

## Early Opportunities for Application of Carbon Capture & Storage

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### 1. Abstract

This paper draws on many aspects of work by IEAGHG, including for example the identification of potential sources and sinks for CO<sub>2</sub>. The paper's focus is on technical potential and barriers to the adoption of CCS, but it also addresses: commercial and financial issues, legal and regulatory issues, public outreach, and international mechanisms. Various aspects of CCS technology are discussed and a proposal as to how a 'systems-approach' to matching of CO<sub>2</sub> sources and sinks could lead to the early development of CO<sub>2</sub> supply networks for use in Enhanced Oil Recovery.

### 2. Introduction

CO<sub>2</sub> capture combined with geological storage is one of the technologies IEA GHG has studied that has the potential to make deep reductions in CO<sub>2</sub> emissions to atmosphere. However, the technology faces a number of barriers to its widespread introduction. One of the key barriers is the cost of removing CO<sub>2</sub> from combustion exhaust gases; the cost of CO<sub>2</sub> capture is largely a result of the extensive processing required of exhaust-gas streams containing low concentrations of CO<sub>2</sub> (Say, 4-14% by volume). There are however, opportunities for isolating CO<sub>2</sub> that are considerably less expensive than treating flue gases. Amongst these are:

- Removal of CO<sub>2</sub> from raw natural gas (often necessary to meet pipeline specification)
- Hydrogen production, e.g. by gasification of petroleum coke
- Other industrial processes, e.g. cement manufacture

If such high-concentration sources of CO<sub>2</sub> can be identified and matched with low transport costs and with relatively low storage costs there are attractive opportunities for reducing CO<sub>2</sub> emissions to atmosphere at minimal cost.

If, in addition, use can be made of existing infrastructure such as pipelines, and the CO<sub>2</sub> used for Enhanced Oil Recovery (CO<sub>2</sub>-EOR) the reduction in CO<sub>2</sub> emissions to atmosphere might even be achieved at negative cost – i.e. be a profitable activity.

A key barrier to the early implementation of such Carbon dioxide Capture and Storage (CCS) schemes is the lack of a stable support system that would encourage companies to invest for the long-term in CCS. Uncertainties with regard to CO<sub>2</sub> emissions reduction mechanisms add to the difficulties arising from volatility in the cost of and demand for fossil fuels. For example, the Kyoto protocol and Marrakech accords do not clearly specify steps for international trading of Kyoto protocol emission units based on CCS projects. Agreed adoption of CCS as a mitigation option under emissions trading schemes such as the Clean Development Mechanism (CDM) could provide significant incentives.

This paper describes some of the issues involved and opportunities that are now arising.

## 2. Existing CCS projects

At present there are 3 CCS projects that can be said to be operating 'commercially' at a significant scale. These schemes each capture and store approximately 1 million tonnes/year of CO<sub>2</sub>. This total, of about 3 million tonnes/year of CO<sub>2</sub>, is roughly equivalent to the CO<sub>2</sub> emissions from one modern coal-fired power plant of 500MW capacity.

### *Sleipner (started 1996)*

Statoil operates the Sleipner field on behalf of a group of partners. Before the raw gas can be sold its CO<sub>2</sub> content has to be reduced from about 9% to around 2.5%. The CO<sub>2</sub> is captured using an amine solvent. The captured CO<sub>2</sub>, about 1 million t/yr, is injected beneath the seabed into the Utsira sandstone formation rather than being released to air. The Utsira formation lies at a depth of 800-1000 metres and has been estimated to be capable of storing up to 600 billion tonnes of CO<sub>2</sub>. If the CO<sub>2</sub> had been allowed to escape to atmosphere the licensees would have been liable for approximately NOK 1 million/day (160,000 US\$/day) in CO<sub>2</sub> taxes. This was the first large-scale project to demonstrate that CO<sub>2</sub> can be successfully stored and monitored.

