GeoH$_2$ Research Program

Summer 2026 Open Invitation Webinar

GeoH$_2$

Bureau of Economic Geology

GeoH2 Summer Open Invitation Webinar
August 4, 2026

Objectives:

- Build awareness of $GeoH_2$ research and capabilities
- Make connections to identify possible research opportunities and collaborations

Agenda
GeoH$_2$ Summer Webinar
August 4, 2026

Times
US CDT

0800 Introduction to GeoH2 (Shuster)

- ❑ Research Mission
- ❑ Research Capability (people & capability)
- ❑ Direction

0805 Experimental Research (Dr. Toti Larson)

- ❑ Hydrogen generation (Dr. Tongwei Zhang)
- ❑ Implications for geologic and stimulated hydrogen production (Dr. Toti Larson)
- ❑ Hydrogen reactions and geomechanics: impacts on reservoir and seal (Dr. Peter Eichhubl)
- ❑ Pore-scale flow (Dr. Ruichang Guo)

0825 Modeling (Dr. Mojdeh Delshad)

- ❑ Reservoir (porous media) simulations (Dr. Mojdeh Delshad)
- ❑ Storage capacity [salt cavern] (Dr. Leo Ruiz Maraggi)
- ❑ Techno-economic analysis (Dr. Ning Lin)

0845 Geologic hydrogen prospectivity (Dr. James Thompson)

- ❑ Texas study
- ❑ Field-based reconnaissance studies

0855 Close out/Q&A (Shuster)

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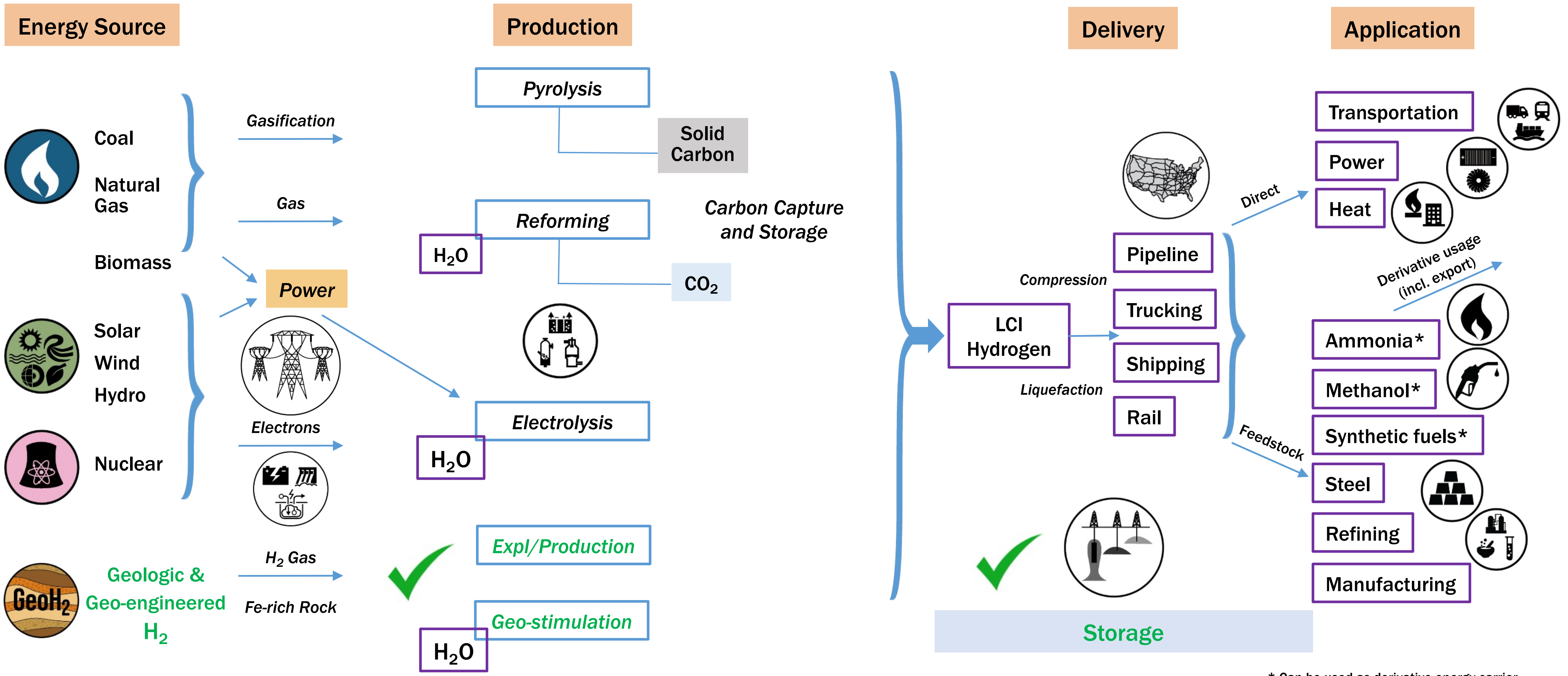
Hydrogen Pathways



* Can be used as derivative energy carrier

✓ $GeoH_2$ research

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GeoH$_2$ Research Themes

Geological Storage

- Reservoir Characterization and Flow Modeling
- Risk Assessment, Field Testing and Monitoring Design

Economic Analysis

- Techno-economics
- Value Chain Analyses
- Market Assessment

Geologic & Stimulated H$_2$

- Geologic Hydrogen Occurrence
- In Situ & Geo-stimulated H$_2$ Generation

Goals:

- Understand Geologic Reservoirs and H$_2$ Subsurface Behavior
- Develop Technology and Workflows to Inform Best Practices

- Assess Value Chains Linking Supply-Transportation-Storage-Usage for Market Scenarios
- Develop and Calibrate Storage Screening Tools

- Understand key factors controlling natural and geo-engineered hydrogen generation in the subsurface

Team $GeoH_2$ 2026

Reservoir Characterization, Geology, Geochemistry, Geophysics, Petrophysics, Geomechanics, Reservoir Engineering, Energy Economics


Nur Schuba


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Seyyed Hosseini


Peter Eichhubl


JP Nicot


Mojdeh Delshad


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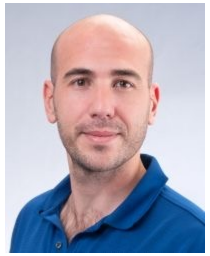
James Thompson


Tongwei Zhang


Jay Kipper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RESERVOIR

The University of Texas at Austin
Center for Subsurface Energy and the Environment
Cockrell School of Engineering

State of Texas Advanced Resource Recovery
STARR

Research Directions

- Continue reservoir-focused hydrogen storage research
  - Experimentation
  - Simulation

- Continue salt cavern capacity research (applicable to hydrogen & natural gas)

- Continue geologic hydrogen and stimulated hydrogen research
  - Experimentation (hydrogen generation and enhancements)
  - Soil and subsurface sampling

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TEXAS The University of Texas at Austin | Bureau of Economic Geology | University of Wyoming | GeoH2

Toti Larson

Esti Ukar

- **ARPA-E GeoH2 project**
  - H_2 production from abiotic catalyst-enhanced stimulation of iron-rich rocks
    - Toti Larson (PI) and Esti Ukar (co-PI)

Andras Fall

Tongwei Zhang

Orsolya Gelencser

- **Bureau of Economic Geology**
- **The Jackson School of Geosciences**
- **The University of Texas at Austin**

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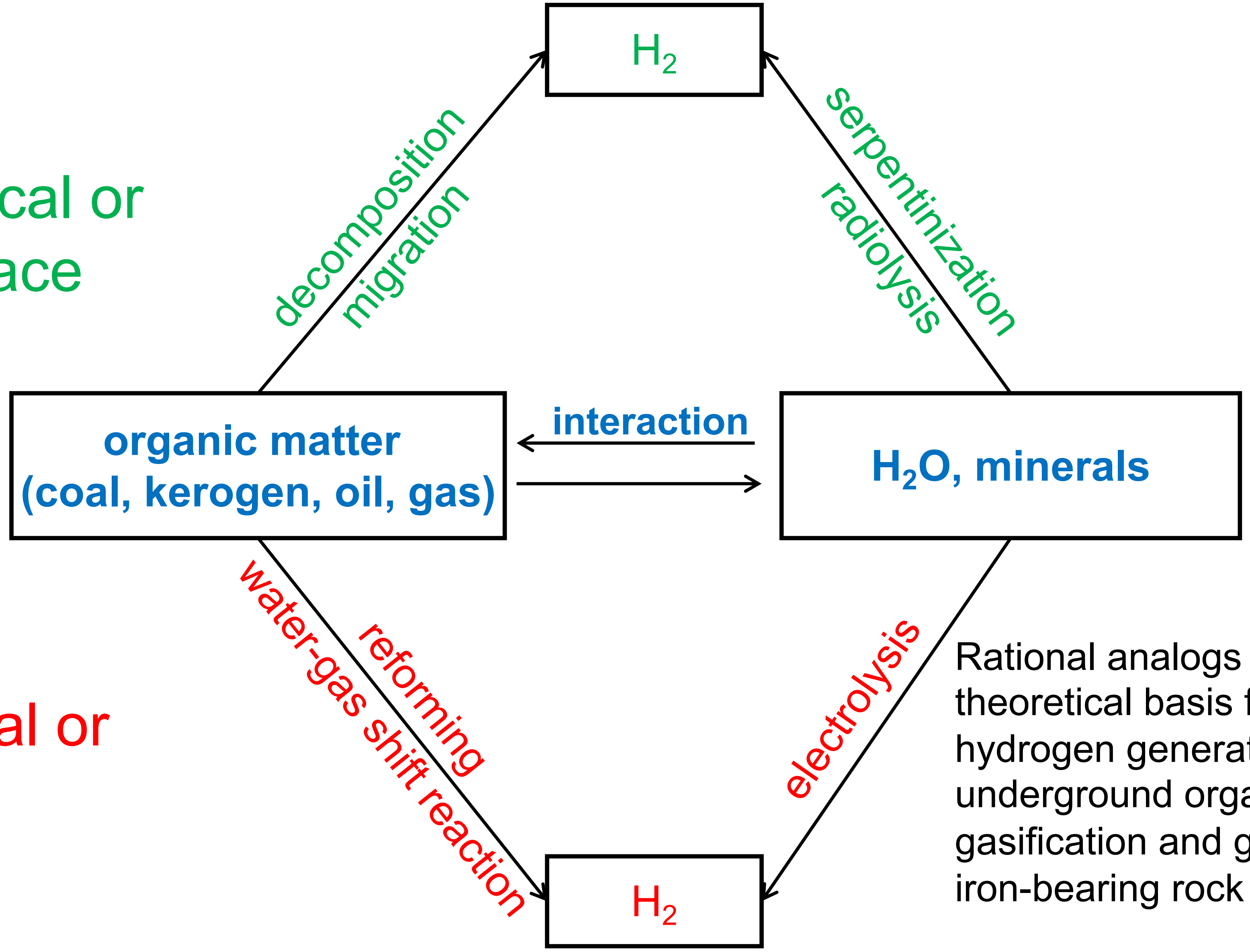
ARPAE™ AWARDEE

Hydrogen generation mechanisms

Geological or subsurface



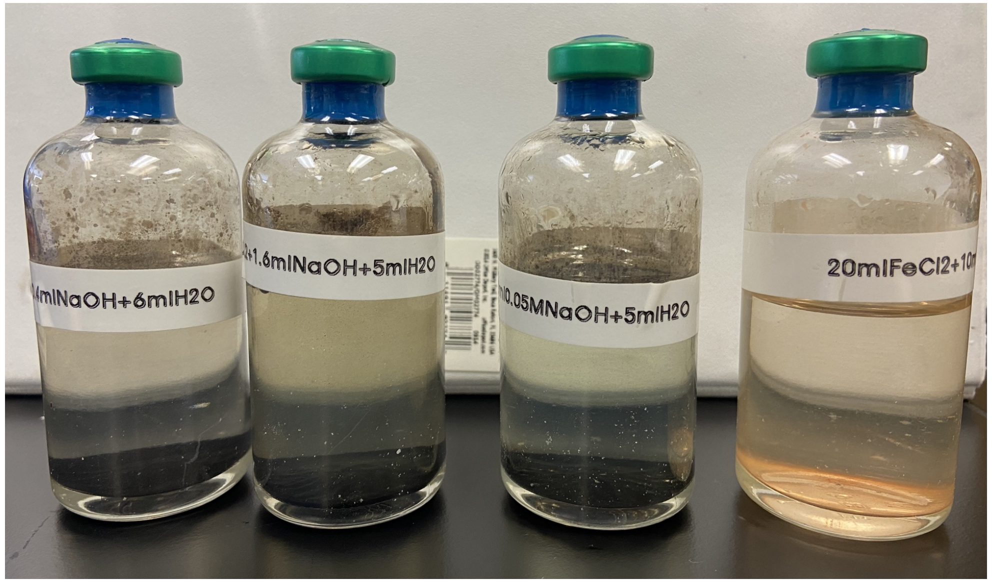
Chemical or surface

Rational analogs provide a theoretical basis for in situ hydrogen generation from underground organic matter gasification and geoengineering of iron-bearing rock serpentinization.

