

Introduction to the thematic set: Geological storage of CO₂, gas and energy



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This thematic set emerged out of the 3rd EAGE Sustainable Earth Science Conference, held in the picturesque town of Celle in Lower Saxony, Germany, on 13 – 15 October 2015. This conference series was established to develop and promote an emerging group of applied geoscience topics focused on technologies for sustainable use of the subsurface to serve the energy transition; and the focus so far has been mainly on geothermal energy, CO₂ storage and energy storage. Inspired by the research emerging from this conference, the conveners proposed a thematic set on the common ground between long-term geological storage of CO₂ and the shorter-term cyclic storage of energy. The resulting set of papers is very rewarding, since they capture examples of all these topics and illustrate the complementary nature of subsurface studies on the storage of energy and CO₂. We have arranged the set to start with two review papers, followed by three papers on energy storage and then a further three on CO₂ storage.

In the first review paper, **Ringrose** takes a global look at the low-carbon energy transition, which is expected to be as significant as the industrial revolution two centuries earlier. This global-scale change in energy comes with many challenges, both sociological and technical. The sociological challenges are addressed by explaining the physical basis behind the urgent need to protect Earth's atmosphere from excessive emissions of greenhouse gas and by arguing for a sustainable approach to developing low-carbon energy systems. The more technical challenges involved in the energy transition are reviewed in terms of recent progress and future potential of three dominant components of the low-carbon energy transition, namely: developing new sources of renewable energy, switching from coal to natural gas, and deploying CO₂ capture and storage (CCS). To achieve the objectives of the recent Paris climate agreement, all low-carbon energy options must be deployed at an increasing rate in the coming decades. The second review paper by **Aochi et al.** looks at the challenge of controlling and managing seismic risk – a topic of common concern to geothermal, CO₂ storage and energy storage projects. Despite recent developments allowing more accurate 3D modelling of the subsurface, the understanding of coupled hydromechanical processes is still rather immature, and unexpected seismicity cannot be completely avoided. The authors propose a unified strategy encompassing improved understanding of the hydromechanical origins of induced seismicity, leading in turn to an improved basis for seismic risk evaluation. They show how probabilistic approaches can be used to give quantitative estimates of seismic risk.

Two papers address the geoscience underpinning energy storage.

Wang & Bauer look at compressed air energy storage (CAES) in porous formations and describe feasibility studies for a hypothetical CAES scenario using an anticlinal structure. Assuming extraction

cycles of 6 hours (in order to complement peak solar energy production) and a 321 MW gas turbine, they demonstrate the viability of a six-well system to deliver energy from compressed air stored in a 20 m-thick permeable rock formation. Their analysis both demonstrates the overall character of CAES systems (with power output dropping continuously from an initial maximum) and identifies non-linear behaviour caused by well interference. The following paper by **Pfeiffer et al.** looks at hydrogen storage for the scenario where excess renewable electricity is used to generate hydrogen, which then stored for later use in power generation. The concept of large-scale hydrogen storage in porous sandstone formations is investigated via numerical simulation of a storage operation at an existing anticlinal structure in the North German Basin. Different geological scenarios (facies models) were evaluated for cases using nitrogen as an initial cushion gas, followed by H₂ filling and withdrawal cycles. The study shows how the storage system can sustain a continuous power output of around 245 MW, with peak performance as high as 363 MW.

The more conventional form of energy storage, namely seasonal natural gas storage (CH₄), is addressed in the paper by **Otto**, who shows how more advanced subsurface mapping requirements will be needed for expanded use of gas storage in a sustainable energy context. Using the case of a salt-cavern gas storage facility at Jemgum in the Lower Saxony Basin (NW Germany), the author shows how advanced 3D seismic interpretation workflows, also used in petroleum exploration, can be usefully applied during planning and development of gas storage sites. Project challenges encountered include mapping of complex salt-tectonic structures, reconstructing surface meshes and understanding the fluvial heterogeneities in the overburden sequence. Future gas storage projects will need to use this type of integrated subsurface analysis in order to meet engineering requirements and to ensure safe operations.

Three papers in this set address different aspects of CO₂ storage. **Clarke et al.** look at the large-scale question of the estimation of CO₂ storage capacity in depleted gas reservoirs. A key question here is to what extent conventional methods for estimating gas reserves can be applied to CO₂ storage. Using production data from four depleted gas reservoirs on the UK Continental Shelf, the authors show how the effects of water influx can be quantified in terms of estimated CO₂ storage capacity. Effective storage capacity estimates were found to be around 50–80% of the theoretical estimates. Moving down to the pore scale, **Baritantonaki et al.** look at mineral reactions for the case of CO₂ storage in the Rotliegend sandstone, characteristic of the Rotliegend gas fields in NE of The Netherlands. Geochemical batch-reaction experiments for different grain-size samples were used to establish reaction rates associated with

dolomite dissolution. The experiments show that in an acidic regime, the dissolution of dolomite in brine is a factor of 2 faster than in deionized water, with grain size also playing an important role. Finally, in the paper by **Thibeau *et al.***, the topic of well-system integrity is addressed for the Rouse CO₂ storage demonstration pilot in France. Here, following CO₂ injection between 2010 and 2013, the injector well was plugged and permanently abandoned, giving a unique opportunity to study risk assessment associated with the project closure. The authors discuss and model the hypothetical presence of micro-annuli in the outer cement of the

well, concluding that migration of CO₂ into the local aquifer will not occur due to pressure gradients caused by the depleted reservoir. Although flow of aquifer water down into the reservoir could occur, the rates are extremely low.

Of course, these eight papers only give a small window into the world of geological storage of CO₂ and energy, but they also give an excellent pointer towards the issues that will occupy the next generation of geoscientists. We expect this to be a busy arena for future geoscience and welcome further contributions at future editions of the EAGE Sustainable Earth Science Conference.