in one well. The ultimate top seal is provided by the Zechstein evaporites. Wells are hydraulically fractured to achieve commercial rates of production, although some wells exhibit natural fractures. The drive mechanism is natural depletion. Evidence suggests there is little or no aquifer pressure support.

**Gas fields with no data.**

No data were available from the Amethyst, Audrey and Galleon fields for this study.

**Notes for CO<sub>2</sub> storage in the gas fields**

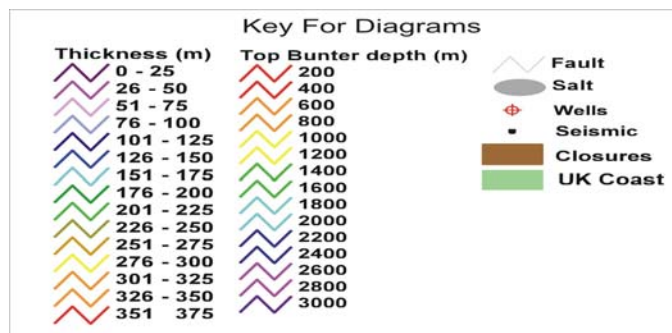
CO<sub>2</sub> storage may be made more difficult due to various geological conditions within the reservoir discussed here. Compartmentalised fields such as Barque, Indefatigable, Schooner, Viking and Leman may require more wells to access all of the available storage in each compartment. Faults present within the reservoir that act as barriers to flow during production will make injection harder and more complicated. Fields in which the reservoir has been artificially fractured to allow increased production rates may also be problematic for CO<sub>2</sub> injection as the CO<sub>2</sub> wells may also need this treatment, examples of such fields are Clipper and Trent. Gas fields, which have more than one separate accumulation in different reservoirs, for example Trent, may prove more costly to inject CO<sub>2</sub> into, as more wells or deviated wells may have to be drilled to access each depleted reservoir.

Large amounts of water influx into the gas fields after production, for example South Sean field, will cause a problem as CO<sub>2</sub> injected into the field will have to push the water back out of the pore spaces making injection more difficult. Fields without any evidence of water ingress back into the field after production (e.g. Clipper, Barque and Leman) would be a better choice for CO<sub>2</sub> storage because empty pore spaces at lower pressure than the initial reservoir would make CO<sub>2</sub> injection back into the reservoir much easier.

As fields are depleted and the pressure decreases the caprock may become damaged, allowing CO<sub>2</sub> migration out of the reservoir during re-injection. However, the ability of salt (which is a major component of the Zechstein cap rocks overlying the gas fields) to creep may counteract any cracking due to compression of the reservoir. As a general rule the initial reservoir pressure of the gas field should not be exceeded in the injection period, unless the seal is tested before injection.

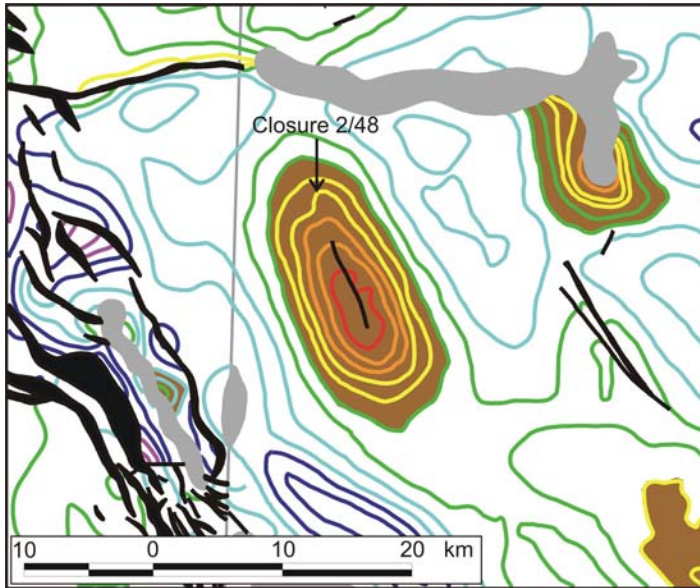
**5 Basic information in the Chosen Bunter Sandstone Formation Storage sites**

All of the identified closures were considered for the scenarios (Figure 1 and Table 2). Closures were selected based on the proximity to the gas fields identified and if the scenario dictated use of an aquifer site.