Ni Catalyst controls on geologic hydrogen generation

Experimental conditions

- 65ml serum vial – Ar purged
- 20ml 0.04M $FeCl_2$
- 0-10ml 0.008M $NiCl_2$
- 0 ml - 3.6 ml 0.5M NaOH
- Temperature: 60, 75, 90°C
- Reaction time 0 to 50 hours

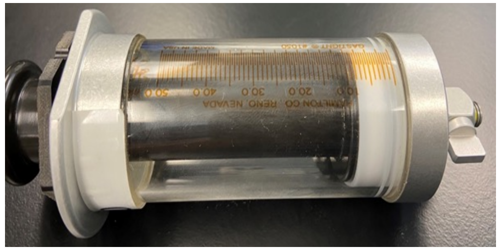


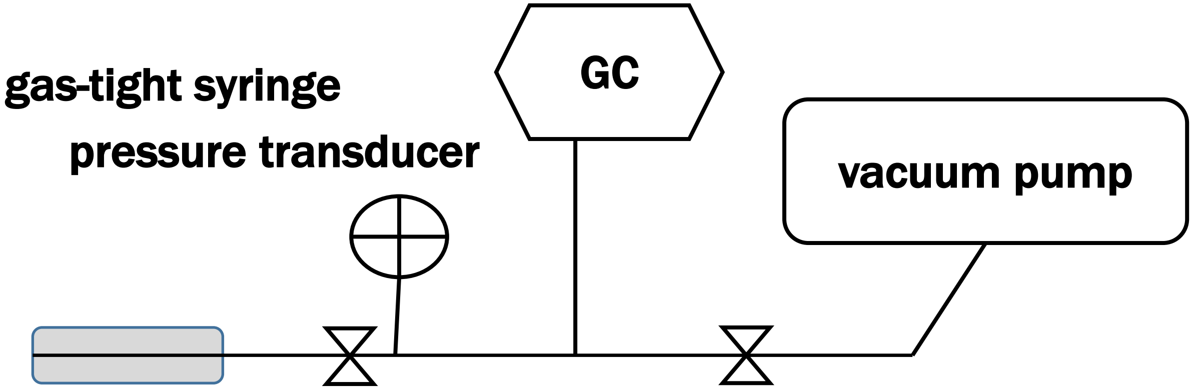
React at temperature
- 60, 75, 90°C

GC Headspace analysis
- H_2, N_2, O_2, CH_4

Aqueous analysis
- pH, Fe^T, Ni, Na, Cl

Solid analysis
- XRD, SEM





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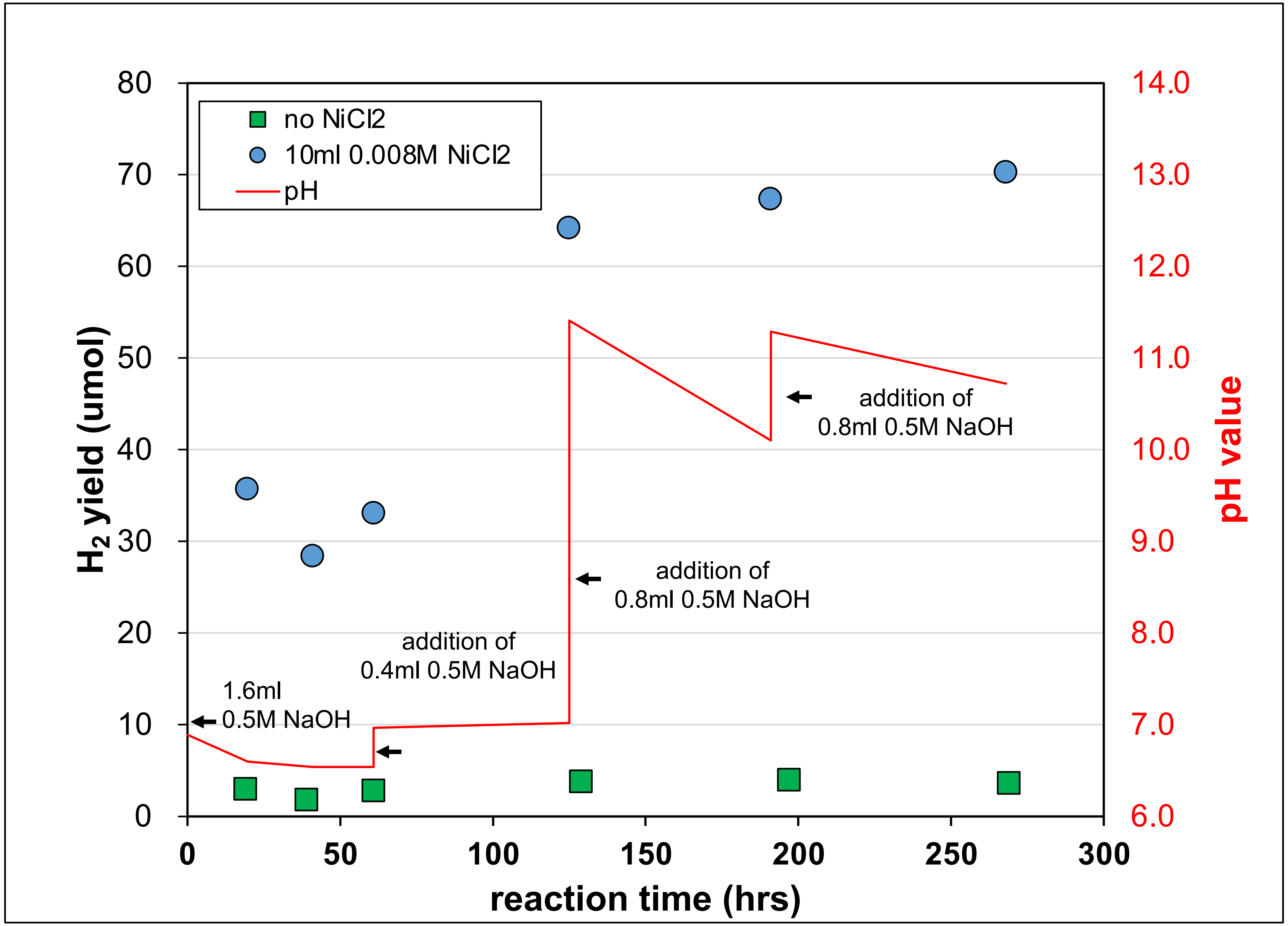
Results: Initial loading: 20ml 0.04M $FeCl_2$; 10ml 0.004M $NiCl_2$ at 90°C

- Ni catalyzes H_2 generation from H_2O by Fe^{2+} oxidation
- Reactive species <u>are not</u> aqueous Fe^{2+} and solid $Fe(OH)_2$

Key finding – <u>Both</u> $(Fe,Ni)(OH)_2$ complex <u>and</u> Fe^{2+} in solution are necessary for H_2 generation



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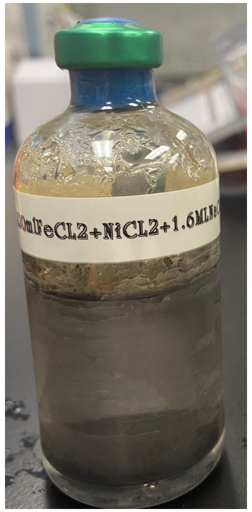
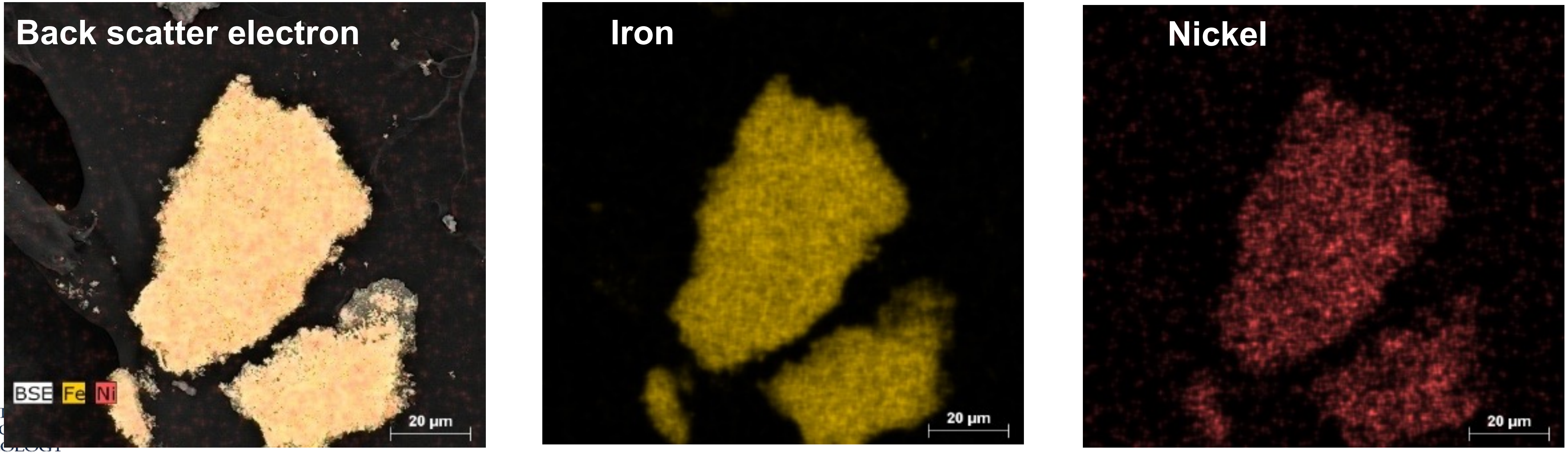
Post reaction products - solids

- Magnetite confirmed by Energy Dispersive Spectroscopy (EDS)
- Nickel incorporated with magnetite

Solid precipitates →



Scanning electron microscopy of post-reaction products

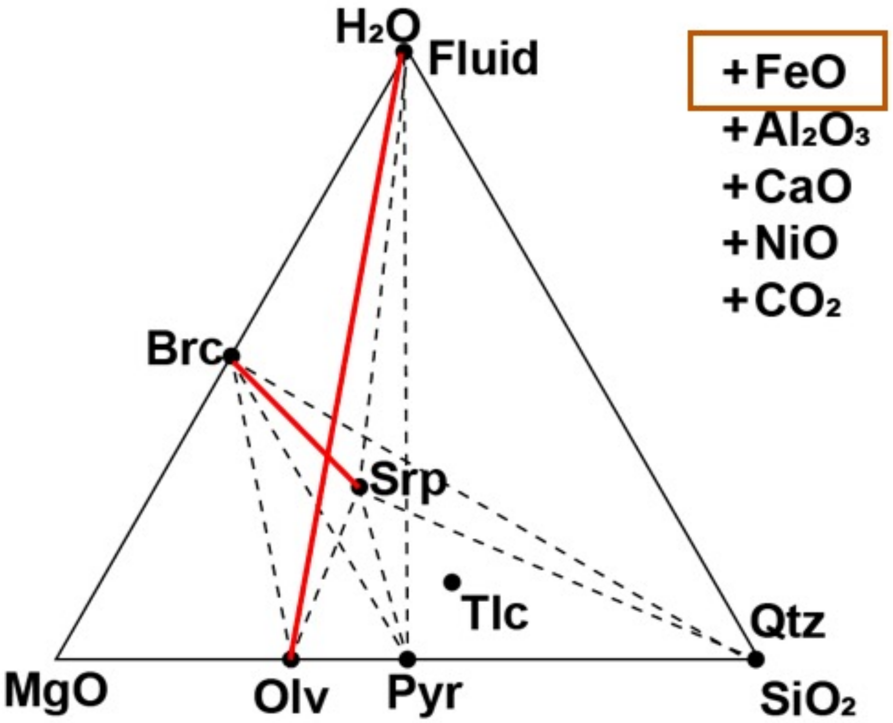


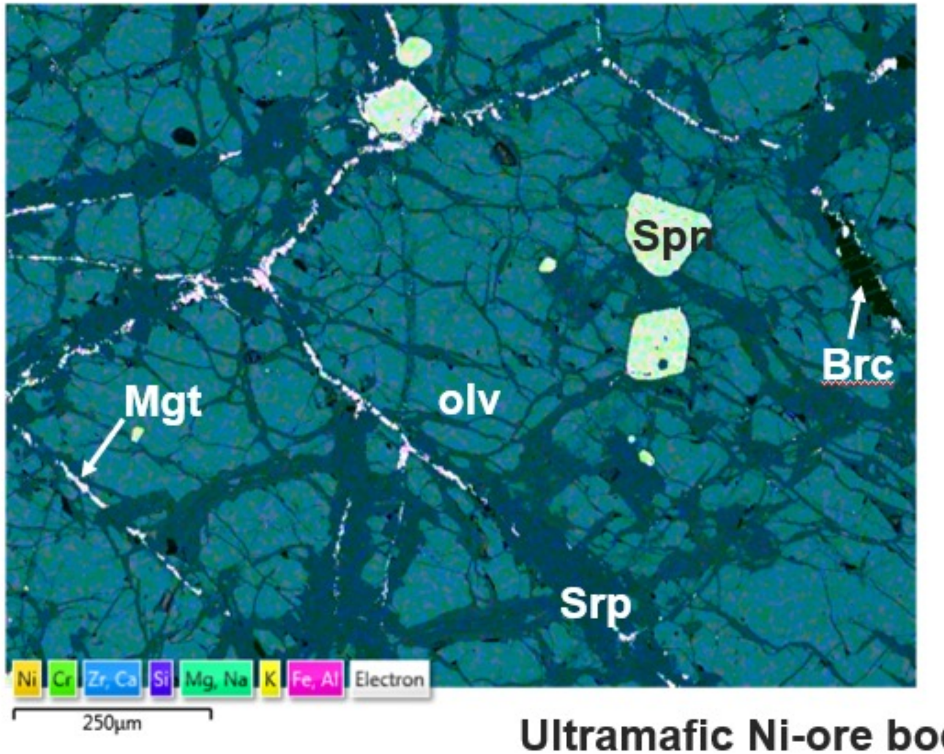
Application of Ni catalysts to rock systems

$$2\,(Mg,Fe^{II})_2SiO_4 + 4\,H_2O = (Mg,Fe^{II\,III})_3Si_2O_5(OH)_4 + (Mg,Fe^{II})(OH)_2 + (Fe^{II,III})_3O_4 + H_2$$

Fe-olivine + water = Serpentine + brucite + magnetite + H2

Fe-oxidation





Ultramafic Ni-ore body

Rock samples – Quantify mineral and compositional controls on H_2 production

Ultramafic rocks

Degree serpentinized protolith →

Minerals	San Carlos	CAV-005	CAD-005	CAV-017	Uvalde (Alkali basalts)
Olivine	100	25	13		18.0
Serpentine		65	73	68	
Fe-Brucite		7.3	10.5	8	
Pyroxene			1.6		49.3
chlorite			1.4		
Spinel		1.8	0.7	11	
Magnetite				13	6.4
Amphibole					
Plagioclase					25.9
Quartz					
Fe^{2+} as FeO	8.97	3.2	4.7	5.8	8.8
Fe2+ / FeT		53.3		62.2	
FeT		6%	7.1%	9.32%	

