Appendix 3

Background information on the potential for CO_2 sequestration in unmineable coal seams in Switzerland

Ronny Pini, Institute of Process Engineering, ETH-Zürich

Coal seams have been proposed as possible locations for permanent geological storage of carbon dioxide (IPCC, 2005). In particular, the coal seams that can be exploited for storage purposes are those with characteristics that preclude economic mining. These so-called unmineable coal seams are too thin, too deep or too high in sulphur content and mineral matter (White et al., 2005).

The way CO_2 is stored in a coal bed differs from other geological formations in the fact that, besides filling the available fracture and pore volume, the gas is adsorbed on the coal surface and within the coal matrix. In this form it has a much higher density than gas, and so the storage capacity of the available porosity is enhanced. During the geological processes that lead to formation of coal beds, significant amounts of methane are generated and retained in the coal bed, thus confirming that this storage mechanism is indeed taking place (Levine, 1993). Such coal bed methane can be recovered from the coal seam and used for energy production. Conventional primary recovery of methane, which is performed by pumping out water and depressurizing the reservoir, allows retrieval of 20-60% of the methane originally present in the reservoir (White et al., 2005). As in the case of enhanced oil recovery (EOR), such primary production could in principle be enhanced by injecting CO_2 into the coal seam from a second well. The injection of CO_2 effectively displaces the methane, owing to the higher adsorptivity of the former compared to the latter. As a rule of thumb, for each molecule of CH_4 desorbed, two molecules of CO_2 are adsorbed. Ultimately, most of the methane is recovered and the coal seam contains mainly CO_2, which is retained there by the same mechanisms that were acting on the methane. This technology, which in principle offsets the costs of CO_2 storage by the added value of the methane recovered, is termed Enhanced Coal Bed Methane (ECBM) recovery (White et al., 2005; Mazzotti et al., 2009).

The worldwide estimated storage potential of coal seams is small compared to other geological formations and varies between 3 and 200 $GtCO_2$ (IPCC, 2005). These values, together with a distribution of potential coal seams that do not always match the location of large CO_2 sources, suggest that the contribution of coal seams to the underground storage of CO_2 will be limited. This amount is nevertheless still significant compared to the current anthropogenic CO_2 emissions of almost 30 $GtCO_2$ per year (IPCC, 2007), and needs to be taken into account in the effort of finding ways for reducing greenhouse gas emissions.

In Switzerland, the presence of Permo-Carboniferous sediments is well known from alpine outcrops and NAGRA (Nationale Genossenschaft für die Lagerung radioaktiver Abfälle) drilling campaigns (F. Marillier, 2006). In particular, the well drilled at Weiach in 1983 first demonstrated the existence of coal-bearing strata in the Upper Palaeozoic Trough of Northern Switzerland, a structural depression bounded by faults and filled with sediments from the Carboniferous and Permian periods (Matter, 1988). Before reaching the crystalline basement, the well intersected several coal seams at depths between 1401-1752 m, with a cumulative coal thickness of about 32 m (Diebold, 1988). Unfortunately, this drilling test was not designed for the sampling of coal for laboratory analysis, with the consequence that significant material losses occurred. Preliminary

analysis of the recovered coal samples showed a high ash content (more than 20%), thus the Weiach sediments are classified as bituminous shales rather than coal (Diebold, 1988). Lower ash contents were measured only for the two coal seams that were crossed at a depth of 1542 m and 1585 m, respectively. The former is 50 cm thick, whereas the latter, with a thickness of 4 m, is recognized as the main seam of the whole formation. However, owing to their great depth, these coal seams are not commercially mineable (Diebold, 1988).

