Opportunities for Low-Cost Carbon Capture and Storage Demonstration Projects in China

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Abstract

Several CO_2 storage demonstration projects must be carried out in a variety of geological formations to help prove the viability of CO_2 capture and storage (CCS) as a major option for climate-change mitigation. Project costs will be dominated by costs for CO_2 capture, transport, and storage and will be borne mainly by governments. There is a strong incentive to identify scientifically interesting demonstration opportunities (e.g., in depleted oil and natural gas fields and deep saline aquifers) close to low-cost sources of CO_2.

China has several low-cost CO_2 sources at sites that make NH_3 from coal via gasification using modern coal gasifiers. At these plants CO_2 generated in excess of the amount needed for other purposes (e.g., urea manufacture) is vented as a relatively pure stream. These are potentially economically interesting candidates for storage demonstration projects, if there are suitable storage sites nearby.

In this study, a survey (including site visits to NH_3 plants) and an analysis were carried out to determine CO_2 availability at modern coal-to-NH_3 plants in China. Results indicate that quantities of available, relatively pure CO_2 per site, ranged from 0.6 to 1.1 million tons per year. The CO_2 source assessment was complemented by an analysis of possible nearby opportunities for CO_2 storage. These point sources were mapped in relation to China's petroliferous sedimentary basins where prospective CO_2 storage reservoirs most likely exist. Four promising pairs of sources and sinks were identified. Prospective demonstration project costs were estimated for each of these sites. In addition, potential enhanced oil recovery and enhanced coal bed methane recovery opportunities near these prospective sources were also examined.

Introduction

Carbon and coal in the Chinese economy

- China was the world's second largest emitter of CO_2 in 2001, contributing 19.8% of total world CO_2 emissions with 3,050 x10^6 tons CO_2 [1].
- IEO2004 projects by 2025, China's share of world CO_2 emissions will reach 29% or 6,666 x 10^6 tons CO_2, increasing at an annual rate of 3.3%, the highest in the world. In comparison, from 2001-2025, the US's share of world CO_2 emissions will decrease from 37% to 35% (Figures 1 and 2) [1].
- Estimated increase in CO_2 emissions is due to China's growing energy demand which from 2001 to 2025 is projected to grow from 39.7 quadrillion Btu to 91 quadrillion Btu [1]. Most of this demand will be met by increasing the consumption of coal, China's most abundant energy resource and the most carbon intensive of the fossil fuels.

