From desk studies to field demonstration to commercial scale projects:

CO_2 storage in underground coal seams while simultaneously enhancing CBM production

TNO led the international consortium that executed the first pilot project of CO2 storage in underground coal seams while coal bed gas was simultaneously being produced. This demonstration in the Upper Silesian Basin of Poland, named RECOPOL, showed that CO2 can be injected into low permeability coal seams at substantial rates. At the same time, it established that the production rates for coalbed gas could be increased.
In 2006 a follow-up study, named MOVECBM, was initiated by TNO.

The world is in need of technology options that will allow it to continue using fossil fuels without substantial CO_2 emissions. Subsurface storage of CO_2 in geological systems is considered a promising option and it is currently being investigated worldwide. The research window for projects on subsurface CO_2 storage has slowly but surely shifted from desk studies to demonstrations, for the most part. One of the options considered in this context is the storage of CO_2 in underground coal seams. The injection of CO_2 into coal while simultaneously producing coalbed methane (CBM) combines the production of a 'clean', hydrogen-rich fossil fuel (methane) with CO_2 sequestration. In 2001 the RECOPOL project was set-up to perform the first European field demonstration of this technique. The main goal of the project, co-funded by the European Commission, was to demonstrate that CO_2 injection in coal is feasible under European conditions. The MOVECBM project aims at the monitoring and verification of the CO_2 storage site in Poland and other locations.

The principal targets for injection were coal seams between 1.3 and 3.3 m thick, of Carboniferous age, in the depth interval between 900-1100 m. The coal is high-volatile bituminous with a rank of about 0.8-0.85 %Rr. A new injection well (Figure 1) was drilled to a depth of 1120 m in the summer of 2003, 150 m from the existing production well). After the pilot site was completed in 2003, the initial injection tests were performed with water in early July 2004. Liquid CO_2 from an industrial source has been injected since August 2004.

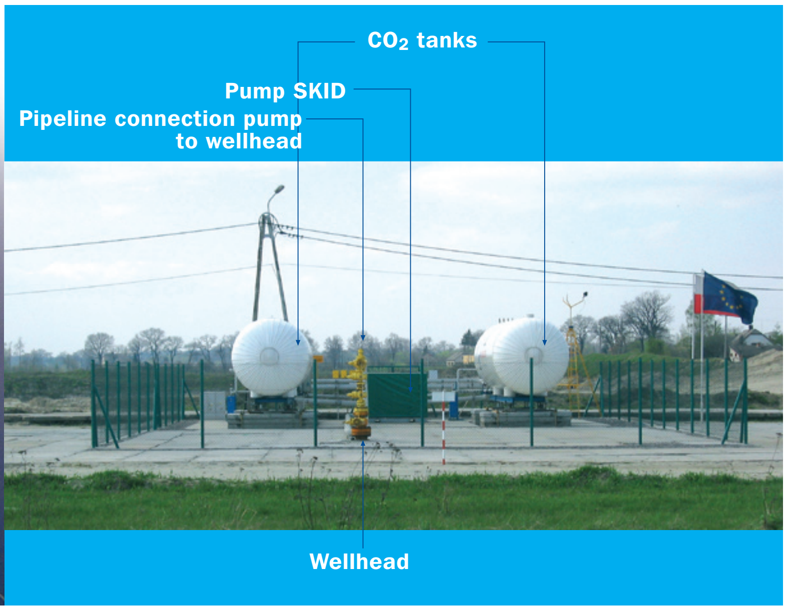

Figure 1 Picture of the RECOPOL pilot site.

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In the first phase of the operations it was impossible to maintain continuous injection under the pressures and injection rates applied. The injection pressures required were higher than initially anticipated. The pressure was increased over the course of the project but continuous injection was not achieved. Meanwhile, well-head and downhole pressure and temperature data were recorded and evaluated so that researchers could learn about the reservoir behaviour. More actions were taken to establish continuous injection and this was eventually achieved in April 2005, following a frac job of the coal seams. This stimulation was also required because the permeability of the coal seams had been reduced over time, presumably due to swelling as the result of contact with the CO_2. Similar observations were made in Canada and the United States, where they were also attributed to coal seam swelling. After fraccing, approximately 12-15 tonnes per day were injected in continuous operation from late April to early June.

