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THE NORWEGIAN CO2–INFRASTRUCTURE INITIATIVE: A FEASIBILITY STUDY

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ABSTRACT

The Norwegian debate regarding carbon dioxide (CO2)* has focussed considerable attention towards implementation of capture technologies for low-emission gas-fired power plants (Hustad, 2000). Such work has confirmed that capture is technologically feasible, but will currently reduce plant efficiency by between 8 to 10 percentage points and add from +10 to +18 mills/kWh to the cost of producing electricity. About one-third of <u>total</u> avoidance cost is due to final transportation and injection underground—this can be attributed to what is essentially the need for a CO2-infrastructure.

Figure 1: The North Sea Basin Region.

The present study proposes to evaluate if CO2-sequestration may be economically handled through developing and optimising such an infrastructure connected to saline aquifers and oil reservoirs for 'enhanced oil recovery' (EOR). It is well established that the CO2-storage capacity of the North Sea basin is equivalent to several hundred years of current European power plant emissions. Notably, a large portion of this capacity lies within the Norwegian sector.

If feasible, then how extensive should this network be? And what may be the potential socio-economic benefits such as new jobs, regional investment, technology development, etc. Is it eventually possible to commercialise the handling of European CO2-emissions?

Such solutions also need to be considered within the context of evolving GHG-trading mechanisms, and possibly revised legal frameworks renewing existing petroleum and maritime law. Furthermore there may be implications concerning the handling, geological storage, health and safety with respect to CO2. The purpose of the proposed study is to identify all these aspects, and to develop an economic model for optimising the eventual cost of CO2-sequestration. We believe this modelling will contribute to more accurately predicting the real cost of CO2-avoidance measures in the future, and provide a comparison with other available options for GHG-reductions.

INTRODUCTION

Recent greenhouse gas (GHG) studies have focussed on evaluation of technologies for low-emission power plants and the possibility for decarbonisation of existing fossil fuel reserves. Furthermore, one has confirmed a potential for commercial application of carbon dioxide (CO2) in conjunction with enhanced oil recovery (EOR). It is however important to also consider such

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* Readers some times comment on the use of CO2 as opposed to CO_2—both would appear to be valid. Simply stated the former is an acronym, which should be defined when it is first encountered in a piece of text, while the latter is a well-known chemical abbreviation. The reason why some authors prefer the first alternative is because it is readily transferable between available fonts in different document and text formats.

technological initiatives within the context of GHG-emissions trading which will probably become an integral part of the evolving 'Kyoto-like' mechanisms for reducing overall emissions.

There are several competing technologies for CO2-capture (Herzog *et al.*, 1997). Although these differ, they all result in relatively pure CO2, which subsequently needs to be disposed of in a permanent manner. Recent studies by Undrum *et al*. (2000) have shown that around one-third of the sequestration cost is due to transportation and final injection underground.

All these studies infer that current best available CO2-capture technology will reduce the overall plant efficiency by between 8 to 10 percentage points, and the cost for sequestration varies from US$ 35 to 55 per tonne of CO2 removed. This is typically between +10 to +18 mills/kWh on cost of electricity (COE) produced. The goal of technology development should be to reduce avoidance costs to a more economically acceptable level (thought to be between US$ 15 to 25 per tonne of CO2-avoided), and minimise the increase in COE to less than +5 mills/kWh.

CO2–Cleaning versus Trading

Articles 6, 12 and 17 of the Kyoto Protocol opens for the use of *flexible trading mechanisms* to supplement the use of CO2-cleaning technology at home. These mechanisms are Joint Implementation (JI), Clean Development Mechanisms (CDM), and the establishment of international GHG-emissions trading (IET). Considerable work has been conducted showing how these can in the short-term provide a cost-effective route for compliance with the Kyoto Protocol (Holtsmark, 1998). It is important to note that we believe these mechanisms should, as far as practicable, encompass all of the GHG's in order to be as flexible as possible.

The trading mechanisms will ensure that a market develops to determine a price on CO2-equivalent emissions. A country not able to meet its GHG-commitment will thus have the opportunity to buy emission quotas in the market and/or invest in technology. Alternatively by reducing its own emissions, a country may become a net seller of CO2-emission certificates. The trading costs for reducing CO2-emissions will therefore be of major importance in determining the market price, and a key driver for technology development.

Best estimates suggest that the initial CO2-trading price will lie in the region between US$ 5 to 15 per tonne of CO2—this being lower than the CO2-avoidance cost. However with time the trading alternative will become more expensive so that implementation of sequestration technology will become commercially attractive. It is not possible to state when capture will become competitive with the trading option, be it in year 2008, 2012 or even 2016. Indeed the answer may depend upon our short-term response and the way in which we formulate legislation to coerce industry and consumers to move in the right direction. Notable by year 2005 the signatories of the Protocol are supposed to have documented conclusive actions towards reducing their GHG-emissions.