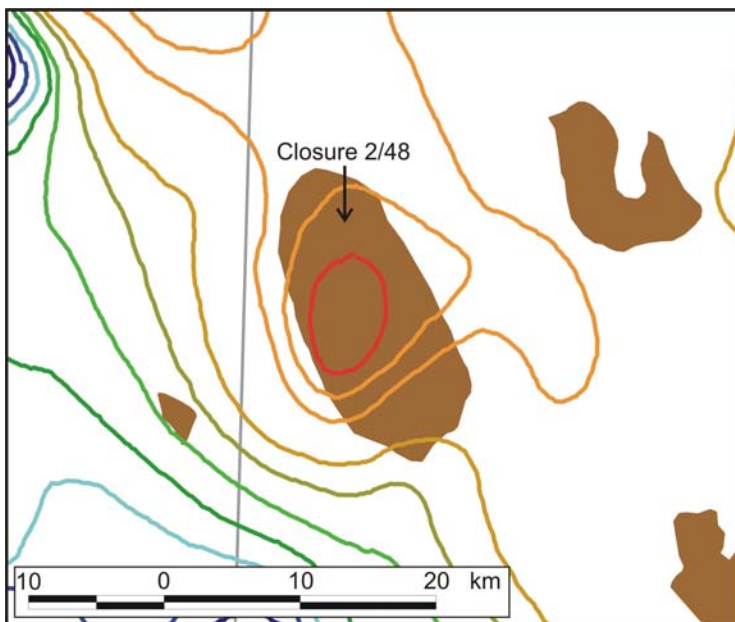


**Figure 3 Key for the maps of the Bunter Sandstone Formation Closures**

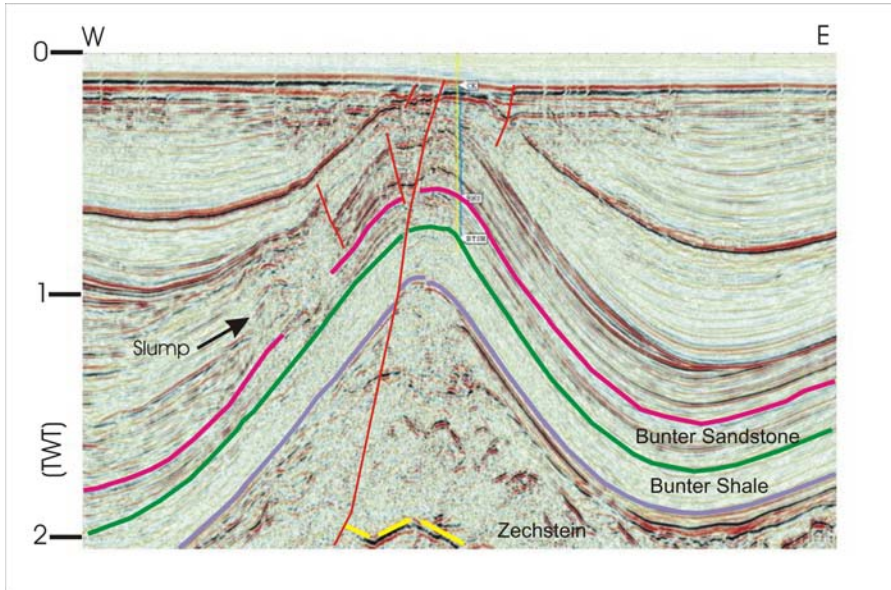




**Figure 5** Depth map of top Bunter Sandstone Formation of closure 2/48



**Figure 6** Thickness map of closure 2/48



**Figure 7 Seismic line through closure 2/48. Data courtesy of Western Geco.**

### **Aquifer 3/48**

The closure 3/48 has 12 wells drilled into it (Figure 8). The total pore volume of the closure is 879692 Km<sup>3</sup>. At 40% pore space saturation with CO<sub>2</sub> the structure could potentially hold 2302 Mt of CO<sub>2</sub>. The closure is elongate and trends roughly NW – SE. In the crest of the structure the Bunter Sandstone lies at a depth of approximately 1200m and is 275m thick (Table 6). The salt anticline has a relatively low relief, and there are many faults in the seal above the Bunter Sandstone, these faults may compromise the integrity of the closure. Faults are also present in the Bunter Sandstone Formation (Figure 11).

The site was considered on the criteria of location and storage capacity alone. If this structure were to be considered for CO<sub>2</sub> storage, it is likely it would be rejected due to the intensity of faulting in the reservoir and cap rock unless the faults could be proved to be sealing.

**Table 6 Properties of storage site 3/48**

Reservoir	Triassic Bunter Sandstone formation
Seal	Rot Halite (Haisborough Group Evaporites)
Closure Type	Salt induced anticline
Faulting	Large scale faulting the caprock and reservoir, reaching seabed.
Reservoir depth to top	1200 m
Thickness of reservoir	275 m
Area	17715633 m <sup>3</sup>
Porosity	18% (average core porosity)
Permeability	100 – 700 md (average)
Salinity of pore fluid	130 000 – 205 000 ppm (average)
CO <sub>2</sub> density in reservoir	0.654
Storage capacity	2302 MT CO <sub>2</sub>

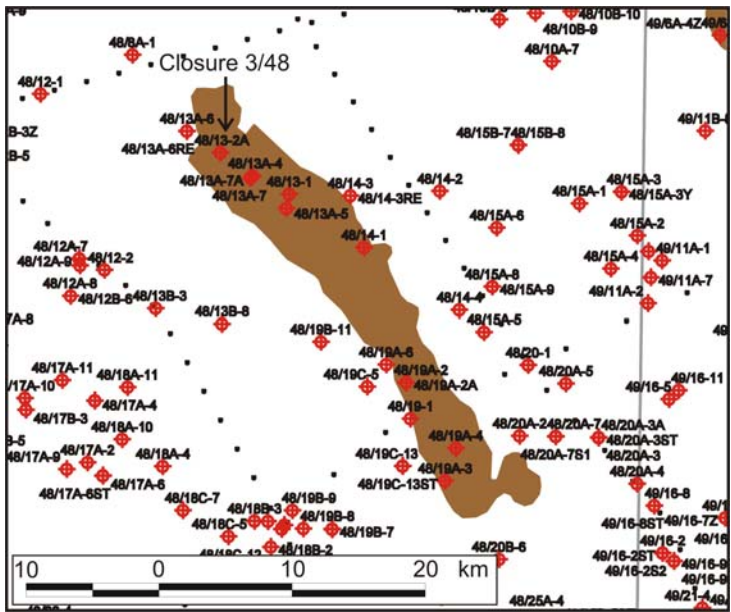


Figure 8 Location of seismic and wells above closure 3/48

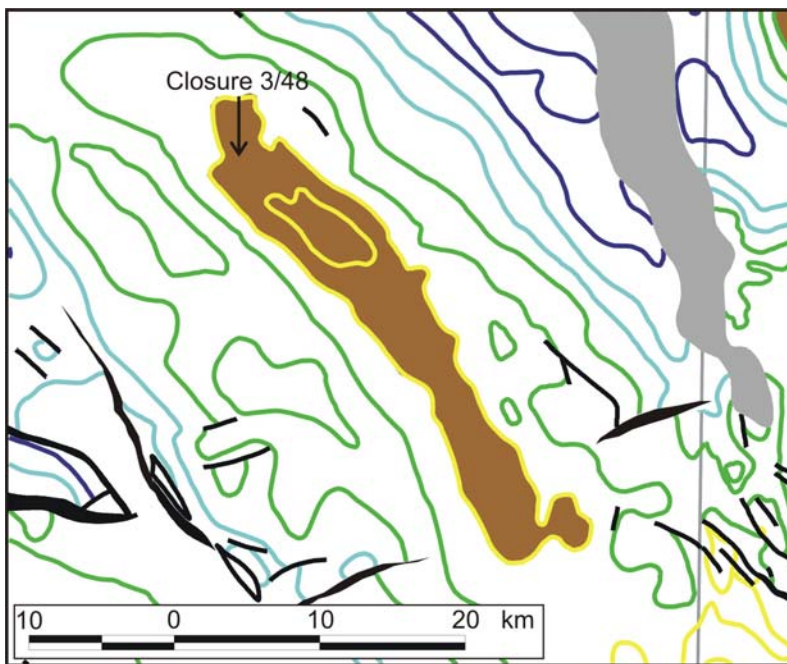
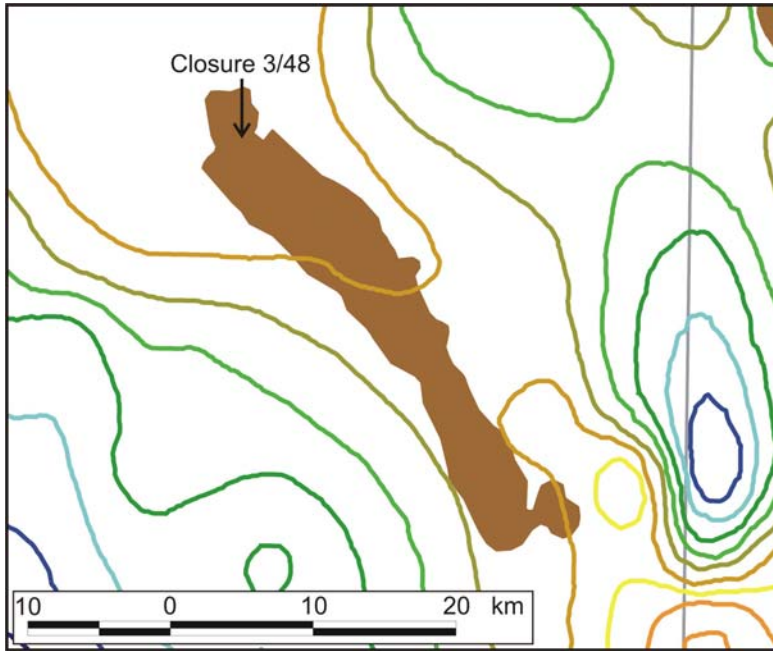
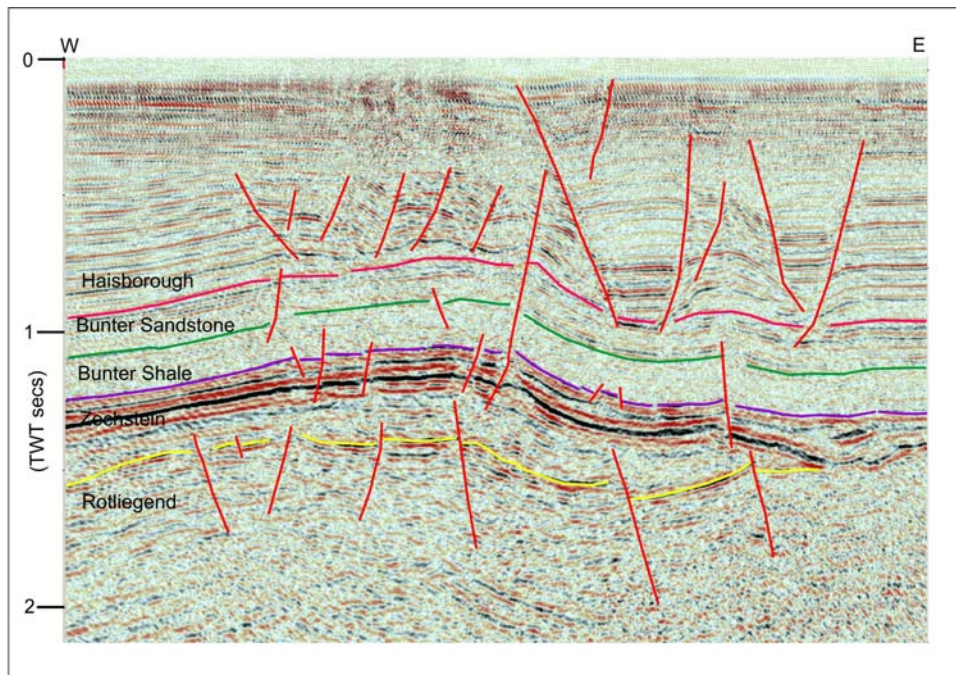