Amount of Fe^{+2} Coupled to mineralogy is important

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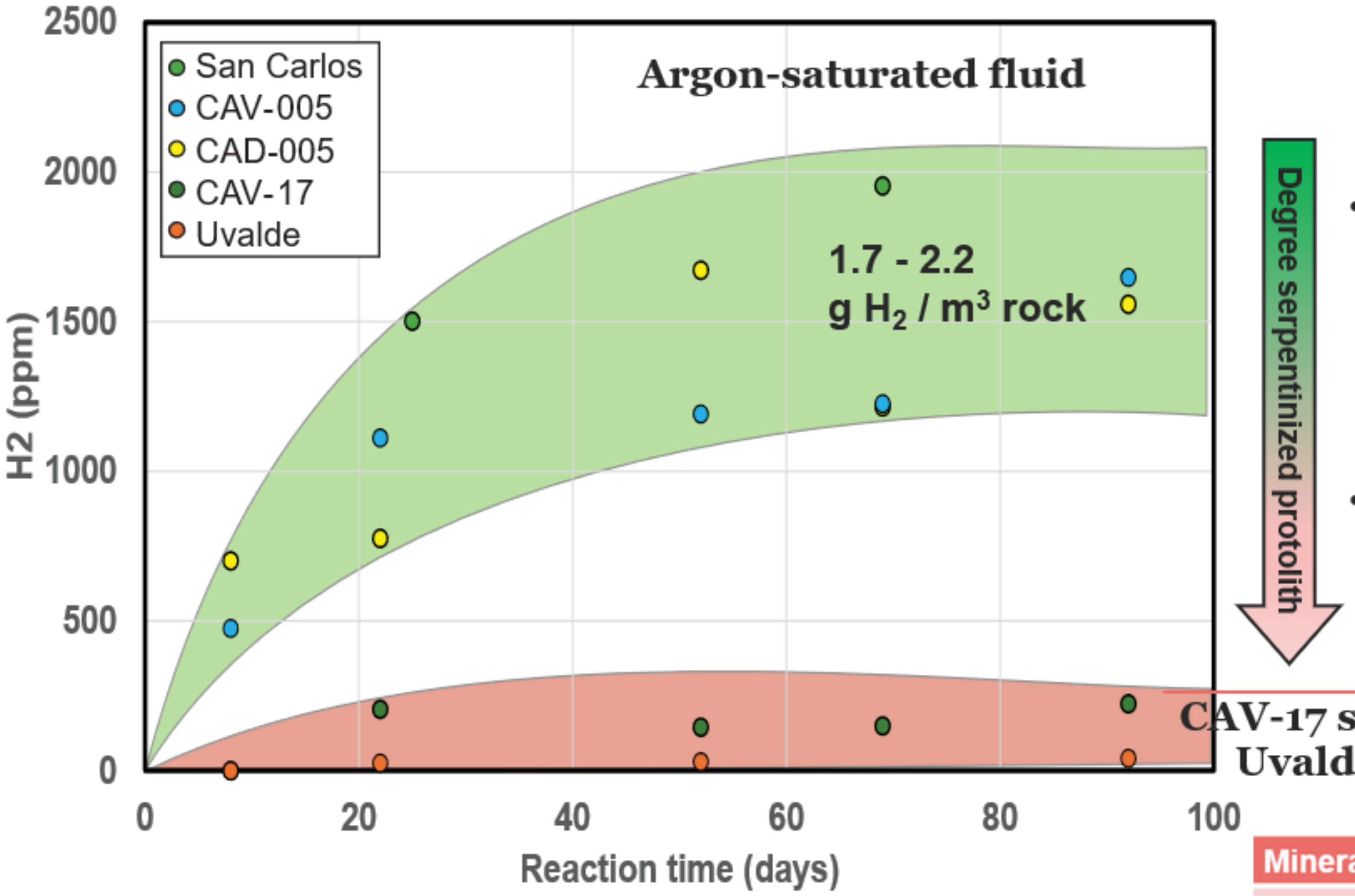
Batch experiment results – Mineralogy control on H_2 production rates



- H_2 generated at 80°C in San Carlos, and ultramafic samples with olivine and pyroxene
- Alkali basalts and fully serpentinized protoliths are sluggish

Minerals	San Carlos	CAV-005	CAD-005	CAV-017
Olivine	100	25	13	
Serpentine		65	73	68
Fe-Brucite		7.3	10.5	8

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Similar Fe+2 concentrations. Different olivine and serpentine content

Conclusions

- Hydrogen generation is primarily controlled by degree of serpentinization of host rock (Fe^{2+} availability)
- **Low temperature (80°C) H_2 production after three months**
- Yield of low temperature (80°C) H_2 production is low, but not unexpected:
  - Measured = 2.5 g H_2 / m^3
  - At 2 $Fe^{2+} \rightarrow 1\ H_2$, Theoretical maximum H_2 = 4,596 g H_2 / m^3

$$\frac{2.5}{4{,}596} \times 100 = 0.054\%$$ yield **in three months**

- In aqueous solutions, H_2 yield from water reduction and Fe^{2+} oxidation is about 20-100 times higher in the presence of $NiCl_2$ at 90°C.
- Formation of (Fe,Ni) $(OH)_2$ complex and Fe^{2+} (aqueous) availability are necessary.

This is only a three-month view. Production wells perform on 5 – 10 years cycle

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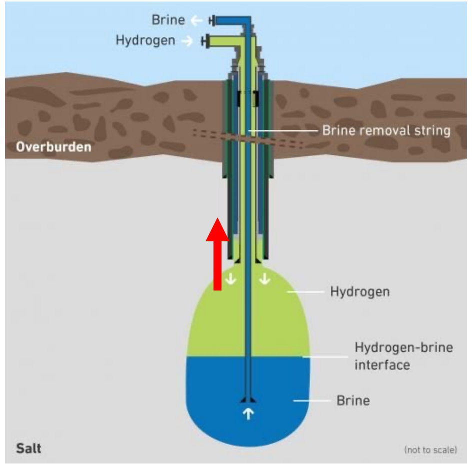
Hydrogen reactions and geomechanics: impacts on reservoir and seal

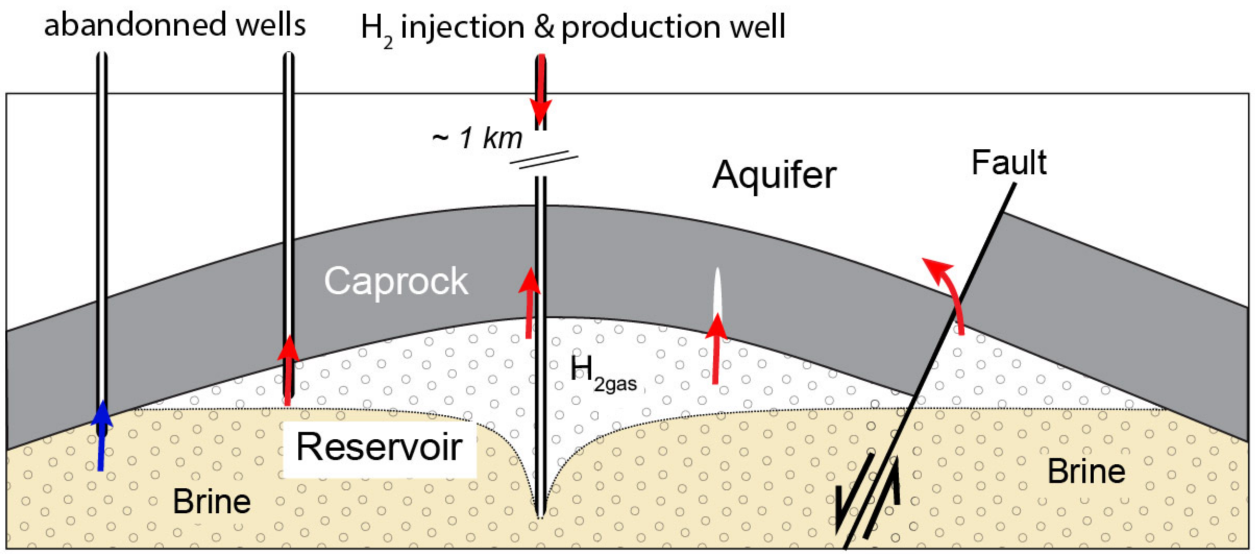
Peter Eichhubl, Dawid Gajda, Mohammed Abu Alreesh

- Stored or natural H_{2gas} has higher migration tendency/higher leakage risk compared to NG or CO_2
  - Higher diffusivity
  - Lower density → higher pressure on caprock for given column height
  - Higher tendency to spread in a porous reservoir, increasing risk of leakage along fractures, existing wells, faults
  - Possible reactions of H_2 with rock, wellbore cement



Source: Uniper

- H_{2gas}-brine-rock interactions can <u>enhance or inhibit</u> fracture growth
  - Dehydration (displacement of brine)
  - Gas exchange reactions (CO_2)
  - <u>Mineral reactions</u>

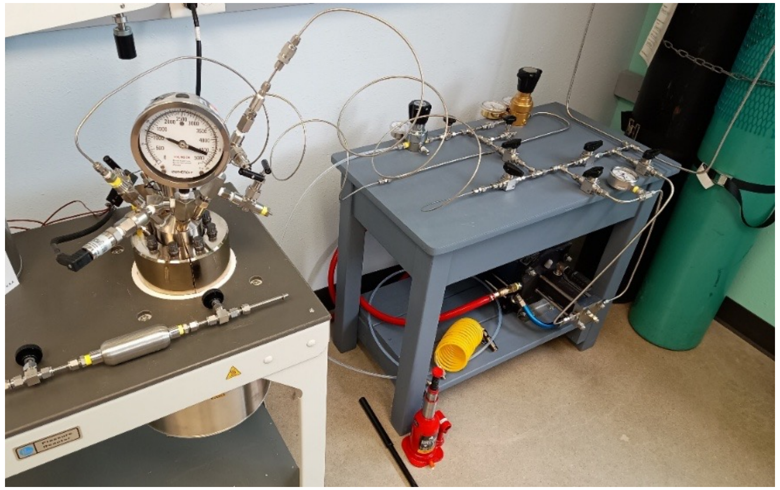


- Effects can be local e.g. wellbore-adjacent
- <u>Reaction-enhanced failure</u> can occur below stress levels for critical (mechanical) failure

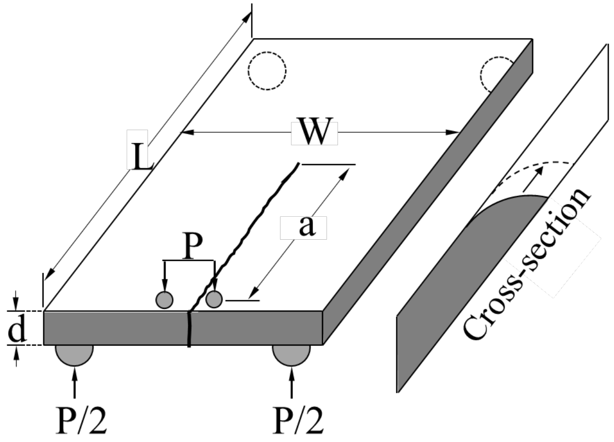
Reaction experiments and environmental fracture testing

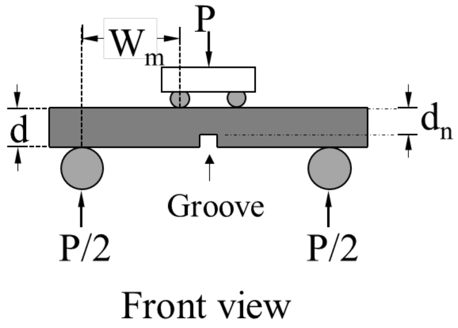
Autoclave reaction experiments

- Mineral, rock, or wellbore cement
- Aqueous fluid with H_2 gas mixture
- Reservoir pressure, temperature
- Water chemical analysis (ICP-MS)
- Gas chromatography
- Rock imaging (SEM-EDS)
- Reaction modeling

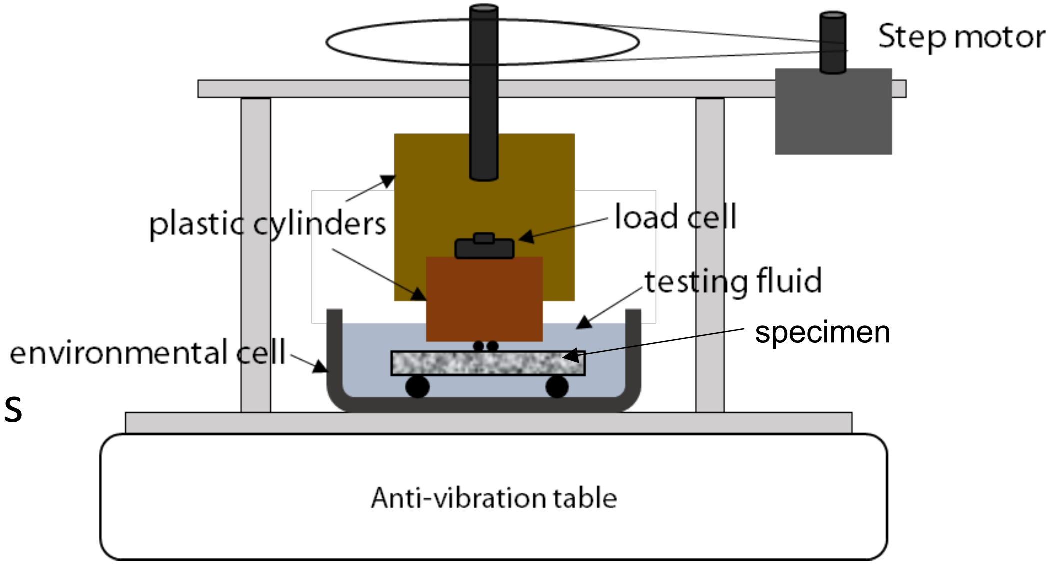


Double torsion fracture testing



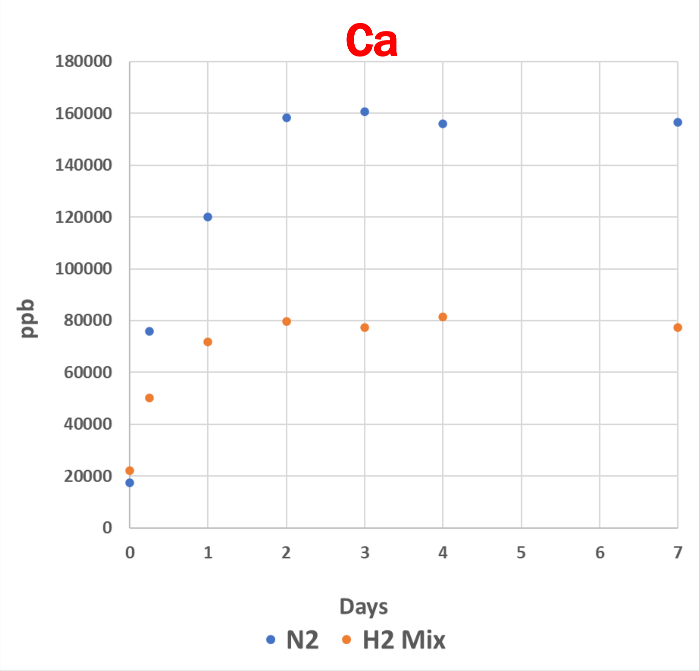


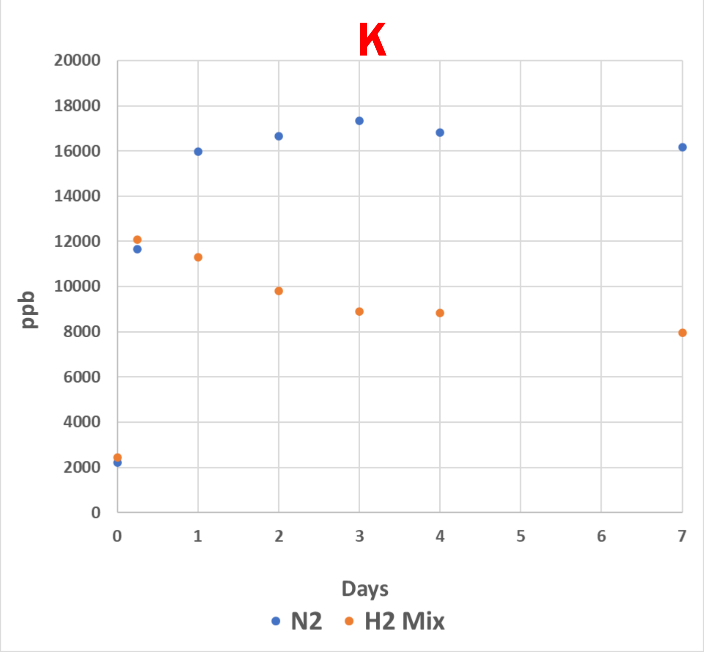
- Sample can be submerged in aqueous brine
- Tests conducted in ambient air, N_2, H_2, or CO_2 gas environment