### *Weyburn EOR (started 2000)*

EnCana are injecting CO<sub>2</sub> into the existing Williston Basin oil field, Canada, in order to boost oil production. This Weyburn project is expected to produce at least 122 million barrels of incremental oil through miscible/near-miscible displacement with CO<sub>2</sub>. Ultimate oil recovery will increase to approximately 34%. The CO<sub>2</sub> is produced in North Dakota in the USA in a lignite gasification plant. Sales of CO<sub>2</sub> add about 30 million US\$/year to the plant's income. Cross-border transfer of CO<sub>2</sub> from the USA to Canada is by 330km long pipeline that cost US\$100 million. There is no financial incentive to store CO<sub>2</sub> but about half the CO<sub>2</sub> injected for EOR purposes remains in the ground. It is estimated that about 20 million tonnes of CO<sub>2</sub> will be stored over the 20-25 year life of the project.

### *In Salah (started 2004)*

This Algerian project is a joint activity of BP and the state energy company Sonatrach. The initial development is of 3 fields that lie closest to the existing Algerian gas export structure. Depending on location, CO<sub>2</sub> levels in the raw gas can be between 1% and 10%. The 310 mile long gas gathering system includes CO<sub>2</sub> removal facilities to produce a gas with <0.3% CO<sub>2</sub>. The CO<sub>2</sub> collected is re-injected underground into the boundaries of the gas field; this will result in a reduction of CO<sub>2</sub> emissions to atmosphere of circa 900,000 tonnes/year.

In all three of these projects it is noteworthy that they are: (i) integrated with an existing infrastructure, (ii) have a convenient store, and (iii) the cost of the CO<sub>2</sub> is considerably less than the projected cost of capturing it at a power station (which would be, say, 30-40 US\$/tonne). In the cases of Sleipner and In Salah the CO<sub>2</sub> has to be removed to produce pipeline quality gas, and in the case of Weyburn the gasification plant removes CO<sub>2</sub> from its syngas production. The additional cost attributable to CO<sub>2</sub> production is therefore likely to be in the region of the 10 US\$/tonne it costs to compress it rather than vent it to atmosphere.

### 3. Proposed CCS projects

There are several proposed CCS projects that are at various stages of development; again the common features are a relatively cheap source of CO<sub>2</sub>, a convenient store, and the possibility of taking advantage of an existing or proposed infrastructure development. All these projects are essentially 'commercial ventures' as distinct from demonstration facilities. Relevant to this discussion are:

#### *Snohvit (Operation start 2006)*

Construction is well underway on this project. Statoil and its partners on the Snovit field in the Barents Sea plan to begin shipment from Europe's 1<sup>st</sup> LNG export project in 2006. Raw natural gas in the field contains about 5% CO<sub>2</sub>. This has to be removed as part of the LNG manufacturing process. Approximately 0.7 million tonnes CO<sub>2</sub>/year will be captured and transported back to the field via a 160km pipeline. The CO<sub>2</sub> will be injected into the Tubasen sandstone formation which is 45-75 metres thick and lies deeper than the gas formations. Geological storage will minimize CO<sub>2</sub> taxes payable by field licensees. It is noteworthy that the Norwegian government has a 30% direct financial interest in the project.

#### *Gorgon (operation start 2008-20100)*

Chevron as operator of the Gorgon gas field 130km off the NW coast of Australia are proposing a larger CO<sub>2</sub> sequestration project in which 3.3 million tonnes CO<sub>2</sub>/year would be stored in an aquifer. The raw natural gas has a CO<sub>2</sub> content of approximately 14% which needs to be removed before the gas can be processed to Liquefied Natural Gas (LNG). The store will be the Dupuy saline reservoir which is approximately 2300metres below Barrow Island and approximately 500metres thick.

#### *Miller-Peterhead-DF1 (operation start 2009)*

This BP-initiated project will manufacture hydrogen by reforming North Sea natural gas and capture the resulting CO<sub>2</sub>. The hydrogen will be used in a converted existing gas-fired power station to produce 'carbon-free' electricity. The CO<sub>2</sub> will be transported via an existing offshore pipeline to the Miller field in the North Sea where it will be used for EOR. The power plant is 475MWe and about 2 million tonnes of CO<sub>2</sub>/year will be produced.

#### *Carson-DF2 (operation start 2011)*

BP and Edison Mission Group (EMG) are planning a 1 billion US\$ hydrogen-fueled power plant in California that will generate clean electricity with minimal hydrogen emissions. 500MW of power will be produced by gasification of petroleum coke from BP's Carson refinery to produce the hydrogen. Approximately 4 million tonnes of CO<sub>2</sub>/year will be captured. Discussions are taking place to develop options for sequestering the CO<sub>2</sub> in Californian oilfields by using it for EOR.

