# VESTA - Very-High-Temperature Heat Aquifer Storage

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## ABSTRACT

Energy storage on a large scale is one of the key challenges of the energy transition. Eight international partners from Germany, Switzerland and the USA address this challenge in the joint project VESTA. The goal of VESTA is the generic development and demonstration of high-temperature aquifer thermal energy storage (HT-ATES). The involvement of four pilot sites in the DACH (Germany-Austria-Switzerland) region in various geologies and project phases allow feedback loops between generic scientific investigations and application of new geothermal technologies. Specifically, the pilot sites shall: 1) demonstrate HT-ATES technology, 2) evaluate technical and non-technical barriers, 3) support development and implementation by providing techniques and optimized component design, 4) provide field data to support coupled process modeling to assess HT-ATES system performance, and 5) support agencies with scientific and technical knowledge as a basis for advancing regulatory provisions. With this scientific program, VESTA shall form a technical-economic basis for future operational concepts.

## 1. INTRODUCTION

Energy storage is one of the key challenges of the energy transition. This applies in particular to heat, as this is subject to large seasonal fluctuations in supply and demand. Seasonal energy storage systems that make surplus energy from the summer months available as needed in the cold seasons contribute to the expansion of climate neutrality in a sector that causes a significant share of total $CO_2$ emissions. To this end, storage facilities must be developed in urban areas from which existing and future district heating networks can be fed. Because of the large volume required, underground storage facilities are an obvious choice. Due to the lack of experience and existing uncertainties, it is necessary to subject these to a more detailed scientific and technical examination.

Since the existing heat networks often require temperatures exceeding the supply temperature of about 85°C at the customer, demand temperatures of more than 100°C are common in the supply system during winter conditions. Industrial processes also often require a higher temperature, the input and output storage temperature would even have to be well above 100°C. New types of high-temperature storage (HTS) - i.e., deep underground storage - come into question for this purpose and must be designed, scientifically investigated and tested. Deep systems designed for this temperature range extend the existing use of geothermal energy, as they do not require large, interconnected flow paths, but only localized, permeable structures.

## 2. SCIENTIFIC CONCEPT

Within the scope of the VESTA project, which is being carried out by partners from Germany, Switzerland and the USA, it is intended to scientifically investigate the use of HTS systems on demonstration projects, since no corresponding test data on a commercial scale is yet available for high injection and withdrawal temperatures of more than >100°C. Many technical, regulatory, legal, environmental, and economic challenges need to be resolved to enable broader application of HTS. The overarching goals of VESTA are to:

- Demonstrate HTS at selected pilot sites with recommendations and conclusions for future projects,
- Evaluate technical and non-technical barriers, building on experience to date,
- Support the development and implementation of commercial projects by providing process understanding, modeling and monitoring techniques, and optimized component design,
- Provide field data to support coupled process modeling to assess HT-ATES system performance,
- Support government agencies with scientific and technical knowledge as a basis for further development of regulatory provisions.

Specifically, these goals will be realized through the development of tools that theoretically quantify the development and the challenges to be overcome, record them through laboratory experiments and monitoring on demo projects, and compare or validate the results with measured data. The generic scientific investigation results and products, (e.g., from numerical simulations and laboratory experiments), will be applied in the pilot projects, validated and further developed, and fed back into the generic development work, thus achieving transferability of the VESTA results (Figure 1). The conclusions generated by these efforts will be incorporated into recommendations that can serve as the basis for a new regulatory framework. Based on the specific experiences from previous HTS projects and complementary activities of the project partners in VESTA, this shall provide a technical and economic basis for future operating concepts.

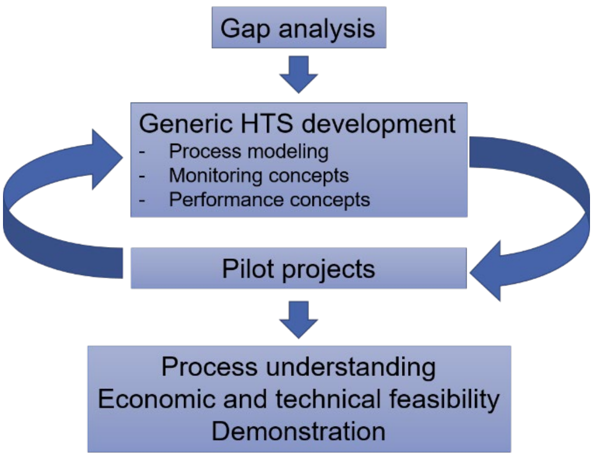


**Figure 1: Working structure of VESTA. Close feedback loops between generic work packages and pilot sites will provide a scientifically founded technical-economic basis for future operational concepts.**

The following scientific and technical objectives are addressed in the VESTA project:

- Identifying challenges to be overcome, based on lessons learned from previous HTS projects and preliminary investigations by partners.
- Process modeling for simulating the condition of the wells and reservoir, supported by laboratory experiments, incorporating realistic site-specific boundary conditions. The physical parameters obtained will be used for a proof-of-concept with benchmarking and calibration.
- Testing and validation of subsurface data through sensing and monitoring that characterizes the economic and technical feasibility and potential environmental impact of HTS.
- Proposing concepts of operation, system components, and appropriate environmental monitoring measurements, each with risk and mitigation analyses to meet regulatory requirements.
- Developing best practice guidelines for mitigating project risks and evaluating the potential for further siting and scaling up of the investigated demonstrator concepts.

