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Underground Space Use for Renewable Energy Production and Storage

Antonia Cornaro and Michael Kompatscher

Abstract The use of underground spaces for renewable energy production and storage has gained increasing attention as a strategy for making cities more sustainable. Underground spaces offer several advantages for energy production and storage, including insulation properties, thermal stability, and relatively low environmental impact. This paper explores the potential of underground spaces for renewable energy production and storage and highlights some promising examples and case studies. In addition to renewable energy production, underground spaces can also be used as storage facilities for renewable energy. One promising technology is underground pumped hydro storage. Another promising technology is compressed air energy storage (CAES), which involves compressing air into underground caverns or other spaces during periods of low energy demand and then releasing the air through turbines to generate electricity during periods of high demand. The SubSpace Energy Hub initiative that was created in June 2022 in the Hagerbach Test Gallery in Switzerland offers a platform for the development, prototyping, and installation of new technologies that promote best practices in sustainable energy use and storage. The aim is to be a model ecosystem of sustainable energy storage and delivery in support of green energy use in future cities. While there are still challenges to be overcome, such as the relatively high cost of some underground technologies and the need for appropriate regulatory frameworks, the examples and case studies outlined in this article demonstrate that there is already progress being made toward creating more sustainable cities using underground spaces.

Keywords Renewable energy · Underground · Technology

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1 Introduction

The use of underground spaces for renewable energy production and storage has gained increasing attention as a strategy for making cities more sustainable. Underground spaces offer several advantages for energy production and storage, including insulation properties, thermal stability, and relatively low environmental impact. This short paper explores the potential of underground spaces for renewable energy production and storage and highlights some promising methods and applications.

2 Sustainable Energy Sources

The pressing need for sustainable energy sources has led to a growing interest in harnessing renewable energy. However, the intermittent nature of renewable energy generation poses challenges to its widespread integration into the energy grid. The subsurface provides a unique opportunity to address these challenges by enabling efficient energy production and storage. This short paper explores several subsurface-based technologies and their potential to revolutionize the renewable energy landscape.

3 Geothermal Energy Extraction

Geothermal energy harnesses the heat from the Earth's interior, offering a consistent and reliable energy source. By tapping into subsurface reservoirs of hot water or steam, geothermal power plants generate electricity through steam turbines. Enhanced Geothermal Systems (EGS) are another technique that involves creating permeability in hot rock formations. EGS can unlock the geothermal potential in regions without natural hydrothermal reservoirs. Diagram 1 illustrates the geothermal power generation process. Alternative solutions under development are Advanced Geothermal Systems (AGS) based on a closed loop system harvesting the heat in deep rock formations and using water or CO2 as continuous heat transfer fluid. AGS have the advantage of being without fracking and long-term deterioration of fine cracks due to sintering (Fig. 1).

4 Underground Pumped Hydroelectric Storage (UPHS)

UPHS is a form of energy storage that utilizes the subsurface to store excess electricity for later use. It involves pumping water from a lower reservoir to an upper reservoir during periods of low energy demand and releasing it back through turbines to