Figure 9 Depth map of top Bunter Sandstone Formation, closure 3/48



**Figure 10 Thickness map of the Bunter Sandstone Formation, closure 3/48**



**Figure 11 Seismic line through closure 3/48. Data courtesy of WesternGeco.**

#### **Aquifer 4/49**

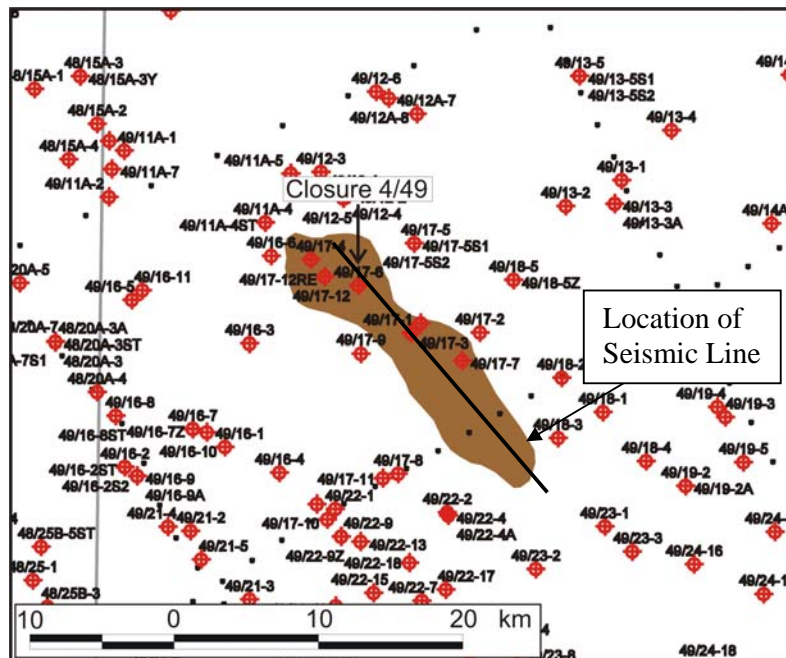
This structure lies directly above the Viking Gas Field. Analysis from 3D suggests the north-western part of the dome has many of the characteristics that make a suitable CO<sub>2</sub> storage site. The 3D seismic shows the broad shape of the structure in the Bunter Sandstone that immediately overlies the Viking gas complex. It is part of a larger structure formed above a salt pillow, which extends off the 3D seismic further to the southeast. 2D data indicates that

the whole structure is closed to a depth of 1400m (closure 4/49, Figure 13). The northern part of the dome in the Bunter Sandstone is separated from the southern part by a lower bridge or saddle. This allows the possibility of using just the northern culmination as a CO<sub>2</sub> storage site. The movement of the salt has caused faulting on the flanks of the structure. Some of these faults extend upwards to the seabed. There are no faults on the crest of the northern culmination that penetrate the Bunter Sandstone; the crestal faults only reach as far down as the Haisborough Group (Figure 15).

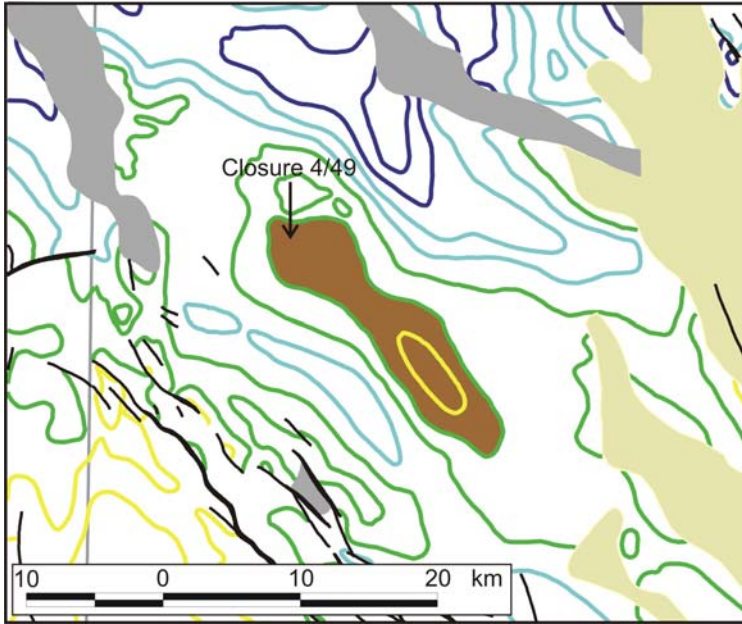
For this study all of the closure is considered for storage, not just the NW portion. The top of the Bunter Sandstone Formation lies at a depth of 1200m and is 480m thick (Table 7). The pore volume of the closure is 425921 Km<sup>3</sup> and at 40% pore space saturation with CO<sub>2</sub> the structure could potentially store 1114 MT of CO<sub>2</sub>.