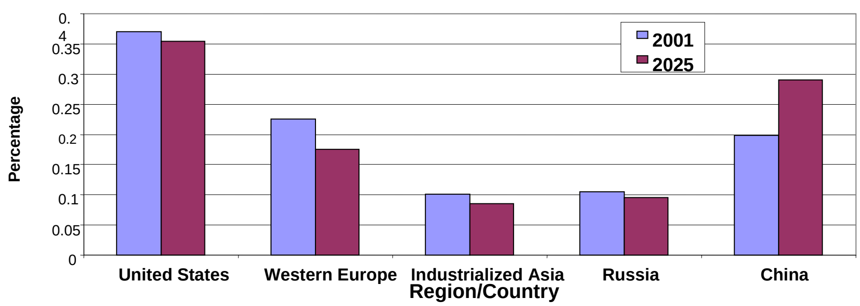


Figure 1: Percentage of world CO_2 emissions by region

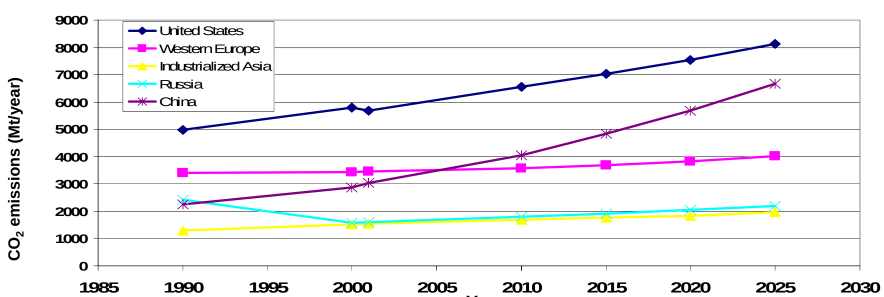


Figure 2: Historic and projected CO_2 emissions by region

Building a case for CO_2 storage demonstration in China

- Because of its dependence on coal, China, in a carbon constrained world, will likely pursue CCS for its coal-fed energy systems.
- Although carbon capture has been proven technologically, carbon storage needs to be proven in a variety of geological media through demonstration projects before CCS can be implemented on a large-scale.
- Until a climate mitigation policy is enacted, demonstration projects will likely be funded by governments who will be interested in storage opportunities near low-cost sources of relatively pure CO_2.
- China is one of the few countries where there are currently large streams of relatively pure CO_2 vented at coal-fed ammonia plants.
- These opportunities will likely be supplemented in the near future by larger streams of relatively pure CO_2 generated at plants that make liquid fuel via coal gasification currently being developed in China.
- China has a number of sedimentary basins near present and prospective pure CO_2 sources where there might be suitable sites for demonstration projects involving CO_2 storage in deep saline aquifers and for EOR projects in near-depleted oil fields. There might also be opportunities for storing CO_2 in beds of unminable coal possibly involving ECBM.
- China has expressed interest in CCS and is a member of the Carbon Sequestration Leadership Forum (CSLF).

CO_2 sources for CCS

China's ammonia plant as candidates for CCS

- Effective carbon storage requires a steady stream of relatively pure CO_2.
- Although there are large volumes of CO_2 available in the flue gas of fossil fuel power and industrial plants in China, these streams contain CO_2 at low concentrations (generally 8-15%) [2] which makes them unattractive for CCS without installing costly capture equipment.
- Over the last two decades, China has introduced modern gasification technology (Texaco and Shell gasifiers) for ammonia production. These plants obtain the H_2 needed for ammonia by separating relatively pure streams of CO_2 from shifted dry syngas (a gas comprised mostly of H_2 and CO_2). In contrast to older, smaller plants in China that emits CO_2 diluted with N_2 via the water-gas process, these new plants vent streams of relatively pure CO_2.
- There are currently 6 coal-fed and 8 oil-fed ammonia plants that use modern gasifiers in China. 10 new gasification projects are currently planned.

Compiling a list of CO_2 sources

- China's modern gasification projects were reviewed as presented in the US DOE World Gasification Database [3].
- This information was supplemented and updated with information gathered from site visits, interviews with Chinese ammonia industry experts and representatives from Shell and Texaco.
- CO_2 emissions factors were determined for 4 types of gasifiers: Texaco-Coal, Texaco-Oil, Shell-Coal, Shell-Oil. (Gross CO2 = Ammonia produced x emissions factor).
- Net CO_2 emissions = Gross CO_2 – CO_2 used (mainly for urea and methanol synthesis).
- Plants that emitted < 400 kt CO_2/year were not considered.
- Final list consists of 9 coal-fed ammonia plants with net emissions ranging from 570–1070 kt CO_2/year (Figure 4 and Table 1).

