From Characterization to Monitoring: Preparing for Hydrogen Injection at the Devine Test Site

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Summary

The Bureau H_2 test at the Devine test site aims to advance hydrogen storage in aquifers through detailed site characterization and innovative monitoring techniques. The Devine test site, near San Antonio, Texas, offers extensive infrastructure and geophysical data. The Olmos Sandstone at 1,600 feet, with 30% porosity and 400 mD permeability, was identified as the target aquifer.

A comprehensive site characterization survey, including ultra-high-density 3D seismic and VSP, has already been acquired to capture heterogeneity and inform monitoring design. Two new wells with hydrogen-proof behind-casing instrumentation will be drilled for the injection test. The initial monitoring focus is on borehole-based methods, with plans for DAS, DTS, and DSS measurements, along with 4D VSP and cross-well seismic and ERT to track the plume.

Reservoir simulations suggest that two instrumented wells—an injector and a monitoring well spaced 50 to 150 feet apart—are ideal for tracking plume dynamics. Simulated travel time shifts of up to 2 ms in the early injection stages highlight the importance of high-resolution, repeatable measurements.

The Devine site has the potential to become a premier hydrogen research platform, de-risking hydrogen storage operations by validating instrumentation, refining monitoring techniques, and developing cost-effective solutions in a controlled, low-pressure environment.

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Introduction

Hydrogen is expected to play an increasingly significant role in energy storage and decarbonization. In particular, aquifer storage presents an economically attractive option for large-scale hydrogen storage. However, it also carries the greatest subsurface risks due to the complex interactions between hydrogen, surrounding rocks, and fluids. While hydrogen shares some similarities with other gases used for subsurface storage, it exhibits significantly higher mobility and a greater tendency to influence subsurface conditions, such as triggering bacterial activity and inducing geochemical reactions that may affect the rock matrix. In preparation for the hydrogen injection test at the Devine test site, we describe the site's characterization surveys conducted in anticipation of the injection and assess the feasibility of various monitoring techniques to identify those that are most effective in tracking hydrogen movement and reservoir behavior.

Devine test site and injection experiment plan

The Devine test site near San Antonio, Texas, is a significant asset for UT Austin (Devine Test Site, BEG UT Austin). It has been extensively utilized for geophysical testing, both in boreholes and at the surface. The site boasts established infrastructure, including five strategically placed deep boreholes, with the deepest reaching 3,000 feet (Figure 1a). Additionally, it offers a wealth of geophysical data, including seismic surveys, vertical seismic profiling (VSP), cross-well, and other data.

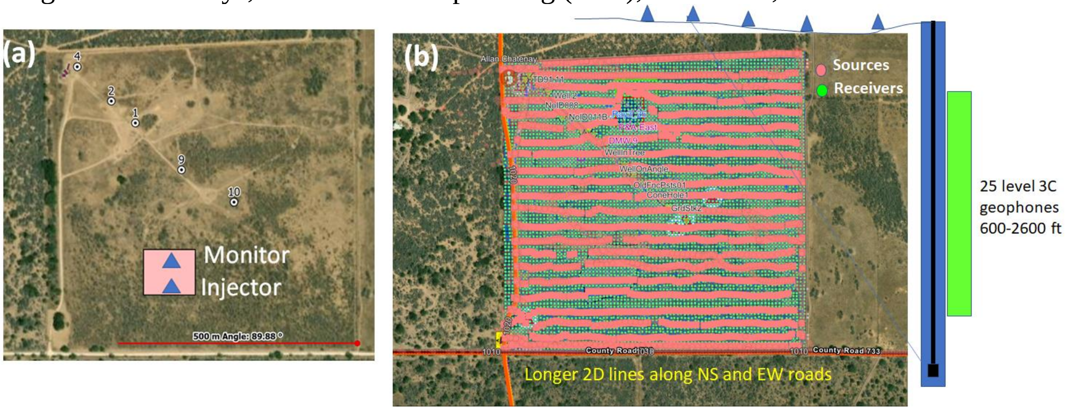

__Figure 1__ Layout of the Devine test site: (a) existing infrastructure with wells represented by circles and planned new wells indicated by triangles within the injection pad (shown in pink); (b) acquisition geometry for the ultra-high-density (UHD) 3D seismic survey combined with 3D VSP in Well #9.