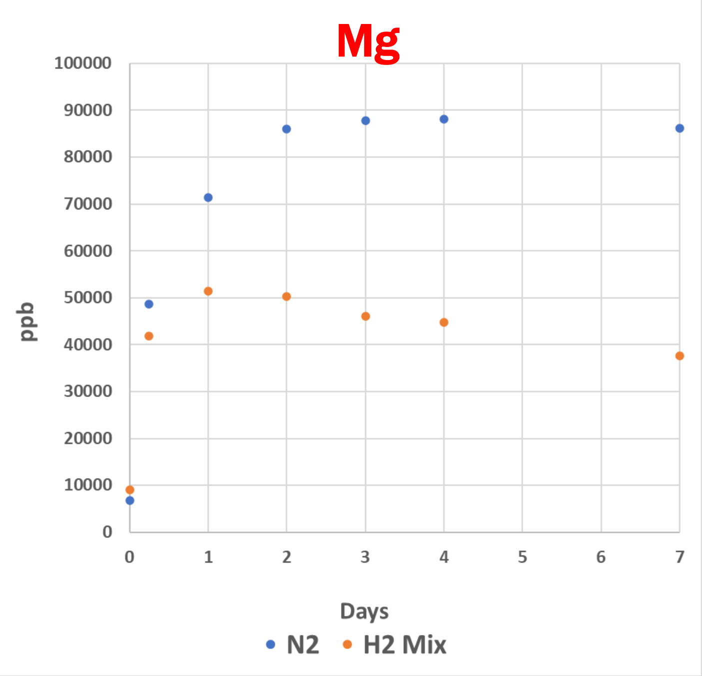


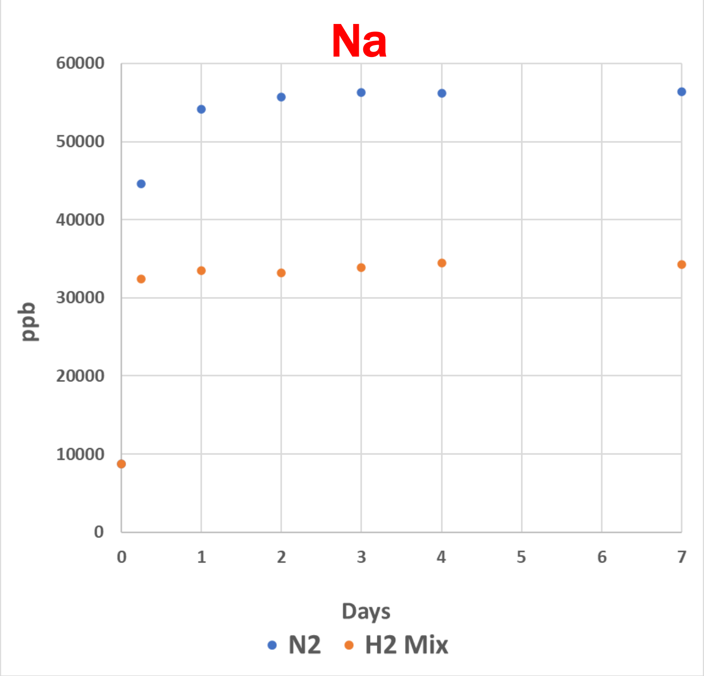
Effect of H_{2gas} on mineral dissolution in shale

- Autoclave reactions of wafers of Mancos Shale:
- 54%quartz, 14% dolomite, 7% K-feldspar, 4% albite,11% illite, 6% calcite, 4% kaolinite
- Reacted in DI water (W:R 2.5:1) at 10 MPa, 60°C for 7 days
- Two runs with headspace gas of
  1. 100% N_2
  2. gas mix of 5% H_2 + 2.5% He + N_2
- Findings:
  1. Less dolomite and feldspar dissolution in the presence of H_{2gas} but precipitation of clays (?)
  2. Reactions may reflect effect of headspace gas composition on dissolved CO_2









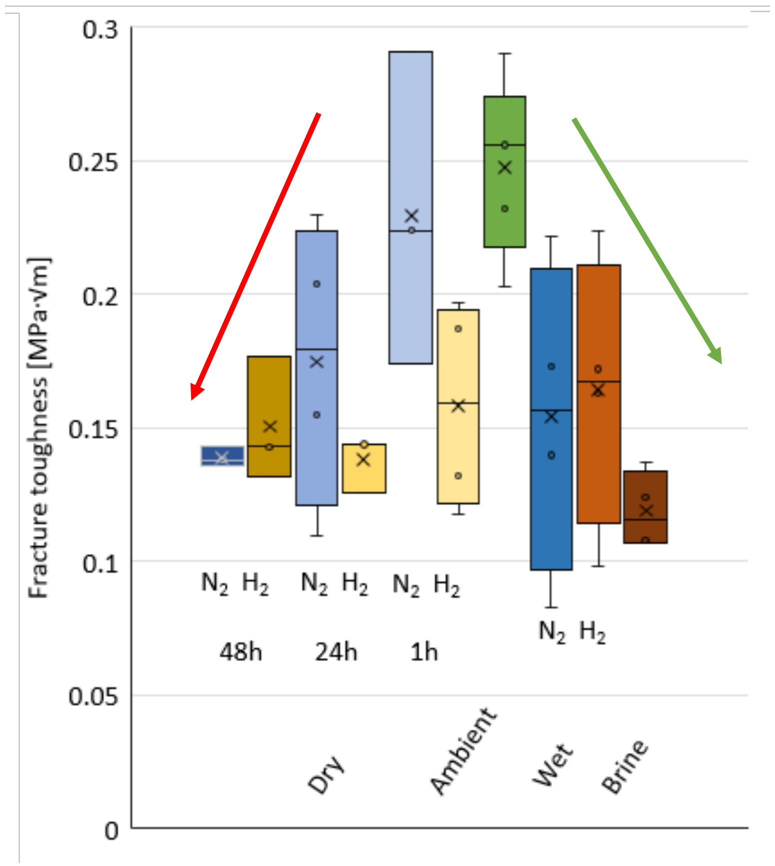
Fracture mechanics of polycrystalline halite: Effects of H_2 vs N_2 gas and water saturation

Two fracture parameters are tested:

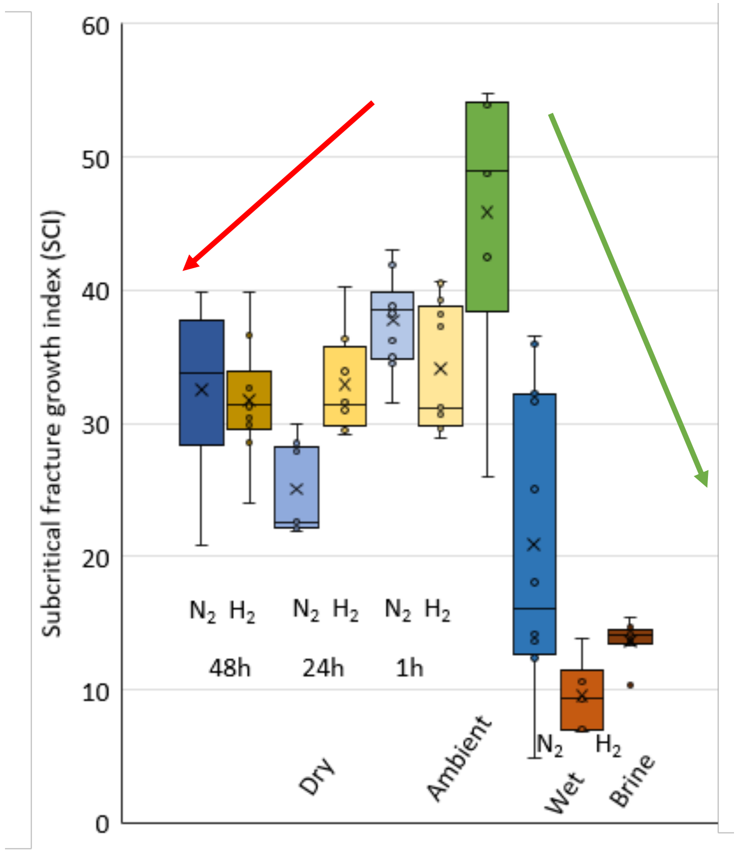
1. <u>Fracture toughness</u>, a measure of stress needed to fracture the rock (high values are better)
2. <u>Subcritical fracture growth index</u>, a measure of how fast a fracture will grow (low values are better)

Tested in dry N_2 and H_2 gas, humid air, partially wet with N_2 and H_2 gas, and fully brine saturated.

Fracture toughness



Subcritical fracture growth index



Findings: Water saturation has big effect (e.g. filling of a salt cavern with gas and displacing the brine); gas composition has minor effect. Salt cavern is strongest after filled with gas, and most prone to failure when filled with brine. Dry-out effect is faster with H_2 gas compared to N_2 gas.

Pore-scale flow

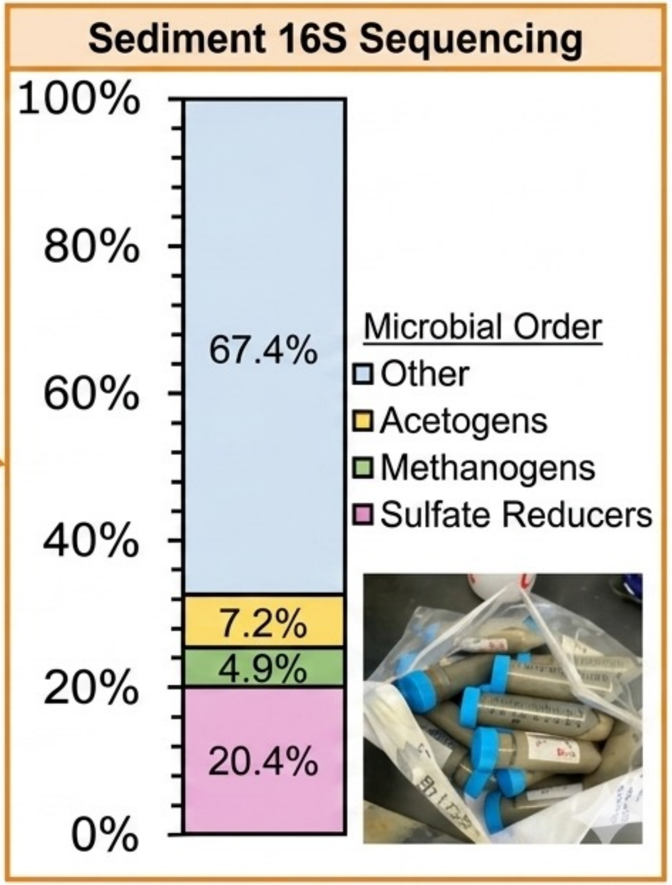
Ruichang Guo, Hailun Ni, Seyyed Hosseini

GeoH2

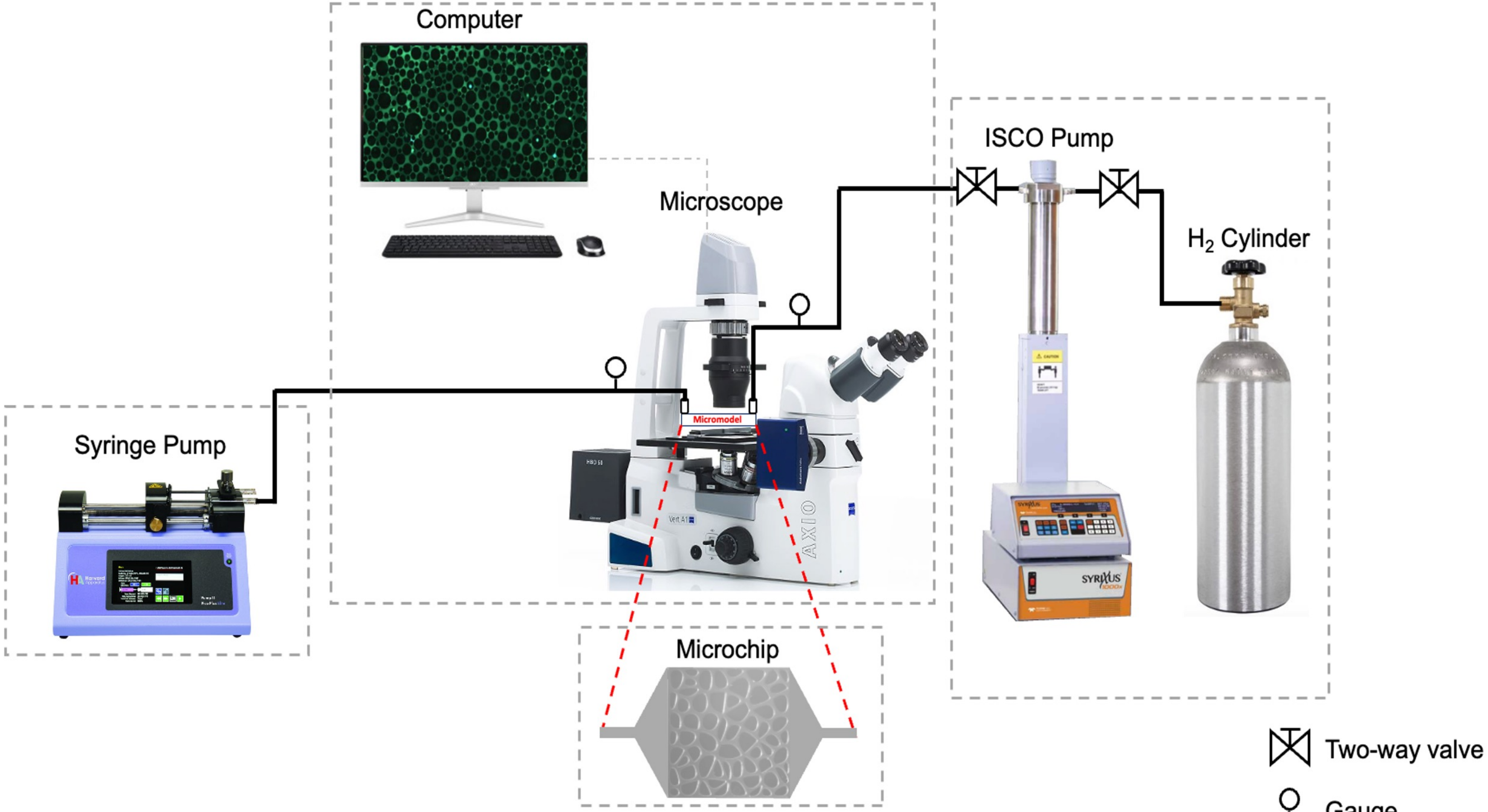
Bacteria: sulfate-reducing bacteria (SRB)

Bacteria strain was sampled from natural brine. The SRB was separated and cultured in the lab.

