CO_2 Storage Potential in the North Sea via Enhanced Oil Recovery

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Abstract
The potential and the associated costs for CO_2 storage in the oilfields of the North Sea via the implementation of enhanced oil recovery (EOR) projects are estimated in this paper. The assessment shows that the potential for CO_2 storage in the oilfields of the North Sea, when standard EOR practices that imply the minimisation of CO_2 injection are applied, is of the order of 5 Gt. This is, however, not significant when compared to the total greenhouse gas emissions of the EU (approximately 4.5 Gt annually). The incremental oil production, however, could be considerable, estimated at approximately 7 billion barrels (the EU25 annual production in 2003 was just over 1 million barrels). The attainable potential in both cases will however be limited by technology, the specific conditions for each reservoir, but most importantly by economics. A preliminary economic assessment of fifteen oilfields, which are nearly depleted, indicates that the CO_2 storage capacity in these fields could reach 60 Mt annually, with the simultaneous annual production of 180 million barrels of oil under favourable oil prices and CO_2 storage incentives.

Keywords: EOR, CO_2 storage, North Sea, Economics

Introduction

Enhanced oil recovery using carbon dioxide (called CO_2-EOR hereafter) is a method that can increase oil production by 4-18% beyond what is typically achievable using conventional recovery methods. In principle, CO_2 injected into the reservoir is either dissolved with oil, improving the fluidity of crude oil and hence facilitating its extraction (miscible CO_2-EOR), or the CO_2 remains as a distinct phase, raising the reservoir pressure, hence enhancing the reservoir drive (immiscible CO_2-EOR) [1]. During this process, a significant amount of injected CO_2 is retained underground. Hence, this process can simultaneously improve the security of oil supply, by increasing oil production, and contribute to combating climate change, by facilitating the storage of CO_2 in the oil reservoir, as indicated in the newly published Green Paper on a European Energy Strategy [2].

The technique has been commercialised, mainly in North America. Although there are no applications of CO_2-EOR in Europe at present, two projects have recently been announced involving oilfields Miller and Draugen [3,4]. Major barriers to implementation in Europe include the lack of availability of low cost CO_2 and the high cost of development of a CO_2 transport system to the oil fields, the majority of which are offshore. Under the oil-pricing regime of the near past the cost of CO_2-EOR has been prohibitive for such oil production operations in the North Sea. There are also technical difficulties, associated with offshore operations, but these do not seem to be major factors in the decision to implement CO_2-EOR.

However, the European energy scene is changing. The urgent need to curb CO_2 emissions in compliance with the Kyoto commitments and beyond makes CO_2 capture and storage technologies an option worth considering. Furthermore, the emissions trading scheme could provide financial incentives for this decarbonisation option. This is likely to lead to a situation where large quantities of CO_2, captured from large combustion plants would be stored permanently in suitable geological formations. At the same time, higher oil prices may now justify investment in oil recovery operations that were deemed uneconomic in the past.

The changes in the European energy market coincide with the end of life of many oilfields in the North Sea. Decisions need to be taken for a number of oil fields to be either completely abandoned and the infrastructure dismantled, or to be kept operating through investments on improved oil recovery methods.

The combination of these factors has recently stimulated an increasing interest in CO_2-EOR. This paper aims at identifying the CO_2 storage potential offered by the oilfields in the core region of the North Sea. This is the most important oil-producing region in Europe, producing approximately 4 million barrels of oil daily (Mbbl/d), or 73% of the crude oil produced in the European Economic Area (EEA).

Methodology

Eighty-one active oilfields from the UK, the Norwegian and the Danish sectors of the North Sea are considered in the analysis, selected based on their reserves (higher than 73 Mbbl each). In the first stage of this analysis the technically feasible potential for CO_2 storage and additional oil production using CO_2-EOR is estimated for each oilfield, disregarding the economic performance of each EOR project. The analysis is performed for two different scenarios of incremental oil recovery rates as shown in Table 1.

Table 1 Incremental oil recovery factors assumed in the study (percentage of original oil in place -OOIP-)

Oil Recovery	**High**	**Low**
Miscible (% OOIP)	9%	4%
Immiscible (%OOIP)	18%	9%

For fields classified as miscible, the CO_2 requirement is estimated at 0.33 t CO_2/bbl of incremental oil produced, representing the average value based on the US experience with such projects when standard practices are applied. Standard practices imply the minimisation of CO_2 usage and the maximisation of CO_2 recovery after injection in the reservoir, to improve the economics of the process, by reducing CO_2 purchases. In this context, any CO_2 produced along with the incremental oil is separated and recycled for re-injection.

