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Biogeochemical Conditions Impacting Hydrogen Storage in Gypsum-Anhydrite-Rich Salt Caverns

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The widespread deployment of wind and solar energy across the United States, along with the increasing use of electrolyzers to convert excess off-peak energy into pure hydrogen from freshwater, offers a promising pathway to reduce the nation's reliance on carbon-based fossil fuels and facilitate a steady transition to reliable renewable energy sources. Hydrogen is an attractive energy carrier because of its high energy density, natural abundance, and carbon dioxide-free oxidation process. The produced hydrogen can then be injected into solution-mined cavities within salt formations, offering a large-scale, long-term storage solution to supplement energy production during periods of low wind and solar output.

Gypsum-anhydrite-rich formations interbedded with halite are of particular interest for hydrogen storage due to their self-healing properties, large deformation capacity, and geographical overlap with existing renewable energy hubs in the US. However, significant knowledge gaps still persist regarding the feasibility of long-term hydrogen storage in salt caverns, primarily due to hydrogen's high reactivity and the complex biogeochemical conditions within these caverns. Sulfate-reducing bacteria, anaerobic halophiles commonly found in salt caverns, are of particular concern due to their ability to utilize dissolved sulfate minerals as electron acceptors and hydrogen as an electron donor, reducing sulfate to hydrogen sulfide–a highly corrosive and toxic byproduct. This reaction can lead to the leakage of hydrogen sulfide through pore fractures into overlying potable groundwater aquifers, contaminating drinking water sources and threatening public health. Additionally, this reaction depletes stored hydrogen and alters brine chemistry, posing significant risks to the efficiency and safety of underground hydrogen storage systems.

Understanding the role of sulfate reducing bacteria in hydrogen consumption and their potential adverse effects on overlying potable water aquifers is imperative as hydrogen storage in salt caverns becomes a widely adopted energy storage solution. By utilizing a biogeochemical modeling software, CrunchFlow, the impacts of hydrogen leaks into shallow aquifers above storage sites will be analyzed, offering relevant information required to optimize underground storage system efficiency, performance, and scalability.

The model will simulate hydrogen consumption over time in batch experiments, taking into account factors such as electron acceptors, pH, and ionic strength. The model will also include mineral speciation and gas-water-rock partitioning reactions at equilibrium. The simulation will be modeled as a closed system, with both a liquid phase for the brine present in cavities and a headspace containing gaseous components such as hydrogen and nitrogen, assuming ideal behavior for gas partitioning. Key factors influencing sulfate reduction, such as pH, partial pressure, and brine salinity, will be systematically varied to assess their impact on sulfate reduction reaction kinetics.

The modeling results are expected to identify parameters governing hydrogen consumption over time in batch experiments and increase reaction kinetic parameter accuracy for hydrogen consumption calculations associated with other microbial communities expected to be found in halite storage reservoirs.

Ultimately, this research aims to identify environmental conditions that minimize microbial-driven hydrogen consumption in underground halite reservoirs, supporting the large-scale deployment of hydrogen storage and advancing the transition to a more sustainable energy future.

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References

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