Experimental Brine Solution[1]	
Salt	**mg/L**
NaCl	30,978
KCl	744.5
$MgCl_2$	5,712
$CaCl_2$	2,218
NH_4Cl	500
KH_2PO_4	140
TMS	10 mL/L soln
Casamino Acid	2% w/v



Experimental setup



Experimental conditions:

- Pressure: 20 psi.
- Temperature: 20.8 ℃.

Bacteria-SRB:

- The SRB, cultured at room temperature (~20 ℃), remained active in the batch experiment.
- SRB mobility is ensured. SRB size (0.1-0.5 um) much smaller than average pore size (>80 um)

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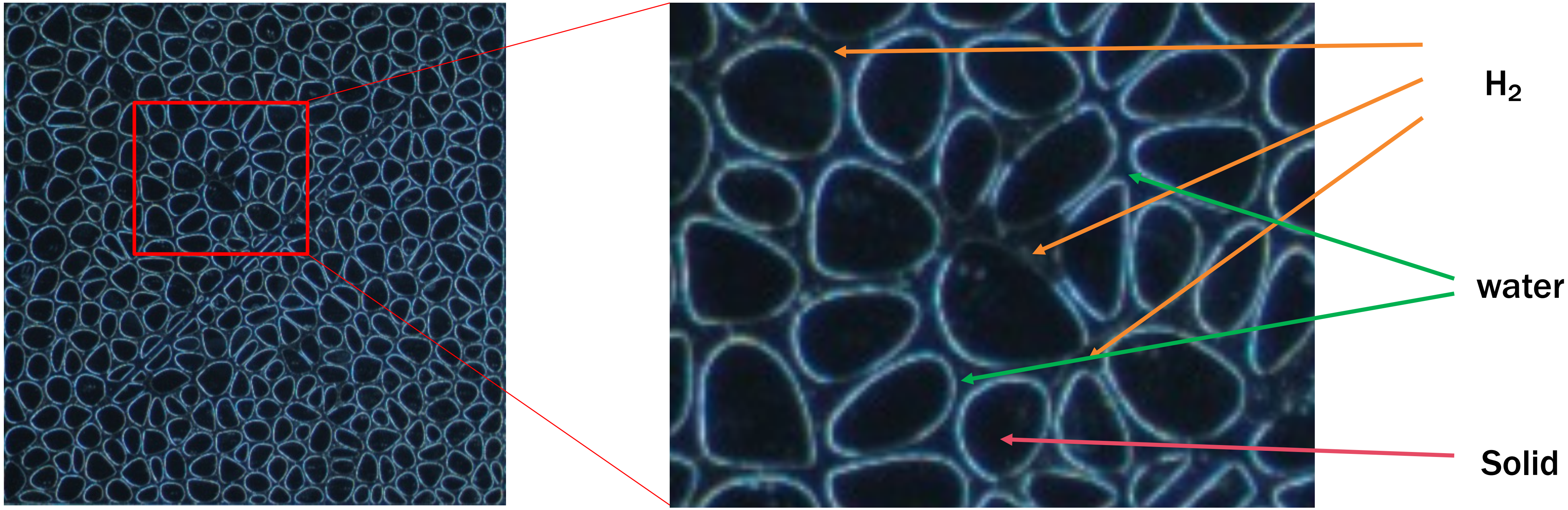
Results: original images

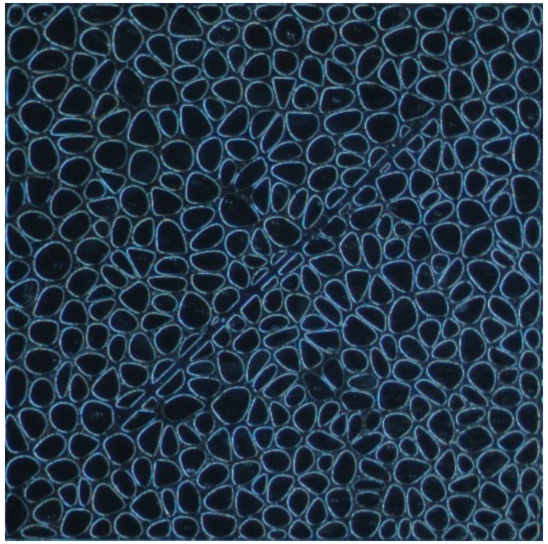
One group of experiment was finished



- To keep SRB alive, no fluorescent agent or dye is added
- The H_2–solid interface appears darker than the water–solid interface

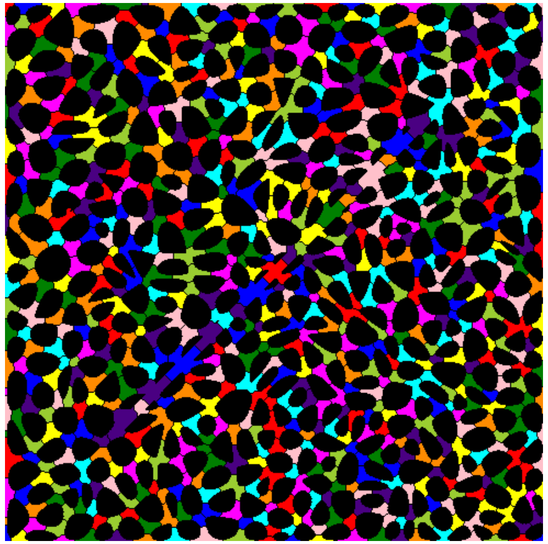
Results: Segmentation method

Raw image



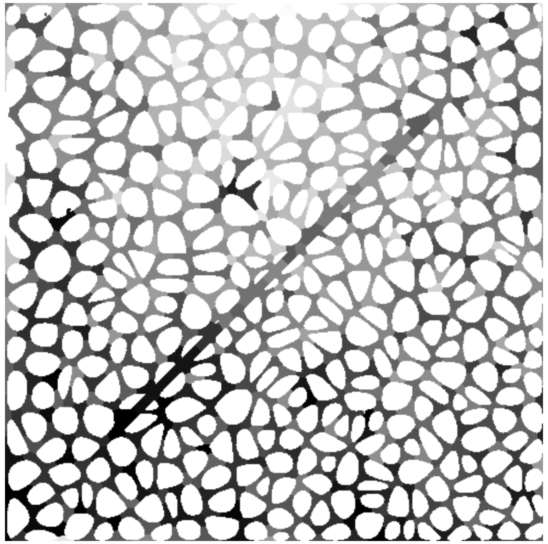
- Raw experimental photo

Pore size distribution



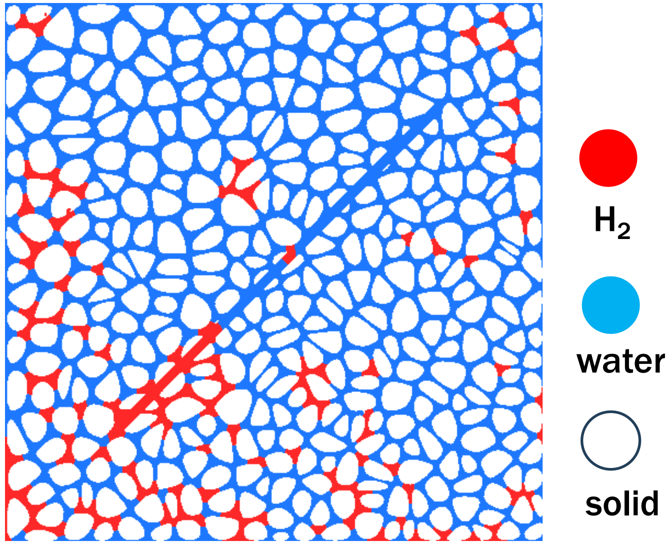
- Use watershed method to segment pores

Pore light intensity map



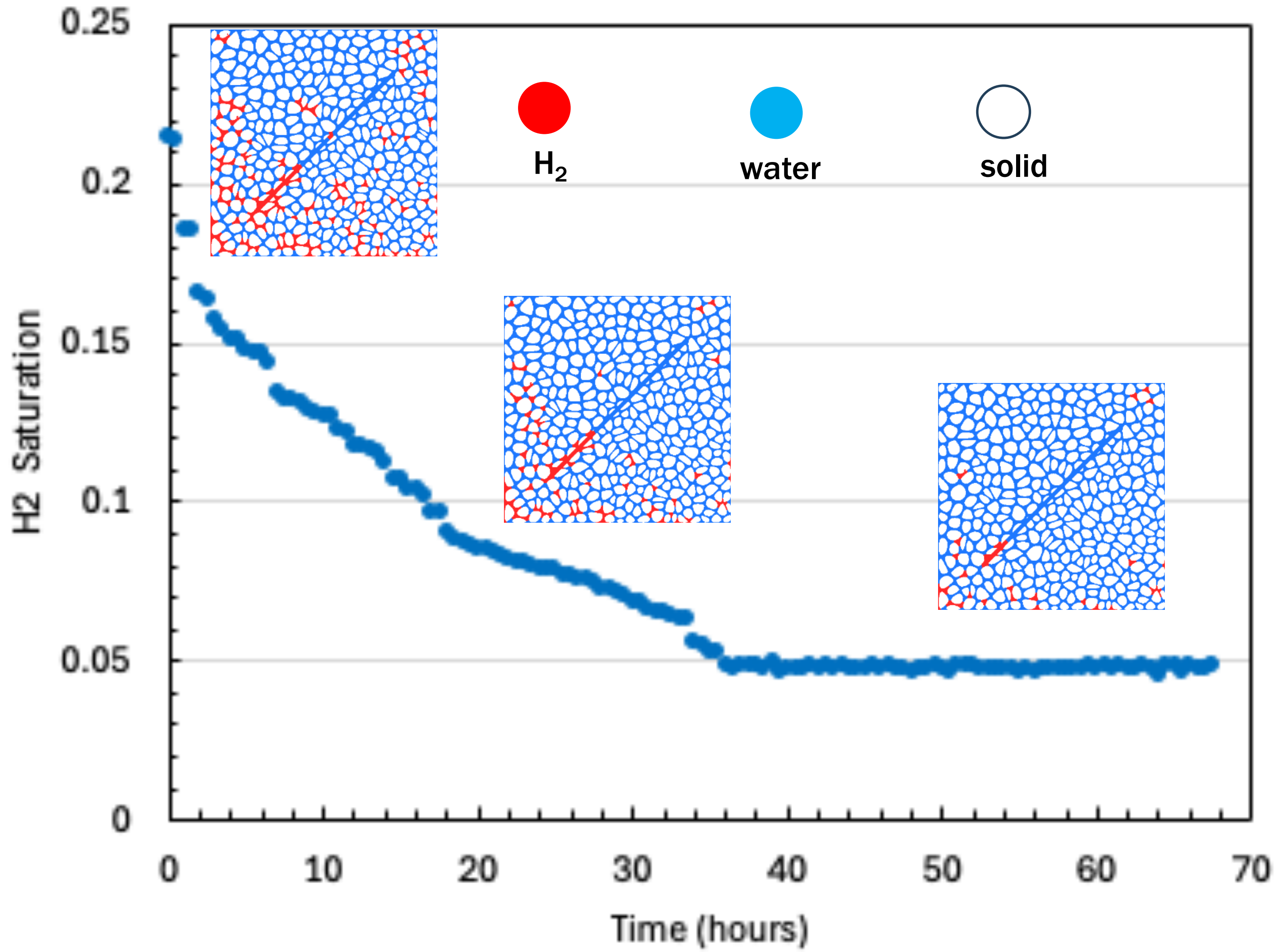
- Calculate the light intensity of solid edges adjacent to each pore
- Assigned the average light intensity at the edge to each pore

H_2-water-solid distribution



- Segment H_2 phase based on average light intensity at the edge

Results: Temporal evolution of H_2 phase



- The H_2 concentration continued to decrease and reached a plateau after approximately 34 hours.
- Next-step work: Conduct control experiments to quantify the H_2 reduction caused by SRB activity
- Segmentation method improvement to reduce error

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Modeling and Technoeconomic

1- UHS in Porous Media Reservoir

M. Delshad, M. Hotan, S. Hussein

2- Subsurface Energy Storage Potential of Domal and Bedded Salt Formations

L. Maraggi

3- *A Research-Rooted Tool Supports Commercial Decisions*

N. Lin

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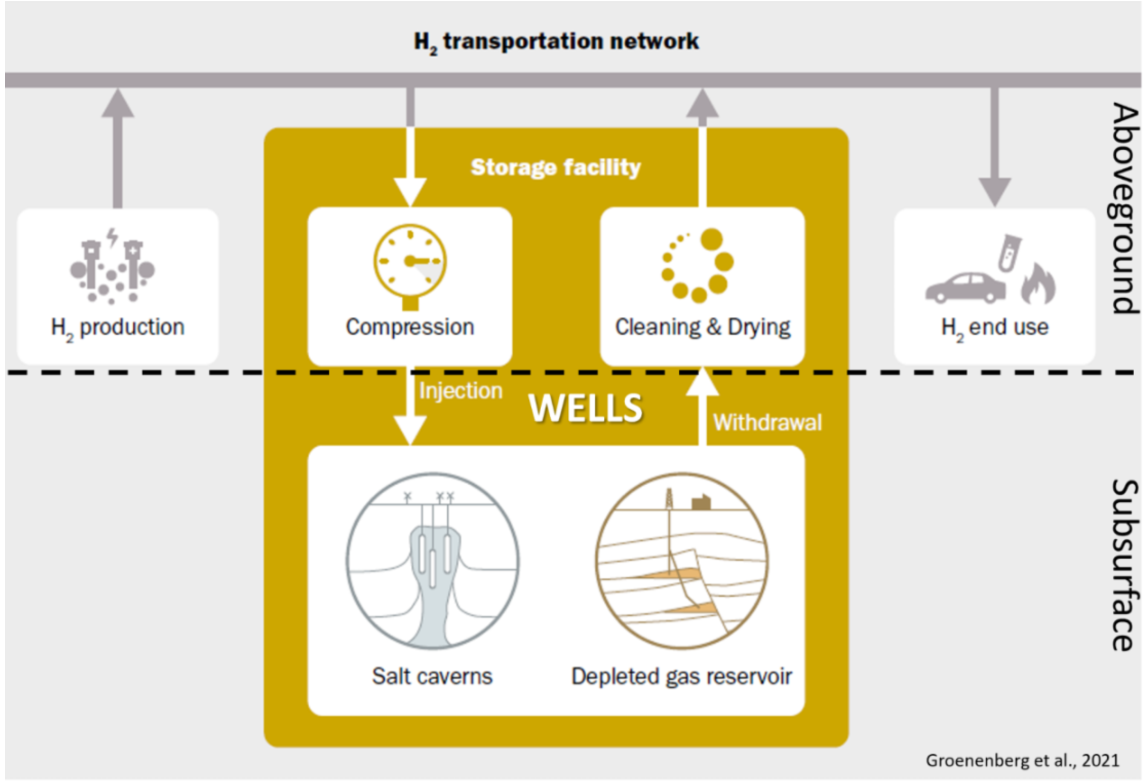
1-Motivation and Goals