Gas production in RECOPOL

The coal seams have a fairly good gas content, although diffusion rates are low. The existing coalbed methane production well was cleaned, repaired and put back into production at the end of May 2004, to establish a baseline production. Gas was produced from the production well to evaluate possibilities for enhancing the gas rates. There was a clear response in the production well to the injection activities.
In April 2005, after stimulation of the injection well, gas production increased rapidly within a few days. The CO_2 concentration in the production gas also increased rapidly, clearly indicating the breakthrough of the gas. However, the amount of CO_2 produced daily was much lower than the amount of CO_2 injected daily, indicating a clear sink of CO_2 in the reservoir. The absolute amounts of CH_4 that were produced are significantly higher than the estimated baseline production with conventional production (Figure 2). It can therefore be concluded that the injection activities had a positive effect on the gas recovery within the project's lifetime, probably due to exchange reactions. However, it appears that sufficient time is required to allow for diffusion of the gas into and out of the coal matrix.

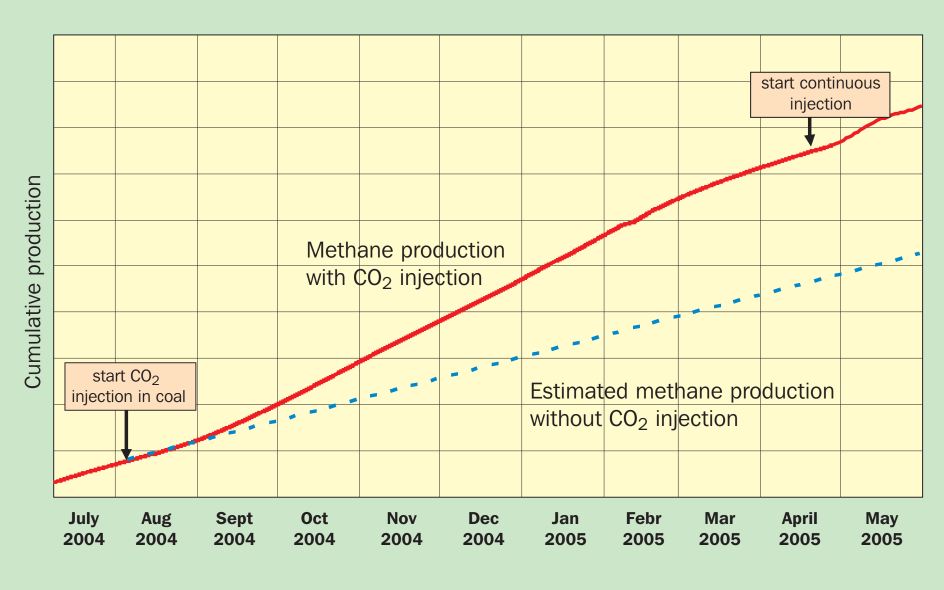

Figure 2 Cumulative amount of methane produced over time in the RECOPOL project. The positive effect on gas production of the injection activities is clearly evident when compared to the projected baseline production.

CO_2 storage in RECOPOL

In total approximately 760 tonnes of CO_2 were injected between August 2004 and the end of June 2005 (Figure 3). The amount of the injected CO_2 that was produced back by the MS-4 production well, mainly after the frac job, was estimated at 68 tonnes. The amount of CO_2 produced was much lower (approx. 9 %) than the amount of injected CO_2, indicating a clear sink of approximately 692 metric tonnes of CO_2 in the reservoir. This sink was confirmed by the rapid decrease in production rates after continuous injection stopped in June 2005. Shut-in tests of the production well and measurements of the water level, done in June 2005, showed that the reservoir pressure around the production well had increased slightly compared to the initial pressure but was returning to its equilibrium level. This also seems to confirm that CO_2 is being adsorbed around the production well.