## 3. PILOT SITES

### 3.1 DeepStor

DeepStor is a scientific infrastructure tackling research and development of high-temperature heat storage in the deep underground. Located in a former oil reservoir and in the area with the highest measured thermal anomalies in Germany, the project envisages high-temperature aquifer thermal energy storage (HT-ATES) in Tertiary sandstones. As a demonstrator, DeepStor serves to validate the technical feasibility of this storage technology at > 100 °C. As a research infrastructure, DeepStor enables loading and unloading experiments for investigating the associated coupled thermal, hydraulic, chemical and mechanical processes in the thermal water cycle.

The DeepStor site is located in the central Upper Rhine Graben (URG) at the KIT Campus North. The URG represents the central part of the European Cenozoic Rift System. The area includes Germany's largest temperature anomaly with about 170°C at a depth of 3’000 meters (Baillieux et al., 2014). The URG in the area of the DeepStor location accumulated > 2’000 meters of sediments. The depositional conditions are mostly shallow marine and result in thick deposits of marls with interbedded sand layers. The DeepStor target horizons, the calcareous fine-grained sandstones of the Niederrödern and Froidefontaine Formation, are located at about 800 and 1’300 meters’ depth, respectively. At the site, these sandstone layers are up to 10 meters thick with subsurface temperatures of about 70-80°C (Figure 2).

The DeepStor infrastructure has the following main objectives:

1. Systematically investigate HTS reservoir parameters to calibrate and benchmark numerical models and experimental approaches in WP2 using former hydrocarbon sandstone reservoirs (Stricker et al., 2020) and high-salinity fluids as examples (Banks et al., 2021).
2. Demonstration of the technical suitability of Tertiary sandstone reservoirs in the URG as HTS to optimize the planning of further projects.

During the VESTA project phase, the first well will be drilled. The following logging and testing will be executed as part of the VESTA work package:

- Sampling of formation waters in two reservoir horizons
- Petrophysical and structural logging
- Hydrotesting.

The temporal coincidence of the construction of "DeepStor" and the execution of the VESTA phase allows an optimal transfer of the experimental observations into further HTS developments. Logging and hydraulic test data will be collected for this purpose. Additional site monitoring will also be conducted to ensure that the field activities do not have any harmful environmental impacts.