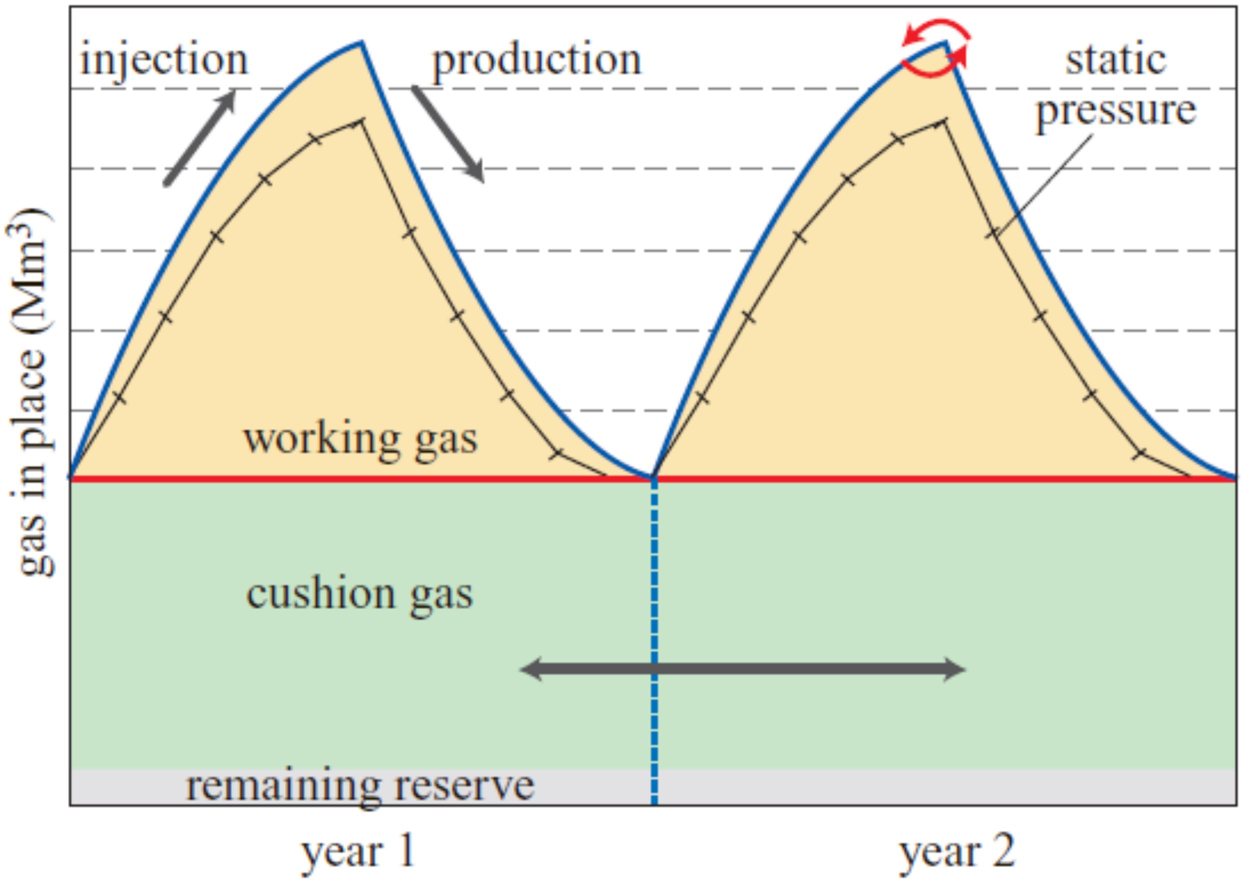
Motivation: Large-scale storage is required to balance temporal variability in energy supply and demand, a mismatch inherent to energy systems but amplified by the variability of renewable generation.



Why Modeling/Simulation?

- Provide data for technoeconomic analysis and support future storage projects.
- Define operational limits for safer and more flexible storage.
- Evaluate durability and reliability of underground hydrogen storage sites.
- Improve understanding of how repeated injection–withdrawal influences mechanical response and degradation at field scale.
- A unified modeling framework connecting operations, loading conditions, and mechanical degradation.

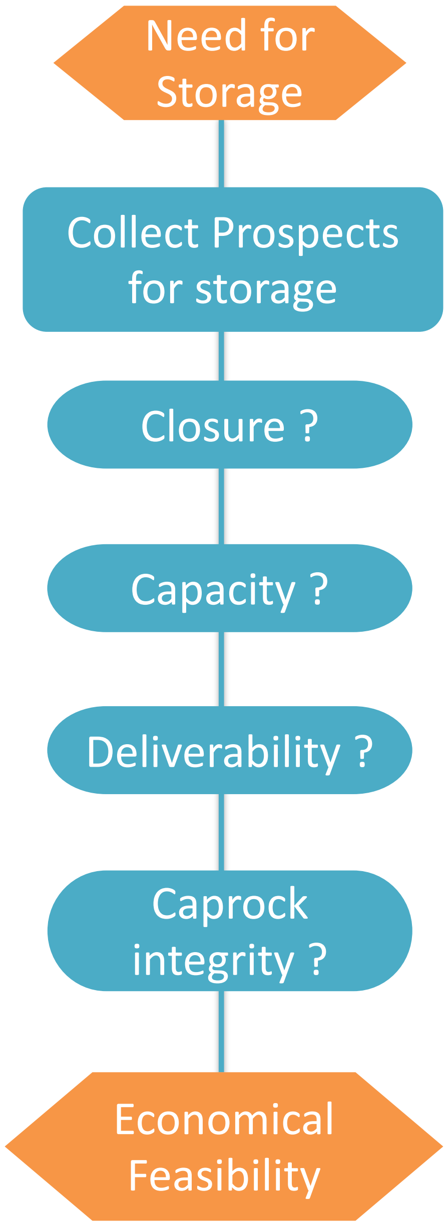
Insights & Guidelines



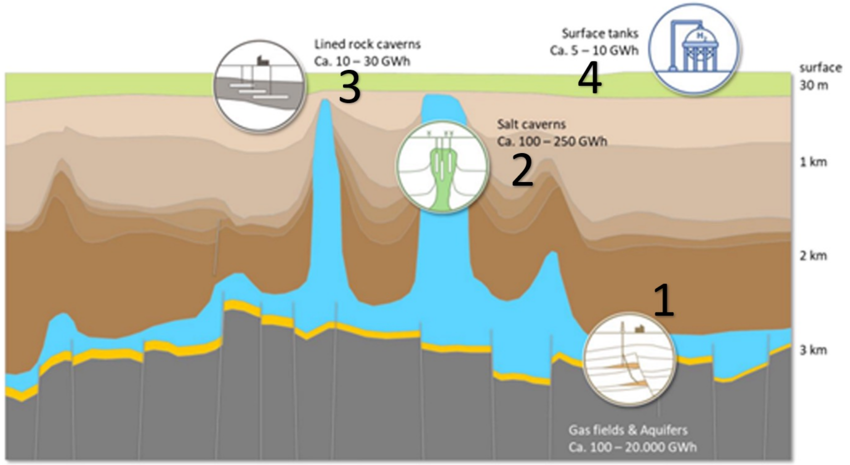
Max Capacity

Gas in reservoir

Cushion



Geological Underground H_2 Storage (UHS)



Storage Type	Top Advantages	Top Challenges
Salt Caverns	• Ultra-low permeability → excellent sealing • Self-healing creep closes microfractures • High H_2 purity (chemically inert halite) • Rapid injection/withdrawal • Proven Performance from decades of NG & HC	• Hydrogen embrittlement (wellbore integrity) • Interlayer leakage in bedded salt • Long-term creep shrinkage • Brine disposal during leaching
Depleted Oil & Gas Reservoirs	• Large storage volume • Existing infrastructure • Known geology • Proven trap integrity for millions of years.	• Residual hydrocarbons → contamination risk • Microbial conversion (H_2 → CH_4/H_2S reported in porous media) • Higher permeability → leakage risk • Large cushion gas requirement
Aquifers	• Wide geographic availability • Very large theoretical capacity • No prior hydrocarbon contamination	• Poor characterization (uncertainty) • Hydrogen–water–microbe reactions • Groundwater contamination risk • Lower containment reliability vs salt

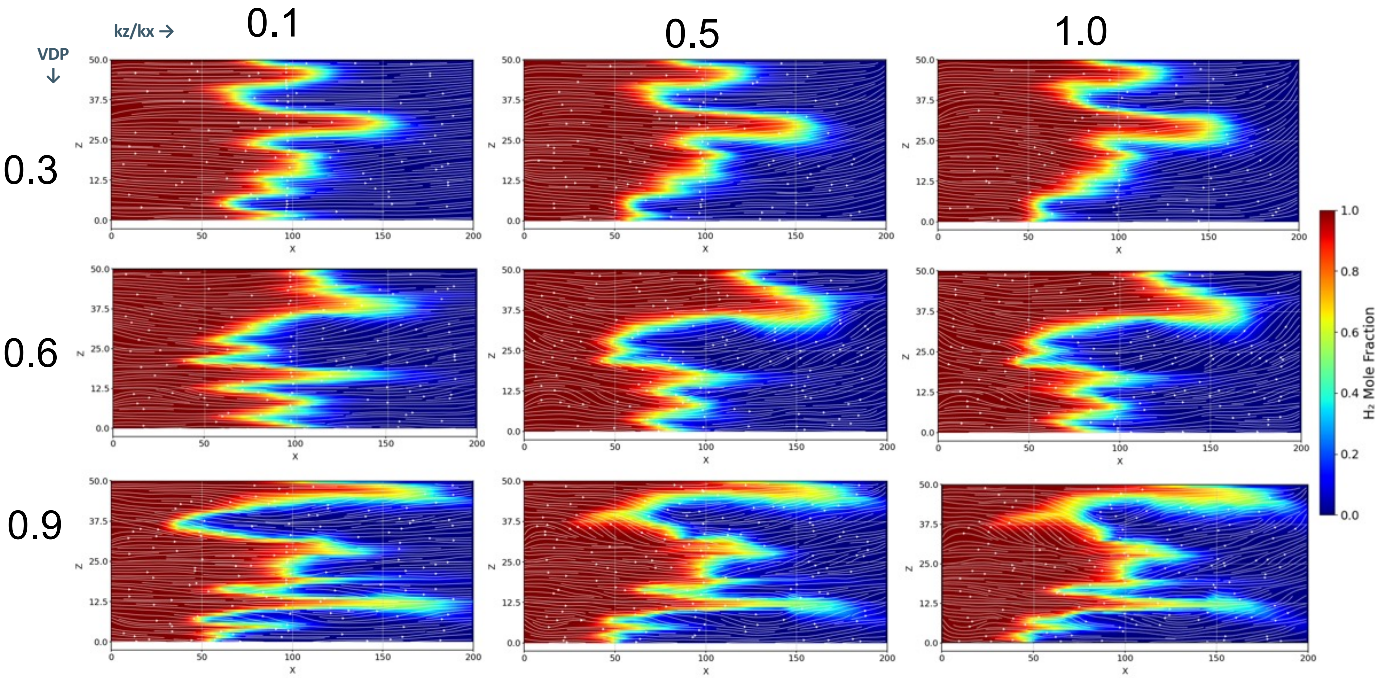
H_2 Dispersion and Heterogeneity in Gas Reservoir

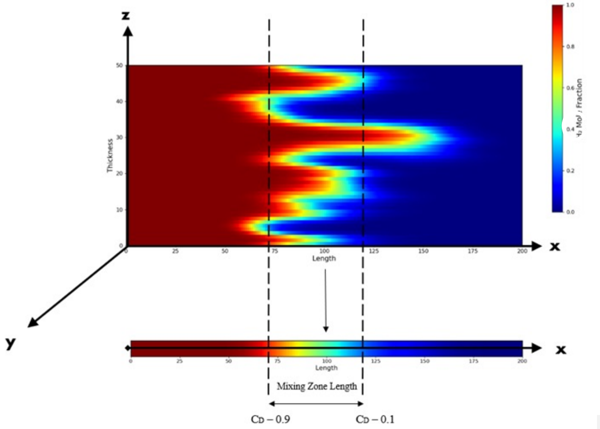
Effect of Heterogeneity:

- Low VDP (0.3): Near piston-like displacement; gravity dominates and H_2 rises to the top
- High VDP (0.9): Severe channeling; displacement front is highly irregular

Effect of Vertical Permeability:

- Low kz/kx (0.1): Horizontal layering dominates; gravity segregation is limited vertically
- High kz/kx (1.0): Strong vertical communication; gravity override is significantly amplified