#### *Draugen (operation start 2010)*

Shell and Statoil are proposing to co-operate in a project that will deliver about 2.5 million tonnes CO<sub>2</sub>/year to the Draugen field in the North Sea. The CO<sub>2</sub> will be used for EOR and stored under the seabed having being obtained from a land-based gas-fired power station of 860MW capacity.

Note that most of the projects mentioned above are significantly larger than existing CCS projects. We have no first hand knowledge of the proposed financial structure of

proposals such as those above. However, given that the costs are greater than they would be for conventional/traditional processing, it would seem obvious that included in such deliberations would be:

- Applicable state/national/international incentives
- Taxes applicable to incremental oil/gas
- Risk sharing
- Finance sourcing/cost
- Long-term liability issues

#### **4. Transport – sources & sinks**

The cost of transporting CO<sub>2</sub> is significant, particularly if the CO<sub>2</sub> has been obtained from an early-opportunity source like those mentioned earlier. Hence, the incentive to try and match sources and sinks. Work by IEA GHG has shown that in many cases this is possible.

Transport costs are reduced markedly when multiple sources and large quantities are involved. Rule-of-thumb figures are that pipeline costs for transporting <5 million tonnes CO<sub>2</sub>/year are in the region of 5US\$/tonne.250km, but are reduced to the region of 1-2 US\$/tonne.250km if >20 million tones CO<sub>2</sub>/year are transported.

It is noteworthy that the only major instance of wide-spread EOR is in the Texan Permian Basin; around 70 projects are in operation many of them receiving their CO<sub>2</sub> from natural underground sources.

Considerations such as the above have led several people to suggest ways in which the existing infrastructure of North Sea pipelines might be re-used as a CO<sub>2</sub> supply network. Such considerations lead to examination of the CCS value chain and, for example, suggestions that there is a need for companies that have a primary business in supplying and/or storing CO<sub>2</sub>. It is clear that it is cheaper to collect CO<sub>2</sub> from several sources and transport it in a single pipeline than to transport small amounts separately. Implementation of a 'backbone' CO<sub>2</sub> supply/distribution structure would reduce costs but would need a large initial investment that could not be expected to be incurred by early individual CCS projects.

#### **5. CO<sub>2</sub> stores**

The options for underground CO<sub>2</sub> storage can be categorised in various ways; for the purposes of this discussion it is helpful to think of storage that either results in enhanced recovery of hydrocarbons or doesn't. A major difference between the two is that in the case of storage without enhanced recovery of hydrocarbons the store design will be based on maximising the quantity of CO<sub>2</sub> stored at minimum cost. This applies to storage in saline formations and depleted oil/gas fields. Storage accompanied by EOR (or enhanced gas recovery) is not designed to maximise the CO<sub>2</sub> stored. In conventional EOR projects the CO<sub>2</sub> remaining underground is a project cost as more CO<sub>2</sub> has to be purchased. Typically 2-3 tonnes of CO<sub>2</sub> are left underground for each tonne of oil recovered. The interrelationship between maximizing EOR and CO<sub>2</sub> stored is not clear at present although people are working on it. For early-opportunity CO<sub>2</sub>-EOR projects replacement of the CO<sub>2</sub> stored is likely to be a significant cost and therefore any project will be based on maximizing oil recovery.

For CO<sub>2</sub> storage to be effective as a mitigation option it must be stored for many hundreds of years. This raises issues of permanence and liability that are still being debated. Recent discussions amongst parties potentially interested in the application of CCS to the Clean Development Mechanism have proposed the following in initial discussions:

- Storage sites should be selected so as to have zero or negligible (unmeasurable) seepage of CO<sub>2</sub> from them.
- Storage sites should be subject to stringent site selection procedures. Best Practice documentation is needed to support this.
- Monitoring is essential and should be a risk-based approach. Best Practice guidelines are needed.
- Quoting potential % seepages from stores is not meaningful and has no basis.
- Ultimate liability for the stores has to lie with governments as a lifetime of several hundred years for commercial entities can not be guaranteed.