Long-Term Solutions for CO2

A key element within the current GHG-debate is that we require solutions for the long-term. And our short-term decisions must be compatible with our long-term strategy (Herzog *et al.*, 2000). Ultimately, GHG-mitigation is much more complex than simply extrapolating comparisons of current cost estimates—essentially we are witnessing the evolution of a 'carbon constrained' economy. The implication of this has yet to significantly impose itself on the way we quantify the 'Total Net Value Added' of our commercial activities, but it is really just a question of time!

This attitude also appears to be reflected by a large portion of industry, which accepts that we are preparing for a paradigm change. In this context it is pertinent to note that non-ratification of the Kyoto Protocol is a possibility, but will probably result in regional restrictions until a revised post-Kyoto (that is for the period after year 2012) consensus is attained. However the final solution—namely a global reduction and eventual stabilisation of GHG-emissions—will only occur with the "meaningful participation" of the developing countries, and when we implement the technology and infrastructure that will permit us to use energy in a sustainable manner.

Essentially there is currently felt to be three viable paths towards such long-term solutions:

i) Use available fuels more efficiently.
ii) Further promote the transfer to renewable energy sources.
iii) Remove and store the carbon from existing fossil fuel based emissions.

The answer regarding which is the best option, is probably all three. This simply acknowledges that different countries and regions will have different means of achieving reduced GHG-emissions, whilst maintaining satisfactory economic growth, and continued raising of living standards—this being particularly important for the non-developed countries.

However for a majority of countries, it is the third option (continued use of existing fossil fuels) which will be the most viable path, and remains compatible with existing energy systems as well as future primary energy resources (Bilger, 1999). This is particularly true for Norway with its plentiful supply of oil and natural gas. At the same time the North Sea basin has long-term storage capabilities equivalent to several hundred years of European CO2-emissions (Holloway, 1997), and is in relatively close proximity to some of the major industrial regions in northern Europe.

AN INTEGRATED SYSTEM FOR CO2-SEQUESTRATION

The idea of an infrastructure is similar to what has already been developed during the past two centuries regarding the supply of water, treatment of sewage, electricity distribution, and communication (such as canals, railways, roads, telephony, information technology, etc.). These are now part of the economic foundations for our commercial activities, and considered a prerequisite for economic growth. Furthermore they are often examples of public expenditure, which has evolved in a 'non-optimal' manner, requiring considerable support from the taxpayer.

Inevitably, a 'co-ordinated' infrastructure development requires foresight, planning, and incentives regarding the role society would like our industrial activities to embrace. For this reason it is often the responsibility of governments to lead—either through legislation, tax incentives, or direct capital investments. Such considerations appear to be exemplified with the long-term challenges posed by climate-change and anthropogenic GHG-emissions, (see for example US-DOE, 1999).

For these reasons we propose to evaluate whether a long-term reduction in overall GHG-emissions may be achieved by developing a CO2-infrastructure in conjunction with large-scale storage possibilities within saline aquifers and oil fields in the North Sea basin. We will investigate the commercial use of CO2 for EOR, and consider overall social benefits in the form of new jobs, environmental considerations, regional investment and technology development. If feasible, then how should this infrastructure be developed? How is our existing legal framework geared to handle such an evolution? And can we apply these studies to other industrialised areas around the globe where similar storage capacities may exist in the vicinity of industrialised regions.

Use of CO2 for Enhanced Oil Recovery

Injection of CO2 in various forms has been applied by the oil industry for secondary and tertiary EOR since the early sixties (Ramsay and Small, 1964). By the late 1970's removal of CO2 from the flue gas of power plants was well documented (McRee, 1977), and several commercial CO2-capture plants have been constructed. However limited economic incentives due to relatively low oil prices has meant that it is the GHG issue that now primarily drives technology development. Nevertheless, there are currently around 70 oil fields using CO2-injection to recover additional crude oil, a majority of these being in the US and Canada.

In the North Sea, a conventional approach to EOR is use of water or hydrocarbon gas. However studies have also been undertaken regarding the use of nitrogen, inert flue-gas, and CO2 (Holt and Lindeberg, 1993).

The typical response with CO2 over a 20-year reservoir life is shown by the generalised curves in Fig.2 for gas induced EOR. Initial water injection peaks during the first four years of operations to produce an optimised oil recovery from around the sixth to twelfth year of operations. Eventually, larger volumes of breakthrough gas need to be handled and possibly re-injected. The purpose of an infrastructure is therefore to spread this procedure over several oil reservoirs, and additionally have the possibility of direct sequestration into nearby aquifers whenever this is most sensible with regards optimised EOR (Holt *et al.*, 1995).

