Potential for Geological Storage and EOR from CO_2 Injection into UKCS Oilfields

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Abstract

The injection of CO_2 is an established and successful technique for recovering additional oil from onshore North American oil fields. It is not as yet an established technique offshore in the North Sea, though there is clear technical potential for both incremental oil and CO_2 sequestration. Although there are some detailed subsurface issues to be resolved, the main initial challenges with respect to its North Sea application are likely to be logistical and economic. CO_2 injection into offshore UKCS fields would not currently be economic without some value placed on CO_2 sequestration. The aim here is to report estimates of the technical potential for CO_2 injection into UKCS fields from screening studies in terms of both incremental oil recovery and CO_2 sequestration. We shall also note some of the main risks involved.

To understand the potential, it is necessary to distinguish between the two principal injection techniques, WAG (Water Alternating Gas) and GSGI (Gravity Stabilising Gas Injection). Applied to offshore UKCS, these techniques have different characteristics of project size and number, duration, robustness, exposure, economics and potential for IOR and CO_2 sequestration, which we shall compare.

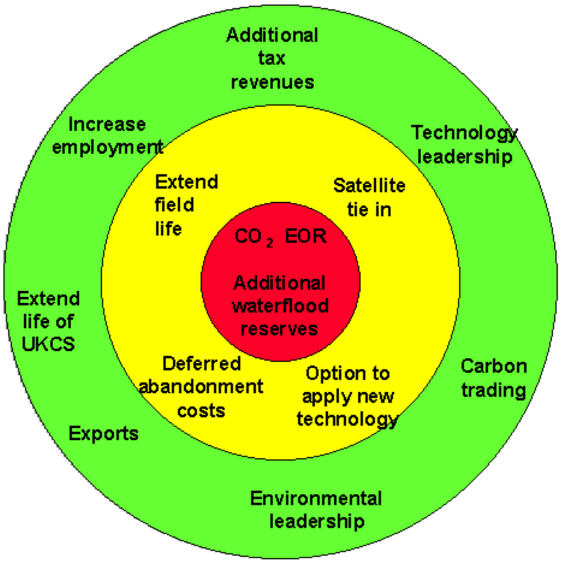
There are over 60 potential WAG projects on the UKCS, but relatively few GSGI opportunities. However, the total potential incremental oil and sequestration volume is about a factor of three greater for potential GSGI projects because individual GSGI projects are potentially much larger. On the other hand, WAG projects are likely to be shorter and provide earlier incremental oil.

The potential for both IOR and sequestration from UKCS CO_2 injection is substantial. The total CO_2 that might be sequestered through injection into UKCS fields has been estimated to be of the same order as the current total emissions in the UK in a single year. Similarly, the potential for incremental oil is of the same order as the current total UKCS oil production in a single year. The window of opportunity for UKCS CO_2 injection is currently expected to decline steeply after about 2010, and again after 2016. It would be a major challenge to develop the infrastructure hub and co-ordinate the developments that would be required to realise this potential.

Background

The drive to meet the Kyoto Agreement targets for CO_2 emissions is prompting investigation of various alternatives for CO_2 sequestration. Injection into oil fields is of particular interest since it also offers the additional benefit of production of valuable incremental oil. However, unless substantial account is taken of the environmental value of CO_2 sequestration, CO_2 injection offshore into UKCS oil fields is not currently economic [1], so there are therefore no current such projects.

It is therefore of interest to consider the associated benefits of offshore CO_2 injection shown in **Figure 1 (Associated Benefits of CO_2 Injection into Oil Reservoirs)**.