For immiscible projects the amount of CO_2 to be delivered to the oilfield is that required to replace the volume of hydrocarbons produced by the end of secondary recovery (and therefore restore reservoir pressure). This also represents the maximum storage capacity available. The same method is also used to estimate the maximum amount of CO_2 that could be stored in miscible projects should financial incentives make it worth maximising the use of CO_2 rather than using the standard practice assumed above.

This assessment procedure produces the theoretical maximum potential estimates for additional oil production and CO_2 storage. The actual potential will be limited by technology, the specific conditions for each reservoir, but most importantly by economics.

Fifteen oilfields, which are more than 80% depleted, were selected for a preliminary economic evaluation as individual, stand-alone projects, under two scenarios for oil and carbon trading prices. The assumed values for oil and CO_2 prices are shown in Table 2. The project life was set to 20 years. A three-year period was assumed for construction and one year for decommissioning. One-year lag is assumed between the beginning of injection and the start of incremental oil production. Financing of the projects is considered to be 100% equity and the discount rate was set at 10%. It is further assumed that the mechanism for receiving financial credits from CO_2 storage has been agreed and such credits are viewed as income. All economic evaluations were performed taking into account initial investments and cash flows before tax, without considering inflation.

Table 2 Pricing scenarios for oil and CO_2 credits assumed for the study

Price Scenarios	**High**	**Low**
Oil price ($/bbl)	35	25
CO_2 credit (€/t)	25	15

The location of the CO_2 sources was selected amongst large (over 500 MW_e) existing coal-fired power stations located close to the coastline surrounding the North Sea. However, the assumption is that the CO_2 will come from new units equipped with CO_2 capture technology serving similar capacity rather than from retrofitted existing stations. The selection of plant technology and the cost of CO_2 capture are based on results from previous work by the authors [5]. The transportation of CO_2 is done through dedicated pipelines to each oil field with the pipeline route designed to follow the route of existing natural gas pipelines where possible. The pipeline specifics and capital costs are calculated according to the IEA Greenhouse Gas R&D Programme report on "Transmission of CO_2 and Energy"[6]. The resulting cost range is 1-3 €c/t·km. The main assumptions for capital and operating costs relevant to the modifications, necessary to convert the infrastructure to accommodate a CO_2-EOR project are given in Table 3.

Table 3 Main assumptions for the different costs, which are used as input for the economic assessment

Topside modifications	2	€/bbl of incremental oil	
Drilling of new wells	1.75	M€/km	an equal number of old and new wells is assumed per project
Reconfiguration of old wells	0.5	M€/well	
Operation & maintenance	7.5 10	€/bbl (oil production) €/tCO_2 (CO_2 injection after the end of EOR)	
Decommissioning	250-450	M€ (depending on platform size)	
CO_2 cost at power plant gate	25.2	€/t	

Results

The assessment of the 81 oilfields without economic constraints indicates that the maximum storage potential for CO_2 in the North Sea is between 4.5 and 5.5 Gt, when standard practices are applied. This is not very high compared to the total greenhouse gas emissions in the EU (approximately 4.5 Gt annually), but it will represent a sizable fraction of the emissions from power plants and other large CO_2 emitters in countries around the North Sea. More specifically, the storage capacity of the oilfields in the UK and Norwegian sectors is estimated to average between 1.8 and 3.1 Gt of CO_2 respectively, depending on the oil recovery rates that could be achieved, while the estimate for the Danish sector is 0.1 Gt. If, however, the storage of CO_2 had a commercial value, for example through emissions trading, CO_2-EOR operations could be designed to maximise injection and hence the storage of CO_2 underground [7,8]. In this case, the UK storage capacity could increase to approximately 3.5 Gt, that of Norway to 6.2 Gt, while an extra 0.45 Gt could be stored in the Danish sector.

The average UK potential for incremental oil recovery from these operations is estimated at 2.7 billion barrels (B bbl) (ranging between 1.8 and 3.7 B bbl depending on the achievable oil recovery factor), or 58% of the UK proven reserves in 2003. The average Norwegian and the Danish potentials are estimated at 4.0 B bbl (38% of proven reserves) and 0.4 B bbl (28% of reserves) respectively. These results represent the technically achievable maximum potential for the 81 fields considered without taking into account the economic viability of these projects.

