# Status Report on $CO_2$-ECBM Research Activities

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## INTERNATIONAL ENERGY AGENCY

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## ACKNOWLEDGEMENTS AND CITATIONS

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## Background

The IEA Greenhouse Gas R&D Programme (IEA GHG) has been monitoring the progress of practical R&D activities on $CO_2$ Enhanced Coal Bed Methane ($CO_2$-ECBM) production for several years. A series of file notes have been produced documenting the status of $CO_2$-ECBM and future research needs[1], the last of which was written in 2005. It was proposed in the study voting round of the 30th ExCo meeting (Vaasa, Finland), that an updated review could be undertaken but this was not accepted by members at that time. However, since the last meeting the USDOE has provided a report on a study that they have undertaken[2] which negates the need for a new IEA GHG activity. The study has undertaken a review of current research work and field tests that have been completed on $CO_2$-ECBM and provides a summary of essential future research needs. The USDOE funded study has found that if the extensive coal basins found over a widespread area of the United States of America are found to be a viable option for $CO_2$ storage, there are a large number of point sources (mainly electrical power plants) in close proximity to these resources. This could therefore provide a great opportunity for many power plant operators in the USA to manage their $CO_2$ emissions economically and effectively.

The purpose of this report therefore is to outline the current state of research and knowledge on $CO_2$-ECBM based on the USDOE study, while suggesting what actions need to be taken in order to progress our knowledge and overcome the technical barriers with this technology.

## Results and Discussion

### *Summary of Results from Field Activities*

Of the field activities either completed or ongoing, the Allison pilot project in the San Juan Basin, New Mexico, was by far the longest running operation. A $CO_2$-ECBM project, it commenced in 1995 and ran for a period of 6 years. Over this period, a total of 370,000 tonnes of $CO_2$ were injected into the coal seams at a depth of around 900 metres. This figure take into account 70,000 tonnes of $CO_2$ produced with the methane which was re-injected, leaving a net stored amount of 300,000 tonnes of $CO_2$.During the same period, circa 93,000 tonnes of coal bed methane was produced from the coal seams; this represents an increase from 77% to 95% of the gas-in-place being produced following the injection of $CO_2$. This project provided the first documented field evidence for the long predicted existence of the coal swelling phenomena. After this first occurrence of coal swelling, and related reduction in injection rates, there was a notable rise in injection rates, which was not expected. It was concluded that the increase was due to the production of methane. This reduced the pressure in the reservoir, and allowed the adsorbed $CO_2$ to desorb from the coal, and migrate further along the coal seam before re-adsorbing to the coal. This resulted in greater permeability at the injection site, which then allowed the injection rates to rise once more.

The RECOPOL project in the Upper Silesian Basin in Poland used a three well set up. Two wells were used for the production of methane, which were refurbished existing Coal Bed Methane production wells, and the third was a newly drilled $CO_2$ injection well. The project targeted 3 thin seams of high volatile bituminous coals, at a depth of around 1000 – 1100 metres, and with a thickness of between 1.8 and 2.6 metres. It was rapidly established that continual injection was not immediately possible, and it wasn't until the coal seam had undergone a fracturing procedure that continual injection, close to the anticipated injection rate of 20 tonnes per day, was achieved. Unfortunately, this level of injection was maintained for a little over a month, as the $CO_2$ supply was depleted at the scheduled end of the project.

[1] Three files notes have been produced, the first in March 2002, which was followed by further updates in May 2004 and March 2005.
[2] Technology Design and Implementation Plan for $CO_2$ Storage in Deep Unmineable coal Seams, Report prepared for USDOE by Advanced Resources International Inc. March 2, 2006

During the project, it was established that the production of methane at the site was enhanced considerably. During previous CBM production activities, production at the site peaked at around $100m^3/d$. Following injection of $CO_2$ into the fractured coal seams, this rose to around $700m^3/d$. Many of the challenges met by the RECOPOL project have helped to establish guidelines for proper equipment design, and have provided useful experimental data on the effects of fracturing the coal seam on methane production.