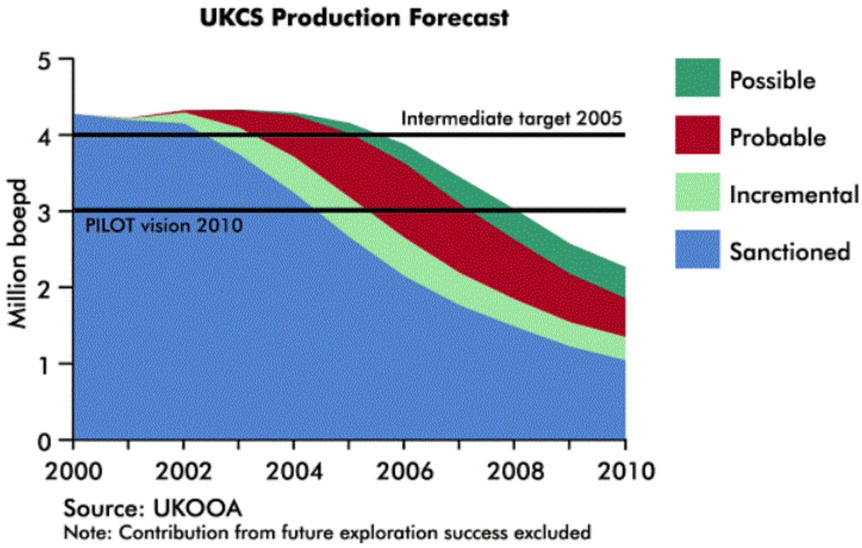
These include prolonging the producing lives of fields which may enable additional reserves to be recovered from other reservoirs using the same infrastructure. New satellite fields may also be developed through the same infrastructure which would not have been otherwise. Past experience also shows that extending the lifetime of fields also provides a window of opportunity during which developing technologies may be applied to further increase recovery. More general benefits include those to the wider economy, including additional tax revenues and increased employment. Large scale projects injecting CO_2 offshore in the North Sea would also give an opportunity for both technology and environmental leadership with a potential benefit to exports.

UKCS Gas Injection

Screening studies [2] have shown that many UKCS reservoirs are technically suitable for Improved Oil Recovery (IOR) through injection of gas. Typical expected ultimate oil recovery from the better UKCS reservoirs by the standard waterflooding technique is about 45% [3]. Gas injection might typically increase this by the order of 10 percentage points.

Although there are some UKCS reservoirs into which hydrocarbon gas is being injected, gas injection is far from being a widely applied technique. This is partly because hydrocarbon gas often has a significant sales value and the deferment of this value can substantially degrade the economics of such projects. Hydrocarbon injection is therefore more likely to be applied when there is no sales outlet for the gas. The high cost of providing CO_2 for offshore injection and necessary facilities upgrades to counter its corrosive properties have prevented it being adopted as an alternative in the North Sea to date.

However, the UKCS is now entering a period of decline in production as more mature waterflooded fields cease production, see **Figure 2 (UKCS Production Forecast)**.



Although there are a number of initiatives, mostly under the government/industry joint initiative PILOT, to mitigate this projected decline, CO_2 injection could also make a significant contribution.

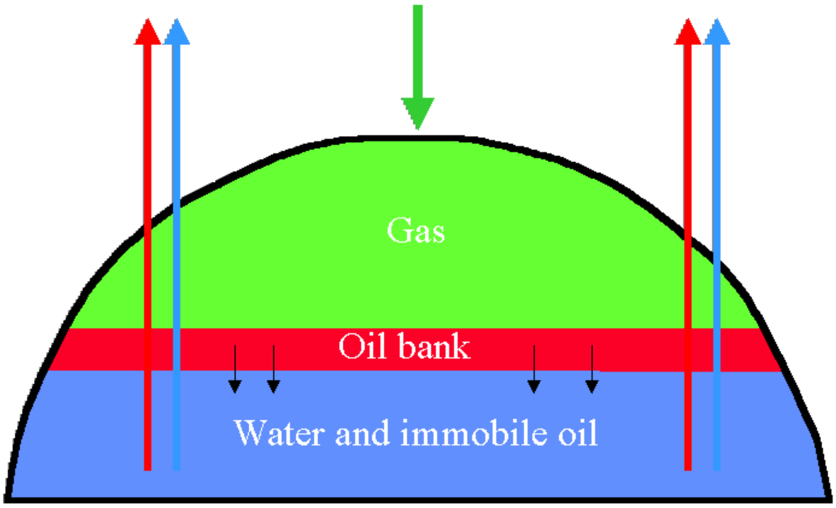
CO_2 Injection

CO_2 injection for IOR is an established technique in onshore North American fields. It has been widely practised in the Texas Permian Basin fields since the 1970s, where it is estimated to recover an additional 4 to 12% STOIIP (Stock Tank Oil Initially In Place) [4]. Although CO2 sequestration has not been the driver, retained gas volumes are typically in the range 10 to 25% HCPV (HydroCarbon Pore Volume). This is mainly through the WAG (Water Alternating Gas) technique, but the alternative GSGI technique gives much higher retention factors where applicable (see later).