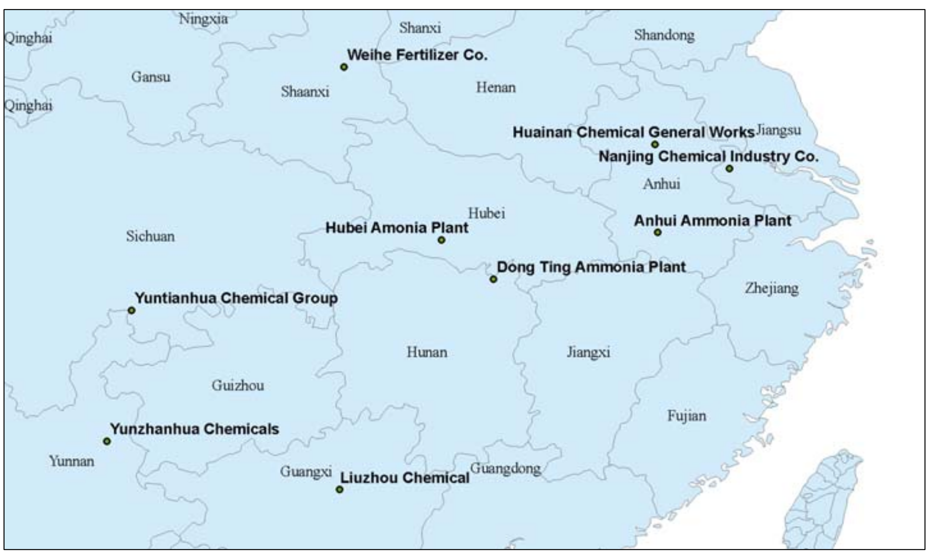


Figure 4: Locations of CO_2 sources for CCS

Name	Location	Gasifier	Year	Coal Input	Syngas Capacity (Nm³/d)	Annual Prod. Secondary Product(s) (kt)	CO_2 uses (kt CO_2/y)	NH_3 prod (kt/y)	Gross CO_2 (kt/y)	Total CO_2 used (kt/y)	Net avail. CO_2 (kt/y)
Anhui Ammonia Plant	Anqing, Anhui	Shell	2006	2000 t/day	3,400,000	Urea: 582	Urea: 427k drinks: 0.067	330	1297	428	869
Dong Ting Ammonia Plant	Yueyang, Hunan	Shell	2005	2000 t/day	3,400,000	Urea: 582	Urea: 427 drinks: 0.067	330	1297	428	869
Huainan Chemical General Works	Huainan, Anhui	Texaco	2000	255 MWth	1,400,000	Urea: 300 MeOH: 50 NH4NO3: 110	Urea: 219 MeOH: 69	360	1138	288	850
Hubei Ammonia Plant	Zhijiang, Hubei	Shell	2006	2000 t/day	3,400,000	Urea: 582	Urea: 427 drinks: 0.067	330	1297	428	869
Liuzhou Chemical	Liuzhou, Guangxi	Shell	2005	1200 t/day	2,100,000	Urea: 300 MeOH: 100 NH4NO3: 180	Urea: 220 MeOH: 137.5	300	1002	357.5	644.5
Nanjing Chemical Industry Co.	Nanjing, Jiangsu	Texaco	2004	358 MWth	4,045,080	Urea: 520, H2 oil refinery	Urea: 381.3 Dry ice: 40	300	1492.5	421.4	1071.1
Weihe Fertilizer Co.	Weinan, Shaanxi	Texaco	1996	372 MWth	2,040,000	Urea: 520	Urea: 381.3	300	948	381.3	566.7
Yuntianhua Chemical Group	Shuifu, Yunnan	Shell	2006	2000 t/day	3,400,000	Urea: 582	Urea: 427 drinks: 0.067	330	1297	428	869
Yunzhanhua Chemicals	Qujing, Yunnan	Shell	2006	2000 t/day	3,400,000	Urea: 582	Urea: 427 drinks: 0.067	330	1297	428	869

Table 1: Properties of identified CO_2 sources

CCS opportunities in deep saline aquifers

Identifying disposal sites

- China's geology is rich with petroliferous sedimentary basins typically containing deep saline aquifers near hydrocarbon traps [4].
- China has over 420 basins with an area of 2000 km^2 or greater [5].
- CO_2 sources were mapped in relation to China's sedimentary basins and known oil and gas fields based on USGS data (Figure 5) [6].
- Four ammonia plants are located within 150 km of known oil/gas fields: Nanjing, Dong Ting, Hubei, Yuntianhua.
- Information on some geological properties was obtained for each oil/gas field (Table 2) [7].
- The following four pairings of plants and oil/gas fields are candidates for possible demonstration projects: Nanjing→Zhenwu, Dong Ting→Wangchang, Hubei→Wangchang, Yuntianhua→Weiyuan (Figures 6-9).