**Table 7 Properties of closure 4/49**

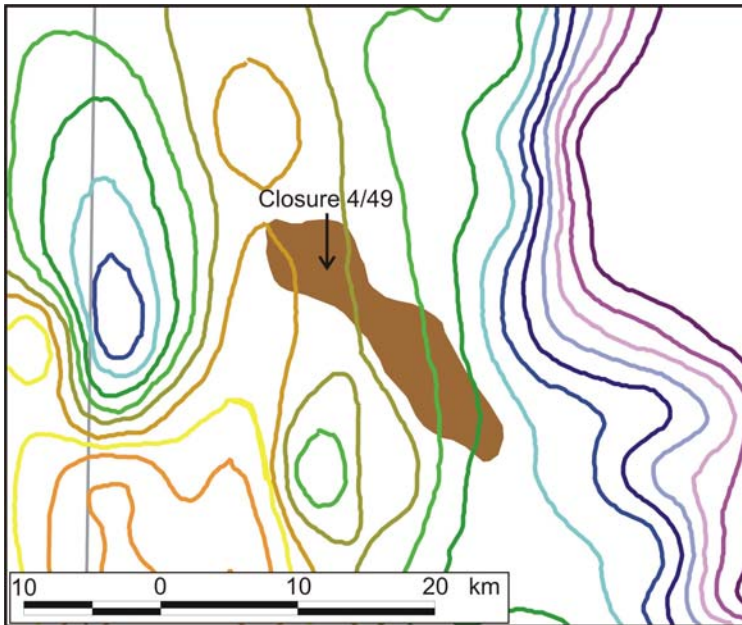
Reservoir	Triassic Bunter Sandstone formation
Seal	Rot Halite (Haisborough Group Evaporites)
Closure Type	Salt induced anticline
Faulting	Faulting on the crest of the dome does not reach the reservoir
Reservoir depth to top	1200 m
Thickness of reservoir	480 m (maximum)
Area	94649285 m <sub>3</sub>
Porosity	17.66% (from neutron logs)
Permeability	100 – 700 md (average)
Salinity of pore fluid	130 000 – 205 000 ppm (average)
CO <sub>2</sub> density in reservoir	0.654
Storage capacity	1114 MT



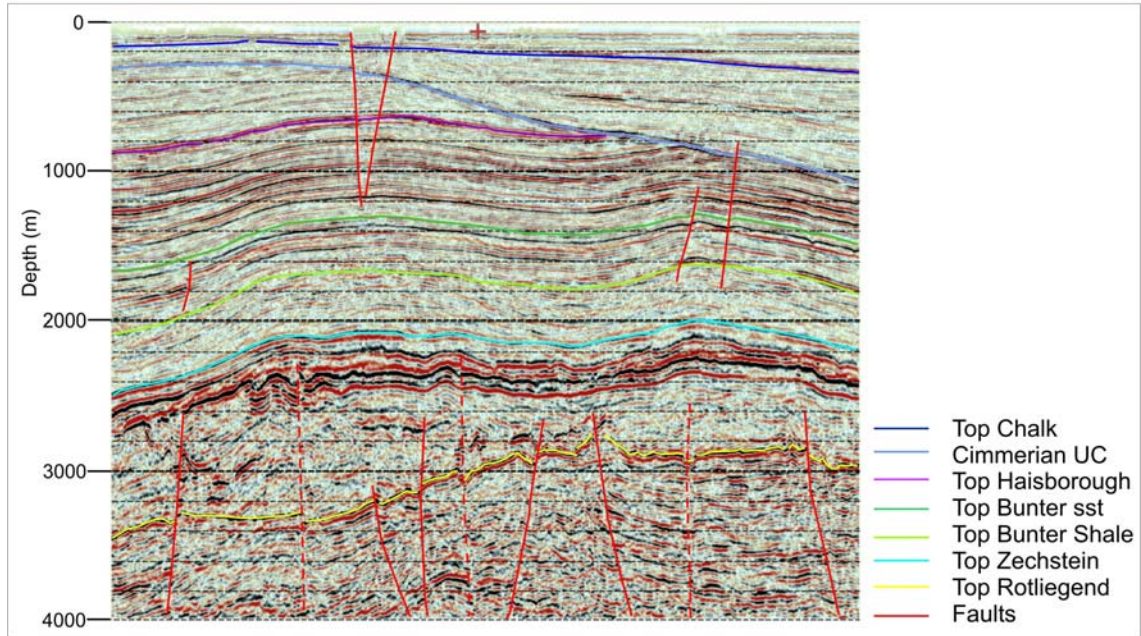
**Figure 12 Location of seismic lines and wells over closure 4/49**



**Figure 13** Depth map of top Bunter Sandstone Formation, closure 4/49



**Figure 14** Thickness map of the Bunter Sandstone formation, closure 4/49



**Figure 15 Seismic section through closure 4/49. Data courtesy of ConocoPhillips**

## **6 Tyndall Centre scenarios**

Each of the scenarios used a different rationale for choosing storage sites, e.g. to use gas fields only or storage sites near to the Bacton gas terminal. The rationale is explained at the beginning of each scenario. The CO<sub>2</sub> available for storage from the power plants for each scenario is detailed in Table 18, Appendix 1.

### **6.1 Fossilwise**

Total accumulated CO<sub>2</sub> available for storage in this scenario is 1936 MT.

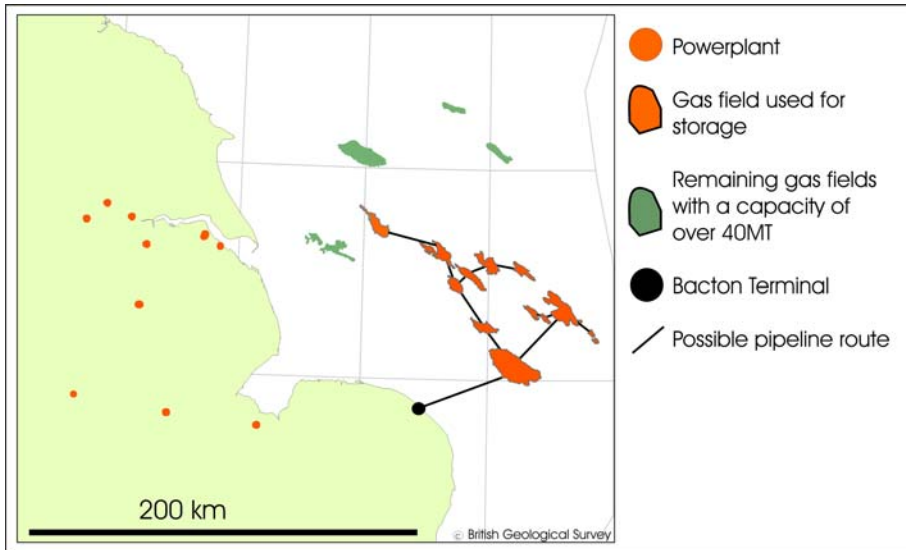
#### **Fossilwise I**

This scenario aims to use available storage space in gas fields. This is a ‘risk averse’ strategy due to the larger amount of available data and greater confidence in storage security of gas fields (they originally retained gas for millions of years and therefore they are likely to be able to retain CO<sub>2</sub>). The gas fields used (Figure 16) are marked in orange. A theoretical pipeline system from the Bacton terminal on the coast to serve all of the gas fields is also shown in Figure 16. Table 8 shows the storage capacities of each of the fields used and the total storage capacity available.

