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INTERVIEW

with Prof. Rainer Helmig about wheather underground energy storage systems represent a threat to groundwater

RESEARCH

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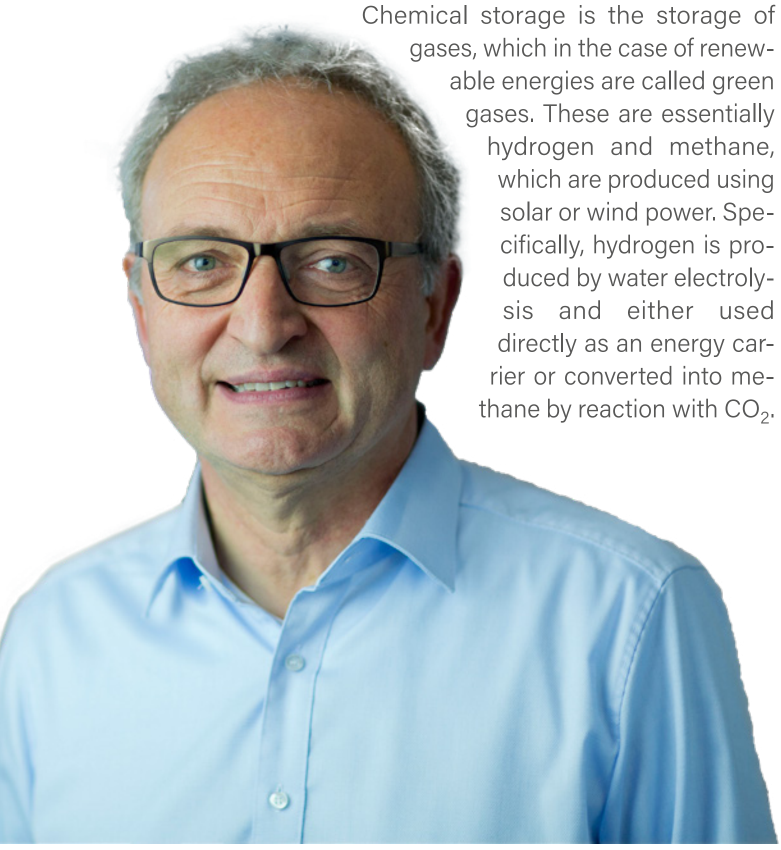
Underground energy storage systems: a threat for the groundwater?

Climate change is forcing us to reduce anthropogenic CO_2 emissions to zero. According to the Paris Climate Agreement of 2015, this goal is to be achieved by 2050. On the one hand, this requires maximum efforts to expand renewable energies. On the other hand, strategies are also needed to store renewable energies and energy sources so that they can be used continuously, regardless of the seasons or weather conditions. In addition, technologies are needed to recycle the CO_2 separated from exhaust gases or even from air, or to transport it to places where it cannot be released back into the air within a short period of time. Underground space is considered for a variety of uses in this context – but it is also precisely where a large part of the freshwater reserves, the groundwater, is located. Whether and to what extent underground energy reservoirs of various kinds can influence the quality or availability of groundwater is the topic of our interview with Prof. Rainer Helmig, head of the Department of Hydromechanics and Modelling of Hydrosystems at the University of Stuttgart.

Prof. Helmig, what possibilities for underground energy and/or CO_2 storage are currently being discussed?

There are three ways to store alternatively generated energy: mechanically, thermally, or chemically. Mechanical storage involves injecting air under high pressure into the subsurface and returning it to a turbine when needed. Thermal energy storage involves pumping water that has achieved a higher temperature during the summer into the ground. In winter, the water is brought out again and the energy stored in the water is recovered.

Chemical storage is the storage of gases, which in the case of renewable energies are called green gases. These are essentially hydrogen and methane, which are produced using solar or wind power. Specifically, hydrogen is produced by water electrolysis and either used directly as an energy carrier or converted into methane by reaction with CO_2.



Which geological formations are suitable for the storage of the possible energy sources?

Deep aquifers below an impermeable layer, a so-called caprock, are suitable for compressed air. The pumped-in air is distributed in the aquifer and displaces the highly saline deep groundwater. There are two problems with this storage technology that impair efficiency: first, the initial high pressure already decreases somewhat as the air distributes in the reservoir. The second challenge is temperature control: air is heated during compression, and cools again during expansion. If the heat generated during the pressure increase cannot be conserved during underground storage, heat may have to be added from outside during expansion to prevent icing when the air expands in the turbine – this means a loss of efficiency.

Gases are stored in underground caverns and chambers, e.g., in exploited salt domes, or in the pores and fractures of rock formations. These could be natural gas reservoirs or deep aquifers. Hot water could be stored in groundwater reservoirs near the surface. We have studied this storage method in India, for example, where the water is heated significantly during hot summers. I know of another example of this type of heat storage from a large project in Perth, Australia: there, a large computer center is cooled with groundwater. The volumes of water that are exchanged in the process are huge. In Germany, however, cooling with groundwater is subject to strict limits in terms of the temperature increase it causes.