Conclusions of RECOPOL

This project, finished in 2005, showed the potential of this application. Several months of injection showed that injection without stimulation is difficult under the local field conditions. It had been expected that a small additional pressure above the reservoir pressure would be sufficient to establish continuous injection, but this was clearly not the case. The injection pressure required was nearly twice the reservoir pressure. Apparently, this was the result of a decrease in permeability of the reservoir during injection, most likely due to swelling of the coal.

Advances were made in terms of understanding the process, which will lead to improvements in the dedicated numerical simulators. Enhancement of methane production was proven, although the underlying process is not fully understood. Further field experiments and laboratory studies should be undertaken to improve our knowledge of the processes involved. The permeability of the coal remains a critical factor, even though the project demonstrated that the injectivity in low permeability coal could be increased by substantial rates. The injected amounts provide a good basis for a future upscaling of operations.

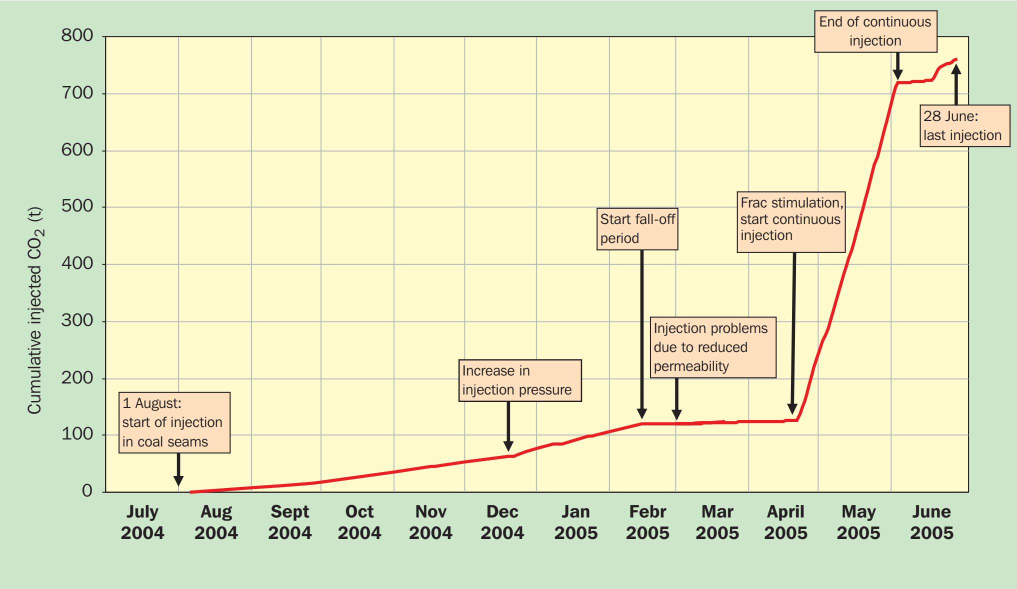

Figure 3 Cumulative amount of CO_2 injected over time in the RECOPOL project.

Project leaders are convinced that they can find other locations in the Upper Silesian Basin that have higher permeability, thicker seams and higher gas content, thus providing better prospects for gas production. Based on the experiences of this project, they are in a position to optimize fields and enhance production at future sites. Since the process appears to be diffusion-controlled, planners need to find an optimum distance between the wells that will guarantee sufficient contact time between the injected CO_2 and the in situ coal. Other well completions, such as horizontal or 'fishbone' drilling, need to be researched to assess their impact on injectivity and productivity. The recovery factor could be enhanced even further through dedicated operational schemes with varying injection and production intervals. We strongly recommended instituting operational flexibility, in terms of the applied pressure and flow rates, to manage the swelling effects.
The consortium showed conclusively that it was possible to set up an onshore CO_2 storage pilot in Europe and handle all the 'soft' issues (permits, contracts, opposition, etc.) related to these kinds of innovative projects. The lessons learned in this operation can possibly help others overcome the start-up barriers to future CO_2 storage initiatives in Europe.