In the early 1990s, the question was raised as to whether it would be feasible to extract methane from the coal seams at Weiach. This was mainly motivated by the successful gas production from several coal seams in the USA. However, the decision was made not to drill further exploration wells in Weiach, as the potential for economically profitable gas production was considered very low (Lahusen, 1995). More recently, a study was undertaken to assess the potential of the Weiach coal for CO_2 storage and ECBM recovery (Wallquist, 2008; Pini, 2009). In particular, high pressure adsorption isotherms of CO_2, CH_4 and N_2 were measured at different temperatures on three coal samples taken from the Weiach well at depths of 1586 m, 1701 m and 1743 m, respectively (Pini, 2010). For these samples, the observed CO_2 adsorption capacity per unit mass of dry coal at the pressure conditions found at those depths (hydrostatic gradient) ranges between 3 and 6 wt%. For the main seam intersected at Weiach, Diebold (1988) estimated coal reserves between 100 and 200 Mt. This implies that the theoretical maximum storage capacity would be 3.3–12 $MtCO_2$. These values must be treated with caution as they are based on many assumptions. First, the geophysical investigations performed by NAGRA (mainly seismic reflections) do not permit a comprehensive reconstruction of the complex structure of the Permo-Carboniferous Trough (Diebold, 1988), and so estimation of the coal reserves is difficult. Second, the storage capacity has been estimated assuming that the coal is dry; however, even though the first step in ECBM implementation involves dewatering to reduce the reservoir pressure (Durucan, 2009), the coal seam may still be partly saturated with water. Any competitive water adsorption would reduce the capacity estimates given above.

It is clear from the above considerations that more studies are required to establish whether the Weiach coal could be used for CO_2 storage. In particular, more seismic surveys and additional wells are needed to elucidate the structure of the trough and the sealing properties of the caprock, the latter playing an essential role in the permanent trapping of CO_2. Moreover, a new well would provide fresh coal samples for laboratory analysis. Such coal characterization is aimed at understanding the mechanisms acting during the process of injection and storage in coal seams and can be achieved by experimental and modelling studies (Pini, 2009). Considering the limited extent of the coal seams in Weiach, the logical follow up of the preparatory studies would be a field injection test, rather than a large scale injection operation. The information gained from this test would be added to that obtained from other field tests worldwide, providing a basis to evaluate the effective storage capacity of the Weiach coal seams.

References

Diebold, P. (1988) Der Nordschweizer Permokarbon-Trog und die Steinkohlefrage der Nordschwiez. Viertaljahrsschrift der Naturforschenden Gesellschaft in Zürich, 133 (1): 143-174.

Durucan, S., Shi, J.-Q., 2009. Improving the CO2 well injectivity and enhanced coalbed methane production performance in coal seams. Int. J. Coal Geol. 77 (1-2), 214-221.

IPCC (2005) IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change. [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC (2007) Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds)]. IPCC, Geneva, Switzerland.

Levine, J. R. (1993) Coalification: The evolution of coal as source rock and reservoir rock for oil and gas. In: Law, B., Rice, D. (Eds.), Hydrocarbons from Coal (AAPG Studies in Geology)] 38: 39-77.

Lahusen, P. H. and Wyss, R. (1995) Erdöl- und Erdgasexploration in der Schweiz: Ein Rückblick. Bull. Schweiz. Ver. Petroleum-Geol. U. –Ing., 62 (141): 43-72.

Matter, A., Peters, Tj., Bläsi, H.-R., and Ziegler, H.-J. (1988) Sondierbohrung Weiach-Geologie. Nagra Technischer Bericht 86-01, Nagra, Baden.

Pini, R. (2009). Enhanced coal bed methane recovery finalized to carbon dioxide storage. ETH Diss. Nr. 18483, ETH Zurich.

Pini R., Ottiger S., Burlini. G., Storti G., Mazzotti M. (2010) Sorption of carbon dioxide, methane and nitrogen in dry coals at high pressure and moderate temperature. International Journal of Greenhouse Gas Control 4: 90-101.

Wallquist, L. and Werner, M. (2008) Carbon dioxide Capture and Storage – CCS. Studie zum Entwicklungstan von CCS in der Schweiz. ETH Zurich, Institute for Environmental Decisions (IED) im Auftrag des Bundesamt für Umwelt BAFU, 2008.

White, C. M., Smith, D. H., Jones, K. L., Goodman, A. L., Jikich, S. A., LaCount, R. B., DuBose, S. B., Ozdemir, E., Morsi, B. I., Schroeder, K. T. (2005) Sequestration of carbon dioxide in coal with enhanced coalbed methane recovery - a review. Energy Fuels 19 (3): 659-724.