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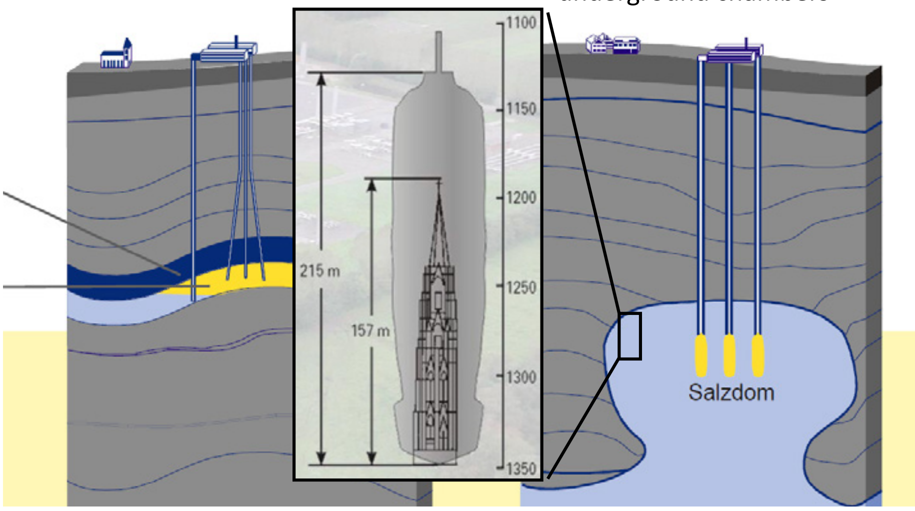

Figure 1: *Possibilities of underground gas storage with illustration of the required storage volume by comparison with the Ulm Cathedral.*

CO_2 storage does not count as energy storage, but it has been discussed as an option for climate protection for a very long time. Where are there large CO_2 storage facilities?

CCS concepts (CCS = Carbon Capture & Storage) originated with the ulterior motive of separating the CO_2 from the exhaust gases of conventional power plants fired with coal or gas, so that it is not released into the atmosphere. The CO_2 can be stored in a supercritical state, i.e., at a pressure of at least 74 bar and a temperature of around 31°C or above, in saline aquifers or exploited gas or oil deposits (on shore) or under the seabed (offshore). In Germany, underground CO_2 storage is possible in principle, but not realistically feasible due to political constraints. However, it was considered for years for research purposes.
In Norway, CCS technology is used on a large scale, but offshore under the seabed. We are also cooperating intensively in this area.

Let's look at the possibility of storage in salt domes. Is there still free capacity?

I am not an expert on this, but according to the information I have received, the salt domes are already exploited to a high degree, i.e., the caverns are already formed. Should we get to 100% renewable energy supply, we will need much higher storage capacity for the new gases. The existing storage capacity in salt caverns is only a small fraction of what is needed. I.e., you need completely different orders of magnitude. To illustrate this, I drew the Ulm Cathedral into a salt dome for a lecture (**Figure 1**).
In the case of a gas storage facility, it should also be noted that about one third to one half of the gas must remain in the storage facility as so-called cushion gas. Since these huge cavities are not available, we have to rely on the deep saline aquifers.

What conditions must be met here?

The most important requirement is the presence of a water impermeable layer, and this should be saturated with water. Because if this layer is saturated with water, there is a capillary barrier and a gas stored under high pressure underneath cannot migrate. But if there are fault zones in the system or circulations in existing well systems, leaks may occur.
If we are looking at supercritical CO_2, we need a minimum depth of about 700–800 m to maintain this critical pressure.

Interview partner

- Prof. Dr.-Ing. Rainer Helmig studied civil engineering at the Münster University of Applied Sciences and at the University of Hannover. At the University of Hannover, he obtained his doctorate focusing on the theory and numerics of multiphase flows in fractured porous media. Rainer Helmig then continued his scientific work at the University of Stuttgart, where he earned his habilitation with the topic of coupled underground flow and transport processes – a contribution to hydrosystem modeling. After a stopover at the TU Braunschweig, he returned to the University of Stuttgart in 2000, where he established the Department of Hydromechanics and Modelling of Hydrosystems (LH2) at the Institute for Modelling Hydraulic and Environmental Systems (IWS). From 2009 to 2021, he was the Dean of Studies for the study program "Simulation Technology" and was a member of the Board of Directors of the Cluster of Excellence EXC 310 and EXC 2075 (SimTech) at the University of Stuttgart. Since 2018, he has been the spokesperson and principal investigator of the Collaborative Research Centre (SFB) 1313 "Interface-Driven Multi-Field Processes in Porous Media – Flow, Transport and Deformation", funded by the German Research Foundation (DFG). From 2019 to 2022, he was also Magne Espedal Adjunct Professor at the University of Bergen in Norway, where he is involved in ongoing research on CO_2 storage.

"As far as CO_2 storage is concerned, one huge obstacle is the lack of acceptance among the population."