We have identified the Olmos Sandstone with 30% porosity and 400 mD permeability, a shallow aquifer at approximately 1,600 feet, as the target formation for hydrogen injection. Due to the small size and high mobility of hydrogen molecules, it can migrate easily through porous media. To ensure a robust monitoring framework, we plan to drill two new wells (blue triangles in Figure 1a) —designated as injector and monitor—which will serve as the primary means for observing the distribution of hydrogen during and after the injection.

The formation has a gentle dip of about two degrees and lacks a structural trap, making it an ideal setting to study hydrogen migration within the aquifer during an injection-only (no withdrawal) experiment. Our primary objectives are to track hydrogen propagation and evaluate its interactions with the surrounding rock frame and fluids, including any potential geomechanical and geochemical effects.

Characterization survey to describe subsurface details and optimize monitoring setup

Subsurface characterization is crucial for hydrogen storage due to its high mobility compared to other gases, such as CO_2. Hydrogen can travel much farther, making small-scale geological features, such as faults or fractures, critical for understanding its migration within the target formation. Given this complexity, effective site characterization plays a pivotal role. In addition, it helps guide the development and design of an effective and reliable monitoring setup, especially when using a sparse configuration.

We completed the characterization survey with a focus on dense surface and borehole seismic acquisition (Figure 1b). Previous studies, such as Bakulin et al. (2024), have demonstrated that the signal-to-noise ratio (SNR) from characterization surveys can directly predict the repeatability required for monitoring, making this connection both quantitative and actionable in identifying optimal locations for surface sources and receivers in the monitoring setup.

As part of the survey, we deployed an ultra-high-density 3D seismic survey with a nodal receiver spacing of 7.5 x 7.5 meters and a source grid of 7.5 x 30 meters (Figure 1b). The same source grid was also recorded using three-component borehole sensors in Well #9, resulting in a simultaneous 3D VSP dataset collected with 25 three-component receivers. This combination of surface seismic and VSP yielded excellent data quality for processing.

However, the data revealed significant variability, with near-surface events obscuring the weak reservoir reflector at shallow depths, posing a key monitoring challenge. The shallow reservoir makes the signal more susceptible to noise. The dense acquisition geometry helped mitigate near-surface noise, achieve high SNR, and generate detailed attributes for optimizing the monitoring array. It also allowed exploration of potential acquisition points across the site to identify the most effective placements for a sparse monitoring configuration.

Geophysical monitoring feasibility

A comprehensive monitoring program is planned, incorporating repeat time-lapse logs, in-well fiber-optic monitoring (Distributed Acoustic Sensing [DAS], Distributed Temperature Sensing [DTS], and Distributed Strain Sensing [DSS] in both the injector and observation wells), 4D DAS VSP, permanent seismic sources, cross-well seismic and Electrical Resistivity Tomography (ERT), microbial activity assessment, and geomechanical evaluation.

Significant efforts are underway to characterize the sandstone reservoir through seismic surveys, core measurements, and log analysis to understand rock properties. These efforts are complemented by reservoir simulations to evaluate hydrogen plume dynamics. Given the small injection volumes, the initial focus is on borehole-based surveys, such as cross-well seismic, ERT, and walkaway VSP.

The sensing program relies on DAS receivers for VSP, cross-well, and passive measurements, as well as ERT receivers all positioned behind casing in both the injector and monitor wells. This study emphasizes the feasibility of cross-well seismic monitoring based on initial rock physics modeling and examines the saturation and velocity profiles at two boreholes—one located 50 feet and another 100 feet from the injector. Simulated cross-well travel times are analyzed to understand their evolution and inform the optimal placement of the monitoring wells.