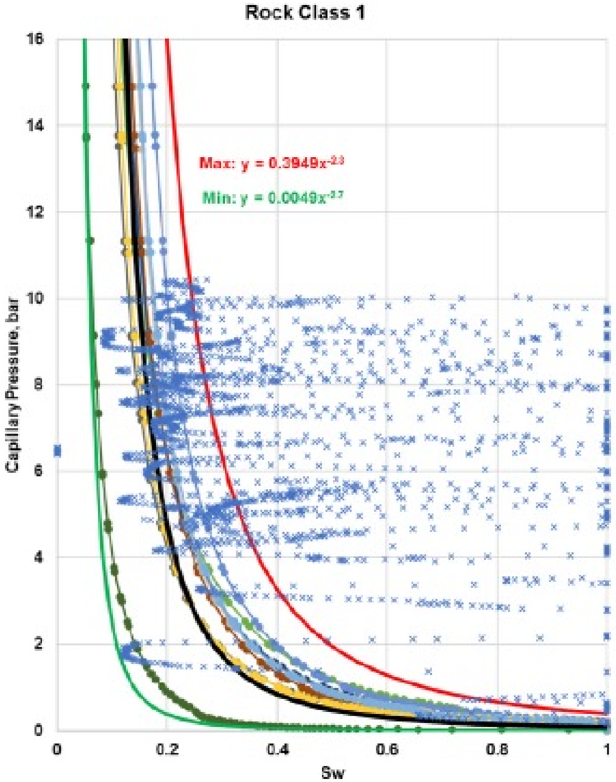


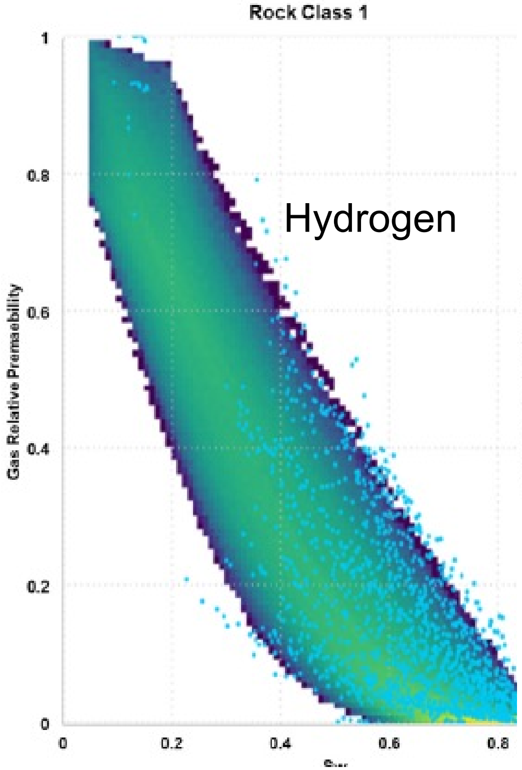


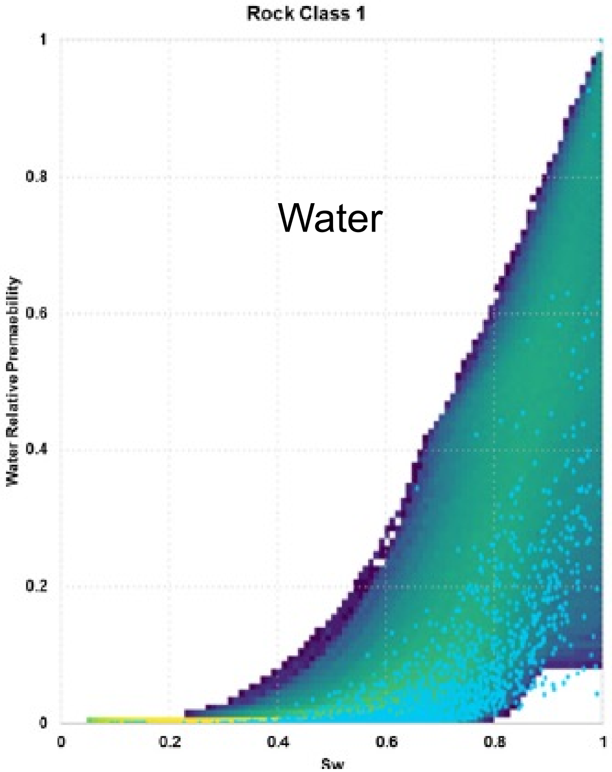
- **Dykstra-Parsons coefficient (VDP) (top to bottom: 0.3, 0.6, and 0.9)**
- **k_z/k_x (left to right: 0.1, 0.5, 1.0).**
- **Dimensionless time = 0.5 PV**

K. Mawa, B.R.B. Fernandes, M. Delshad, L. Lake, K. Sepehrnoori, Clean energy and Sustainability, 2026

Uncertainty in H_2/Brine Relative Permeability







Use MICP data, log saturations, and the relative permeability database.

Underground hydrogen storage in a depleted underground gas storage field in Austria: Forecasting under uncertainty and pilot test design

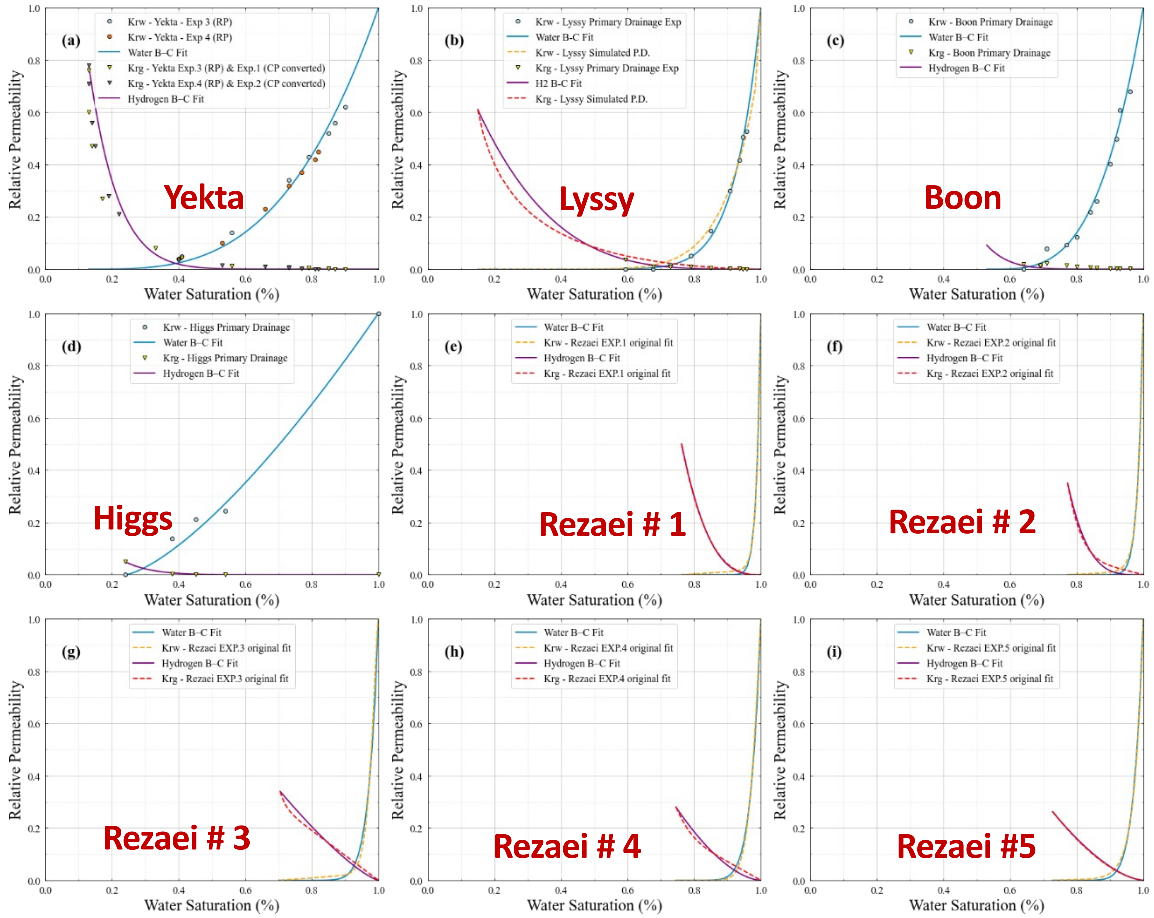
Vladislav Arekhov *, Albert Gauer, Torsten Clemens, David Boeck
OMV Exploration & Production GmbH, Trabrennstrasse 6-8, 1020, Vienna, Austria

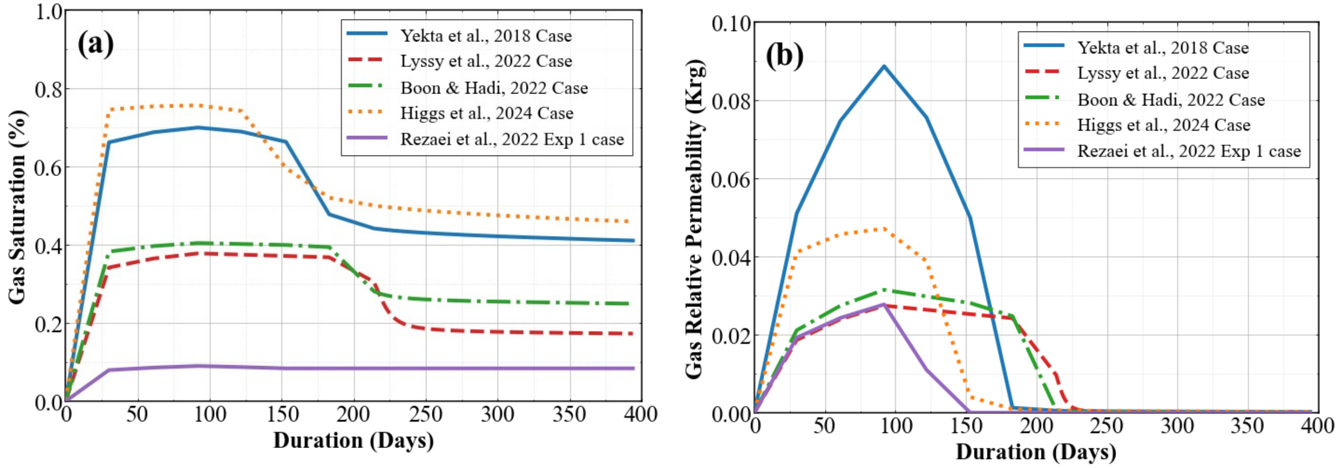
International Journal of Hydrogen Energy 227 (2026) 154633

Uncertainties in H_2-Water Relative Permeability

Published data

	S_{wr}	K_{rgMax}	n	m
Yekta	0.13	0.78	10	3.18
Lysyy	0.15	0.61	4.74	10.8
Boon	0.53	0.092	4.7	3.7
Higgs	0.24	0.049	9.5	1.4
Rezaei Exp. 1	0.76	0.5	3	18.3
Rezaei Exp. 2	0.77	0.35	3.8	13.9
Rezaei Exp. 3	0.7	0.34	1.3	10
Rezaei Exp. 4	0.74	0.28	1.7	8.6
Rezaei Exp. 5	0.73	0.262	1.6	9.6
Rezaei Exp. 7	0.53	0.17	2.4	6.5



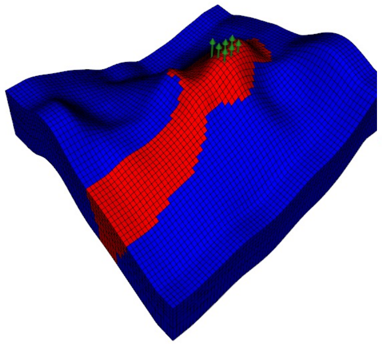


M. Hotan, M. Delshad, K. Sepehrnoori, Energy, under review, 2026

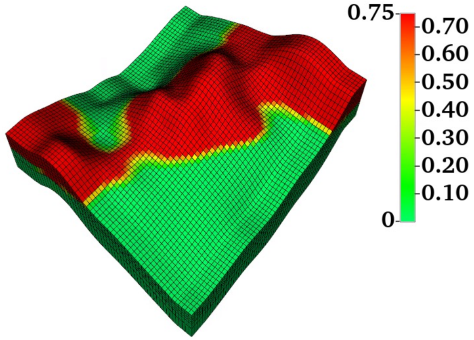
Commercial-Scale Consideration (10 Bcf)

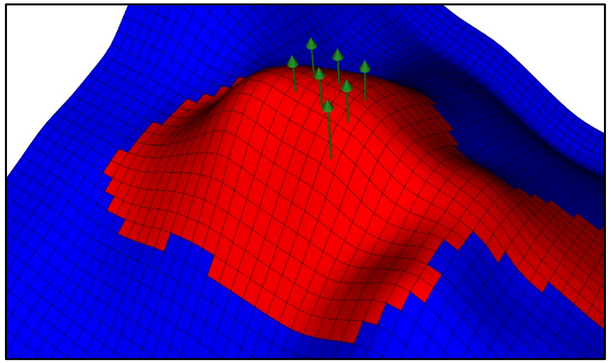
2002 -2023: Gas reservoir being depleted
2023 – 2053: Hydrogen storage (2 months of H2 inj before 2023)
2053 – 2063: End-of-life depletion