CO_2 has some particular physical characteristics which affect its performance as an injectant. It tends to be more easily miscible with oil than hydrocarbon gas. This is important as miscibility enhances IOR by helping mobilise trapped oil. The critical point of CO_2 [1071 psi, 88^{o}F] is in the range of parts of some UKCS reservoirs cooled by waterflooding and shallower viscous reservoirs. A complex phase behaviour with up to five components can occur: aqueous, liquid hydrocarbon, liquid CO_2, gaseous CO_2 and solid asphaltene precipitate. Detailed modelling will therefore be necessary for each particular UKCS application.

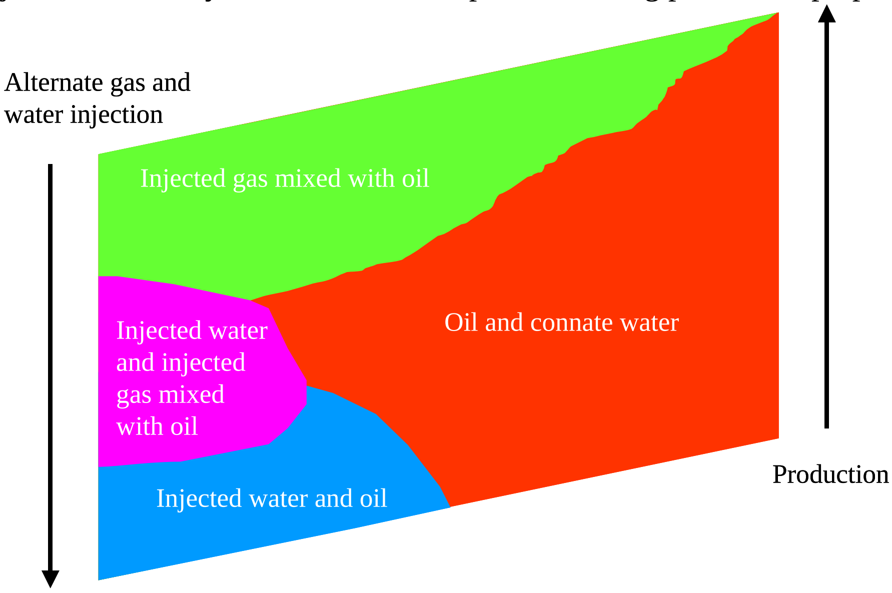
Gas Injection Techniques
There are two basic techniques, GSGI (Gravity Stabilising Gas Injection), applicable where gravity forces dominate and WAG (Water Alternating Gas), applicable where viscous forces dominate. It is important to distinguish between these two techniques which have quite different characteristics in terms of sequestrable gas, timescales and economics.

GSGI is illustrated in **Figure 3 (Schematic of GSGI Technique)** which shows gas being injected at the crest of an anticlinal reservoir and water and oil being produced from a downward moving oil bank.



This technique would be applied near the end of a reservoir's normal producing life. It is a natural technique for CO_2 sequestration in that the volume of gas that can be injected depends mainly on the hydrocarbon pore volume. This means, however, that in its classical application, large volumes of gas may have to be injected relatively slowly to fill up the reservoir, while maintaining a stable flood front before IOR can be obtained. Projects may therefore be relatively long, perhaps of the order of 10 years. Additional wells will also be required and recompletions will also be necessary as the flood front moves downwards. Although the technically achievable IOR from this technique may be large, these last two factors significantly reduce the economic value of the oil produced. However, if substantial credit is available from sequestrating CO_2, incremental oil might be deferred. This would allow CO_2 injection at a high rate and subsequent oil production only after some time, when the some equilibration has occurred and oil has had time to drain downwards under gravity.

WAG is illustrated in **Figure 4 (Schematic of WAG Technique)** which shows gas being injected alternately with water downdip and oil being produced updip.



Water is injected alternately with the gas in order to help stabilise the displacement. For this technique, applicable to viscous dominated reservoirs, the ideal is for the flood front to proceed along the reservoir layers and for the CO_2 to be miscible with the oil. Two main mechanisms may operate. Oil displaced primarily by gas rather than water may be more mobile, facilitating production. Gas may also sweep different pathways to water, for example, local highs, recovering oil uncontactable by water injection. These alternative mechanisms give the technique some robustness, particularly with respect to reservoir heterogeneities.