The Hokkaido project in the Ishikari coal field was a two well $CO_2$ ECBM project. One injection well with one production well 65 metres apart. There was evidence of leakage around the injection well so injection pressures could not be raised above 70 bar. This leakage was due to poor cementing practices around the well casing. Methane production was around 90% lower that expected, and it is thought that this was down to coal fines blocking the well perforations. Following these slightly disappointing results, both wells have been re-completed, and a more thorough $CO_2$ injection test is planned.

A small "huff and puff" test project was performed in the Qinshui Basin in China. In this project, a single well was used for both $CO_2$ injection and $CH_4$ production purposes. The project began in October 2003 and was concluded in August 2004. During this time, it is reported that circa 200 tonnes of $CO_2$ were injected at a rate of approximately 10 tonnes a day over a 22 day period. A further multi-well test is planned in the same region.

The Alberta Research Council conducted two single well projects in the Fenn Big Valley region in the 1990's. These were both on the micro-pilot scale, and the injected gasses were $CO_2$ and flue gas. The information and data obtained from these projects have not been publicly released, and the extent of public knowledge is that the results have been instrumental in the planning and design of a larger scale pilot project at the same location.

The CONSOL project is operating in the Marshall County region of West Virginia, and the project plans to inject $CO_2$ into the coal seams, with the aim of improving the methane recovery from the coal beds. The objective is to achieve improvements from the current 50-60% of gas-in-place, to around 70-80% of gas-in-place. The project commenced in 2001 and is scheduled to run for a total of seven years, over which time the operator plans to inject approximately 26,000 tonnes of $CO_2$.

Throughout the research activities detailed above, there emerge two key technical barriers which have been encountered in varying degrees. The first is coal seam permeability. Coal seams contain a series of tight, closely spaced fractures which are referred to as the cleat system. Gas is stored in coal either as an adsorbed component on or within the coal matrix as a free gas or within the cleat system. The coal cleat system is important in CO2-ECBM because it is these interconnected fracture networks (or permeability) which allows fluids and gas to move through the coal and to wells for production. The widths or openings in the cleats (the reservoir permeability) tend to reduce with depth due to the weight of overlying rock. The adsorption of $CO_2$ results in the coal seam swelling which can close the cleat system particularly around the injection well. This reduction in reservoir permeability can prevent migration along the coal seam of $CO_2$ as experienced in the Allison project. A stimulation procedure (typically fracturing) on the coal seam to forcibly re-open the cleat system and maintain the cleat open using a propant (sand) can be used to ensure injection of $CO_2$ is maintained and storage in the coal seam can occur. Both the Allison and Qinshui Basin projects demonstrate injection into fairly high permeability coals permeability coals is attainable, whilst the RECOPOL and Hokkaido projects both show potential problems associated with low permeability of the coal seam. Clearly, further field data is required in order to fully understand and subsequently develop methodologies to overcome this problem.

The second technical barrier is an inability to accurately model the behaviour and interaction between the $CO_2$, methane and the coal seam. This is a major focus area for future research. The differences in experiences between the Allison and RECOPOL projects in particular show distinct contrast. RECOPOL encountered unsustainable injection rates, leading to the stimulation of the coal seams. After this stimulation, continual, sustained injection was achieved in the order of around 15 tonnes of $CO_2$ per day. No reduction in injection rates was experienced after this point; although injection was sustained for less than two months at this rate as the project ran to its scheduled end. In contrast, while the Allison project encountered similar reductions, they also experienced a subsequent unexpected rise in injectivity, not experienced during the RECOPOL field work. This could reflect the longer duration of the project, or the scale of the site – the Allison project site coal seams were approximately 13 metres thick on average, compared to the average of 2 metres thick in the RECOPOL project.

***Summary of Results from Laboratory Activities***

The previous section outlined and explained the key instrumental field studies undertaken in the area of $CO_2$-ECBM, but there have also been some influential laboratory based research projects completed. The key findings of two of the largest such projects are outlined below.