Although RECOPOL showed the potential of the technique, it also showed that the fundamental processes are still not fully understood. Especially, for optimal storage and enhanced CBM, the adsorption kinetics (and rate) and the diffusity of gasses into fractures / coal matrix and related monitoring were identified as main research targets. In general, monitoring CO_2 storage is situation specific. Here migration of free CO_2 and CBM through relative thin, deep coal seams and its overburden need to be monitored. For these reasons, the follow-up project MOVECBM was initiated by TNO, which started in November 2006, has a duration of 2 years, and is executed by a consortium of 17 research partners (Figure 5). The objective of the MOVECBM project is to improve the current understanding of CO_2 injected in coal and, hence, the migration of methane in order to ensure a long-term reliable and safe storage. The laboratory work and modelling will be based on parameters of the previously investigated test site in Kaniów, Poland. The injection well, realised in the EC RECOPOL project, is used in 2007 to produce gas from the coal seams (Figure 4). The composition of this gas is continuously monitored to define the actual adsorption of CO_2 that was injected in the coals seams during the RECOPOL project.

Figure 4 The well in Kaniów that was used as CO_2 injection well and that is used as production well in the MOVECBM project.

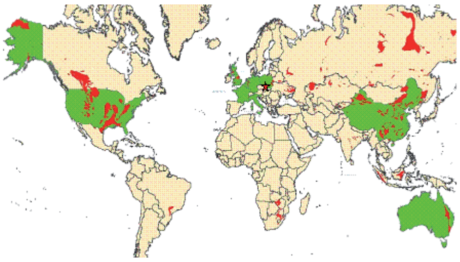

Figure 5 In red are indicated the major coal basins, in green is indicated the countries of the participating members of the MOVECBM research consortium. These are the Netherlands Organisation for Applied Scientific Research (TNO), The Netherlands, as coordinator; Central Mining Institute Poland (CMI), Poland; Shell International Exploration and Production (Shell), The Netherlands; Etudes et Productions Schlumberger (EPS), France; Universita di Roma "La Sapienza" (URLS), Italy; Faculté Polytechnique de Mons, Wallonia-Brussels Academy (FPM), Belgium; Universiteit Utrecht (UU), The Netherlands; State Key Laboratory of Coal Conversion (SKLCC), P.R. China; Rheinisch-Westfälischen Technischen Hochschule (RWTH), Germany; Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS), Italy; International Energy Agency-Green House Gas (IEA), United Kingdom; Environmental Research & Industrial Co-operation Institute (ERICO), Slovenia; Advance Resources International (ARI), U.S.A.; Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia; OXAND, France; Research Institute of Petroleum Exploration and Development, PetroChina (RIPED), P.R. China; China United Coalbed Methane Company (CUCBM), P.R. China.

Besides the field production test in Kaniów, a small scale combined injection and production experiment will be carried out in the Velenje coal mine in Slovenia. Horizontal injection and production wells are drilled in the coal. The results from the mine will fill the gap between the larger scale field experiment in Kaniow and the laboratory work.

These laboratory and field results of the MOVECBM project will allow to test optimal storage and production regimes and corresponding optimal monitoring methodology. Besides the coal reservoir and the cap rock also the wells and the (near) surface are monitored. Research will be performed on the resolution, geometry and time-intervals of the applied monitoring techniques. The combination of monitoring and modelling is essential for predicting long-term CO_2 and CH_4 behaviour and, subsequently, the long-term reliability and safety. A methodology is developed where, based on field test and laboratory results, models are updated and used to predict future behaviour and can be used to optimise the storage process.

Monitoring and verification guidelines for site certification are derived from modelling results and compared to broadly accepted standards. It is emphasised that the storage technology developed in this project can also be applied to other countries (e.g. China, Australia, USA), where major CO_2 emitters are located near large coal resources. These are optimal conditions for ECBM.

Acknowledgements

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17 research partners of the MOVECBM project (Figure 5) are also acknowledged for their contributions and financial support.

CO_2 Storage

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