DeepStor - High-temperature deep-underground thermal storage

Background

To limit global warming to 2°C above pre-industrial conditions, our society is confronted with the pressing need to accomplish the transition towards a sustainable energy system worldwide (IPCC, 2018). The decarbonization of the heating sector is of crucial importance for the energy transition and the implementation of climate protection aims in mid- and high latitudes since a large portion of the final energy consumption is used for heating purposes and industrial thermal processes. In Germany, the **heating sector produces almost 50% of the CO_2 emission** (Ausfelder et al., 2017). A climate-neutral society further requires solutions for the increasing share of fluctuating renewable energies (IEA, 2017) and the seasonal mismatch between the main supply of thermal energy in summer and the high demand in winter (REN21, 2019). Both can be addressed by thermal energy storage systems of high capacity (e.g. Lee, 2013). Geothermal technologies offer large perspectives in this context. One prominently utilized technology is the so-called ATES *("Aquifer Thermal Energy Storage")* with over 2'800 systems in operation in the shallower underground, especially in the Netherlands, providing more than 2.5 TWh for heating and cooling purposes per year (Fleuchaus et al., 2018). Of these systems, 99% operate at low temperatures <25°C, and very few at temperatures up to 80°C.

Envisaged **high-temperature storage systems (HT-ATES)** at greater depths exceeding the realized low to medium operation temperatures have the potential to play an important role in future thermal energy storage scenarios.

Potential

HT-ATES systems up to 150 °C could expand concurrent usage targeting mainly domestic needs to meet the demand of industrial processes or district heating systems by storing excess heat, e.g. solar thermal energy or waste heat. Areas of **former hydrocarbon production** could provide the necessary reservoir conditions for the realization of HT-ATES. The great advantage of these former hydrocarbon reservoirs is that they are well explored and parameters such as porosity and permeability are therefore known. The **water-bearing areas at the rim of these reservoirs**, which contain only small amounts of hydrocarbons, are potential target formations for HT-ATES. The Upper Rhine Graben (URG) comprises such systems, additionally having one of the highest temperature gradients of Central Europe of up to 100°K km^{-1} (Baillieux et al., 2013).

Generic numerical modeling of a possible installation in the URG shows that the **recovery efficiency** of HT-ATES in such systems significantly increases over time from 66% in the first year to 82% after ten years. The storage capacity of these systems primarily depends on reservoir permeability and thickness, injection/production flow rate, and the well geometry. A preliminary potential analysis study for the URG hydrocarbon province demonstrates that HT-ATES may be applied to a majority of the water-bearing rim areas of the former oil fields in this area (Fig. 1). In summary, it points to a total **storage capacity of approximately 10 TWh a^{-1}**, which is a considerable portion of the thermal energy needs in this area (Stricker et al., in prep). Against this background, existing knowledge and local experience may be transferred from the long history of hydrocarbon and geothermal exploration and operation (e.g. Böcker et al., 2017; Grimmer et al., 2017) to this promising future technology.

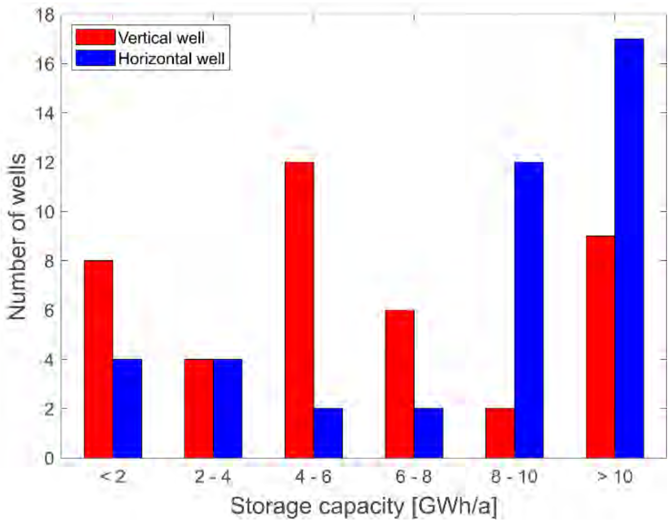

Fig. 1: Distribution of the storage capacity of suited oil fields in the URG. The bars illustrate the storage capacity of these reservoirs for both vertical (red) and horizontal (blue) exploitation wells.

