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Editorial: Microbiology of underground hydrogen storage

Nicole Dopffel[1], Biwen Annie An-Stepec[1], Julia R. de Rezende[2], Diana Z. Sousa[3] and Andrea Koerdt[4]*

[1]NORCE Norwegian Research Center AS, Bergen, Norway, [2]Lyell Centre, Heriot Watt University, Edinburgh, United Kingdom, [3]Laboratory of Microbiology, Wageningen University & Research, Wageningen, Netherlands, [4]Federal Institute for Materials Research and Testing (BAM), Berlin, Germany

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Editorial on the Research Topic
Microbiology of underground hydrogen storage

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EDITED AND REVIEWED BY:
Uwe Schröder,
University of Greifswald, Germany

*CORRESPONDENCE
Andrea Koerdt,
✉ Andrea.Koerdt@bam.de

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As the energy demand of the growing world population rises, we are challenged with transforming our energy system from fossil fuel towards renewable. Hydrogen (H_2), as a universal energy carrier, has been proposed to be a front-runner during this energy transition. It can be used to de-carbonize industries that cannot use electricity directly like steel production, chemical production, aviation or heavy transport, and also be stored to overcome periods with low production of renewable energy (no wind and/or Sun) (Adam et al., 2020; Wang et al., 2022; Razzaq et al., 2023; Xuan et al., 2023). Massive amounts of H_2 need to be stored to provide mid- to long-term or seasonal storage for industries or even cities. Underground geological formations offer these required volumes in additions to the advantages of improved safety, low operational costs, and already existing infrastructure. Different types of underground hydrogen storage (UHS) can be used or considered depending on the storage period and demand. For seasonal storage, porous media structures like deep aquifers or depleted oil/gas reservoirs provide the necessary large volumes. Furthermore, artificial salt caverns and hard rock caverns can help to stabilize short-to mid-term energy demands. All these subsurface environments have in common that they are not devoid of life but harbor diverse microbial communities that can thrive under harsh conditions such as, oxygen-free, high temperature, high salinity, and/or high pressure.

The aim of this Research Topic is to draw attention to possible microbially induced challenges in the storage of hydrogen in the subsurface. What influence can microbiological processes have on the storage of hydrogen? What consequences can occur, what products can arise (e.g., toxic or corrosive H_2S), how can the risk be reduced, and how can we model, simulate in the laboratory, or predict the potential risks?

The aspect of microbiology is often not considered when planning underground hydrogen storage. However, many different microorganisms (both Bacteria and Archaea) can be present which is highlighted by all of the contributions of this Research Topic (Liu et al.; Schwab et al.; Strobel et al.; Tremosa et al.). Hydrogen is a universal energy carrier also for microbes and can be used as an electron donor by various microbial groups. In addition to a potential loss of the hydrogen (and thus economic loss), biological processes can also cause other potentially hazardous/costly/environmentally important consequences like H_2S formation, CH_4 formation, biological plugging, corrosion and can cause various geochemical reactions. The three microbial metabolisms of biggest concern are sulfate reduction, methanogenesis and acetogenesis.

Theoretically, the mentioned processes can be present in any storage site, but the complexity of biology does not yet allow a generally valid conclusion. It is rather the case that seemingly identical conditions and similar microbial communities can lead to completely different reactions for reasons not yet understood.

In the study of Liu et al., the hydrogen consumption by a halophilic sulfate-reducing microorganisms was studied in a pressurized microfluidic chip mimicking the porous media structure. The H_2 consumption and the potential effects caused by biofilm formation in porous rock, which can hinder hydrogen recovery, are considered. The microbial strain consumed the H_2 and this decreased the overall amount and also disconnected H_2 bubbles, which will lead to a less efficient recovery. They also observed that the wettability of the pore rock was altered by the microbes, which is an important chemo-physical parameter within reservoir engineering. The wettability changes were probably caused by the attached cells or by biofilm formation. However, clear evidence for bio-plugging was not seen but this result could look very different when using a different strain or a microbial community. The results show that under perfect conditions, sulphate reducers can consume significant amounts of H_2. More studies looking at different strains are necessary and whether the observed rates will also be possible in the field.

In contrast to the previous study, Schwab et al. used mixed communities enriched from hypersaline gas storage sites to perform microcosm experiments under H_2 atmosphere to test the effect of varying salt concentration and carbon sources. At regularly scheduled intervals, the cell numbers, acetate, lactate and sulfate concentrations, and the gas composition were monitored and after the experiment the composition of the microbial community was assessed by 16S rRNA gene-based amplicon sequencing. They showed a strong impairment of microbial activity with increasing salinity, including reduced sulfate reduction, leading to extremely slow rates. At low to moderate salinity concentrations, the addition of various carbon sources showed increased sulfate reduction. Without carbon sources, homoacetogenic activity at high salinity apparently facilitated sulfate reduction. In conclusion, they highlight that the effects of different acetate concentrations on sulfate-reducing activity in hypersaline systems will be a key issue for further research.

There are some known cases of microbially induced conversion during H_2 storage trials, e.g., Ketzin (Germany), Beynes saline aquifer (France), underground Sun storage project by RAG Austria AG (Austria) or in Lobodice town gas storage (Czech Republic). The latter showed the unintentional conversion of about 10%–20% of stored H_2 into methane which is typical sign of activity by methanogenic archaea.

In the study of Tremosa et al., based on this case of damage, it was examined whether three already existing models can simulate the loss of H_2 accurately. They included values/data of different parameters collected before the damage and evaluate which of the models simulate the observed situation best and what are the weak points of other models. They demonstrated the importance of considering the effects of microbial kinetics on aqueous redox reactions with hydrogen as an electron donor to properly simulate hydrogen reactivity. Testing the various ways to account for methanogenesis, sulfate reduction, and acetogenesis using different reactive models showed that an appropriate level of hydrogen reactivity can only be captured if kinetics controls these reactions. Calibration of kinetic rates and work on transferring redox reaction rates from the aqueous laboratory to the reservoir scale needs to be further developed. Furthermore, observational data from other hydrogen reservoirs are needed to better constrain hydrogen reactivity and its relationship to ambient conditions.

The increasing cases of subsurface hydrogen conversion by methanogens gave rise to a novel concept, the so-called bio-methanation process, where green H_2 and captured CO_2 are introduced into the subsurface and converted by methanogenic archaea into carbon-neutral CH_4. Focusing on this, Strobel et al. carried out laboratory experiments combined the results with modeling. With the focus on a methanogenic archaeon, data on growth kinetics, hydrogen conversion rates, changes in carbon concentration and gas concentration changes in the liquid or gas phase are considered in batch or chemostat experiments. They could culture the microbe and saw repeated H_2 conversion over time. They could successfully use their experimental data and built a first model as a basis to be used for predicting bio-methanation in future trials. The authors of the study, also draw attention to the weaknesses of their own study (e.g., changes in gas compositions could not be measured and therefore yield coefficient cannot be calculated, no diffusion coefficient was considered, the reactor was running without porous material). They highlight that more studies with an interdisciplinary background are needed to design meaningful modeling approaches, which will help to understand and predict microbial activity in the subsurface.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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