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Hagerbach Test Gallery – The Underground Future Lab

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ABSTRACT: The Hagerbach Test Gallery (VSH) - the Underground Future Lab - is an underground research laboratory with an over 5 km long unique network of caverns and galleries. Since 2025 VSH is recognized as a Swiss Research Infrastructure of National Importance. It offers ideal real-scale conditions for research activities underground. This paper will give insight into selected demonstrator projects showing the potential of the underground space.

Examples are the 'Underground Edge Computing' and the real scale 'Tunnel Digitalization Center', both offering the possibility to demonstrate and test new technologies and innovative developments. The concept of the Digital Twin will be extended to the complete VSH infrastructure to offer a broader portfolio for future R&D activities in addition to the physical testing site. The 'Underground Farming' installation is a real-scale prototype to produce regularly in precommercial smaller quantities salads of high quality. This Innosuisse project is executed in collaboration with the Zurich University of Applied Sciences, a company active in vegetable production, as well as an engineering consultancy for underground construction. More recently, activities in carbone dioxide removal (CDR) by storing hydrochar produced from wet biomass have been launched. Cavern thermal energy storage (CTES) will be tackled with a large-scale prototype installation for R&D purposes.

Jointly with partners from academia and industry, the Hagerbach Test Gallery will further intensify its activities and infrastructure investments in the mentioned focus areas and continue establishing large-scale prototyping for both scientifically relevant and application related questions for the future.

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1 INTRODUCTION

The origins of the Hagerbach Test Gallery Ltd. ('VersuchsStollen Hagerbach' (VSH) in German) date back to 1971, when after the closure of the nearby Gonzen mine (canton of St. Gallen, Switzerland) the necessity for a test site for underground heavy machinery became apparent. Shortly after, a certified testing laboratory for cementitious and rock material was established. Since then, numerous testing and research activities with industry in various field of the underground were carried out, over the years also in areas different than the original tunnel construction domain.

Since 2025 the Hagerbach Test Gallery is recognized by the Swiss Government as a *Research Infrastructure of National Importance*, allowing for significant investments into the infrastructure as well as for acting as a research partner in different R&D projects. This new status allows VSH to expand its activities in the future jointly with industry and academia.

This paper will present the underground infrastructure, past activities, and current and future projects in our four focus areas: a) energy, b) space habitats and safety, c) smart city, and d) heavy construction & operation.

2 UNDERGROUND INFRASTRUCTURE

Over the last 50 years, the Hagerbach Test Gallery has grown into an over 5 km long tunnel and cavern system including the mentioned materials testing laboratory as depicted in Figure 1. An overall surface of 25'000 m^2 gives the opportunity to perform industrial testing, academic research, and prototyping in a real environment but under laboratory-like conditions. The infrastructure allows industrial actors to test their developments at the forefront of market entrance as well as for training activities, supported by the available seminar rooms. Besides industrial and academic actors, the VSH infrastructure is

Figure 1. Hagerbach Test Gallery situation plan

regularly used by professional associations from Switzerland and abroad for various types of training and presentation events.

3 PAST ACTIVITIES

3.1 Tunnel Digitalization Centre

Over the years, digitalization has become an essential tool throughout the different phases of a construction project's lifecycle. This includes initial design and planning, construction, commissioning, operation, maintenance and also extension and modification. In collaboration with the Swiss Centre for Applied Underground Technology (SCAUT) and several industry partners, the Hagerbach Test Gallery has established the TDC, the tunnel digitalization center aimed at demonstrating and exploring efficient applications of digital tools in tunnelling and related underground activities.

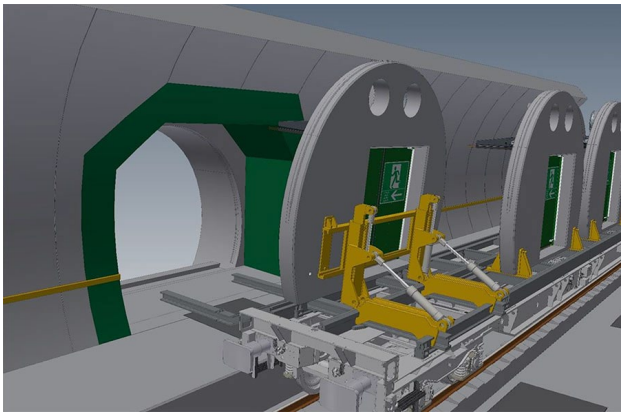

Figure 2. Digital Twin of the Gotthard Base Tunnel Safety doors

One initial application involved evaluating and testing of the technical feasibility and complete installation logistics for specially designed tunnel safety door systems for the Gotthard Base Tunnel as shown in Figure 2. Without the use of a digital twin,

this process is both time- and cost-intensive. The combination of BIM models and prototypes enables more flexible planning and improved optimization of the installation process compared to the traditional methods. The developments carried out by VSH and the different partners resulted in significant time savings of up to 80% during installation. In addition, the use of active sensors enables more efficient maintenance planning and faster response when interventions are required. Figure 3 shows the physical test installation used for practical verification of the installation process.