The impact of economics was assessed on 15 oilfields coming close to depletion, considering capital and O&M expenditure and income from oil and CO_2, as well as the expected return for the investors. The economically achievable CO_2 storage potential is shown in Figure 1 and Figure 2 for the assumed discount rate of 10%, which is marked as a limit on the graphs. For the case of high incremental oil recovery and low prices, annual incremental oil production could reach 100 Mbbl, while approximately 20 Mt of CO_2 could be avoided annually for the 20-year project lifetime following standard practices, as shown in Figure 1. In a high price scenario, when all oil fields studied could be profitable for CO_2-EOR operations, the annual incremental oil production could reach 180 Mbbl and the yearly amount of CO_2 avoided 60 Mt. These figures are reduced, when a lower oil recovery factor is considered, to 57 Mt of CO_2 for a high price scenario and just 4 Mt CO_2 avoided for a low price scenario (Figure 2). Increased oil production would be 80 Mbbl and 20 Mbbl per year respectively.

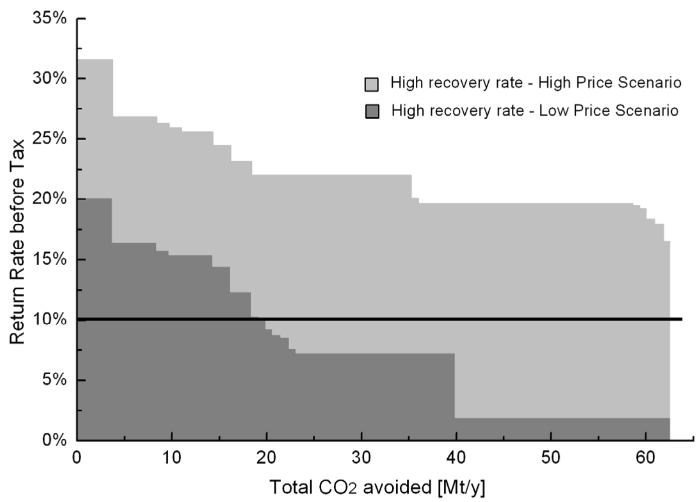


Figure 1: Cumulative CO_2 avoided by CO_2-EOR for the 15 fields coming close to depletion, depending on the acceptable project return rate for realisation. High incremental oil recovery.

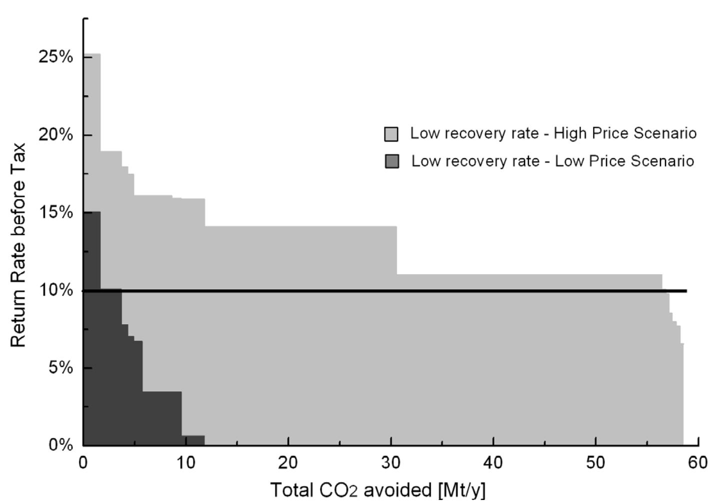
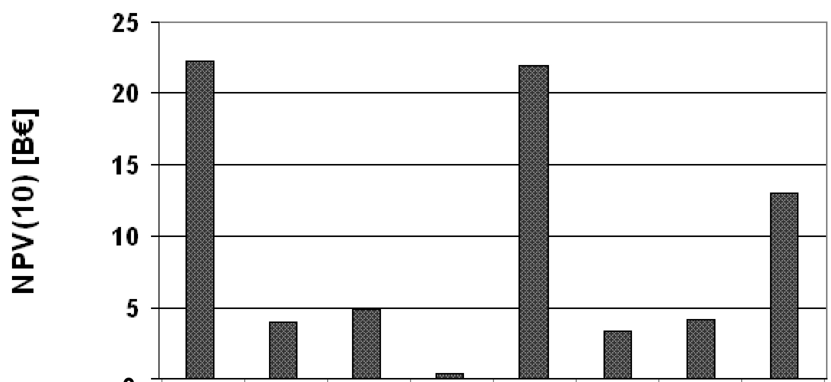


Figure 2: Cumulative CO_2 avoided by CO_2-EOR for the 15 fields, depending on the project return rate for realisation. Low incremental oil recovery.

