FILE NOTE

"OPPORTUNITIES FOR EARLY APPLICATION OF CO_2 SEQUESTRATION TECHNOLOGY"

Overview

One of the aims of the IEA Greenhouse Gas R&D Programme (IEA GHG) is to understand how to facilitate the introduction of technologies capable of making deep reductions in CO_2 emissions, for example capture and geological storage of CO_2. This technology faces a number of barriers[1] to its introduction, such as the high cost of capture of CO_2 from power plant. This high cost arises from the amount of equipment required to scrub the CO_2 from the flue gas streams due to the low concentration of CO_2 (4-14% by volume) in the exhaust gases. However, many industrial processes generate exhaust gas streams containing high purity (>90%) CO_2, which means that the cost of capture from these sources would be significantly lower.

If high purity CO_2 sources could be linked with storage opportunities, and transportation costs could be kept to a minimum, then these systems could be attractive as investments to protect the climate. They would provide opportunities for early application of CO_2 capture and storage technology. This concept has been the subject of a major study[2] carried out for the IEA Greenhouse Gas R&D Programme, which is summarised in this paper.

The aim of this study was to identify early opportunities for use of CO_2 capture and storage technology. 120 large, high purity CO_2 sources were identified together with 488 potential enhanced recovery operations within a 100km distance of these sources. This is a higher number of possible projects than was anticipated at the outset of the study. All these source/reservoir combinations represent potential early opportunities for CO_2 capture and storage projects. Four cases studies were selected for detailed analysis. These showed that both CO_2-EOR and CO_2-ECBM could present attractive opportunities, although the former would provide greater economic return than the latter.

A benefit of identifying such "low hanging fruit" should be an acceleration of the demonstration of CO_2 capture and storage technology. In this way, the technology will gain wider acceptance as a safe and effective method of reducing emissions.

This study has also considered the options for financing these projects. A number of barriers to the implementation of CO_2 capture and storage technology were identified, such as the current market price of CO_2 and current ineligibility for inclusion under the flexible mechanisms. Other barriers include: the lack of credits for such projects, current regulatory requirements needed to verify CO_2 emission reduction credits, and safety/environmental issues related to the storage reservoir.

Through the identification of potential projects, and by considering the most appropriate support mechanisms, this study provides a source of reference for opportunities for early application of CO_2 capture and storage technology.

[1] Barriers to Implementation of CO_2 Capture and Storage – Depleted Oil and Gas Fields, Report PH3/22, February 2000.

[2] Opportunities for Early Application of CO_2 Sequestration Technology, report Ph4/10, September 2002.

Technical Background

The exhaust gases of certain industrial processes, such as ammonia fertiliser production, natural gas processing and hydrogen production at oil refineries, may contain high concentrations of CO_2 (>90% by volume). Because of the high concentration, the CO_2 can be captured at relatively cheaply; in the best cases, only dehydration of the gas and compression may be required prior to transmission to the store. In a previous study undertaken by IEA GHG, sources of high purity CO_2 emissions were identified and catalogued as part of a database of CO_2 emissions from power plants and other industrial processes[3]. The industrial processes covered included: steel plants, cement plants, refineries, hydrogen plants, ethylene plants, ethylene oxide plants, gas processing plants and fertiliser plants.

This study has focused on matching high purity CO_2 sources, in fertiliser, ethylene, ethylene oxide and hydrogen plants at refineries, with CO_2 storage opportunities. Gas processing plants were not included in the study, despite the fact that the sector potentially contains a number of significant high purity CO_2 sources, because insufficient data were available at the time on CO_2 emission concentrations from these sources.

Storage opportunities close to CO_2 sources were sought, so as to minimise transportation costs.

In some cases, the cost of injecting CO_2 into a geological storage reservoir can be offset by income resulting from enhanced hydrocarbon production. Examples include injection into an oil, gas or coal field, such as by CO_2 enhanced oil recovery (CO_2-EOR), CO_2 enhanced coal bed methane production (CO_2-ECBM) or CO_2 enhanced gas recovery (CO_2-EGR). In these enhanced production operations, a significant proportion of the CO_2 that is injected remains in the field at the end of its production life, so CO_2 storage is coupled with enhanced production. The extra income generated from enhancing hydrocarbon production can help to offset the costs of CO_2 injection.