Significant research has been undertaken by the Department of Energy (DOE) and the National Energy Technology Laboratory (NETL) in the United States of America, covering the area of $CO_2$-CBM. They have developed and tested modelling techniques which simulate $CO_2$ injection in deep reservoirs, allowing optimisation of the design and engineering of equipment and practices as well as aiding in the definition of coal basins favourably suited to $CO_2$-ECBM projects. They have also conducted lab based investigations to further the extent of knowledge and understanding of the interactions between $CO_2$ and methane, including the effects of such interactions on the swelling and shrinkage of coal seams.

The COAL SEQ II Consortium is aiming to carry out feasibility evaluations on $CO_2$ sequestration and ECBM operations in unminable coal seams. While part of this research is necessarily field based, the laboratory work is focussing on developing generalised models of $CO_2$, methane and nitrogen gas adsorption, and the development of simulations illustrating fluid behaviour and bi-directional diffusion under reservoir conditions. They are also conducting experiments to determine the flow rates of gasses through coal seams under controlled temperature and pressure conditions equivalent to in-situ reservoirs. It is anticipated that this work will allow establishment of shrinkage and swelling effects on different permeability coals.

## Technical Barriers

Despite extensive research, both field based and in the laboratory, there are still many technical barriers that need to be overcome before $CO_2$-ECBM can be developed from being classed as 'demonstration phase' to an 'economically feasible under specific conditions' storage option. The technical barriers are:

1. The level of certainty regarding the capacity estimates. With the estimated range between 5Gt and 267Gt, this represents the issues experienced in defining 'unminable coals'. To illustrate this, under European conditions, coal below circa 1000 metres may be considered unminable, but under the conditions encountered in Japan or China, coals of 2 or 3 times that depth may be considered economically minable. Guidelines therefore will need to be drawn up for each coal basin being considered for $CO_2$-ECBM in order to define 'minability'.

2. A lack of data on geological and reservoir properties that facilitate and favour injection and storage of $CO_2$. Without detailed knowledge of the 'best practice' conditions, decisions on site locations for projects are made more difficult, requiring more in-depth background research into an area to determine its suitability.

3. More understanding is required of both the short and long term interactions that can be expected or predicted between $CO_2$, coal seams and methane. One primary factor within this research area is the processes of coal swelling and coal shrinkage and the corresponding reduction and increase in permeability. It has been observed that coal seams swell following exposure to injected $CO_2$, and shrink following desorption of coal bed methane. Although observed in several research projects, no accurate and representative model has been developed to predict the behaviour of coal seams under the presence of injected gasses. Several field based

research projects have experienced a reduction in injection rates as a result of swelling of the coal seam. The development of strategies for well design and high volume injection are imperative if significant volumes of $CO_2$ from point sources are to be stored in unminable coal seams.

4. Although a few integrated $CO_2$-ECBM projects have been carried out, merging the two activities of $CO_2$ storage and enhanced coal bed methane production into an integrated efficient and fully describable system will reap great benefits. A complete approach strategy would enable efficient site selection, quick project start up and when combined with sites previously associated with conventional coal bed methane production, these wells could be refurbished / re-completed, greatly reducing the cost of this as an integrated $CO_2$ capture and storage technology option.

In addition to the major technical barriers outlined above, several further minor issues have been identified by a panel of experts contributing to the US DOE study. These address the general uncertainties and risks involved with $CO_2$ storage compared with those involved with a more mature technology. They also raise the issue of the high costs of $CO_2$ capture from industrial point sources, which could potentially negate any economic advantage gained from $CO_2$-ECBM activities. There are also issues associated with the environmentally friendly disposal of water produced at the methane production well, without entailing excessive costs.

Finally, there is a great need to establish certainty of storage through the installation of monitoring programmes in order not only to detect leaks, but also to mitigate the effects of any leaks to prevent escape to the atmosphere.

