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From Site Characterization through Safe and Successful CO_2 Injection Operation to Post-injection Monitoring and Site Closure – Closing the Full Life Cycle Research at the Ketzin Pilot Site, Germany

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Initiated in 2004, the Ketzin pilot site near Berlin, Germany, was the first European onshore storage project for research and development on geological CO_2 storage. After comprehensive site characterization the site infrastructure was build comprising three deep wells and the injection facility including pumps and storage tanks. The operational CO_2 injection period started in June 2008 and ended in August 2013 when the site entered the post-injection closure period. During these five years, a total amount of 67 kt of CO_2 was safely injected into an Upper Triassic saline sandstone aquifer at a depth of 630 m - 650 m. In fall 2013, the first observation well was partially plugged in the reservoir section with CO_2 resistant cement; full abandonment of this well finished in 2015 after roughly 2 years of cement plug monitoring. Abandonment of the remaining wells will be finished by summer 2017 and hand-over of liability to the competent authority is scheduled for end of 2017. The CO_2 injected was mainly of food grade quality (purity > 99.9%). In addition, 1.5 kt of CO_2 from the oxyfuel pilot capture facility "Schwarze Pumpe" (purity > 99.7%) was injected in 2011. The injection period terminated with a CO_2-N2 co-injection experiment of 650 t of a 95% CO_2/5% N2 mixture in summer 2013 to study the effects of impurities in the CO_2 stream on the injection operation. During regular operation, the CO_2 was pre-heated on-site to $\sim$ 40°C prior to injection to ensure a single-phase injection process and avoid any phase transition or transient states within the injection facility or the reservoir. Between March and July 2013, just prior to the CO_2-N2 co-injection experiment, the injection temperature was stepwise decreased down to 10°C within a "cold-injection" experiment to study the effects of two-phase injection conditions. During injection operation, the combination of different geochemical and geophysical monitoring methods enabled detection and mapping of the spatial and temporal in-reservoir behaviour of the injected CO_2 even for small quantities. After the cessation of CO_2 injection, post-injection monitoring continues and is guided by the three high-level criteria set out in the EU Directive for transfer of liability: i) observed behaviour of the injected CO_2 conforms to the modelled behaviour, ii) no detectable leakage, and iii) site is evolving towards a situation of long-term stability. In addition, two further field experiments have been performed since end of injection. A CO_2 back-production experiment was run in autumn 2014 to study the physicochemical properties of the back-produced CO_2 as well as the pressure response of the reservoir. From October 2015 to January 2016, a brine injection experiment aimed at studying the imbibition process and residual gas saturation. Just prior to final well abandonment, drilling of two sidetracks in one of the wells is scheduled for summer 2017 to recover unique core samples from reservoir and cap rocks that reflect 9 years of in-situ CO_2 exposure and will provide first-hand information on CO_2-triggered mineralogical, mechanical and petrophysical rock property changes.