Figure 3. Installation setup for the Gotthard Base Tunnel Safety doors

3.2 Edge Computing

Led by SCAUT in collaboration with Amberg Engineering, Datwyler IT Infra, Geoeg, and Siemens, the Edge Computing Underground pilot project showcases a modular edge data centre installed within the Hagerbach Test Gallery (VSH). The projects demonstrated how underground space can support sustainable digitalization. Figure 4 shows the underground server installation.

Figure 4. Photo of the Edge Computing installation

3.3 i2Mine

In the framework of the I²Mine project, the goal was to develop innovative methods and technologies, for an efficient exploitation of minerals and disposal of waste carried out underground. The idea is to reduce the volume of surface transportation of minerals and waste, minimising above ground installations and reducing the environmental impact.

VSH as a consortium member was in charge of performing various robotized shotcrete tests (see Figure 5), during which a high-speed camera was used to assess various application phenomena. Material testing and quality control was also part of VSH's contributions.

Figure 5. Application of shotcrete and high-speed camera measurements

4 THE UNDERGROUND FUTURE LAB

The Hagerbach Test Gallery - The Underground Future Lab – has four strategic focus areas in which future research and development will be carried out. The following sections present an overview on currently ongoing projects and give an outlook about future activities.

4.1 Heavy construction & operation

Currently, in the field of *construction materials*, a real-time assessment of the gradation curve during concrete production in the plant is investigated. In a joint research project with the companies Kaiser Engineering GmbH, Fabrimex Systems, and the Universities of Applied Sciences of Eastern (OST) and North Western Switzerland (FHNW), an optical system based on high-speed cameras is used to capture in real-time the aggregate distribution (see Figure 6). This process based on machine learning allows for a constant verification of the real distribution versus the specified values. A closer capture of the real gradation curve allows for a more precise concrete production based on the initial recipe and among other things reduce the cement content, hence contributing to lower greenhouse gas emissions.

Further projects in this area deal with sprayed application of ultra-high performance fiber reinforced concrete (UHPFRC) for structural upgrading as well as natural fibers in concrete for an improved fire resistance.

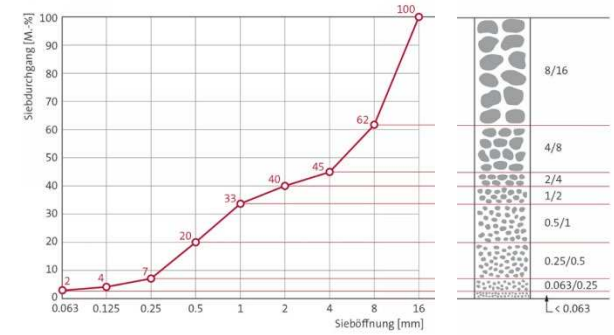

Figure 6. Example of camera captions of concrete aggregates and AI-based classification according to size. The geometric separation allows for a real-time assessment of the gradation curve.

4.2 Energy

Jointly with the *Subspace Energy Hub* (SSEH), various topics dealing with energy storage and usage for underground construction and mines will be addressed in the future. Battery-electric vehicles (BEV, see Figure 7), DC microgrids, autonomous megawatt charging, and hydrogen storage underground are some examples of the planned activities.

Figure 7. Example of a BEV for shotcrete application underground

In collaboration with the University of Applied Sciences Lucerne (HSLU), engineering consultancy Amberg Engineering, specialized contractor Heitkamp and further partners from the industry, a cavern thermal energy storage (CTES, see Parra et al. (2017)) prototype of about 90 m^3 in volume (see Figure 8) will be erected inside the VSH gallery in order to offer a long-term real-scale research infrastructure in the field of seasonal thermal energy storage. A first project will deal with different types of insulation and sealing strategies in order to define best practices regarding the construction and operation of such energy storage systems. A defined measurement system based on fiber optics and other sensoring will deliver information on various parameters such as temperature evolution, rock insulation, leakage effects, etc.

