Introduction

In order to retard further global warming, carbon capture and storage (CCS) is acknowledged as a technically and geoscientifically feasible option for reducing greenhouse gas emissions into the atmosphere. Amongst several other R&D projects related to carbon dioxide storage in depleted hydrocarbon reservoirs, saline aquifers, or unminable coal seams, the R&D project CO₂TRAP (http://www.co2trap.org) focuses on mineral and physical trapping of CO₂ as a permanent and inherently safe storage option.

The CO₂TRAP project is currently performed within the German R&D program “Geotechnologien, Investigation, Use and Protection of the Underground” (http://www.geotechnologien.de/index_en.html), which is funded by the Federal Ministry of Education and Research (BMBF) and the German Science Foundation (DFG). Besides from this, the project is supported by several industry partners, which are the power generating company RWE Power and the E&P company RWE Dea, Evonik New Energies GmbH as an electric power and heat provider, Deutsche Steinkohle AG DSK, involved in German hard coal mining, and, DMT, who offers, amongst others, services in mining, exploration, systems, and civil engineering.

In the scope of the CO₂TRAP project, we study and evaluate two different trapping technologies, mineralogical and physical, applied to future potential candidate storage sites, geothermal reservoirs, and abandoned coal mines. The project also considers site specific geological and technical settings, as well as the availability of different reactive raw materials.
**Technology I – Mineral Trapping: Precipitation of Aqueous CO\(_2\) as Calcium Carbonate in Formations Containing Calcium Sulphates and Feldspars**

In order to transform aqueous CO\(_2\) into geochemically more stable calcite (CaCO\(_3\)), one technology studies the potential of combining CO\(_2\) sequestration with the production of ecologically desirable geothermal heat or electric power.

From the economical point of view, costs for sequestration in deep saline aquifers could be transformed into a benefit.

The technical and scientific feasibility of mineral trapping is studied in a well balanced combination of laboratory experiments (including batch-, mixed flow rate- and core flooding experiments) and numerical modelling using the simulation codes SHEMAT (Clauser, 2003) and PHREEQC (Parkhurst and Appelo, 1999). The transformation of CO\(_2\) into calcite is governed by several site specific geological and operative parameters; e.g., the porosity, permeability, temperature, the salinity, alkalinity, availability of reactive components, as well as the pumping rate and associated flow velocities of the geothermal brine. Mass balance calculations are used to calculate the maximum storage potentials of potential geothermal reservoirs (Stralsund, North Germany) as well as to reveal the limiting operative and geological factors for this technology. With respect to the operative lifetime of a geothermal plant, limitations are given by the maximum amount of CO\(_2\) dissolved in the geothermal brine, followed by the solubility of anhydrite as a natural source for Ca\(^{2+}\) ions.

As an alternative attractive technology for mineral trapping, the potential of CO\(_2\) trapping by reactions of flue gas with alkaline fly ashes (called ALCATRAP, ALkaline CArbon TRAPping) investigates the use of fly ashes, a by-product of coal combustion for power generation. Using an autoclave system, reaction kinetics between alkaline lignite fly ashes and aqueous CO\(_2\) are studied at various solid-liquid-ratios, partial pressures of CO\(_2\), stirring rates, and temperatures. As a result, the technically feasible and promising technology ALCATRAP has a predicted potential to neutralize about 2% of the annual CO\(_2\) emissions of a coal fired power plant. Therefore, it is planned to demonstrate the technology in an industrial-scale pilot plant in the next project phase. A consortium of academic, research, and industry partners plans to optimize the technology in terms of process parameters and available materials at a real waste or biomass incineration plant.

**Technology II – Physical Trapping: Sorptive Storage of CO\(_2\) on Residual Coal and Coal Dust in Abandoned Mines**

Besides mineral trapping of CO\(_2\) as discussed in Technology I, options for physical trapping of CO\(_2\) in coal mines are studied in two conceptual studies: The sorptive CO\(_2\) storage on (i) residual coal and bedrock and on (ii) mining waste. Due to the high physical sorption capacity of coal and dispersed organic matter, unminable coal seams may provide an opportunity for the long-term CO\(_2\) storage and enhanced abandoned mine methane production (CO\(_2\)-EAMM).

As coal mining in Germany and some other European countries is now declining and will eventually phase out in the next decades, one conceptual approach investigates the feasibility of sorptive CO\(_2\) storage on residual coal and organic matter in gob areas and formation damage zones of abandoned coal mines. The main experimental and technical challenge consists in integrating physicochemical data with engineering and mining information. Based on comprehensive experimental studies on foreign and German (Ruhr and Saar Coal Districts) coal samples, CO\(_2\) storage potentials of abandoned coal mines are predicted. Another approach
considers underground CO$_2$ storage on mining wastes. Proven storage techniques developed by German mining research were adapted for underground CO$_2$ storage in gob areas created by longwall workings (Figure 1). Using drag pipes mounted at the roof support shields, the injection of CO$_2$ adsorbed on mining wastes proceeds with the advancement of the longwall face. Here, security considerations as well as the potential of subsidence mitigation by hydraulic stowage using mining wastes are addressed.

Figure 1: Conceptual design of CO$_2$ storage during longwall mining operations (from Busch et al., 2007).
Potential risks of CO$_2$ outgassing into the longwall face or adjacent workings are determined by means of numerical multi-phase and multi-component flow simulations. These allow the evaluation of CO$_2$ storage efficiency and security as well as the development and verification of general CO$_2$ injection and sealing strategies in geological formations.

One case study was chosen to estimate CO$_2$ storage potentials in abandoned coal mines in Germany: The coal mine “Westfalen” was flooded completely in 2007 and therefore reached hydrostatic pressure conditions of about 10 MPa (according to an average depth of the mine of 1000 m) and approximately 40°C - 45°C. The CO$_2$ storage potential of the mine is calculated to amount up to 2.70 Mt CO$_2$ at the assumed reservoir conditions, mainly absorbed on the residual coal but also dissolved in formation waters.

The CO$_2$ storage potential on mining wastes was estimated in a case study considering the utilization of the simultaneous CO$_2$ and mining waste injection during longwall mining (Figure 2) in Germany for the year 2004. A total CO$_2$ storage potential of at least 0.6 Mt/year is predicted for the operating German coal mines for this technology. The calculation is based on experimental data and mining specific information, obtained from German mining research institutions. This technology is applicable to other mining regions world-wide involving increased storage potentials resulting from differences in mining and coal processing techniques.

Figure 2: Side-face of CO$_2$ storage during longwall mining operations (from Langosch et al., 2006, modified by Kempka et al., 2008).
Sealing Efficiency

As a third overriding research topic, the sealing efficiency of several low permeability rocks (mainly shales) is studied in different laboratory experiments, comprising CO\textsubscript{2} diffusion and CO\textsubscript{2} sorption experiments. In a case study conducted on the Australian Muderong Shale, the sealing efficiency was determined. Results indicate a considerably high CO\textsubscript{2} sorption and retention potential as well as a measurable alteration of clay minerals, predominantly micas.

This study is, to our knowledge, the first comprehensive investigation of the CO\textsubscript{2} sorption capacity of natural shales and individual clay minerals under conditions relevant for CO\textsubscript{2} subsurface storage.

References