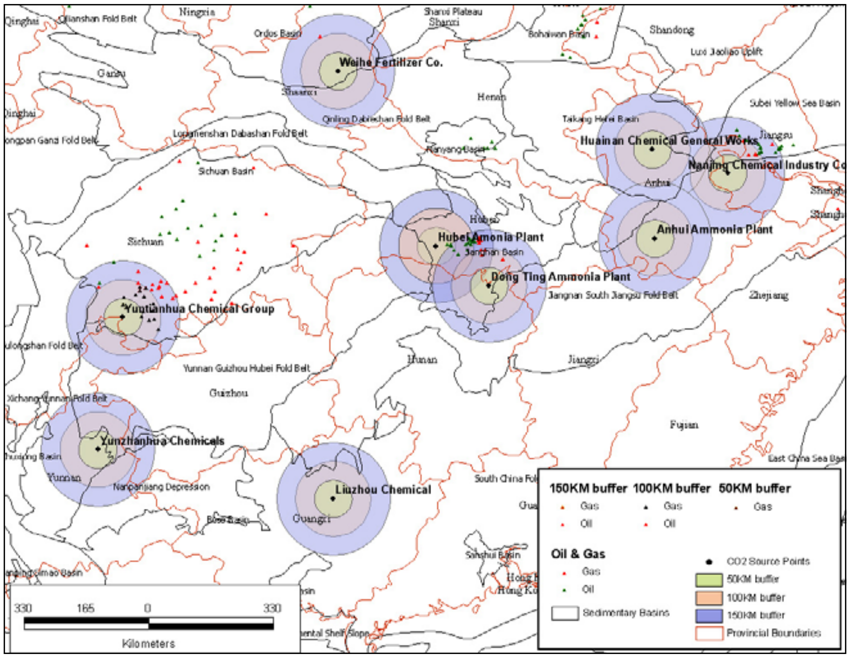


Figure 5: CO_2 sources mapped with sedimentary basins and oil/gas fields in China.

Figure 6: Nanjing and nearby oil fields.

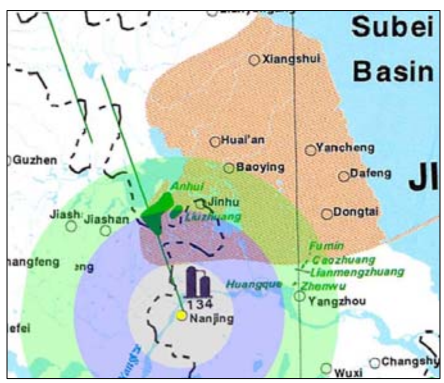


Figure 7: Dong Ting and nearby oil fields.

Figure 8: Hubei and nearby oil fields.

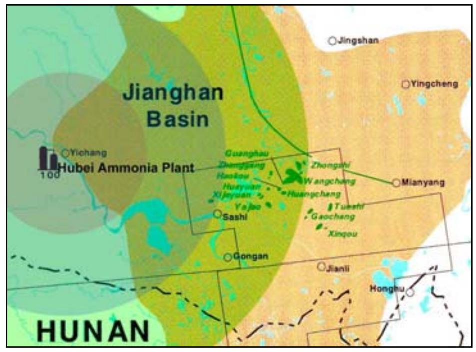
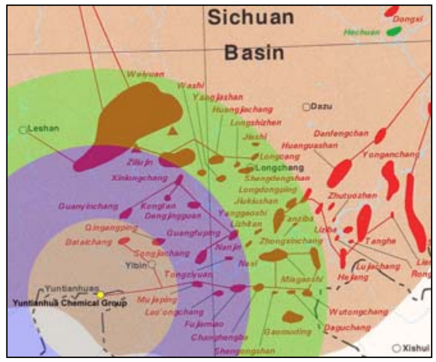


Figure 9: Yuntianhua and nearby gas fields.



Calculating project costs

- It is assumed that costs are dominated by CO_2 compression, transport and storage. The costs for monitoring, modeling and assessment, expected to be much smaller in comparison [8], are neglected.
- For the cost calculations, investment costs are evaluated using a 15%/y annual capital charge rate, and an electricity price of 3.2 ¢/kWh is assumed.
- CO_2 compression costs are based on Larson and Ren (2003) [9]. Model for CO_2 transport and storage costs was developed by Ogden (1997) [10].
- Costs are determined on a per-well basis. Maximum injectivity was estimated for each oil/gas field.
- Costs were estimated for three cases: low, mean and high permeability values.
- Due to high reported permeability values and the fact that none of the CO_2 flows exceeded 1.2 x 10^6 tons CO_2/year, only one injection well was needed for all projects based on mean and high permeability values. For the low permeability cases, only CO_2 disposal in the Weiyuan field requires more than 1 injection well (Table 2).
- Annual costs were estimated to be between $14-20 million/year for all cases.