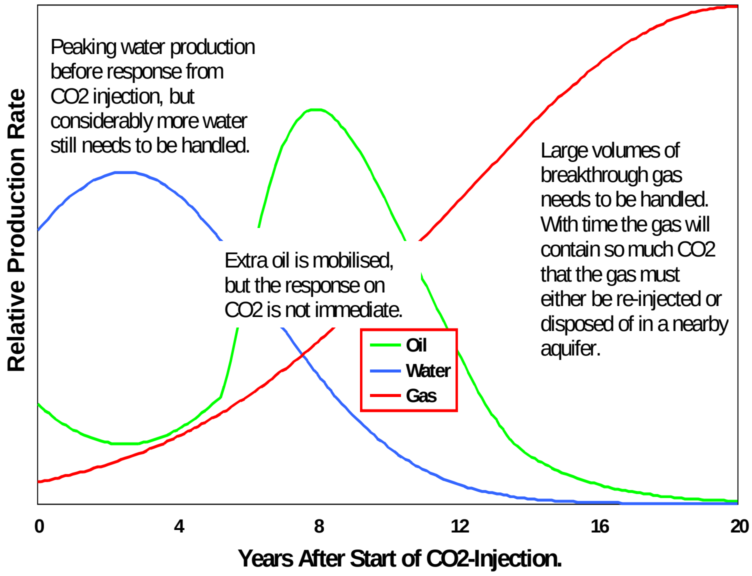

Figure 2: Sketch of generalised reservoir profiles.

Long-Term CO2 Storage in Saline Aquifers

Statoil have since 1996 been re-injecting over one million tonne of CO2 per year into the Utsira formation at Sleipner West in the North Sea. This is commercially feasible due to the imposition of a North Sea carbon tax which was recently reduced from US$ 50 to US$ 36 per tonne of CO2 emitted to the atmosphere. A high concentration of CO2 in the natural gas had to be removed before transportation by pipeline to the European market. This project uses an amine absorption process on a purpose built treatment platform as shown in Fig.3.

Figure 3: The Sleipner T (Treatment) and A Platforms.

The behaviour, modelling, and verification of the CO2 within the aquifer is now part of the on-going industry collaborative SACS (Saline Aquifer CO2-Storage) programme. The results to date have confirmed the feasibility of long-term storage.

The Role for an Economic and Socio-Economic Model

Another objective of the current feasibility study is to develop an economic simulation model which can predict the net sequestration costs for CO2 in an integrated system of industrial point sources, transportation network, oil reservoirs, and saline aquifer storage facilities. We believe that this model may become a valuable tool which will: a) provide predictions of CO2-sequestration cost with time; b) help optimise the extent of such an infrastructure; c) identify socio-economic benefits of CO2-handling and sequestration. We foresee possible end-users to be oil companies, government planners, legislators, and non-government organisations.

The proposed model will be based on an inventory of potential EOR activity and aquifer storage capabilities available in the North Sea region. These, in combination with the potential CO2-emissions from 'oil-related' installations and mainland industrial activity, will form the basis for calculating CO2-sequestration costs. Furthermore, we will include an economic assessment of infrastructure capital development cost, as well as CO2-cleaning, transportation, and injection costs, which together with reservoir characteristics and profiles of incremental oil and gas production, will yield a dynamic cost estimating tool for the capture and sequestration of CO2.

In addition to financial costing, we also propose to quantify the benefits of related activities and permanent storage, with respect to socio-economic and environmental impact. The study will therefore include other aspects: social benefits of industrial activity (in terms of employment, export of new technology, etc.); environmental improvement; regional development and industry clustering.

Trading and Finance Matters

Also relevant within the scope of the present study is assessment of alternative scenarios which take account of the other options available to industry and legislators (Knöpfel, 1999); this relates both to the potential use of the emerging CO2-trading mechanisms, and geographical relocation of industrial activity. An infrastructure will have the capability to generate CO2-emission certificates and thus opens the scope for a trading market; however it is still not resolved how verification of storage in combination with conversion to saleable credits fits with permanent sequestration and international agreements to limit GHG-emissions.

Despite this, financial analysts are already developing, albeit crude tools to predict the cost of sequestration in comparison with the alternative mechanisms such as JI, CDM, and IET. If the forecast return on investment is satisfactory, we may also have the possibility of attracting investment capital to finance the infrastructure development costs.

Legal and Environmental Considerations

Another issue regarding large-scale implementation of permanent CO2 storage focuses on the question of liability, as well as implications regarding licensing, use, and future 'after-use' of available blocks in the Norwegian sector of the North Sea. What happens if the CO2 starts leaking, either polluting a neighbouring oil field, or reappearing (Lindeberg, 1997; Chen *et al.*, 1999). Not only adjacent installations, but also neighbouring countries, and international operators with a vested strategic interest in the region may be affected. Here, the legal framework is very much in its infancy, and needs to be considered.

Health, Safety and Public Relations

Perhaps more dramatic are the consequences if one decides to use geological structures closer to shore, or even on land (Liu *et al.*, 1999). This could reduce costs but would also increase risk (Kruse and Tekiela, 1996). Within this context it is also important to maintain an open dialogue with the public, as already witnessed by other large-scale CO2-sequestration projects (Kildow and Harrington, 1999).

CONCLUSIONS

The current CO2-infrastructure proposal is for an initial evaluation regarding costs, and identifying the practicalities surrounding sub-sea storage of industrial CO2-emissions within the confines of the North Sea basin. If feasible, then this may be a realistic response to growing concern regarding global climate change; furthermore, the concept remains compatible with our existing energy infrastructure and extensive reserves of fossil fuel. The study will identify the scope for commercial handling of CO2—also possibly encompassing emissions from the whole of Northern Europe, as already envisaged by Lindeberg and Holloway (1999).

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