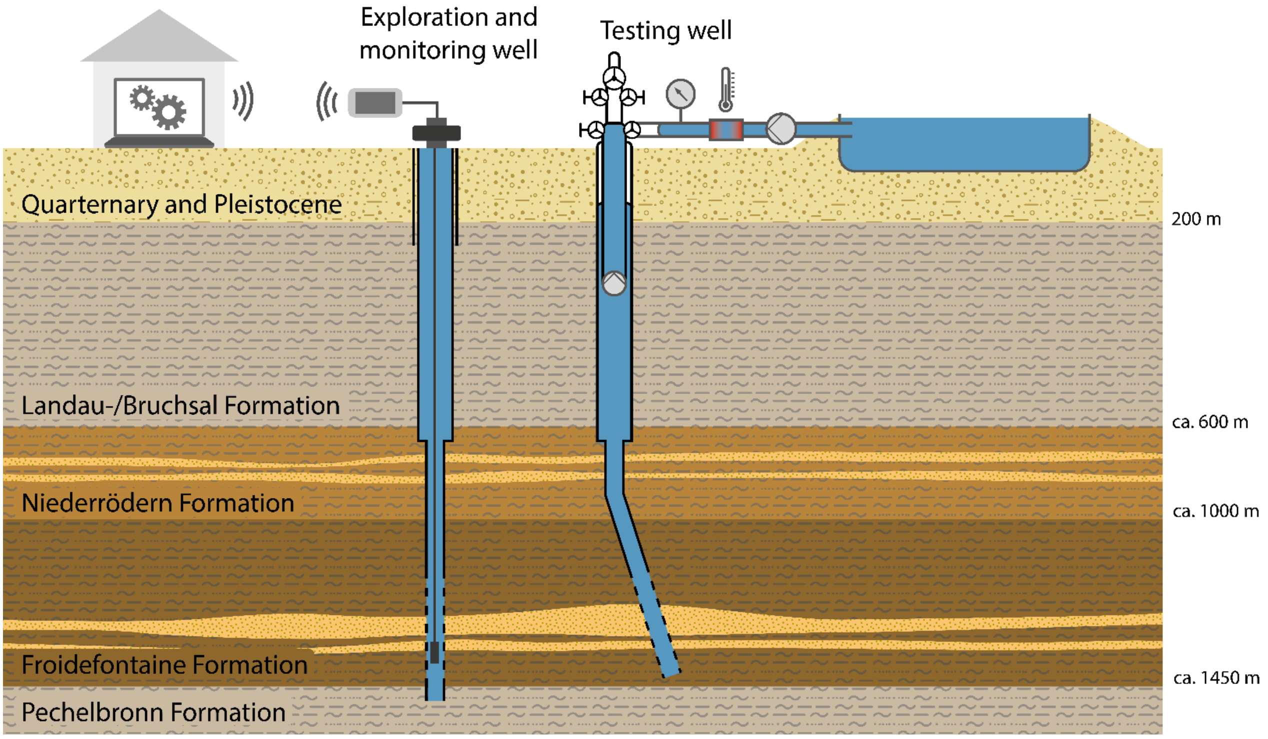


**Figure 2: Design of the Helmholtz research infrastructure DeepStor at the Karlsruhe Institute of Technology including the two wells DeepStor-1 for exploration and monitoring and DeepStor-2 for thermo-hydraulic experiments.**

### 3.2 CONCEPT STUDY MUNICH

The goal of the city of Munich is to provide a 100% $CO_2$-neutral heat supply in 2040 (Figure 3). The city is already one of the most important innovation centers for the utilization of geothermal technologies in urban areas. High-temperature heat storage to secure supply in periods with high heat demand is an important component of this goal. The HT-ATES shall be used for peak load supply, complementary to base load provided by conventional geothermal plants. In the VESTA project, the examination of the requirements for the feasibility of a HTS in the Malm carbonates at multiple sites in Munich is being executed. The following aspects are studied:

- Hydro-thermal, geochemical and geo-mechanical conditions
- Reliable monitoring methods
- Power plant concepts and integration into the district heating network (DHN)
- Heat management
- Regulatory frameworks
- Economic viability

A holistic approach is being followed by SWM, integrating the results of reservoir models, experiences and aspects of drilling engineering, production engineering, power plant concepts, DHN integration, and economic feasibility.

**Figure 3: Renewable heat generation: Construction site of Germany's largest geothermal plant in Munich (Schäftlarnstrasse)**

### 3.3 CONCEPT STUDY CONTRAST

CONTRAST is the acronym for **C**arb**ON**iferous **T**empe**RA**ture **St**orage and is the concept study of the Fraunhofer Institute for Energy Infrastructure and Geothermal Energy (IEG). Within a feasibility study, a basic understanding of the geological situation, the tectonic stress field, the required borehole design and the hydraulic regime shall be obtained by deep geophysical exploration below the IEG in Bochum. For this purpose, the folded and fractured sandstones of the Carboniferous will be investigated and characterized with regard to their thermal water flow and storage capacity. The IEG has a suitable location with the geothermal permit field "Future Energy". The focus of the feasibility study is the planning, execution and evaluation of a seismic survey in order to image exploration depths up to 2000 m below the IEG drilling site, if possible. In addition to the structural reconnaissance of the subsurface, the seismic survey also serves the execution planning for future deep geothermal drilling projects at the IEG.

### 3.4 PILOT SITE FORSTHAUS BERN

The goal of this pilot site (Figure 4) is to establish a geostorage for seasonal heat management as part of an urban district heating supply system. With the Forsthaus Bern geostorage system, the technical feasibility and economic viability are to be demonstrated. This will be done by design studies, testing of different loading/unloading schemes including possible resting periods, borehole simulations, sensitivity and uncertainty analyses, and power-to-benefit calculations.

The drilling of three 200 - 500 m deep boreholes in fluvial sediments of the Lower Freshwater Molasse was started in October 2022. Five wells (cold legs) will be drilled around one well in the center serving as injection well (hot leg). The boreholes are to be equipped with fiber optic cables to record temperature, acoustic and strain data. The monitoring with fiber optic sensors will be tested and validated to ensure the operation of the HTS and optimize its performance.

**Figure 4: The "Geospeicher Forsthaus" is being built on the site of the Forsthaus energy center.**

## 4. CONCLUSIONS AND OUTLOOK

The VESTA project deals with technical, economic, legal and organizational aspects of high-temperature thermal storage in the deep underground. Four pilot sites in various project phases and geologies in the DACH region are the backbone of the project and allow feedback loops between generic HTS development and scientifically accompanied implementation at pilot sites. In the development of new technologies, demonstration sites constitute an important step between research and industrial utilization, as they enable integrated system perspectives, drive risk mitigation strategies and foster public acceptance.

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