## Research and Development Needs

One of the primary research needs is to increase the number of field pilot projects investigating the integrated $CO_2$-ECBM option of storage. This would enable more comprehensive modelling when combined with laboratory work, and extend the level of understanding of reservoir characteristics. It will ultimately allow the categorisation of coal basins around the world, making accurate capacity estimates possible and identify optimal locations and conditions for successful $CO_2$-ECBM operations on a commercial scale. When further field activities have been completed, it should be possible to compile a subject library covering the composition and characteristics of all the major coal basins around the world, together with their individual storage capacities, to enable geographical matching of basins to $CO_2$ sources.

Secondly, research and development is needed in the area of modelling of reservoirs. Researchers must be able to predict the interactions between $CO_2$, coal seams and methane in order to engineer and design equipment and experimental methodologies to best match a specific site. Until the processes of adsorption, desorption and migration are fully understood, there will still be a question mark regarding the long term safety and security of storage.

More work is needed in investigating well stimulation and coal seam fracturing procedures. When more is understood in this area, it is conceivable that fewer wells would be required for a project, helping to reduce the initial cost and therefore making the storage more cost effective and encourage industry to opt for geological sequestration of $CO_2$.

Another area requiring further research is that of the effects if $CO_2$ and methane on swelling and shrinkage of the coal seam, and the associated links to changes in permeability. When these interactions are better understood, well placement and field size will be able to be chosen and adjusted to maximise $CO_2$ injection rates as well as methane production.

As discussed earlier in this report, published capacity estimates for geological storage in coal vary by around 250Gt. There are also variations in estimating at what point storage in coal becomes uneconomical. Without this information industry operators cannot make sound business decisions on geological storage of the $CO_2$ they produce. The other areas identified as requiring research will all filter into the equation for revising capacity estimates, allowing industry to make informed decisions based on scientific evidence and information.

Comprehensive monitoring schedules need to be developed in order to satisfy the concerns of the public and regulatory bodies alike regarding the safety of $CO_2$ storage in coal. Best practices should be decided upon; along with a full suite of mitigation options should a leak be detected. Much of this analysis could be based in the laboratory before being verified in the field.

The final area requiring investigation is management and disposal of waste water as a result of $CO_2$-ECBM activities. As water is produced with the methane, low-cost, environmentally friendly disposal options need to be formulated. It is realised that the options available and relevant to each project would vary depending on location, situation and proximity to potential industrial customers.

## Summary

The results of this review indicate that there is still considerable research needed before $CO_2$-ECBM can be regarded as a technically viable mitigation technology. However, we are still not in a position where we can discount this option. The paper presents what are in effect the essential elements of a future research programme that is needed to prove the technology. Whilst the research requirements have been developed essentially with the USA in mind they are equally appropriate to any country that is considering developing CO2-ECBM as a geological storage option.

## Next Steps

IEA GHG is aware that there are a number of its members that have expressed an interest in $CO_2$-ECBM as a geological storage option and are pursuing research programmes on this topic. These countries include: USA, Japan, Canada, Australia and Netherlands/France/Germany as part of a new EC supported research programme. There is also considerable interest in this option in China, India and South Africa. It may therefore be appropriate to bring together these different activities under the framework of an International Research Network on $CO_2$-ECBM. The network would aim to use the research plan outlined earlier as a starting point to help promote further international co-operation on this research topic. This would also enable us, after a given time, to establish whether $CO_2$-ECBM is a technically feasible storage option or not. The network would provide a forum for researchers and other interested parties around the world, to coordinate activities and share their experiences and results. It is anticipated that many findings may be transferable between projects, (despite geological differences in locations), facilitating smoother project start up, and promoting a more in depth understanding of best practice methodologies for any given scenario. The network would also share experiences of problems encountered, to enable subsequent projects to avoid the same problems, therefore minimising costs and maximising resources.

IEA GHG would be well placed to use the experience gained from these network meetings to establish an International Research Network on $CO_2$-ECBM. IEA GHG currently supports several international research networks which hold regular network meetings. These meetings regularly attract circa 70 delegates, and therefore act as a sound source of information as presentations are given by those working in the field, and agendas are set in advance to address current issues and disseminate the latest findings and results.