**Table 8 Fossilwise I scenario. Storage site and CO<sub>2</sub> stored.**

	<b>Field Name</b>	<b>CO<sub>2</sub> Storage Available MT</b>
1	Audrey	50
2	Barque	89
3	Clipper North	46
4	Galleon	129
5	Indefatigable	222
6	Leman	870
7	North & South Sean	44
8	Victor	74
9	Viking	215
10	Vulcan	53
11	West Sole	136

<b>TOTAL CO<sub>2</sub> Storage available</b>	<b>1928</b>
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**Figure 16 Map of the Fossilwise I scenario.**

### **Fossilwise II**

Total accumulated CO<sub>2</sub> available for storage in this scenario is 1936 MT.

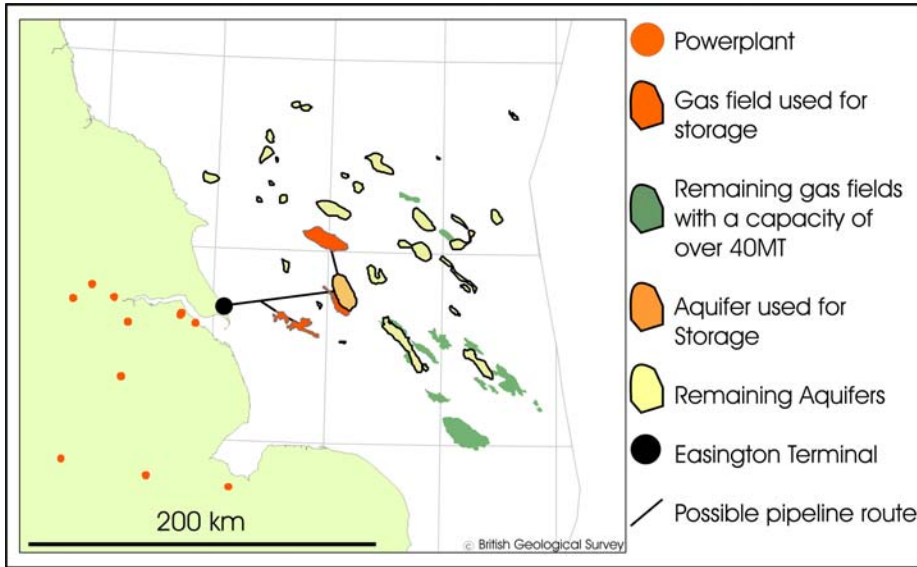
This scenario uses storage sites closest to existing onshore gas terminals and is called a ‘cost averse’ strategy as it uses all of the available sites near to each terminal. A different scenario has been examined for each of the three gas terminals (Easington, Theddlethorpe and Bacton), using one pipeline from the terminal to a cluster of storage sites which branches to reach each site in the cluster. The gas fields were preferentially filled up with CO<sub>2</sub> first before moving on to the nearest aquifer sites, creating a storage hub. The results of the scenarios for Easington are in Table 9 and Figure 17, for Theddlethorpe in Table 10 and Figure 18 and Bacton in Table 11 and Figure 19.

It should be noted that the aquifer reservoirs are not as well understood as the gas fields, and due to a lack of data the presence of faults within the aquifers cannot be ruled out. The aquifers would require geological characterisation before they could be used as storage sites with a high degree of certainty.

### **Easington**

**Table 9 Fossilwise II Easington scenario. Storage sites and CO<sub>2</sub> stored.**

	<b>Field Name</b>	<b>CO<sub>2</sub> Storage Available MT</b>
1	Amethyst west and east	45.97
2	Ravenspurn	69.55
3	West Sole	135.83
	<i>Sub total gas fields</i>	<i>251.35</i>
4	Aquifer 2/48	3169
	<b>Total storage available</b>	<b>3753.87</b>

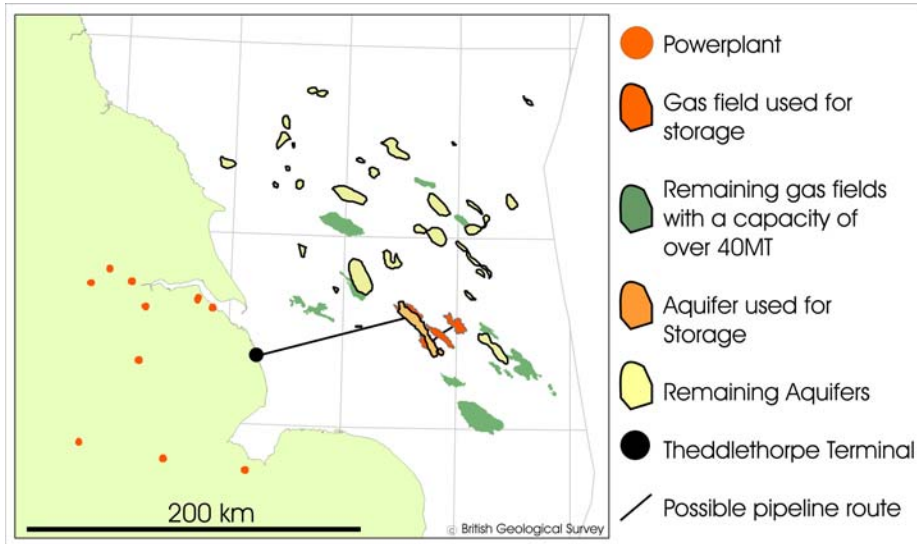


**Figure 17 Map of the Fossilwise II Easington scenario.**

**Theddlethorpe**

**Table 10 Fossilwise II Theddlethorpe scenario. Storage sites and CO<sub>2</sub> stored.**

	<b>Field Name</b>	<b>CO<sub>2</sub> Storage Available MT</b>
1	Audrey	49.49
2	Barque	88.69
3	Clipper North	46.10
4	Galleon	128.66
	<i>Sub total gas fields</i>	<i>312.94</i>
5	Aquifer 3/48	2302
	<b>Total storage available</b>	<b>2927.88</b>