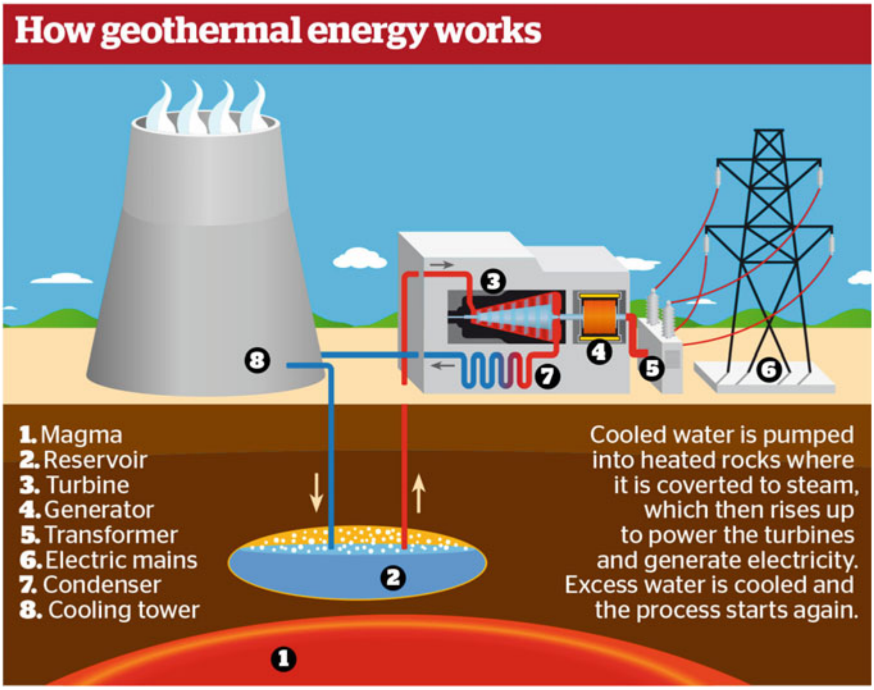

Fig. 1 Diagram of how geothermal energy works, from https://www.japantimes.co.jp/life/2019/03/09/environment/unlocking-japans-geothermal-energy-potential/

generate electricity during peak demand. UPHS has the advantage of high energy efficiency, long-term storage capabilities, and scalability. However, it requires suitable geological conditions and substantial infrastructure investments.

As an example, pictured here is the Grimsel Pumped Storage Power Plant Grimsel 3 in Switzerland which Amberg Engineering worked on in the planning and tender phase. Hydro power plant 660 MW is with the goal of the conservation and use of sporadic energy overcapacity in the power net (i.e., wind and solar energy). This is to lead to a solid stabilization of the Swiss power net. The pumped storage power plant is located under the earth's surface and will use mainly the waters of the existing water reservoirs Oberaar and Räterichsboden lakes (Fig. 2).

5 Hydrogen Storage

Hydrogen is an energy carrier that can be produced using renewable sources and stored for later use. The subsurface offers potential storage solutions for hydrogen, including salt caverns, depleted gas reservoirs, or geological formations capable

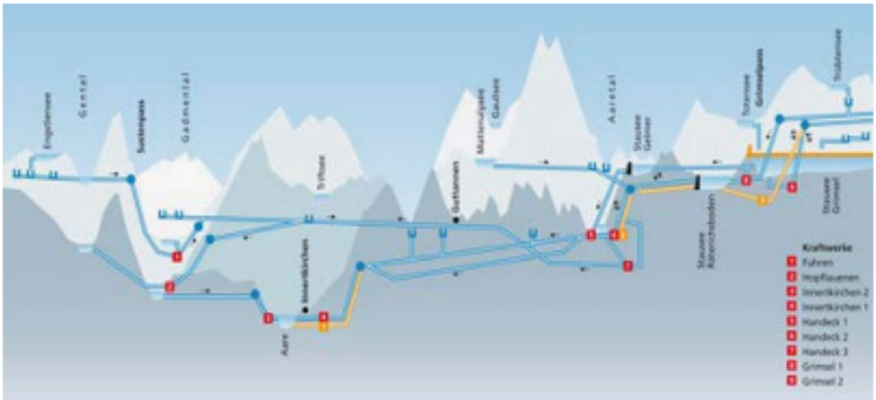

Fig. 2 Layout of supply lines / galleries and power houses of Grimsel Pumped Storage Power Plant Grimsel 3

of trapping hydrogen. Hydrogen can be produced through electrolysis powered by excess renewable energy and injected into subsurface storage.

However, challenges such as hydrogen leakage and cost-effective storage methods need to be addressed for widespread adoption. In order to move hydrogen storage technologies forward, it is important that hydrogen energy storage projects are demonstrated and scaled. This must happen through the support of power generation providers and initiatives like the SubSpace Energy Hub, bringing players together and offering the infrastructure to prototype the process on a small, but 1:1 realscale. This is something SubSpace Energy Hub is working on with industry partners and with tests at the Hagerbach Test Gallery, like geological studies on the acceptance of hydrogen storage solutions in hard rock or proper membrane technology to minimize the gas permeability into the rock.