WAG can be applied a few years before the normal end of field life and does not necessarily require the drilling of additional wells. However, it has a lower gas sequestration potential as gas may travel through complex pathways, rather than uniformly, so a gas cap may not be formed. Gas may therefore arrive earlier at production wells and so a greater degree of gas re-cycling can occur. The volume of gas sequestrated therefore depends more on the reservoir heterogeneity and rock-fluid properties, and less on the hydrocarbon volume. On the other hand, incremental oil may be recovered relatively early compared to GSGI, since less of the reservoir needs to be contacted to produce it, so projects could be shorter, say 3 to 5 years. Lower implementation costs also tend to make this technique more economic for IOR than GSGI.

The applicability of these two techniques is summarised in the following table**.**
Table 1: A Comparison of WAG and GSGI techniques

WAG	**GSGI**
Short	Long
Early oil	Late Oil
Smaller	Larger
Robust	Only one IOR mechanism
CO_2 re-cycling inevitable	CO_2 re-cycling avoidable

UKCS/Permian Basin Comparison

The major technical difference in injecting gas in the North Sea to the Permian Basin is the logistical challenge of working offshore. Facilities need to be designed to meet space, weight and safety requirements and there is less scope for making changes. There is a particular challenge for CO_2 in that it is corrosive, and existing facilities are generally not designed for this.

There are also some important reservoir differences, for example the fact that most UKCS reservoirs are high permeability sandstones, but many Permian reservoirs are lower permeability carbonates. Higher UKCS permeabilities mean that gravity is relatively more important than viscous forces compared with the Permian Basin, which affects the type of gas injection technique which is applicable. UKCS reservoirs also typically have higher temperatures and pressures, although these have a compensating effect on the CO_2 density, which may be similar to that in Permian Basin fields. This would mean, other things being equal, that similar injected CO_2 volumes would be required for UKCS and Permian Basin fields. However, UKCS fields also have much lower well densities, with different well patterns, though production and injection rates tend to be higher.

Sequestration Potential

Most significant UKCS fields were screened for IOR potential including CO_2 injection for the DTI in the late 1980s and early 1990s. The results of this exercise were combined into a spreadsheet model in 2001. The most applicable technically viable technique was chosen for each reservoir, so there was no ‘double-counting’. This included estimates of IOR and CO_2 sequestration potential based on process and individual reservoir technical scores and STOIIP. The timing of potential projects was related to current expected COP (Cessation of Production) dates. As it was some time since the original screening exercise, a few of the results were updated to account for changes since that time, using judgement and experience, though this was minimised. In 2003 these results were also updated for changes in COP dates since 2001. As such this study is expected to be good enough to provide an overall estimate of UKCS potential, though it may not necessarily be accurate for specific fields.

One systematic way in which the results may be biased is that, since the original screening work, an understanding has developed that WAG may be more widely applicable than previously supposed. It is possible therefore that a detailed re-investigation of the original screening work might conclude that some of the GSGI candidates are more suitable for WAG. Work is therefore in progress to review this. However, relatively few reservoirs, 18, were found for which GSGI might be applicable from only 10 fields. In contrast, WAG was found to be applicable in almost 60 reservoirs. However, the bulk of the sequestration and IOR potential comes from the GSGI fields, as is shown by the following table, since the average GSGI field has more than ten times the IOR potential of the average WAG field.