KIT infrastructure DeepStor

Overview

Geothermal research at KIT is dedicated to develop sustainable geothermal exploitation technologies and CO_2-neutral high-temperature heat storage in the deep underground as a new element in the future global energy mix. DeepStor is a planned scientific infrastructure designed to **demonstrate the concept of HT-ATES** targeting former hydrocarbon reservoirs of deep sedimentary rocks. DeepStor is a scientific project and pursues an unprecedented approach. The project follows the **overarching KIT strategy** and is embedded into the Helmholtz Association's research in the *"Materials & Technologies for the Energy Transition"* program and the Helmholtz Climate Initiative.

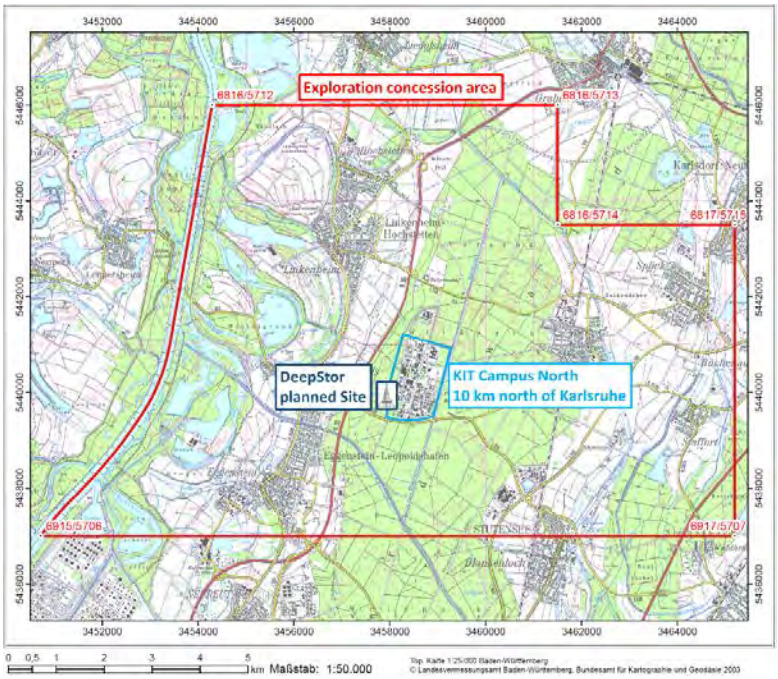

Fig. 2: Area of exploration concession around KIT Campus North. It is jointly held by KIT and EnBW.

DeepStor is located at the KIT Campus North, approximately 10 km north of the city Karlsruhe. This area demonstrates the **highest measured thermal anomalies** in Germany with temperatures up to 140°C in 2 km depth. Around the Campus North, KIT and the EnBW hold an exploration concession area (Fig. 2). The infrastructure project is divided into three phases resulting on the realization of specific milestones. **Phase I** aims at building a basic scientific infrastructure for an extended investigation of an HT-ATES system in rim of the depleted oil reservoirs. Its timeline foresees a construction in 2021 – 2024 and test operation in 2024 – 2027. This real-laboratory testing should provide 1) a detailed characterization of the underground by logging and coring, 2) the evaluation of the structural, hydraulic, and hydro-chemical set-up and the boundary conditions of the reservoir, and 3) short and long-term testing of hydraulic and thermal performance of the reservoir.

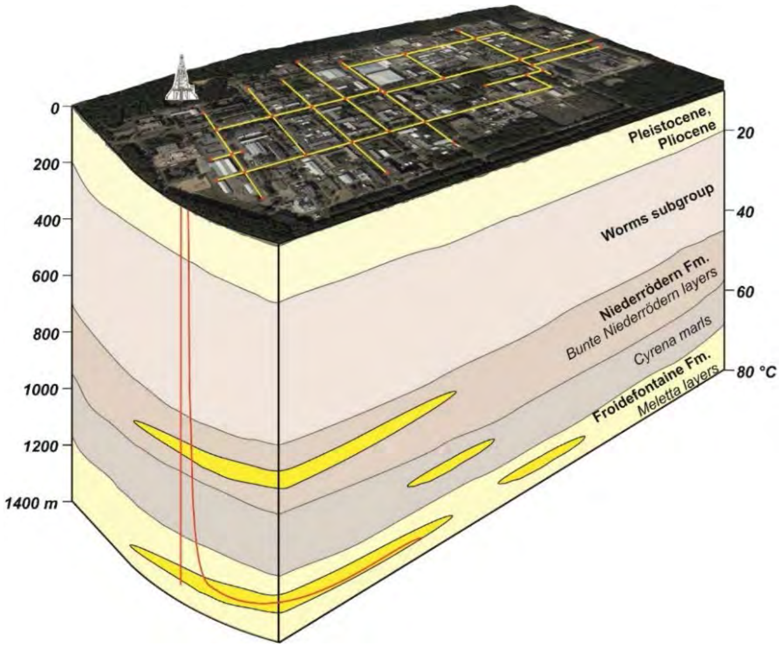

Fig. 3: Conceptual set-up of DeepStor – Phase III with major geological formations, a complete doublet connected to the existing district heating network at KIT Campus North.