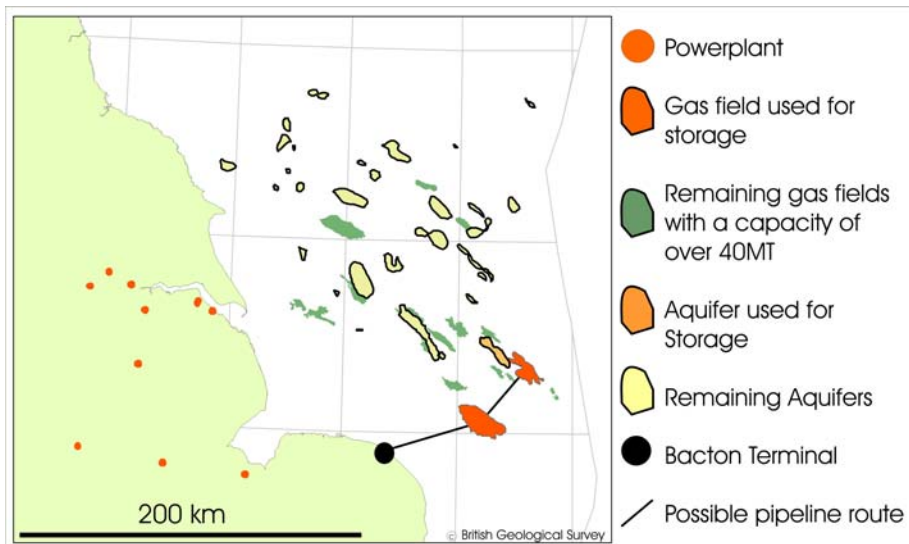


**Figure 18 Map of the Fossilwise II Theddlethorpe scenario.**

**Bacton**

**Table 11 Fossilwise II Bacton scenario. Storage sites and CO<sub>2</sub> stored.**

	<b>Field Name</b>	<b>CO<sub>2</sub> Storage Available MT</b>
1	Indefatigable	221.55
2	Leman	869.55
	<i>Sub total gas fields</i>	<i>1081.1</i>
3	Aquifer 4/49	1114
	<b>Total storage available</b>	<b>2313.2</b>



**Figure 19 Map of the Fossilwise II Bacton scenario.**

**6.2 Capture as a Bridge**

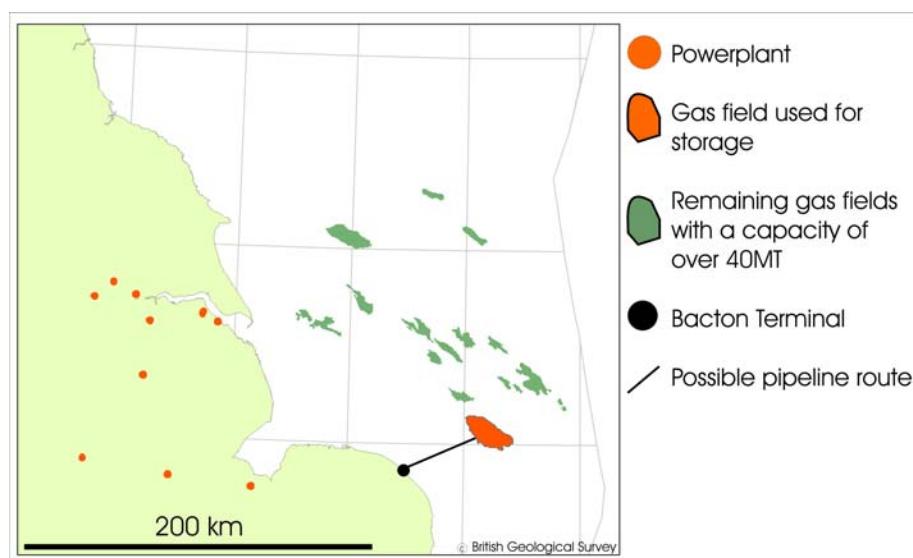
Total accumulated CO<sub>2</sub> available for storage is 212 MT in 2020 and 1279 MT in 2050.

Storage has been considered in gas fields only. This is because there is enough storage in the gas fields between now and the projected end of the scenario in 2050, when carbon capture and storage is phased out. The scenario was played out only from the Bacton terminal and aimed to use as few gas fields as possible, adding nearby gas fields onto the system when required. A snapshot of the scenario was taken in 2020 (Table 12 and Figure 20) and 2050 (Table 13 and Figure 21).

### Capture as a bridge 2020

**Table 12 Capture as a bridge 2020 scenario. Storage sites and CO<sub>2</sub> stored.**

	Field Name	CO <sub>2</sub> Storage Available MT
1	Leman	869.55
	<b>Total storage available</b>	<b>869.55</b>

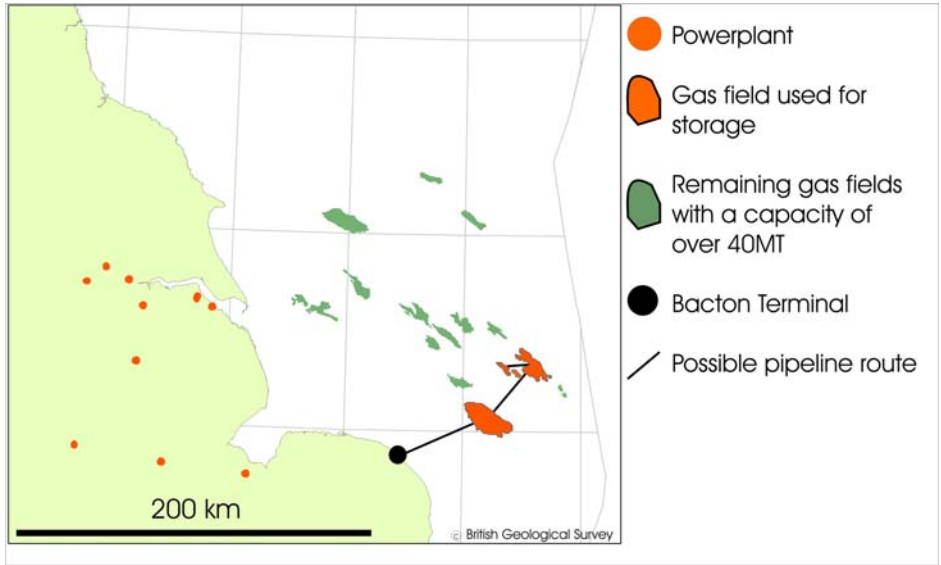


**Figure 20 Map of the Capture as a Bridge 2020 scenario,**

### Capture as a Bridge 2050

**Table 13 Capture as a bridge scenario. Storage sites and CO<sub>2</sub> stored.**

	Field Name	CO <sub>2</sub> Storage Available MT
1	Indefatigable	221.55
2	Leman	869.55
3	Victor	73.47
4	Galleon	128.66
	<b>Total storage available</b>	<b>1293.23</b>



**Figure 21 Map of the Capture as a Bridge 2050 scenario.**

**6.3 Spreading the Load**

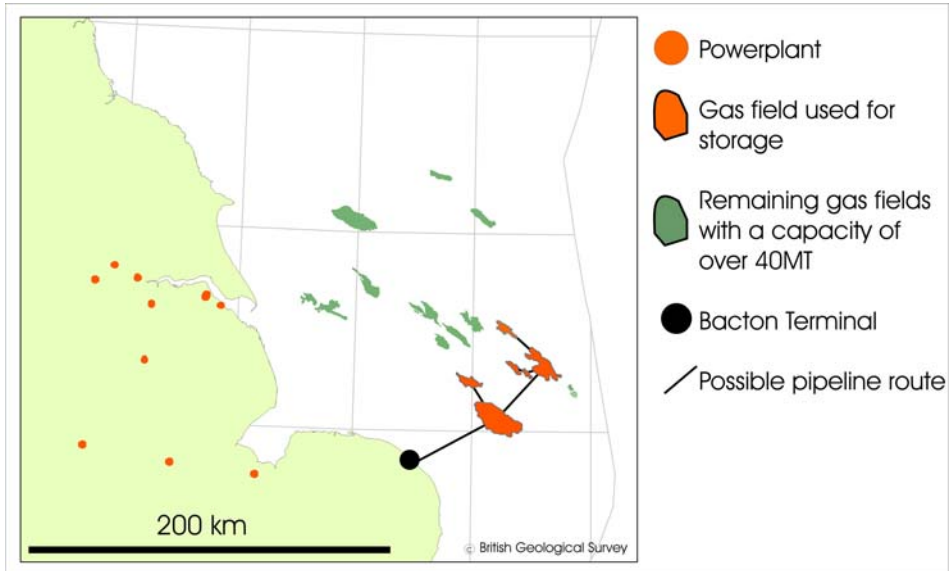
Total accumulated CO<sub>2</sub> available for storage is 1394 MT.

