On the Feasibility of the Underground Hydrogen Storage

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Requested funding amount: $24,964

Summary: Hydrogen is a promising source for clean energy and an important component for achieving the targets of a carbon-free grid and net-zero carbon emission from energy usage. This, however, needs reliable methods to store hydrogen, for which some viable options are porous and permeable formations and mine/salt caverns. Considering that the former is more globally abundant than the latter, they are promising candidates for future hydrogen storage. This, in turn, requires characterizing these formations for their storage and sealing capacity using geological and geophysical data. In addition, after hydrogen injection, it is also necessary to combine time-lapse geophysical data with fluid-flow simulation, geomechanical modeling, and rock-physics into a joint optimization to monitor the migration of the injected fluid and ensure containment and recoverability. In this research, we aim to combine laboratory experiments, optimization theory, data science, and artificial intelligence to study the feasibility of underground hydrogen storage.

The research problem and the long-term benefits: Fig.1 provides the concept of hydrogen (H_2) based energy. Productions from clean renewable resources (solar, wind, hydropower, etc.) seasonally fluctuate, resulting in renewable energy excesses or deficits. Thus, to meet energy demand, H_2 can be produced and stored during periods of excess renewable energy production, (Fig. 1a) and used for energy production during the periods of renewable energy deficit (Fig. 1b). To do so, it is however important to find ways to store hydrogen underground because surface storage facilities are not adequate. And one viable option for such underground storage are porous and permeable formations, such as the saline aquifers and depleted hydrocarbon reservoirs. The success of such Underground Hydrogen Storage in Porous media (UHSP) lies in successfully monitoring them to ensure totality and no loss of the injected gas via leakage, chemical reactions, and capillary trapping. Although the time-dependent behavior of carbon dioxide (CO_2) sequestered reservoirs are well studied, they are mostly untested for UHSP. CO_2 is stable in supercritical phase at the formation depths of interest. H_2 on the other hand, is stable as gas at similar depths. Density of supercritical CO_2 (~0.941 g/cm^3) is close to that of brine. The sound-speed (P-wave velocity or V_P) of supercritical CO_2 (~280 m/s) is, however, much less than that of brine. Consequently, when brine is replaced by supercritical CO_2 in a porous formation, the sharp drop in V_P is detectable from the seismic data. On the contrary,

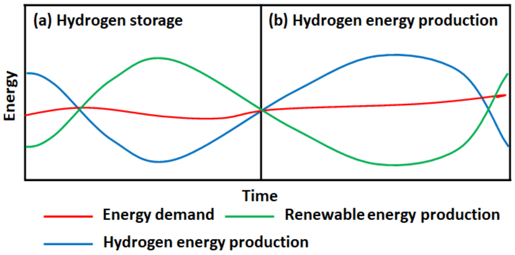

***Fig 1**. The concept of hydrogen storage and production. (a) Production from renewable energy exceeds energy demand. (b) Production from renewables is below energy demand.*