CO_2-EOR is the most developed of the enhanced production technologies. In total there are some 74 CO_2-EOR projects currently in operation, mostly in the USA. About 10% of the CO_2 used in these projects comes from natural gas processing plant and from ammonia production, the rest coming from natural CO_2 sources. CO_2-ECBM is a technology still under development with only one active commercial-scale project (in the San Juan Basin in New Mexico USA). Two new demonstration projects are underway in Canada and Poland, which should demonstrate the technology in coal seams more representative of those occurring worldwide. CO_2-EGR is a new concept that has been tested using reservoir simulation tools, but not physically demonstrated. Concerns exist that the injected CO_2 may mix with the gas in place and contaminate the remaining resource. Due to the immaturity of the technology, enhanced gas recovery was not considered in this study.

Results and Discussion

The following areas are described in this summary:

- Baseline data collection and initial selection of opportunities,
- Selection of CO_2-EOR and CO_2-ECBM case studies,
- Financing options for CO_2 capture and storage projects,
- Case study analyses and implementation issues.

Baseline data collection and initial selection of opportunities

As a first step in the study, data on high purity CO_2 sources were collated using the CO_2 Emission Sources Database already developed by IEA GHG. Initially, a dataset of all emission sources with a

[3] Building the Cost Curves for CO_2 Storage, Part 1 - CO_2 Emission Sources, Report No. PH4/9, July 2002.

concentration of >40% CO_2 was extracted from the database, containing 443 potential sources. Then a cut-off at a minimum emission of 100,000 tonnes per year was applied; this reduced the number of potential high purity sources to 198. The data for the 198 sources was then loaded into GIS[4] software; grids of 100 km^2 (10 by 10 km) were created around each emission source. Digital maps of oil fields and coal basins world wide were then added to the GIS. Information on petroleum occurrences was obtained from the USGS[5] World Petroleum Assessment 2000, which contains digital data sets defining petroleum field boundaries. The digital map of world-wide coal occurrences was constructed from a variety of data sources, including IEA GHG's study on the world wide potential for CO_2-ECBM[6] in unminable coal seams.

The GIS software was then used as a tool to match high purity sources with possible storage sites. For CO_2-EOR a total of 62 sources were identified located within 100 km of oil fields. It is noted that, in many cases, several different oil fields were within 100 km of a source. A list of 409 high purity source/EOR combinations was developed. The country distribution of the high purity/EOR combinations are given in Table 1.

Table 1 Country Distribution for High Purity CO_2 Source/EOR Combinations

Country	**No. of High Purity Source/ EOR combinations**
United States	329
Canada	22
China	21
Kuwait	12
Iraq	7
United Arab Emirates	5
Netherlands	5
Belgium	4
Germany	4
Saudi Arabia	3
Mexico	2
Burma	2
India	2
Indonesia	1
United Kingdom	1
Total	**420**

A similar process was adopted for coal fields - this identified 58 high purity sources within 100 km of a suitable coal field; a list of 79 high purity source/ECBM reservoir combinations was produced. The country distribution for the high purity source/ECBM combinations is shown in Table 2.

[4] Geographical Information System
[5] United States Geological Survey
[6] IEA Greenhouse Gas R&D Programme, Report no. PH3/3, Enhanced Coal Bed Methane Recovery with CO_2 Sequestration, August 1988.

Table 2 Country Distribution for High Purity CO_2 Source/ECBM Combinations

Country	No. of High Purity Source/ ECBM combinations
China	33
Japan	12
Belgium	10
United Kingdom	8
U.S.A.	5
Canada	4
France	3
Germany	1
Georgia	1
Indonesia	1
Australia	1
Total	**79**

Selection of CO_2-EOR and CO_2-ECBM case studies

All of the high purity CO_2 source/enhanced recovery combinations represent potential opportunities for CO_2 capture and storage. A rough estimate of the capacity for storage is 16 Gt CO_2 - for comparison, total global emissions from fossil fuel combustion are currently ~24Gt CO_2/year, so these opportunities provide an opportunity for initial action on CO_2 emissions.

The lists of CO_2-EOR and CO_2-ECBM projects were reduced to a "short list" of projects for further study of their potential for funding by means of a two-step procedure. First, the best reservoir for each source was selected by means of a simple cost-benefit analysis. Second, a Multi Criteria Analysis was performed to produce a short list of 15 CO_2-EOR and 15 CO_2-ECBM candidates[7]. The geographical distribution of the short listed projects is summarised in Table 3. Details of the short listed projects are given in Appendix 1.