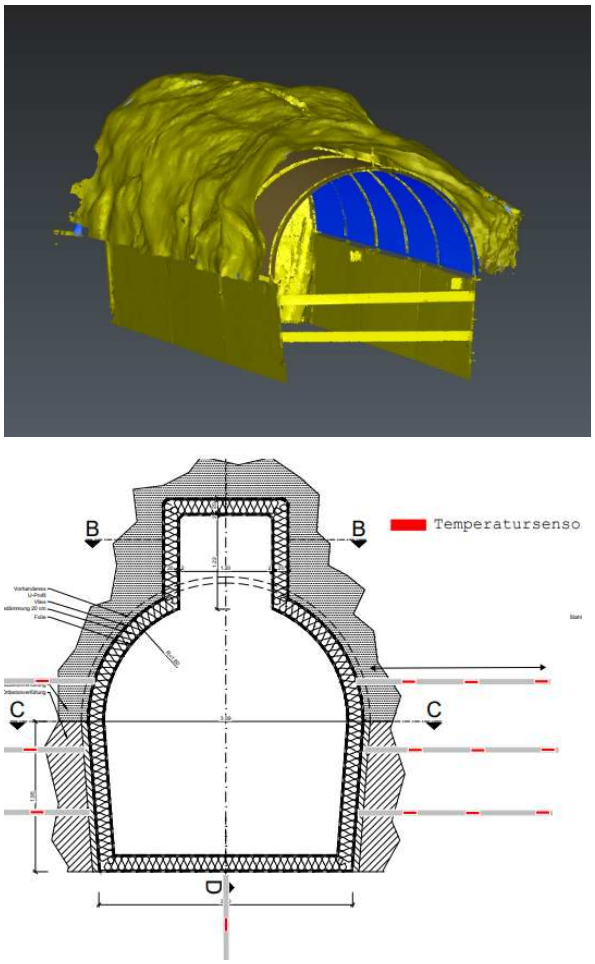

Figure 8. 3D scan of the VSH cavern (top) and section of the planned CTES (90 m³) including temperature measurements setup in the surrounding rock

4.3 Smart City

In collaboration with the University of Applied Sciences Zurich (ZHAW), Amberg Engineering, SCAUT, and food producer Forster Gruppe AG, vertical farming underground in assessed via an industry supported research project (Krzeminska et al., 2025). Stable temperatures during the full calendar year, no required pesticides, and available underground space are some of the advantages that subsurface caverns can offer for such production methods. They would further allow food production in regions where traditional agriculture is not possible due to climate reasons. Besides the technical feasibility, a strong focus of the investigation lies in the development of cost-efficient production parameters to guarantee a competitive solution in comparison to currently available methods. The extended cavern and a representation of the installation for the cultivation with a total length of 20 m is shown in Figure 9.

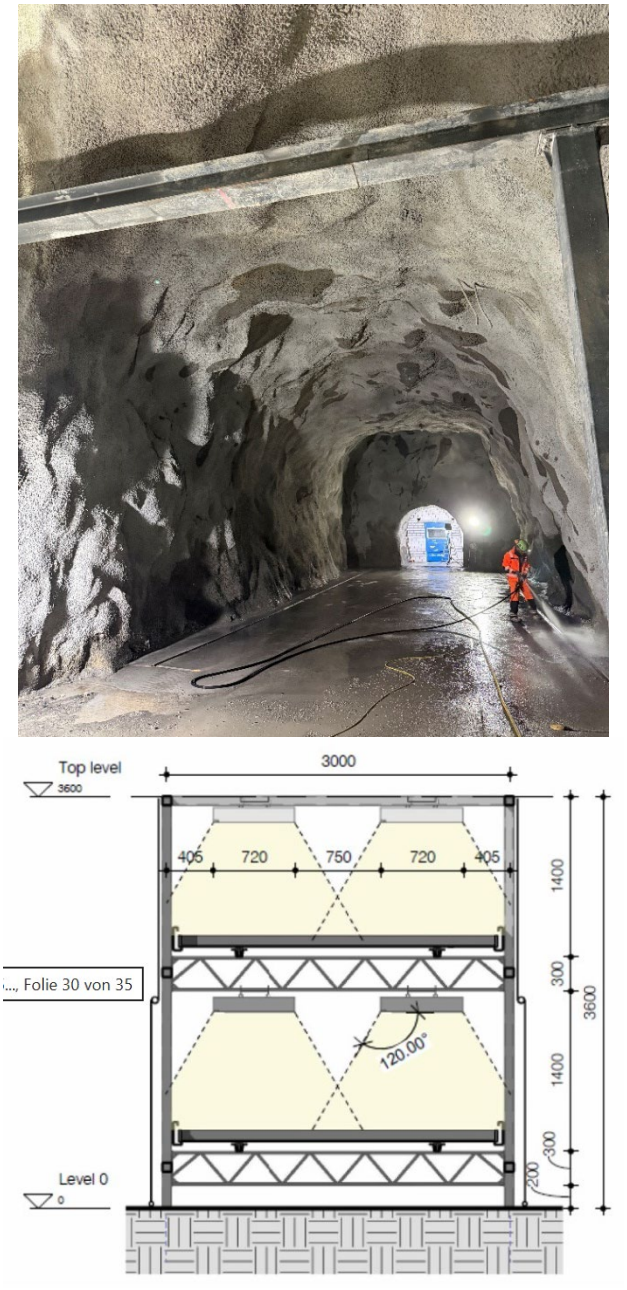

Figure 9. Modified cavern for underground salad production and representation of the 2-storey vertical farming installation