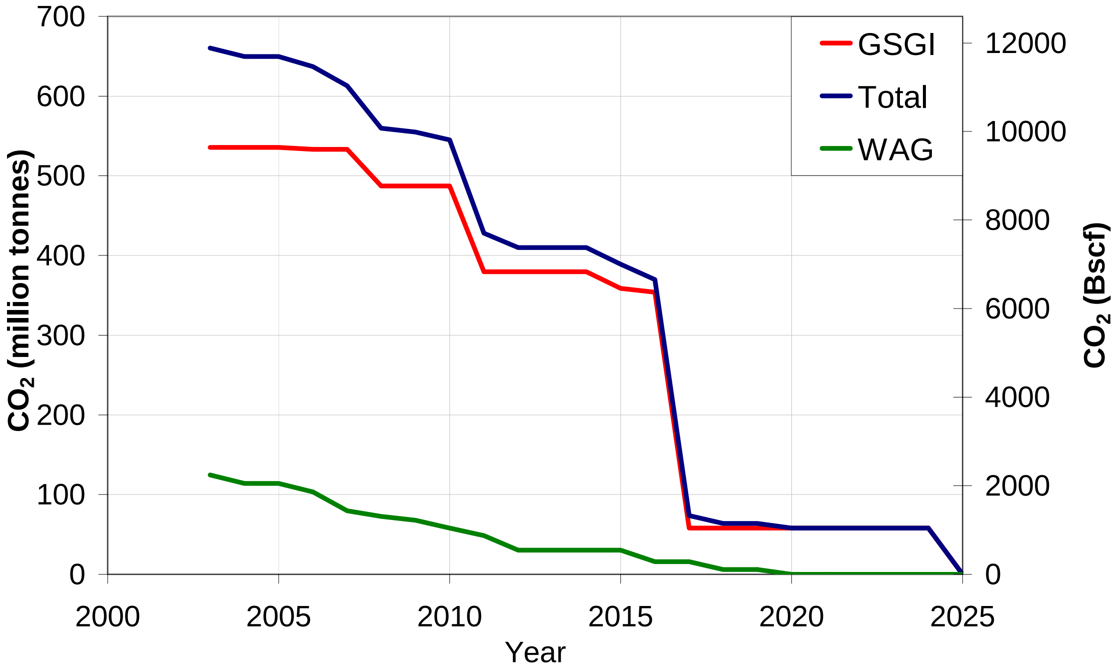
Table 2: CO_2 Gas Injection Potential

Injection Technique	CO_2 Sequestrated (million tonnes)	Incremental Oil Recovery (MMSTB)
GSGI	400-700	800-1400
WAG	50-250	300-750
Total	**450-950**	**1100-2150**

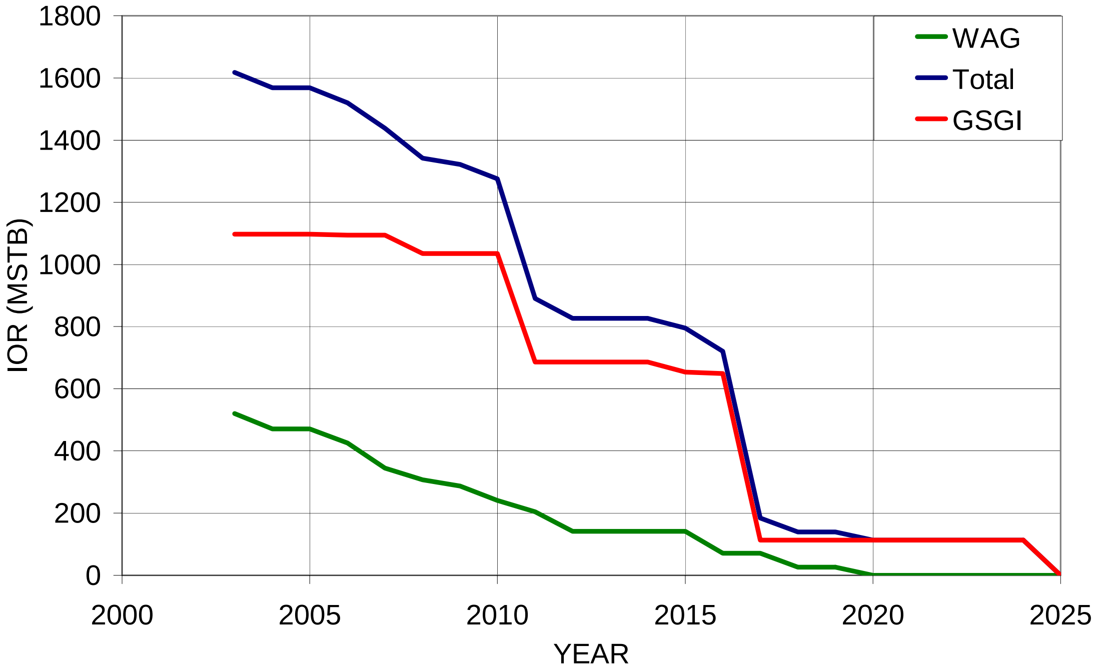
This is a significant sequestration potential of the same order as one years total UK CO_2 emissions [5]. Although this would have to be achieved over some years it promises a substantial contribution towards the targets specified in the Kyoto protocol. The potential IOR is also very substantial, for example, being in excess of the total UK oil production for 2001.

Window of Opportunity

This is illustrated in **Figures 5 (Window of Opportunity for CO_2 Sequestration)**



and 6 (Window of Opportunity for CO_2 IOR) which show the CO_2 sequestration and IOR potentials as they decrease with time as fields cease production.