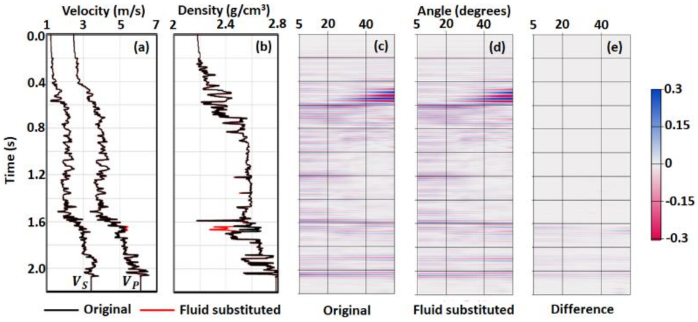

***Fig 2**. Seismic signature to H_2 presence. (a), (b) Model, (c)-(e) computed seismic responses and their difference.*

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V_P of hydrogen gas (~1400 m/s) is comparable with that of brine and its density (~0.00084 g/cm^3) is much less. Consequently, if an 100% brine-saturated rock is replaced by H_2, there is a sharp drop in density (ρ), the S-wave velocity (V_S) remains almost unchanged, and V_P slightly increases (Figs. 2 a, b). This replacement, in turn, produces visible density-driven reflection differences between the original seismic data and that after replacing brine with H_2 for the interval of fluid replacement and underneath (Figs. 2 c-e). Although seismically detectable, we must note that as H_2 is injected, it would move vertically and laterally, controlled by (1) viscosity and diffusivity of H_2 and (2) vertical and lateral permeability of the formation. As pointed out by Heinemann et. al. (2021), the low viscosity and high diffusivity of H_2, in conjunction with the formation permeability anisotropy, would increase the risk of viscous fingering (patchy saturation) of fluid phases. This patchy saturation would increase the risk of unrecoverable H_2, which we must minimize for maximum resource recovery for H_2 based energy production (Fig. 1b). This, in turn, requires (1) running laboratory experiments on the core samples for extracting their physical properties in the presence of H_2, (2) developing a static reservoir model, (3) running fluid flow and reservoir simulation to produce dynamic models, and (4) seamlessly combine steps 1-3 via rock-physics and machine learning for H_2 injection and production to maximize both storage capacity and recoverability. Focusing on these steps would be the objective of our research.

Considering the long-term goals of achieving a carbon-free grid and net-zero carbon emission, H_2 is a vital component of the clean energy portfolio. Consequently, there are potential long-term benefits for this research.

Short-term objectives: We will focus on a synthetic study. We already have core samples, well-logs, seismic data, and a static reservoir model for the Rock-Springs Uplift (RSU). Therefore, our study will be based on the RSU model. We will synthetically inject H_2 in the Weber sandstone formation, which has been thoroughly studied (Grana et. al., 2017), and run fluid-flow and geomechanical simulations to compute dynamic models to develop an understanding of the optimum injection and production rates needed to maximize the H_2 storage and its recoverability for this formation.

Funding sources: We have already submitted one grant proposal to NSF. Because this proposal was based only on conceptual ideas without concrete results, we do not anticipate the chances of our success to be very high. This funding would let us write additional proposals, not only for the Federal agencies like NSF/DOE, but also for the private oil/gas companies and secure additional funding.

References

Heinemann, N., Alcalde, J., Miocic, J.M., Hangx, S.J.T, Kallmeyer, J., Christian Ostertag-Henning, C., Hassanpouryouzband, A., Thaysen, E.M., Strobel, G.J, Schmidt-Hattenberger, C., Edlmann, K., Wilkinson, M., Bentham, M., Haszeldine, R.S., Carbonell, R., and Rudloff, A., 2021, Enabling large-scale hydrogen storage in porous media – the scientific challenges, *Energy & Environmental Science*, **14**, 853-964, https://doi.org/10.1039/D0EE03536J.

Grana, D., Verma, S., Pafeng, J., Lang, X., Sharma, H., Wu, W., McLaughlin, F., Campbell, E., K. Ng, Alvarado, V., Mallick, S., and Kaszuba, J., 2017, A rock physics and seismic reservoir characterization study of the Rock Springs Uplift, a carbon dioxide sequestration site in Southwestern Wyoming, *International Journal of Greenhouse Gas Control*, **63**, 296-309, https://doi.org/10.1016/j.ijggc.2017.06.004.

Budget Description

Category	Amount	Comments
Salary, senior personnel	$3,029	0.1-month summer suport for both PI
Salary, graduate student	$11,892	6-month support for one graduate student
Fringe benefits	$1,453	40.9% of the senior personnel and 1.8% of the graduate student salaries
Publication-cost/Page-charges	$1,150	Publication costs and page charges
Graduate student tuition & fees	$5,440	Tuition and fees for the graduate student
Travel	$2,000	Travel expenses to attend conferences
Total fund requested	**$24,964**	**Total project cost**

Table 1: *Estimated budget.*

Table 1 is the estimated budget for the research. Justifications for each budget category in this Table are as below:

- **Salary, senior personnel:** We anticipate each senior personnel (Mallick and Dejam) must dedicate 0.1 month to advising one graduate student to carry out this research.
- **Salary, graduate student:** Although this research would require one graduate student research for a few years, we request only 6 months support for the student.
- **Fringe benefits:** Calculated at 40.9% of the senior personnel and 1.8% of the graduate student salaries.
- **Publication-cost/Page-charges:** Cost to cover expenses involved for peer-reviewed journal publications.
- **Graduate student tuition & fees:** Six-month tuition and fees for the graduate student.
- **Travel:** Expenses to partially cover the travel costs for attending conferences.