The idea is to bring batteries and hydrogen together to solve energy storage issues in a fast, potentially economic manner and over longer periods. Hydrogen as a chemical energy storage can complement and serve as a reliable alternative to batteries especially when the price for hydrogen will drop and becomes more competitive. Hydrogen storage offers an alternative to offering a carbon-free solution.

6 Compressed Air Energy Storage (CAES)

CAES is another subsurface energy storage method that employs compressed air to store and generate electricity. During low-demand periods, excess electricity is used to compress air and store it in underground caverns or porous rock formations. During high-demand periods, the compressed air is released and expanded through turbines to generate electricity. While CAES offers large-scale storage potential, it requires specific geological formations and may face efficiency challenges due to energy losses during compression and expansion.

At SubSpace Energy Hub, this is a topic of interest from different partners and potential partners, and there is strong interest in testing and showcasing compressed air storage solutions placed in decommissioned oil caverns, or areas where windmills are located. The Energy Storage workstream is continuously developing and the first implementation projects of the partners are currently jointly starting up.

7 Case Studies

SubSpace Energy Hub, together with its partners, including SCAUT the Swiss Underground Center for Applied Underground Technologies, are working on pilots and prototypes for such applications.

The recently created project SubSpace Energy Hub in Switzerland offers a platform for the development, prototyping, and installation of new technologies that promote best practices in sustainable energy use and storage. The aim is to be a model ecosystem at the interface below/above ground for green energy production, sustainable energy storage, and delivery in support of net-zero future cities. Also, the aspect of AC/DC grits, supply stations, and related risk topics are jointly investigated at the site. Current partners include SCAUT, Hagerbach Test Gallery, Amberg Group, Normet Group, Xerotech, Motics, Alumina Systems, Fortescue Future Industries, SoHHytec, Implenia, SAK, Armstrong B2B, Sintef, and SUPSI. The partnerships with companies operating in the energy sector are growing significantly, and these collaborations will lead to more projects exploring the underground space potential to accommodate new solutions (Fig. 3).

With the current SubSpace Energy Hub member companies that offer new technologies and products related to green energy production, various prototyping opportunities are being developed and evaluated that combine these solutions and identify unique ways of approaching green energy in underground spaces. In a recent “Zero Hagerbach Challenge”, students of ETH Zurich from civil and engineering, spatial development, and infrastructure systems as well as architectural and geography backgrounds worked in 12 interdisciplinary teams on developing concepts for subspace energy systems. The task was to develop ideas for the underground research facility Hagerbach Test Gallers to reach net zero by 2040. The students exhibited and presented their work during the Hagerbach Innovation Day in August 2023.

Different assessments and ratings are started to document the continuous progress of transforming the Hagerbach Test Gallery via the SubSpace Energy Hub in a Net-Zero Construction site research environment and shared among the partners.

Fig. 3 SubSpace energy demonstrator in Hagerbach Test Gallery, Switzerland

8 Advantages and Limitations

Subsurface utilization for renewable energy production and storage offers numerous advantages, including enhanced energy reliability, increased grid flexibility, and reduced reliance on fossil fuels. However, there are limitations and challenges to consider, such as site-specific geological requirements, potential environmental impacts, and the need for large-scale infrastructure investments. System change is another aspect to consider, which takes time to implement.

9 Environmental Considerations

While subsurface energy systems offer potential benefits, they must be implemented with careful consideration of environmental impacts. Risks associated with induced seismicity, groundwater contamination, and greenhouse gas emissions from exploration and drilling activities must be thoroughly assessed and mitigated through proper regulation, monitoring, and industry best practices.

10 Conclusion

The utilization of the subsurface for the production and storage of renewable energy presents a promising solution to address the challenges of intermittent renewable energy sources. Geothermal energy extraction, UPHS, CAES, and hydrogen storage are among the viable subsurface-based technologies. However, careful consideration of geological suitability, environmental impacts, and infrastructure requirements is necessary for successful implementation. Further research, development, and collaboration among industry, government, and academia are essential to realizing the full potential of subsurface energy systems and achieving a sustainable and reliable renewable energy infrastructure. Infrastructures like Hagerbach Test Gallery and initiatives like the SubSpace Energy Hub are needed to fast track this path.