These scenarios use the same rationale as Fossilwise. Spreading the Load I is a ‘risk averse’ strategy using gas fields only and the results of creating a hub from Bacton are shown in Table 14 and Figure 22. Spreading the Load II is a ‘cost averse’ strategy, using gas fields and then choosing nearby aquifers. This was applied to each of the gas terminals. Results for Easington are shown in Table 15 and Figure 23, the results for Theddlethorpe are shown in Table 16 And Figure 24 and the results for Bacton are shown in Table 17 and Figure 25.

**Spreading the Load I**

**Table 14. Spreading the Load I, storage sites and CO<sub>2</sub> stored.**

	<b>Field Name</b>	<b>CO<sub>2</sub> Storage Available MT</b>
1	Indefatigable	221.55
2	Leman	869.55
3	Sean	44.32
4	Victor	73.47
5	Viking	214.49
6	Vulcan	53.15
	<b>Total storage available</b>	<b>1476.53</b>

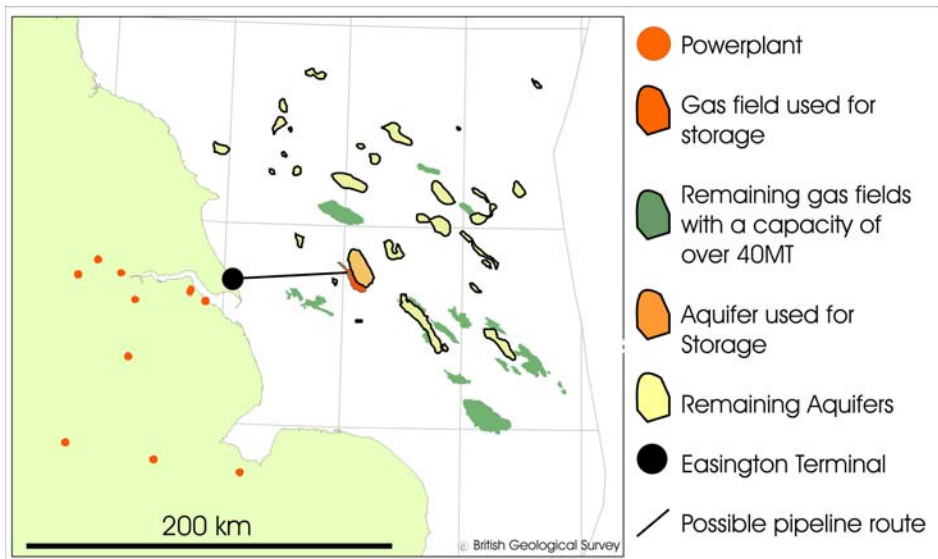


**Figure 22 Map of the Spreading the Load I scenario.**

**Spreading the Load II, Easington**

**Table 15 Spreading the Load II Easington scenario. Storage sites and CO<sub>2</sub> stored.**

	Field Name	CO <sub>2</sub> Storage Available MT
1	West Sole	135.83
2	Aquifer 2/48	3169
	<b>Total storage available</b>	<b>3304.83</b>

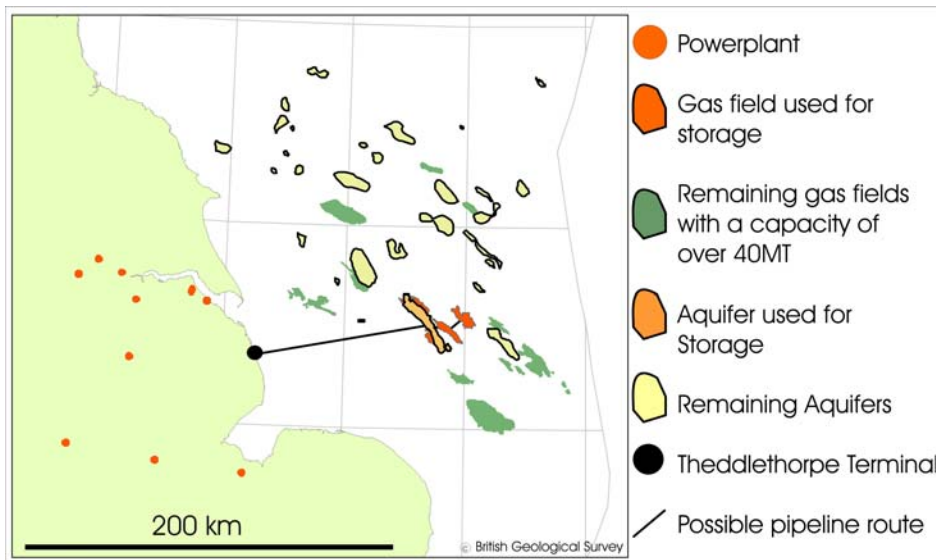


**Figure 23 Map of the Spreading the Load II Easington scenario.**

**Spreading the load II, Theddlethorpe**

**Table 16 Spreading the Load II, Theddlethorpe scenario. Storage sites and CO<sub>2</sub> stored.**

	Field Name	CO <sub>2</sub> Storage Available MT
1	Audrey	49.49
2	Barque	88.69
3	Clipper	46.10
4	Galleon	128.66
	<i>Sub total gas fields</i>	<i>312.94</i>
5	Aquifer 3/48	2302
	<b>Total storage available</b>	<b>2927.88</b>