Phase II addresses the engineering of the reservoir for heat storage. For this purpose, the drilling industry will be involved to optimize the system performance by drilling long horizontal wells. This may serve as a blueprint of geosteering for geothermal applications being rarely used outside of hydrocarbon exploitation. **Phase III** finally aims at integrating the HT-ATES system into the normal operation of the KIT Campus North heat supply (Fig. 3). Based on initial feasibility studies for the future operation scenario, a fully developed HT-ATES with an annual **storage capacity of 5 GWh** is planned, which can be upscaled in future.

Phase I: Experimental set-up

The scientific infrastructure DeepStor - Phase I (Fig. 4) will include the following setting:

- **Exploration well** to be completed as a high temperature test well (< 170°C): According to the results from pre-studies, the borehole will be drilled either vertically or at an inclined angle or even further deviated to optimize the hydraulic testing interval in the specific deep aquifer. Testing will be conducted as injection or production mode.
- **Vertical monitoring well** (incl. isolation of three zones and installation of pressure/seismic sensors, distributed temperature and acoustic sensors, fluid sampling)
- **Basin for testing** (temperature and corrosion resistant): The basin serves as a buffer storage of the pumped subsurface fluids and is having a size of 4'000 m^3 to allow for an extended testing period (i.e. > 20 days at a flow rate of 2 L/sec).
- **Injection and production** pumps and connections to and from the basin including a heat exchanger for heating purposes and oil and gas separators and storage for reinjection.

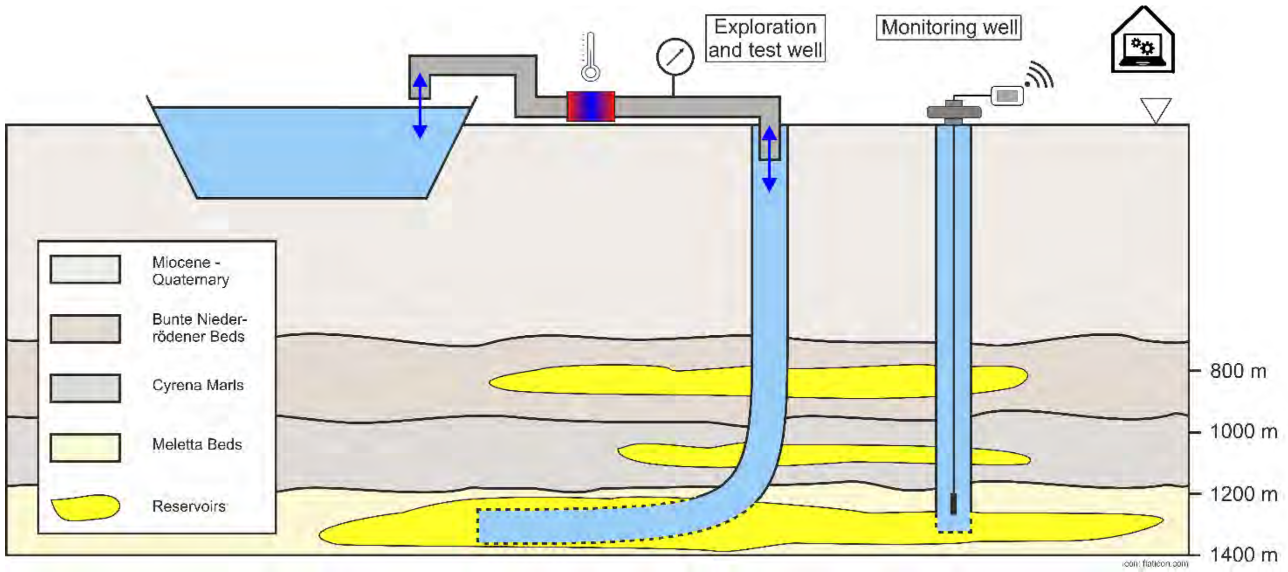

Fig. 4: Schematic illustration of the set-up of DeepStor (Phase I) with two wells for monitoring and injection/production, a heat exchanger, and a basin as buffer.