Table 3 Country Distribution for Short Listed Projects

Country	CO_2-EOR	CO_2-ECBM
Canada	3	-
U.S.A.	9	-
Saudi Arabia	2	-
Mexico	1	-
China	-	9
Belgium	-	2
UK	-	2
France	-	1
Netherlands	-	1
Total	**15**	**15**

[7] Details of the Multi Criteria Analysis undertaken are given in the main report.

To reduce the short listed projects further, a limited technical assessment of the cases was made and expert opinions sought in each case[8]. From the short list, four cases were selected for detailed analysis: two CO_2-EOR cases and two CO_2-ECBM cases. Details of the cases selected are summarised in Table 4.

Table 4 Summary of Selected Early Opportunity Cases Studies

Case Number	1	2	3	4
Case Details				
Type of recovery	CO_2-EOR	CO_2-EOR	CO_2-ECBM	CO_2-ECBM
Type of source plant	Hydrogen	Hydrogen	Ammonia	Ammonia
City	Al-Jubail	Several[9]	Huaxian	Medicine Hat
Province	Ar Riyad	California	Shaanxi	Alberta
Country	Saudi Arabia	USA	China	Canada
CO_2 emission (kt/yr)	260	281	677	293
Distance source-resource (km)	0-50	0-50	0-50	0-50

It should be emphasised that the cases selected do not necessarily represent the best technical options, but are geographically dispersed as well as covering a range of financing options. By selecting a range of options, it was considered that the study was best able to discuss the potential issues and barriers relating to the different financing methods that might arise.

Financing options for CO_2 capture and storage projects

A review has been undertaken of potential financing for CO_2 capture and storage projects. Sources considered included: commercial financing, government sponsored demonstration projects, multilateral donor agencies and the flexible mechanisms of the Kyoto Protocol. General conclusions are that, in developed countries, project funding will come mostly from commercial sources and from public sector sponsored research. In developing countries, domestic/foreign finance supported by the participation of multilateral donor agencies is the most likely source of project finance. Opportunities for funding projects may also exist under domestic and regional emissions trading (ET) schemes in Annex I countries. For the flexible mechanisms, CDM[10] and JI[11] will become options for pilot projects in developing countries and economies in transition.

The current market price of CO_2 in carbon markets is estimated at 3-5 US\$/tCO_2[12]. It is acknowledged that funding under the flexible mechanisms is subject to the eligibility of the projects under UNFCCC rules, which may represent a potential barrier. There are also a number of technical issues, in particular the permanency of storage to be addressed. How any leakage would be treated within CDM, JI and ET schemes will also have to be agreed.

[8] Details of the analysis undertaken and the responses from the experts are recorded in the main report for reference purposes.

[9] There are four refineries within 50 km of the selected storage site that have the potential to provide high purity CO_2. However, plant upgrading is being carried out at some of them which has reduced the concentration of CO_2 in the exhaust stream. Further investigation would be needed of these sites to confirm that the emissions were of sufficiently high purity to serve an EOR project.

[10] Clean Development Mechanism

[11] Joint Implementation

[12] These are prices used in schemes by the World Bank's Prototype Carbon Fund, and the Dutch CERUPT tender.

Case study analyses and implementation issues

Detailed case studies were carried out for each the 4 selected projects; these considered:

- Technical implementation (field tests, demonstration activities)
- Project financeability
- Government policy on CO_2 reduction crediting
- Regulatory issues including the verification and validation of the CO_2 credit (this would necessitate some form of CO_2 monitoring)

The economic evaluations suggest that CO_2-EOR is more attractive than CO_2-ECBM. For the CO_2-EOR cases, net CO_2 sequestration costs were -12 to -14 US$/t CO_2. However, the CO_2-ECBM cases led to positive net CO_2 sequestration costs of between +8 and +13 US$/t CO_2 for the Chinese and Canadian cases respectively.

Although the analysis in the report shows that CO_2 sequestration via EOR presents a seemingly attractive "early opportunity", it does not mean that these projects will be taken up automatically. In practice there are several barriers to overcome before they will be realised. These barriers include:

- ***Technical Implementation* -** there are still technical and environmental issues, such as the permanence of CO_2 storage and the impacts associated with the technology. For CO_2-EOR these issues should be resolved by research work currently underway, such as the Weyburn project. CO_2-ECBM is at a much earlier state of development and pilot projects need to confirm the potential of the technologies first, as well as starting to address the issues of safety and environmental impact.