Hydrogen is injected into the bottom one-third of the target aquifer thickness (Figure 3a), where the gas quickly rises due to gravity, reaching the cap rock layer while also spreading laterally. Figure 3 illustrates hydrogen plume profiles, showing saturation levels from three days to one year, alongside corresponding ΔVp changes. In the injection well, hydrogen rapidly rises to the top of the reservoir. Similarly, in the monitoring well, a delayed but comparable pattern is observed.

At the 50-foot distance, the plume arrives within three days, initially saturating the bottom of the reservoir at approximately 70%, then diffusing to around 40–30% over time. In the well at 100 feet, a similar pattern is seen, with rapid arrival in high-permeability zones and delayed arrival in other sections. The profiles indicate saturation levels between 35% and 75%, missing extremes below 35% or above 80%. Assuming homogeneous saturation, the observed range corresponds to a relatively flat portion of the Vp versus gas saturation curve, resulting in modest velocity changes of around 60 m/s when saturation varies between 80% and 40% (Figure 3a,b,c). In contrast, changes from full water saturation to 10% saturation yield velocity shifts of approximately 430 m/s.

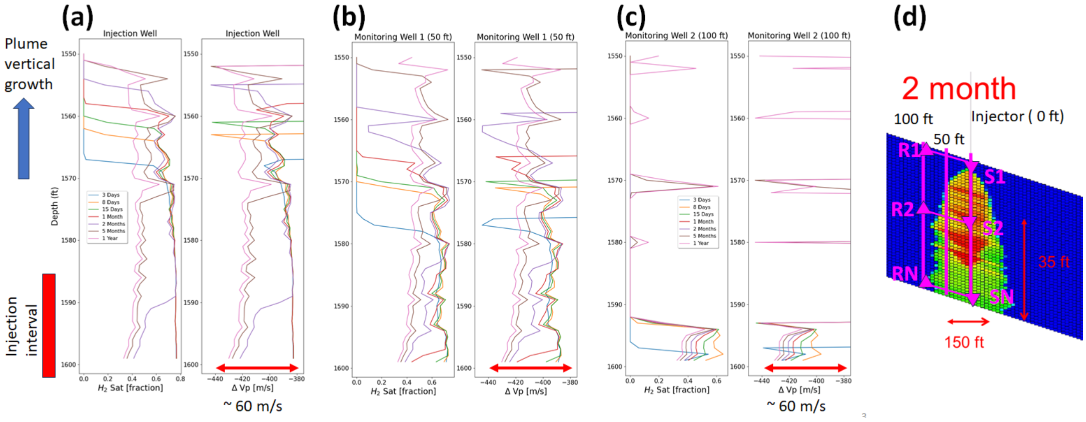

Figure 3 *Saturation profiles and associated changes in compressional velocity: (a) injection well, (b) monitoring well at a 50-foot distance, and (c) monitoring well at a 100-foot distance. Subfigure (d) shows the plume distribution after two months and the configuration of cross-well source-receiver pairs used to evaluate time-lapse travel time differences (Figure 4).*