Project	CO_2 volume (kt/y)	Avg. API	Dist. of transport (km)	Well depth (km)	Case	Perm. (mD)	Max. injectivity (ton/day)	# wells	Cost of CO_2 comp, trans, stor, ($/t CO_2)	Cost of CO_2 comp, trans, stor, ($ million/year)
Nanjing > Zhenwu	1071.1	38.0	120	2.71	Mean K	1110	150000	1	19	20.3
					Min K	95	6600	1	19	20.3
Dong Ting> Wangchang	869	24.0	115	2.61	Mean K	1300	53000	1	18.7	16.2
					Min K	75	3000	1	18.7	16.2
Hubei > Wangchang	869	24.0	145	2.61	Mean K	1300	53000	1	22	19.1
					Min K	75	3000	1	22	19.1
Yuntianhua > Weiyuan	869	N/A	85	3.24	Mean K	20	21000	1	15.8	13.8
					Min K	1.0	1100	3	20.2	17.6

Table 2: Properties of identified oil/gas fields and estimated cost of CCS project.

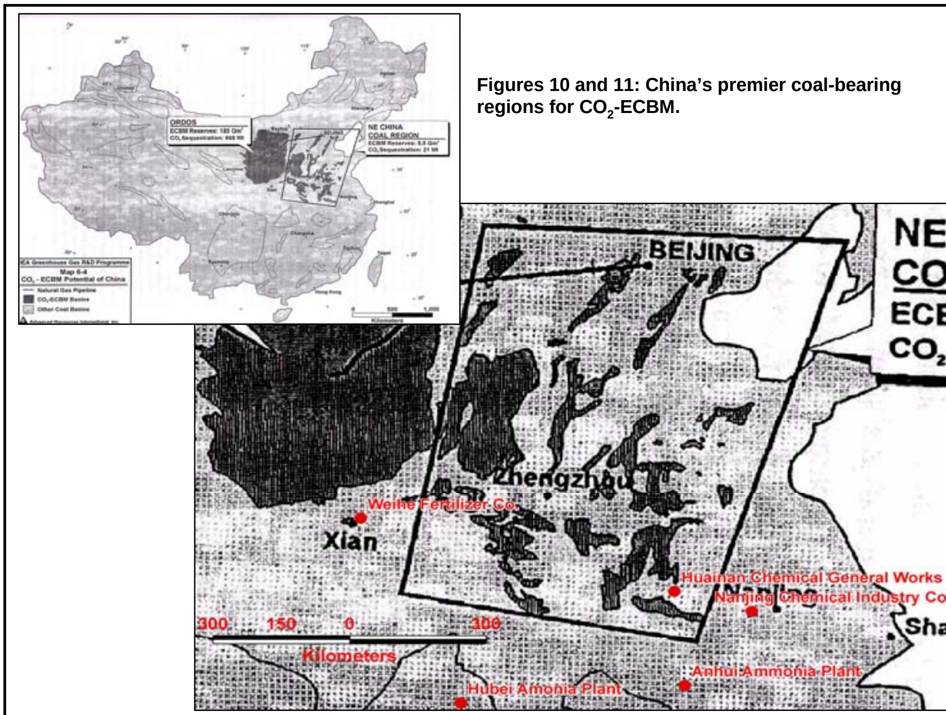
Prospective EOR and ECBM opportunities

Exploring CO_2-EOR opportunities

- Enhanced oil recovery (EOR) can be realized in some near-depleted oil reservoirs by injecting CO_2.
- Three ammonia plants were found to be within 145 km of possible EOR sites: Nanjing→Zhenwu, Dong Ting→Wangchang and Hubei→Wangchang
- The EOR potential and CO_2 required for each oil field was estimated based on method developed by Stevens et al. (1999) [11] and adopted by Lysen et al. (2002) [12].
- All the oil fields examined had modest EOR potential but might be suitable for demonstration projects. The Zhenwu field is the largest of those considered with an estimated EOR potential of 34 x 10^6 BO that can be recovered using 16.3 x 10^6 tons CO_2. The Wangchang field has an estimated EOR potential of 29.8 x 10^6 BO which would require 16.7 x 10^6 tons CO_2.
- Based on mean permeability values, the costs for CO_2 compression and transport for the Nanjing→Zhenwu project is $17.5/t$CO_2$, $17.2/t$CO_2$ for the Dong Ting→Wangchang project and $20.6/t$CO_2$ for the Hubei→Wangchang project.