- ***Project Financing*** – At present, CO_2 capture and storage projects are not being carried out under CDM/JI schemes. It is the stated view of the study contractor that CO_2 capture and storage projects are not eligible for support under CDM/JI schemes but the Programme's interpretation of these schemes is different - because the CDM/JI schemes are at an early stage of implementation, more easily achievable solutions such as renewable energy or forestry schemes are being developed first. In view of current developments, especially the development of a special report on CO_2 capture and storage by IPCC, it is likely that the situation will be clarified in the next few years. Also, the international trading market, which could provide CO_2 credits for capture and storage schemes, is at an early stage of development and it is not fully understand how such activities could be supported under trading schemes. At the current market price of CO_2, the value of CO_2 credits may well not be sufficient to enable CO_2 capture and storage projects to receive funding in this way.

- ***Government policy on CO_2 reduction crediting* -** a key barrier is the general lack of a tax or credit system in most countries to support long term investment by companies in CO_2 capture and storage.

- ***Regulatory* –** currently, there are few regulatory requirements relating to CO_2 capture and storage. In those countries that do have regulatory regimes, monitoring activities are focused on injection activities alone. Little attention is given to monitoring requirements that assure the permanency of storage of CO_2. Monitoring requirements will likely need to be improved to gain public confidence in the technology and to allow formal credit recognition, if a company/operator wants to claim an emission reduction credit. Regulatory measures will also need to be considered to ensure effective exploration of storage reservoirs prior to project set-up, so that the potential impact of any CO_2 leak on potable water supplies, etc. is fully considered. In the longer term some regulatory measures may be needed to ensure that reservoirs that have been used for CO_2 storage are either not considered for further hydrocarbon extraction, or, if the market situation makes further recovery attractive, then future CO_2 emissions resulting from extraction are accounted for.

Major Conclusions

The methodology used, involving the intelligent coupling of large databases of CO_2 sources, oilfields and coal fields with a Geographical Information System (GIS), has proved to be an effective tool in identifying "early opportunities" for CO_2 capture and storage.

A significant number of source-storage matches were identified - 120 sources with 488 potential enhanced recovery operations within 100km. This number is higher than was anticipated at the outset of the study. All these source/reservoir combinations represent potential early opportunities for CO_2 capture and storage projects. Four cases studies were selected for detailed analysis, which indicated that CO_2-EOR represents a more attractive early opportunity than CO_2-ECBM on economic grounds. CO_2-ECBM is also at an earlier stage of technical development than CO_2-EOR.

The study identified a number of barriers to the implementation of CO_2 capture and storage technology, such as the current market price of CO_2 and current ineligibility for inclusion under the flexible mechanisms. Other barriers include: the lack of a Government crediting for such projects, current regulatory requirements needed to verify CO_2 emission reduction credits and safety/environmental issues related to the storage reservoir.

Recommendations

Only a very small number of the potential options identified were examined in any detail - a detailed analysis of all of the options could be undertaken in a further study, which would establish the shape of the low-cost end of the marginal abatement cost-curve for CO_2 capture and storage. Alternatively, member countries of the IEA Greenhouse Gas R&D Programme could undertake feasibility studies on the potential early opportunities in their region

Any further, more detailed study should also look to improve the data accuracy, by specifying the location of the source plant, instead of just assessing the location of the city, as well as the possible injection sites, since the areas of coal or oil occurrences are generally quite large.