It should be noted that the figures for CO_2 given for the 15 projects refer to CO_2 avoided, in contrast to CO_2 delivered to the field or retained underground at the end of the EOR operation. This means that the relevant additional emissions arising from CO_2 capture, transport, injection etc. [5,9] have been taken into account to calculate the actual benefit in terms of greenhouse gas emissions reduction. The CO_2 avoided amounts to 57-61% of the quantity captured for the different projects.

The cumulative net present value based on a 10% discount rate -NPV(10)-, of the viable projects within the 15-project portfolio, for the four study cases presented in Figure 1 and Figure 2, is given in Figure 3, cases 1 to 4. Cases 5 to 7 of the same graph show the effect of continuing CO_2 injection after the end of oil production by standard practices, so as to reach the maximum reservoir CO_2 storage potential before the field is decommissioned. Injection of CO_2 for purely storage purposes, at the same rate as during the EOR project, could continue for 11 miscible fields that will have only reached 26% of the total CO_2 storage capacity at the end of oil production, prolonging the project lifetime between 7 and 84 years depending on the field. This could avoid an additional 0.9 -1.2Gt of CO_2 from emission to the atmosphere. However, given the assumptions for the price scenarios considered, the operation of such a project is only extended at a financial loss. That is, the cost of purchasing CO_2 is higher than the credit received for storage. This leads to a decrease in the total NPV(10) of the projects by 1.5% (case 1 compared to 5), and 15% (cases 2 and 3 compared to 6 and 7 respectively) depending on the price scenario.

Case 8, in contrast, assumes that the aim is to reach the reservoirs' maximum CO_2 storage potential within the 20-year project lifetime and therefore increased volumes of CO_2 are injected from the start of the EOR operation. Under the current price assumptions this proves detrimental to project economics and the total NPV(10) is reduced by 40% (compared to case 1).



	1	2	3	4	5	6	7	8
CO_2 Injection	S	S	S	S	C	C	C	M
Recovery Rate	H	H	L	L	H	H	L	H
Price Scenario	H	L	H	L	H	L	H	H
# of Viable Fields	15	9	10	2	15	9	9	13

Figure 3: Net Present Value (in billion euros) of the profitable fields within the 15-project portfolio based on a 10% discount rate for different oil recovery rates (H: high, L: low), oil and CO_2 price scenarios (H: high, L: low) and CO_2 injection rates (S: standard practices, C: continued after end of oil production to reservoir storage potential, M: injection of increased CO_2 volumes throughout the project, so as to reach the maximum storage potential at the end of oil production).

It should be noted that the assumptions made in this study are very different from those used in feasibility studies performed by oil companies. With current oil prices around \$65/bbl, a number of CO_2-EOR projects in the North Sea could be profitable even without CO_2 credits. The small relative decrease of 1.5% in the NPV of the projects observed when continuing injection after the end of oil production for a high price scenario indicates that, depending on the level of the CO_2 this may be an option worth considering, provided that any legal barriers to this are overcome. However, it seems that attempting the injection of CO_2 in high rates from the start of a project is not an economically sound option under CO_2 credit prices similar to those experienced at present (case 8 compared to cases 1 and 5).

Conclusions

CO_2-EOR is a technological option that could help Europe to simultaneously reduce the emissions of CO_2 by providing for suitable underground storage sites, benefiting especially the countries surrounding the North Sea, and improve the security of energy supply by enhancing and prolonging indigenous oil production. Equally important, CO_2-EOR can encourage the development of advanced power generation technologies and the demonstration and deployment of cleaner and more efficient fossil fuelled power plants that capture CO_2, by providing for its storage and creating an additional income from oil production. The preliminary assessment indicates that under today's oil prices and a carbon trading scheme CO_2-EOR operations in the North Sea could be viable. The amount of CO_2 stored in the short term in nearly depleted oil fields could be as high as 60 million tonnes annually.

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