With respect to the last point it should be noted that it is established practice for governments to grant licenses for raw material extraction and specify conditions for accepting responsibility for the site back from the operator at the end of operations.

Current regulatory measures tend to be focused on the injection activities and little attention has been given to issues of permanence.

## **6. Economic instruments**

A key barrier to early application of CCS is the lack of a tax or other credit system in most countries that would support long-term investment in CCS. International trading markets that could provide financial incentives by offering CO<sub>2</sub> credits are at an early stage of development. There are moves to establish acceptance of CCS as applicable under the Kyoto flexible mechanisms but this has not yet been done. Amongst the key issues still to be accepted in methodologies are:

- Permanence
- Boundaries
- Baselines
- Additionality
- Leakage

This last issue refers to 'leakage' in an emissions trading sense i.e. any change of greenhouse gas emissions outside the project boundary.

Some see the production of incremental oil or other fossil fuels as an issue; arguing that full credit for CO<sub>2</sub> storage can not be allowed if, as a consequence, more fossil fuel is produced. The counter arguments are that fossil fuels are not greenhouse gases in terms of emission accounting e.g. for National Emissions; if the oil was not produced by CO<sub>2</sub>-EOR it might be by other means; if the extra oil was not produced the most likely substitute would be coal or other heavier fossil fuels. Not least for public outreach reasons, an authoritative discussion on this issue is needed.

## **7. A systems-approach towards early opportunities for CCS**

It is clear that if CO<sub>2</sub>-EOR could be encouraged to spread widely from its base in the USA this would enable significant quantities of CO<sub>2</sub> to be stored and result in significant Improved Oil Recovery (IOR). Other IOR methods exist but they do not have the advantage of storing CO<sub>2</sub> nor the potential to bring financial credits for doing so.

From the earlier discussion it is evident that CO<sub>2</sub>-EOR has not spread more widely because sources of cheap CO<sub>2</sub> are not generally available and there is no infrastructure to supply it. It can be argued that we are beginning to see the prospects of wider CO<sub>2</sub> – EOR application at Weyburn, Canada and in the North Sea.

The following is an outline proposal on how other CO<sub>2</sub>-EOR infrastructures might be encouraged to develop:

- Define CO<sub>2</sub>-EOR prospects and their present barriers (typically, around 15% extra of original oil in place could be attainable). Such an analysis may have been done for isolated processing schemes, but could be re-visited with the objective of defining even quite small prospects that could be built up into a CO<sub>2</sub>-EOR network. The location of these prospects is key as is the likely timescale for EOR readiness.
- Define potential sources of CO<sub>2</sub>. This may have also been done on an individual project basis. Again, the new aspect is to develop information on how a supply network might be developed from quite small beginnings and grow to become part of a CO<sub>2</sub> supply industry. Although the emphasis should be on potentially cheap sources the longer-term need for large quantities of CO<sub>2</sub> means that power station options need to be considered.
- Analyse the results of CO<sub>2</sub> sources and sinks to highlight potential collection and transmission hubs where the initial cost of starting CO<sub>2</sub>-EOR can be minimized and there is potential to develop the infrastructure.
- In parallel with the above develop applicable carbon trading cases such as CDM, JI, etc.
- Initiate resolution of legal and regulatory barriers/issues
- Initiate public outreach activities
- Chose 2 or 3 of the best supply-use configurations for detailed evaluation and development.
- Develop the business cases and staged plans for turning the initial developments into a large-scale CO<sub>2</sub>-EOR infrastructure that would store major quantities of CO<sub>2</sub>.

## **8. Conclusions**

A number of early applications of CCS technology on a commercial scale have been reviewed. It is concluded that the key requirements are: (i) A convenient cheap source of CO<sub>2</sub>, (ii) source and sink proximity or other means to reduce the cost of CO<sub>2</sub> transport, (iii) a convenient safe store. If in addition the storage of CO<sub>2</sub> can be combined with EOR the financial prospects are considerably improved; even more so if financial mechanisms for the reduction of CO<sub>2</sub> emissions can be used.

It is suggested that barriers to the wide-spread adoption of CO<sub>2</sub>-EOR need to be examined and removed; how this might be achieved is proposed based on adopting a systems-approach to the development of CO<sub>2</sub>-EOR infrastructures.