JJ Gale
20th May 2003

APPENDIX 1

SUMMARY DETAILS OF HIGH PURITY SOURCE AND EOR/ECBM COMBINATIONS

Contents

Table A1.1 Summary Table of High Purity Source/EOR Combinations

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<tr><th rowspan="2">Country</th><th rowspan="2">Source Type</th><th rowspan="2">Plant Name and/or Company Name</th><th rowspan="2">City, State</th><th rowspan="2">CO_2 Emission Mt/y</th><th colspan="2">Matching Reservoir</th></tr>
<tr><th>Oil Field</th><th>Province Name</th></tr>
<tr><td rowspan="9">USA</td><td rowspan="7">Hydrogen plant</td><td>Atlantic Richfield</td><td>Carson City, Ca</td><td>281</td><td rowspan="4">Fullerton Embayment</td><td rowspan="4">Los Angeles Basin</td></tr>
<tr><td>Tosco</td><td>Los Angeles, Ca</td><td>270</td></tr>
<tr><td>ChevronTexaco</td><td>El Segundo, Ca</td><td>181</td></tr>
<tr><td>ChevronTexaco</td><td>El Segundo, Ca</td><td>188</td></tr>
<tr><td>Motiva</td><td>Convent, Lo</td><td>322</td><td rowspan="2">Wilcox Salt Basins</td><td rowspan="2">Louisiana-Mississippi Salt Basin</td></tr>
<tr><td>Motiva</td><td>Norco, Lo</td><td>161</td></tr>
<tr><td>Phillips Petroleum</td><td>Sweeny, Tx</td><td>268</td><td rowspan="3">Upper Miocene Fluvial Sandstone gas and oil</td><td rowspan="3">Western Gulf</td></tr>
<tr><td>Ethylene plant</td><td>Huntsman</td><td>Port Neches, Tx</td><td>196</td></tr>
<tr><td>Ethylene Oxide plant</td><td>Shell Chemical</td><td>Geismar, Lo</td><td>210</td></tr>
<tr><td rowspan="3">Canada</td><td rowspan="2">Hydrogen plant</td><td>Imperial Oil</td><td>Sarnia, On</td><td>127</td><td rowspan="3">Southern Niagaran Reef</td><td rowspan="3">Michigan Basin</td></tr>
<tr><td>Sunoco</td><td>Sarnia, On</td><td>118</td></tr>
<tr><td>Fertiliser plant</td><td>Terra International Inc.</td><td>Courtright, On</td><td>121</td></tr>
<tr><td rowspan="2">Saudi Arabia</td><td>Hydrogen plant</td><td>Petromin-Shell</td><td>Al-Jubail</td><td>260</td><td rowspan="2">Central Arch Horst Block Anticlinal Oil and Gas</td><td rowspan="2">Greater Ghawa Uplift</td></tr>
<tr><td>Ethylene Oxide plant</td><td>Sharq</td><td>Al-Jubail</td><td>240</td></tr>
<tr><td>Mexico</td><td>Fertiliser plant</td><td>Petroquimica Consoleacaque</td><td>Consoleacaque, Vera Cruz</td><td>2285</td><td>Tambara-Like Debris-Flow-Breccia Limestone Overlying Evaporites</td><td>Villahermosa Uplift</td></tr>
</table>

Table A1.2. Summary Table of High Purity Source/ECBM Combinations

Country	Source Type	Plant Name or Company Name	City, State	CO_2 Emission Mt/y	Matching Coal Basin
China	Fertiliser plant	Dahua Group	Dalian, Liaoning Province	1631	Southern Sichuan-Northern Ghizhou coal basin
		Erlian Chemical Fertiliser Plant	Erlian, Inner Mongolia	1037	Bayanhuxu-Eren Basin
		Inner Mongolia Chemical Fertiliser Plant	Hohehot, Inner Mongolia	1145	Hedong-Weibei Basin
		Jilin Chemical Industry Corporation	Jilin,	2303	Sanjiang Coal Basin
		Lunan Fertiliser Plant	Tengzhou, Shandong Province	1329	South western Shandong Basin
		Lutianhua Group Incorporated	Heijiang County, Luzhou Province	1145	Eastern Sichuan Coal Basin
		Shaanxi Chemical Industry Group	Huaxian, Shaanxi Province	677	Eastern piedmont of Taihang Mountains Coal Basin
		Urumqi General Petrochemical Works	Urumqi, Xinjiang province	579	Junggar coal basin
		Yuantianhua Group Co. Ltd	Shuifu, Yunnan province	1152	Southern Sichuan-Northern Ghizhou coal basin
Belgium		BASF Antwerpen BV	Antwerp	690	Southern Basin
		Kemira S.A.	Tertre	405	
UK	Fertiliser Plant	Kemira Ince Ltd	Ince, Cheshire	388	Pennine Coal Basin
	Hydrogen Plant	BP Grangemouth	Grangemouth,	131	Scottish Coal Basin
France	Fertiliser Plant	Grand Paroisse	Waziers	194	Nord and Pas de Calais
Netherlands	Fertiliser Plant	Hydro Agri Sluiskil BV	Sluiskil	845	Southern Basin