Exploring CO_2-ECBM opportunities

- CO_2 can be stored in beds of unminable coal and in some instances enhanced coal-bed methane recovery (ECBM) might be feasible.
- China's CBM potential is estimated to be one of the world's largest between 16,000 - 35,000 Gm^3 [13]. However, the CO_2-ECBM potential is still uncertain.
- Stevens et al. (1998) identifies the Ordos Basin and the Northeast China Coal Region as regions with the greatest CO_2-ECBM potential [14] (Figure 10).
- The Ordos Basin has a coal-bed methane reserve of 445 Gm^3, a CO_2-ECBM recovery potential of 180 Gm^3 and a CO_2 storage potential of 660 $\times 10^6$ tons CO_2 [14].
- The NE China Coal Region is estimated to have a coal-bed methane potential of 55 Gm^3, a CO_2-ECBM recovery potential of 5.5 Gm^3 and a CO_2 storage potential of 21 x 10^6 tons CO_2. [14].
- The Weihe, Huainan and Nanjing ammonia plants are located near the Ordos and NE China coal-bearing regions (Figure 11).



Figures 10 and 11: China's premier coal-bearing regions for CO_2-ECBM.

Conclusions

- There are several promising sites for low-cost CCS demonstration projects in China.
- This study identified 9 sources of relatively pure CO_2 with flow rates between 570–1070 kt CO_2/year .
- Four potential CCS projects in deep saline aquifers were identified. The costs for compressing, transporting and storing the CO_2 for these projects ranged from \$16 - 22 t/CO_2 which translates roughly to \$14 - \$20 million/year.
- Three possible EOR projects were examined for two oil fields, each with EOR potential ~30 x 10^6 BO and requiring ~16 x 10^6 tons CO_2. CO_2 compression and transport costs for these projects are ~\$16-21 /tCO_2.
- This preliminary survey suggests that more detailed assessments of the prospective pairings identified are warranted.
- Opportunities for international collaboration in implementing and funding such demonstration projects in China should be explored (possibly under the CSLF).

References

1. United States Department of Energy (2004) International Energy Outlook. <http://www.eia.doe.gov/oiaf/ieo/index.html> (April 9, 2005).
2. Hendriks, C., van der Waart, A. S., Byers, C., Phylipsen, D., Voogt, M., Hofman, Y. (2002) Building the cost curve for CO_2 storage: Sources of CO2. Ecofys, Utrecht, March.
3. US DOE (1999) Gasification – Worldwide Use and Acceptance. Office of Fossil Energy and Gasification Technologies Council, US Department of Energy.
4. Hitchon, Brian, Gunter, W.D., Gentzis, Thomas, Bailey, R.T. (1999) Sedimentary basins and greenhouse gases: a serendipitous association. Energy Conversion and Management 40, p. 825-843.
5. Zhai Guangming (1997) China Well Evaluation Conference: Oil and gas resources and their future development in China. Schlumberger Oilfield Services.
6. Hearn Jr., P., Hare, T., Schruben, P., Sherril, D., LaMar, C., and Tsushima, P. (2001) Global GIS Database: Digital Atlas of South Asia, US Geological Survey, Digital Data Series DDS-62-C.
7. Li Guoyu (2002) The collection of China's Basins which contain oil and gas, 2nd edition. The Petrolic Industry Press.
8. S.J. Friedmann, personal communication, April 8, 2005.
9. Larson, E.D., Ren, T. (2003) Synthetic fuels production by indirect coal liquefaction. Energy for Sustainable Development, December.
10. Ogden, Joan (2002) Modeling infrastructure for a fossil hydrogen energy system with CO_2 sequestration. GHGT-6, Kyoto, Japan.
11. Stevens, S.H., Kuuskraa, V.A., and Taber, J.J. (1999) Barriers to overcome in implementation of CO_2 capture and storage (disused Oil and Gas Fields). IEA Report No. PH 3/22.
12. Lysen, E.H., ed. (2002) Opportunities for early application of CO_2 sequestration technology. IEA Report No. Ph 4/10.
13. Zhang, X. and Zhang, X. (1996) Distribution and development of strategy for coal bed methane resources in China. United Nations International Conference on Coal Bed Methane Development and Utilization, Beijing, Oct. 17-21, p.19-24.
14. Stevens, S.H., Kuuskraa, V.A. (1998) Enhanced coal bed methane recovery with CO_2 sequestration. IEA Report No. PH3/3.