Scientific objectives

As HT-ATES systems show a large potential in future energy scenarios, but have never been realized before, demonstrators such as DeepStor are needed under thorough scientific supervision. Three overarching key objectives were identified to be addressed by DeepStor:

- **Feasibility**: to investigate whether the chosen site is suitable to advance it to a fully developed HT-ATES
- **Transferability**: to identify the most important conditions for the future development of HT-ATES systems (e.g. geological setting, sedimentological or geochemical information)
- **Process recognition**: the description of relevant chemo-physical processes that ensure an economically efficient and environmentally safe operation

According to the layout of the whole project, the scientific program will target a stepwise approach to tackle the complex interaction of these objectives. The program includes a central "*Science for Citizens – Citizens for Science*" approach with a close mutual interaction and exchange with the public also on technical topics such as data acquisition and digital information. Among the scientific subjects are:

- Reservoir behavior: Thermal-hydraulic-mechanical-chemical (THMC) processes under loading and unloading scenarios will be quantified using sophisticated numerical modelling applications. A special focus is placed on simulation of two-phase flow (oil/water).

- Hydrochemistry: As the Cenozoic water are known to be highly saline with TDS of up to 130 g/L, a thorough investigation of processes such as borehole scaling and corrosion of surface installations will be of crucial importance.
- Material sciences: Multi-physics simulations will be developed to characterize corrosion processes of materials as basis for the development of improved materials and processes. Novel functional nano tracers will be tested under field conditions and further refined.
- Seismicity and monitoring techniques: The installation of seismic sensors in the monitoring well will allow to investigate the occurrence of micro-seismicity to derive an optimized heat storage scheme. New monitoring schemes are to be developed.
- Informatics and data sciences: 3D visualization concepts will be developed for presenting the interpretation of data acquisition and numerical models. Adopted data concepts will account for the variability of source data to be handled for analyses, legal availability or visualization purposes.
- Sociology: The DeepStor project will also account for new strategies of public acceptance by engaging the public in a co-design process. Thus, the project is expected to have an impact on the acceptance of geotechnologies beyond DeepStor and geothermal storage systems.

It may be noted that there are further important aspects of deep thermal storage to be investigated, like possible conflicts with water legislation on ground water protection.

References

Ausfelder et al. (Hrsg.): Sektorkopplung - Untersuchungen und Überlegungen zur Entwicklung eines integrierten Energiesystems (Schriftenreihe Energiesysteme der Zukunft), München 2017. ISBN: 978-3-9817048-9-1

Baillieux, Paul; Schill, Eva; Edel, Jean-Bernard; Mauri, Guillaume (2013): Localization of temperature anomalies in the Upper Rhine Graben: insights from geophysics and neotectonic activity. In: *International Geology Review* 55 (14), S. 1744–1762. DOI: 10.1080/00206814.2013.794914.

Böcker, Johannes; Littke, Ralf; Forster, Astrid (2017): An overview on source rocks and the petroleum system of the central Upper Rhine Graben. In: *Int J Earth Sci (Geol Rundsch)* 106 (2), S. 707–742. DOI: 10.1007/s00531-016-1330-3.

Fleuchaus, Paul; Godschalk, Bas; Stober, Ingrid; Blum, Philipp (2018): Worldwide application of aquifer thermal energy storage – A review. In: *Renewable and Sustainable Energy Reviews* 94, S. 861–876. DOI: 10.1016/j.rser.2018.06.057.

Grimmer, J. C.; Ritter, J. R. R.; Eisbacher, G. H.; Fielitz, W. (2017): The Late Variscan control on the location and asymmetry of the Upper Rhine Graben. In: *Int J Earth Sci (Geol Rundsch)* 106 (3), S. 827–853. DOI: 10.1007/s00531-016-1336-x.

IPCC (2018): Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Intergovernmental Panel on Climate Change.

Lee, Kun Sang (2013): Underground thermal energy storage. London. Springer (Green energy and technology). Available online at http://www.loc.gov/catdir/enhancements/fy1502/2012942260-b.html.

OECD/IInternational Energy Association (Hg.) (2017): Energy Technology Perspectives 2017. Catalysing Energy Technology Transformations.

REN21 (2019): Renewables 2019 Global Status Report. REN21. Paris, France. Available online at https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf.

Stricker, K., Grimmer, J. C., Egert, R., Bremer, J., Gholami Korzani, M., Schill, E., Kohl, T.: The potential of depleted oil reservoirs for high-temperature storage systems. (*submitted*)