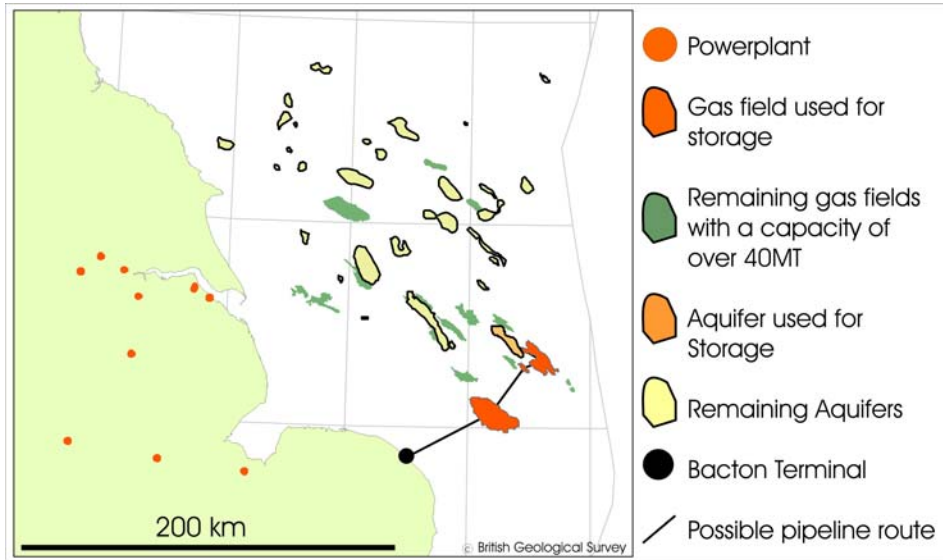


**Figure 24 Map of the Spreading the Load II Theddlethorpe scenario.**

**Spreading the Load II, Bacton**

**Table 17 Spreading the Load II Bacton scenario. Storage site and CO<sub>2</sub> stored.**

	Field Name	CO <sub>2</sub> Storage Available MT
1	Indefatigable	221.55
2	Leman	869.55
	<i>Sub total gas fields</i>	<i>1091.10</i>
3	Aquifer 4/49	1114
	<b>Total storage available</b>	<b>3296.1</b>



**Figure 25 Map of the Spreading the Load II Bacton scenario.**

## 7 Conclusions

There is a huge potential for CO<sub>2</sub> storage in the southern North Sea, in both depleted gas fields and the Bunter Sandstone Formation. However, any of the storage sites considered would have to undergo a rigorous geological site characterisation and risk assessment before use.

Although the scenarios are theoretical and designed to provoke stakeholder's view of the different CO<sub>2</sub> reduction options, they do give an overview of how a CO<sub>2</sub> capture and storage scheme might work. As there is greater geological uncertainty associated with the aquifer storage sites, a sensible strategy for those scenarios using a combination of gas fields and aquifers storage sites might be to test CO<sub>2</sub> injection into the aquifers (to find out whether or not they leak) whilst filling the gas fields.

## Acknowledgements

I would like to acknowledge WesternGeco and ConocoPhillips for the provision of seismic data used in this study and thank Dr. S Holloway and Karen Kirk for their help in putting together this report.

## Appendix 1

**Table 18 Million tonnes CO<sub>2</sub> available for storage by 2020 in the different scenarios**

	2020 Fossil Wise		Nuclear		Renew		Capture as a bridge		Spreading the load	
	MTC	MTCO <sub>2</sub>	MTC	MTCO <sub>2</sub>	MTC	MTCO <sub>2</sub>	MTC	MTCO <sub>2</sub>	MTC	MTCO <sub>2</sub>
Cottam	2.30	8.43	0.00	0.00	0.00	0.00	1.10	4.03	2.30	8.43
Drax	5.60	20.52	0.00	0.00	0.00	0.00	3.60	13.19	2.90	10.63
Eggborough	1.00	3.66	0.00	0.00	0.00	0.00	1.40	5.13	1.10	4.03
FerrybridgeC	1.80	6.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ratcliffe on Soar	2.30	8.43	0.00	0.00	0.00	0.00	1.90	6.96	2.30	8.43
West Burton	2.20	8.06	0.00	0.00	0.00	0.00	1.80	6.60	2.20	8.06
Brigg	0.20	0.73	0.00	0.00	0.00	0.00	0.20	0.73	0.00	0.00
Cottam	0.40	1.47	0.00	0.00	0.00	0.00	0.40	1.47	0.40	1.47

Corby	0.40	1.47	0.00	0.00	0.00	0.00	0.80	2.93	0.40	1.47
Keadby	0.70	2.56	0.00	0.00	0.00	0.00	0.70	2.56	0.70	2.56
Killingholme NP1	0.60	2.20	0.00	0.00	0.00	0.00	0.60	2.20	0.60	2.20
South Humber Bank 1	0.80	2.93	0.00	0.00	0.00	0.00	1.00	3.66	0.80	2.93
South Humber Bank 2	0.50	1.83	0.00	0.00	0.00	0.00	0.80	2.93	0.50	1.83
Sutton Bridge	0.80	2.93	0.00	0.00	0.00	0.00	1.00	3.66	0.80	2.93
Saltend	1.20	4.40	0.00	0.00	0.00	0.00	1.20	4.40	1.20	4.40
<b>Total</b>	<b>20.80</b>	<b>76.21</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>16.70</b>	<b>61.19</b>	<b>16.20</b>	<b>59.36</b>
<b>Total Coal</b>	<b>15.30</b>	<b>56.06</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>8.80</b>	<b>32.24</b>	<b>10.90</b>	<b>39.94</b>
<b>Total Gas</b>	<b>4.30</b>	<b>15.76</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>7.90</b>	<b>28.95</b>	<b>5.30</b>	<b>19.42</b>

**Table 19 Million tonnes CO<sub>2</sub> available for storage in 2050 in the different scenarios**

	2050 Fossil Wise		Nuclear		Renew		Capture as a bridge		Spreading the load	
	MTC	MTCO <sub>2</sub>	MTC	MTCO <sub>2</sub>	MTC	MTCO <sub>2</sub>	MTC	MTCO <sub>2</sub>	MTC	MTCO <sub>2</sub>
Cottam	1.90	6.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Drax	3.80	13.92	0.00	0.00	0.00	0.00	1.90	6.96	3.70	13.56
Eggborough	1.90	6.96	0.00	0.00	0.00	0.00	0.00	0.00	2.00	7.33
FerrybridgeC	1.90	6.96	0.00	0.00	0.00	0.00	0.00	0.00	2.10	7.69
Ratcliffe on Soar	1.90	6.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
West Burton	1.80	6.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Knottingley	1.20	4.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brigg	0.00	0.00	0.00	0.00	0.00	0.00	0.30	1.10	0.00	0.00
Cottam Dev	0.00	0.00	0.00	0.00	0.00	0.00	0.90	3.30	0.00	0.00
Corby	0.00	0.00	0.00	0.00	0.00	0.00	0.50	1.83	0.00	0.00
Keadby	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.73
Killingholme NP1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.73
South Humber Bank 1	0.30	1.10	0.00	0.00	0.00	0.00	0.50	1.83	0.20	0.73
South Humber Bank1	0.20	0.73	0.00	0.00	0.00	0.00	0.30	1.10	0.30	1.10
Sutton Bridge	0.00	0.00					0.00	0.00	0.30	1.10
Saltend	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	1.47
<b>Total</b>	<b>15.00</b>	<b>54.96</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>5.10</b>	<b>18.69</b>	<b>9.30</b>	<b>34.08</b>
<b>Total Coal</b>	<b>14.50</b>	<b>53.13</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>1.90</b>	<b>6.96</b>	<b>7.70</b>	<b>28.21</b>
<b>Total Gas</b>	<b>0.50</b>	<b>1.83</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>3.13</b>	<b>11.47</b>	<b>1.10</b>	<b>4.03</b>

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