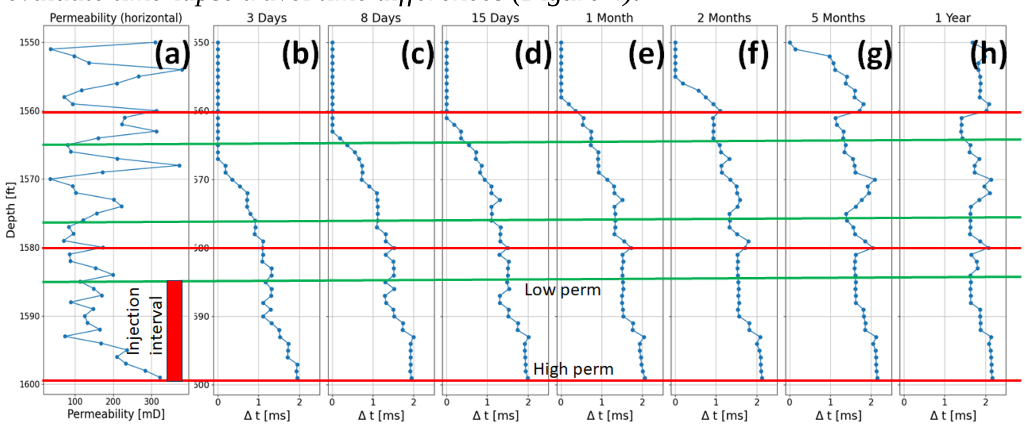

Figure 4 *Vertical distribution of permeability and along-bedding cross-well travel time differences between baseline and subsequent time intervals: (b) 3 days, (c) 8 days, (d) 15 days, (e) 1 month, (f) 2 months, (g) 5 months, and (h) 1 year. Observe the rapid movement of the plume over the first few months, reaching the reservoir top. Also note the more significant travel time changes along the higher permeability layers and lower time-lapse changes along the less permeable streaks.*

Simulated cross-well surveys, with propagation parallel to bedding and a source-receiver separation of 100 feet, reveal travel time changes of up to two milliseconds after three days (Figure 4). These changes gradually expand upward within the reservoir, reaching the top after few month. Layers showing travel time changes within the first few days exhibit only modest additional changes over time, with a maximum two-millisecond shift across the entire reservoir by the end of one year. This behavior is explained by the largest velocity changes occurring during the initial gas sweep. In contrast, even a 40% change in residual gas saturation results in smaller velocity changes, as explained earlier.

With time-limited injection, the majority of plume dynamics occur within the first two months as the hydrogen expands upward and laterally. After this initial growth, changes slow significantly due to the limited injection volume over a few days. Therefore, the expected travel time signatures stabilize at around 2 ms, with values between wells slowly growing but remaining within the range of up to 2 ms, showing rapid changes in the first few weeks to months and incremental changes afterward.

Given this, a limited-duration monitoring program is likely appropriate. The acquisition system must achieve high repeatability and resolution to capture small travel time shifts, making permanent receivers and sources ideal. If permanent sources are not feasible, high-resolution wireline sources are desirable, though impulsive sources pose challenges for maintaining repeatability. Accurate source-receiver positioning is also crucial to detect small time shifts.

Despite these challenges, previous studies have successfully detected similar or even smaller changes using both permanent and non-permanent sources (Zhang et al. 2012; Ajo-Franklin et al. 2013). Therefore, the expected changes in travel times and velocity appear robust enough for quantifiable detection, allowing for accurate tracking of residual hydrogen saturation and plume evolution.

Conclusions

We describe the design and progress of the Bureau H_2 test at the Devine test site—a valuable natural laboratory for advancing hydrogen storage in aquifers. Despite existing extensive infrastructure, we opted to design and drill two new wells with behind-casing, hydrogen-proof instrumentation to support the testing program.

We acquired high-resolution, ultra-high-density 3D seismic and VSP to capture heterogeneity that could influence hydrogen migration. These surveys also help optimize the monitoring design for sparse configurations by identifying optimal positions for permanent source and receiver pairs for VSP and surface seismic.

Reservoir simulations based on expected sandstone aquifer conditions at 1,600 feet, combined with initial assessments of core samples and logs, suggest that monitoring wells spaced 50 to 150 feet apart are most effective for tracking small hydrogen volumes. Borehole methods, such as cross-well seismic and ERT, offer the greatest value for capturing plume dynamics. Our studies demonstrate the visibility of cross-well time-lapse seismic signatures, showing that meaningful results can be achieved using high-resolution sources and behind-casing receivers. Additionally, cross-well ERT is expected to provide complementary insights, particularly for identifying changes in residual saturation.

As our understanding of reservoir properties advances, we are evaluating additional monitoring techniques and conducting feasibility studies to assess their ability to capture time-lapse signatures related to hydrogen injection. The Devine test site has the potential to become a premier hydrogen research laboratory for academia and industry, serving as a platform to de-risk hydrogen storage operations. This includes validating hydrogen-proof wells and instrumentation, refining monitoring techniques, and developing cost-effective solutions in a robust but low-pressure research environment.

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