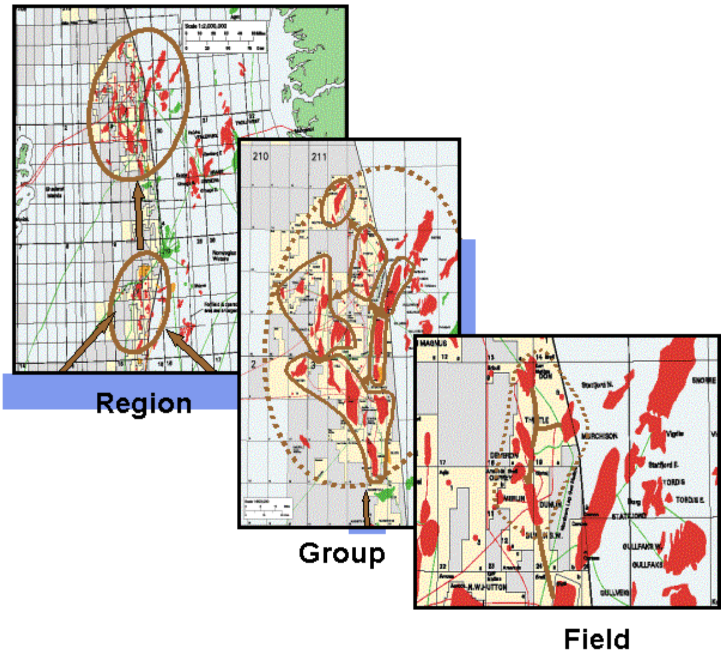


There is a sharp decrease in potential from about 2010, and another after about 2016. Although expected COP dates do tend to recede with time, in practice if the bulk of this potential were to be realised, major progress would have to be made well before 2010.

Implementation

This would require a co-ordinated effort from many different parties including field and pipeline operators and constructors, suppliers and government bodies. This is unlikely without a substantial environmental value being placed on the sequestration of CO_2. The balance between the drive for IOR and sequestration could be significantly affected by this value. Considering the different characteristics of WAG and GSGI fields, a strategy of injecting first into WAG reservoirs, recycling as needed and ultimately sequestrating the bulk of the CO_2 into the relatively few GSGI reservoirs would maximise IOR.

A regional strategy as illustrated in **Figure 7 (Regional Implementation Strategy)** would be needed to achieve this, but details of optimising this are complex, because of the many WAG fields with different expected COP dates.



On the other hand, if a high value is placed on sequestration, this would drive earlier injection into GSGI fields, and may shift attention towards dry gas fields.

Conclusions

1. CO_2 injection into oil reservoirs is an established technique for obtaining incremental oil recovery from onshore North American reservoirs.
2. There are two basic gas injection techniques applicable to UKCS fields, GSGI and WAG. WAG provides earlier incremental oil recovery, but less sequestration potential. It is likely to have better economics if the environmental value of CO_2 sequestration is excluded.
3. The majority of the UKCS potential lies in relatively few large GSGI fields. There are many UKCS fields suitable for WAG. The total UKCS sequestration potential is in the range of one half to a billion tonnes, the same order as recent total UK annual CO_2 emissions.
4. There is a limited window of opportunity to realise the UKCS CO_2 sequestration potential due to some fields expecting to cease production. A steep fall in potential after 2010 suggests that significant progress would need to be made well before this.
5. The major challenge in the implementation of CO_2 sequestration on the UKCS lies in the logistics of offshore application and the co-ordination needed amongst many different parties. UKCS sequestration will not occur without a substantial environmental value being placed on it.

Acknowledgements

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References

1. A CO_2 Infrastructure for the North Sea, Hugh Sharman, Neils Peter Christensen, Nicholas Riley and Erik Lindeberg, DTI IOR eNewsletter, Issue 4, January 2003, http://ior.rml.co.uk
2. The Potential to Increase UKCS Hydrocarbon Recovery using Advanced Recovery Techniques, R W S Foulser, SPE 25028
3. Improved Hydrocarbon Recovery in the United Kingdom Continental Shelf: Past, Present and Future, A J Jayasekera and S G Goodyear, SPE 75171, SPE/DOE 13th Symposium on Improved Oil Recovery, Tulsa, Oklahoma, April 2002.
4. Subsurface Issues for CO_2 Flooding of UKCS Reservoirs, S G Goodyear, I R Hawkyard, J H K Masters, C L Woods and A J Jayasekera, Trans IChemE, Vol 81, Part A, January 2003.
5. Greenhouse gas emission data on http://ghg.unfccc.int