Which storage medium is the most difficult or dangerous in your opinion?
All three subsurface storage options imply interaction with the environment, i.e., all have some form of impact on groundwater.
When using aquifers, a high overpressure is created in the system by injecting compressed air or gas. Depending on the depth of the aquifer and the level of pressure, it is possible that a leak will occur at a fault zone of the impermeable layer. This location may well be at a greater distance from the injection point. Due to the increased pressure, saline deep groundwater can migrate upward through this leak into a freshwater aquifer that is used for drinking water production. This migration occurs in opposition to gravity and density difference. For our students, we once illustrated this process in model experiments (**Figure 2**).
The problem of leaks occurring at vulnerable points in the impermeable rock strata due to high pressures in the reservoirs is, in principle, a given for all gaseous energy sources. Of course, there is already extensive experience with methane as a medium.
As far as CO_2 storage is concerned, a huge obstacle is the lack of acceptance among the population. I was present at numerous citizen consultations. It is a mystery to me how this process can be made clear and understood by our population; I no longer know any solution to this. CCS was once intended as a transitional technology to absorb CO_2 emissions from conventional power plants as long as we still use fossil fuels for electricity generation. That will probably no longer happen in this country. But there is also the possibility of implementing CCS in conjunction with biomass as an actual CO_2 sink.

For hydrogen, too, I personally see difficulties in implementing such underground storage facilities. In the Netherlands, however, a demonstration project for underground H_2 storage in salt caverns was started last fall.
In 15 years of research on CO_2 storage, I have learned that it is not just a technical problem, but a social challenge. Even for trying to make physical relationships understandable, I was approached very aggressively at citizens' events.

How do you evaluate the fear of explosions caused by gases escaping from the ground?
Such situations are usually not to be expected, because high concentrations must be released for this. Youtube videos circulating on such incidents show cases in which flammable gases are carried to the surface with drinking water or groundwater near the surface. These are extreme individual cases. Such high concentrations must first be caused by migration.

Natural gas absorbs water during storage, which must be removed before it is fed into the grid. What volumes of water are we talking about?
This cannot be generalized because water absorption depends on the temperature and pressure in the system. In conventional gas storage systems, gas drying after withdrawal is state of the art. However, the processes that must be used to remove the water from the gas again after withdrawal reduce the overall efficiency of energy storage.

Source: Jan Martin Nordbotten and the FluidFlower team at the University of Bergen, Norway.

Figure 2: *The image shows a CCS set-up, demonstrating CO_2-storage in the underground: the yellow phase shows CO_2 saturated water and CO_2 as gas bubbles is identifiable as a light brown color. The experiment is part of the new Porous Media exhibition of the University of Bergen, displayed in the University Museum of Bergen from April 2022 to April 2023.*

Let's get back to drinking water production: Do you see a compatibility between the need for energy storage and the protection of our drinking water resources?

To do this, we must also master the social task of bringing mining law and water law together. With mining law, we are always digging under water law. We can only solve the problems if, on the one hand, we understand the migration paths, i.e., if we can best assess the risk of possible contamination of the near-surface groundwater. In addition, we need to think carefully about which energy sources will be better stored in which media. This is no easy task.

We always talk about deep aquifers for energy storage. But in some regions, these are already being targeted for drinking water use because upper aquifers contain too much nitrate. That doesn't make it any easier to reconcile energy storage and drinking water protection, does it?

The nitrate problem is exacerbated precisely by the fact that we have less green space, but instead grow energy crops for biogas production. These are then fertilized to the maximum so that yields are high.

With the development of deep aquifers, water suppliers are approaching storage facilities that were previously off-limits. This can of course lead to conflicts with the parties who want to establish new energy storage facilities.

Finally, let's talk about geothermal energy: How do you assess its impact on water management and/or energy storage possibilities?

The effects of geothermal energy differ according to the type of process used to exploit the underground heat: a distinction is made between deep and shallow geothermal energy, the latter being open systems with groundwater wells or closed systems with vertical probes up to about 100 m deep and horizontal collector systems installed at shallow depths. However, it is already evident in places where shallow geothermal energy has been particularly promoted that it leads to groundwater heating. If you apply these technologies in urban centers, I see a problem there. This is exacerbated by the climate-induced decline in groundwater levels. I don't want to demonize this type of energy production in principle, but I am concerned that all the possible interactions between the various uses of the aquifers and the effects on water management have not yet been properly penetrated.

Prof. Helmig, thank you very much for the interview.

The interview was conducted by Dr. Hildegard Lyko, originally for the April issue of the German magazine gwf Wasser|Abwasser (www.gwf-wasser.de).

LH2 University of Stuttgart

- The Department of Hydromechanics and Modelling of Hydrosystems deals with the broad field of flow in porous media. In this field, the University of Stuttgart (Germany) has developed into one of the essential centers of competence in recent years. In various current projects and Collaborative Research Centres (i.e. SFB 1313), interface-driven multi-field processes between porous media and gas- or fluid-filled channels and applications of multicomponent systems with chemical reaction and/or phase change are investigated, and suitable mathematical models and simulation software are developed.