Carbon Dioxide Removal (CDR) is one possibility of reducing the CO_2 content in the atmosphere and thus contributing to net zero goals and strategies. Jointly with company Recoal, the University of Applied Sciences of Eastern Switzerland (OST) and the Swiss Federal Laboratories of Materials Science and Technology (Empa), the underground storage of a carbonized wet biomass is investigated (Marzban et al., (2024). Regular CO_2 content measurements shall demonstrate the long-term stability of the system. For this purpose, a large volume storage of 600 m³ (see

Figure 10) will be installed in a cavern and monitored on the long-term.

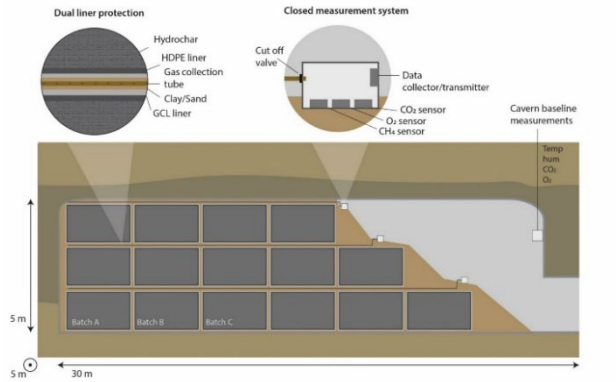

Figure 10. Large-scale underground storage of 600 m^3 carbonized hydrochar for Carbon Dioxide Removal (CDR)

4.4 Space Habitats and Safety

With future space missions on the moon or Mars, space habitats for longer stays will play a big role, this in combination with the local underground characteristics. At VSH, inflatable habitats at presented in Figure 11. will be the subject of investigation. Together with company Akashalabdhi from India, the habitat will be assessed according to various procedures such as component stability testing.

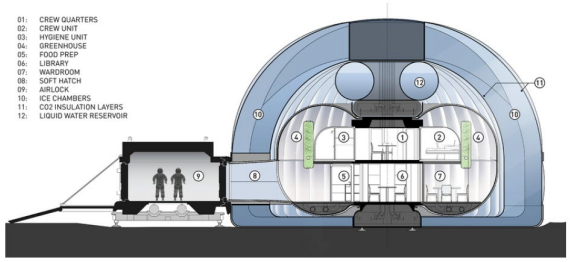

Figure 11. Inflatable space habitat

Additional activities for space application lie in the field of 3D printing technologies to deployed in space as well as in the erecting of a large-scale vacuum testing chamber.

5 VSH AS DIGITAL TWIN

In addition to the physical testing and research environment, a digital twin of the complete infrastructure underground will be established. This will create an added value for both industry partners being able to more efficiently plan their testing activities upfront, follow remotely the test results during execution, and dispose of an enhanced simulation tool. Academic research partners will also profit from the additional digital infrastructure by coupling experiments to material and structural models in real time and thus be able to establish a direct access to the test control and input.

6 OUTLOOK

After 50 years of industrial R&D, the Hagerbach Test Gallery Ltd. was granted the recognition as a Research Infrastructure of National Importance. This new status allows to establish closer ties to the academic world and to launch and expand activities in the four focus areas. Since the start as a test field for heavy machinery in tunnel construction and mining, the activities have been constantly expanded towards new areas in which the underground will play a major role in the future. The impressive underground infrastructure paired with a collaborative network of academic and industry partners will allow to develop new technologies and erecting prototypes to respond to societal challenges of our time.

ACKNOWLEDGEMENTS

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REFERENCES

Müller, D., et al. (2026): Cavern Thermal Energy Storage: state of play and prospects. *Applied Energy* 404, 127141.

Krzeminska, A., et al. (2025): Underground food farms as a climate friendly alternative form of urban agriculture, *Sustainability* 17(21), pp. 13-17.

Marzban, N., et al. (2024): Hydrochar stability: Understanding the role of moisture, time and temperature in its physiochemical changes, *Biochar* 6(38), pp. 1-17.