Permeability

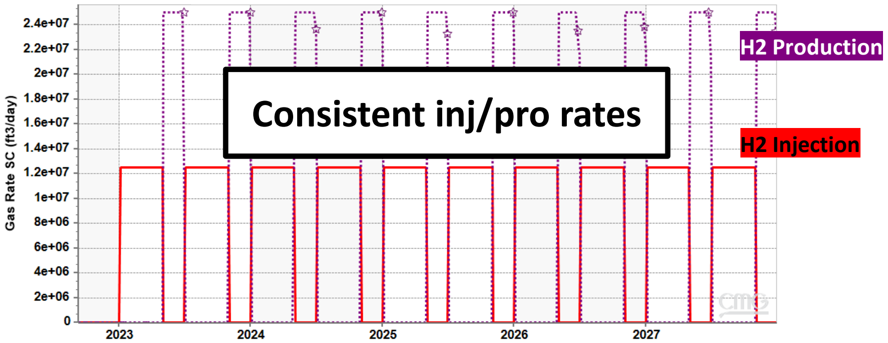


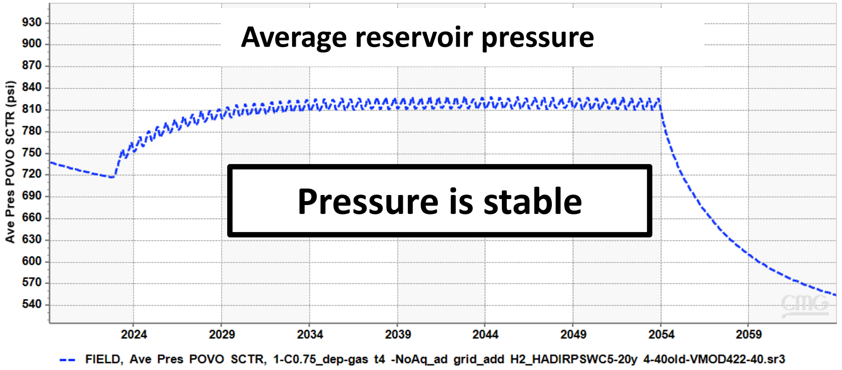
Gas saturation



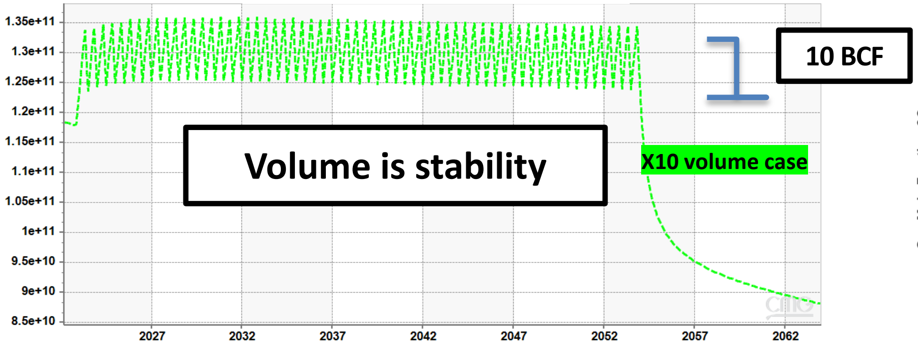


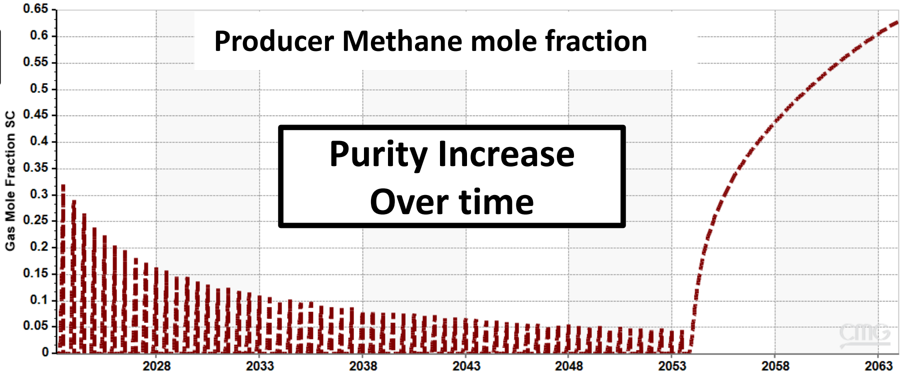
Gas rate of injector and producer





Reservoir gas volume

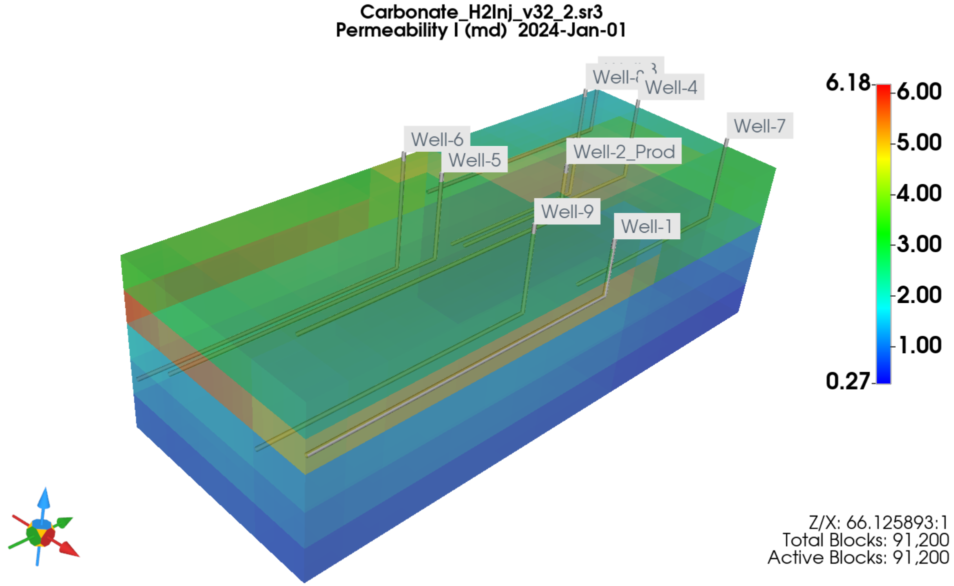




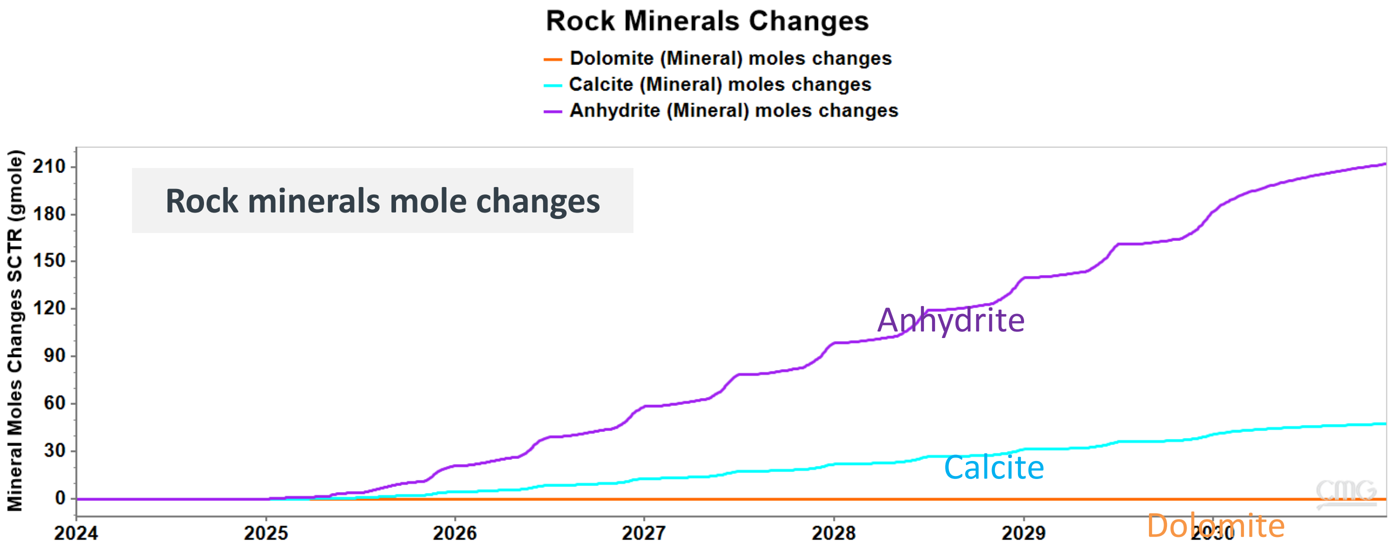
UHS in a Depleted Gas Reservoir (Carbonate)

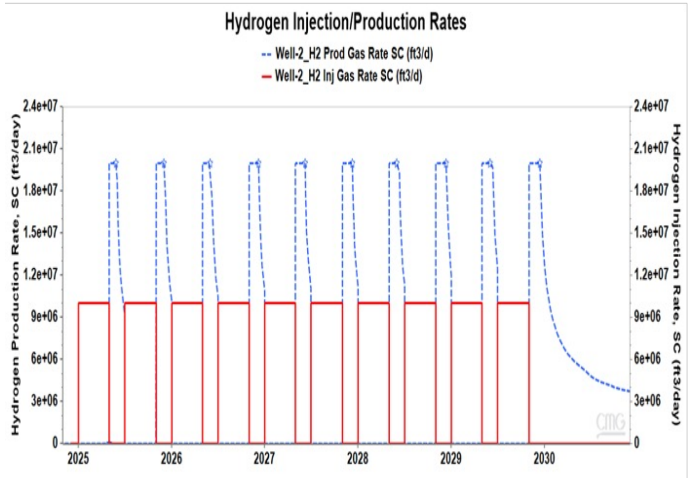
- **Most studies are in sandstone reservoirs; scarce research/data for UHS in carbonate reservoirs!**
- **Geologically complex but significant capacity**

- Assessment in a carbonate reservoir (Williston Basin)
- H_2 purity was ~85% and recovery was 92%

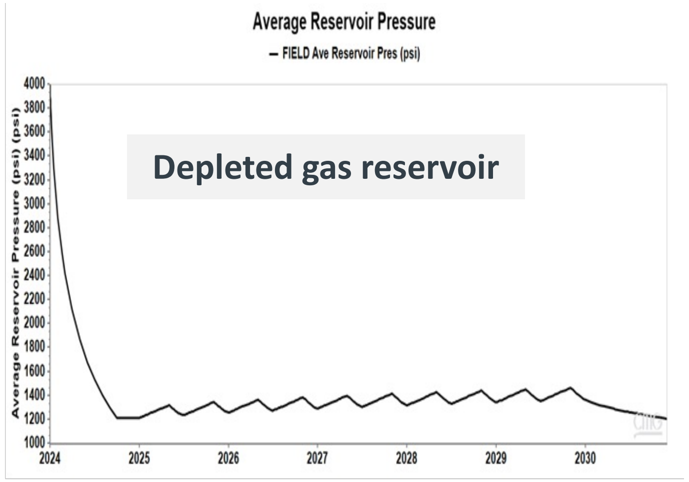


Permeability (mD), showing horizontal wells





H_2 inj/prod cycles



Average reservoir pressure

Hussain et. al (2026) https://doi.org/10.2118/230925-MS

Subsurface Energy Storage Potential of Domal and Bedded Salt Formations

Leo Ruiz Maraggi, Edna Rodriguez Calzado, Anna Cervantes, Daniele Blancone, Leandro Melani, Prasad Pothana, Ander Martinez, Lorena Moscardelli

8/4/2026

Goals of this Research

Leo Ruiz Maraggi, Edna Rodriguez Calzado, Anna Cervantes, Daniele Blancone, Leandro Melani, Prasad Pothana, Ander Martinez, Lorena Moscardelli

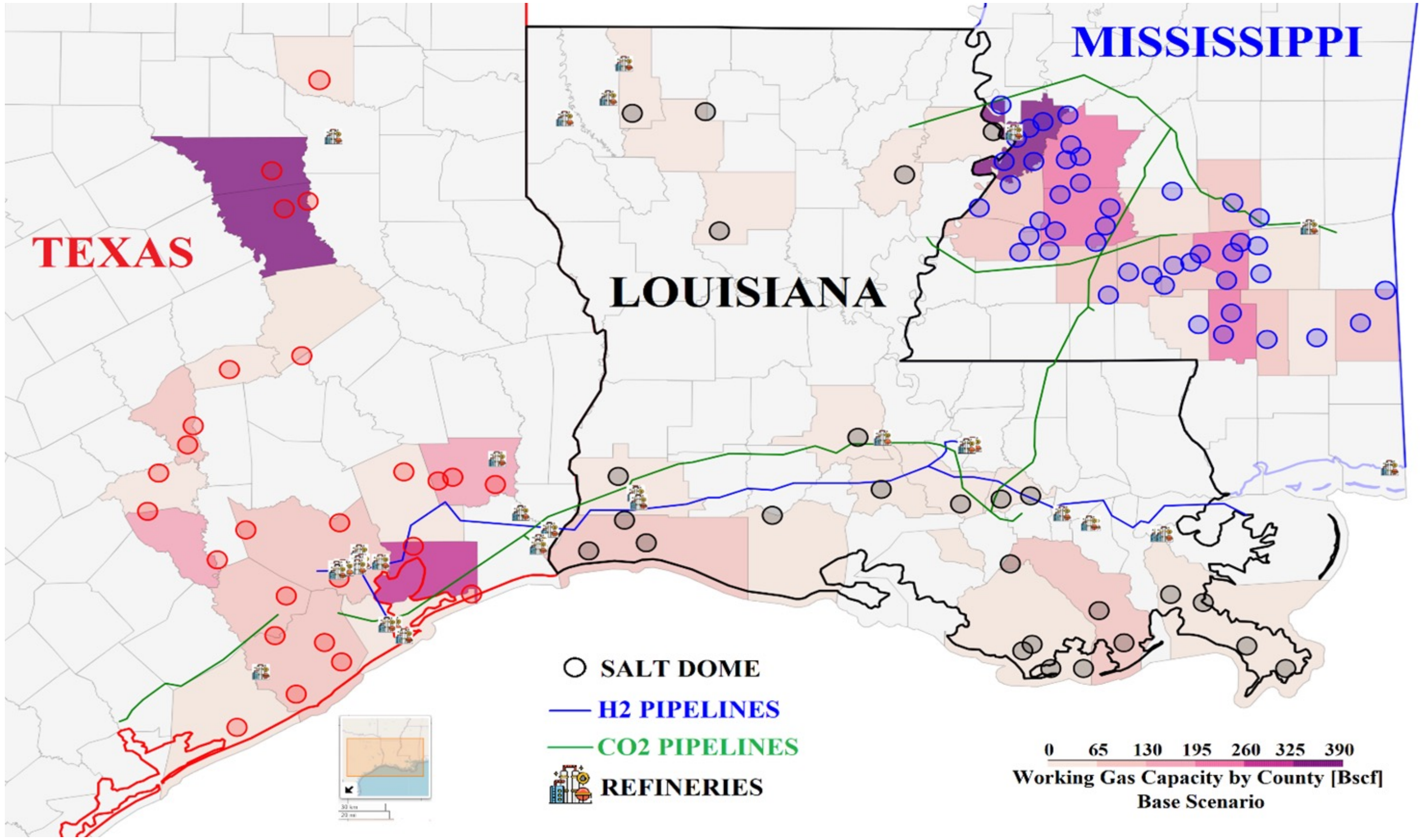
1. Estimate subsurface energy (natural gas/hydrogen) storage potential for domal and bedded salt formations in the U.S and Europe.

2. Quantify the uncertainty associated with natural gas/hydrogen storage potential (variability).

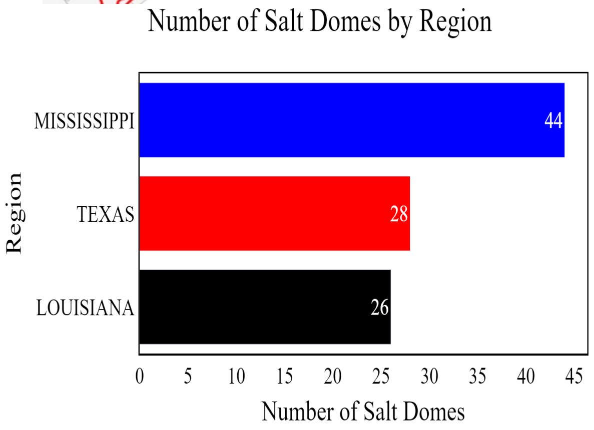
3. Determine the regions with largest potential and lowest uncertainty for energy storage.

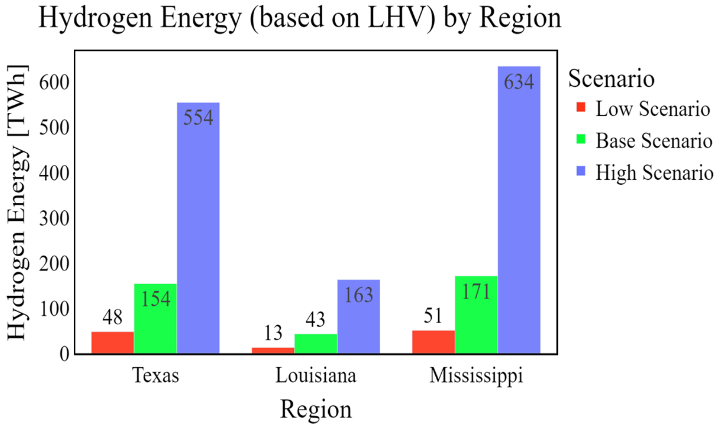
4. Develop GeoH_2 salt web app for energy storage in salt formations.

U.S. Gulf Coast Salt Domes: Hydrogen Storage Potential



- Collected data of 569 salt domes.
- 98 salt domes suitable for energy storage.
- Low, base, high storage scenarios.
- Breakdown of results by state, county, and salt dome.





Journal of Energy Storage 82 (2024) 110585

Contents lists available at ScienceDirect

Journal of Energy Storage

journal homepage: www.elsevier.com/locate/est

ELSEVIER

Research papers

Hydrogen storage potential of salt domes in the Gulf Coast of the United States

Leopoldo M. Ruiz Maraggi *, Lorena G. Moscardelli

Bureau of Economic Geology, The University of Texas at Austin, United States of America

A R T I C L E I N F O

Keywords:
Hydrogen geologic storage
Hydrogen storage evaluation
Salt caverns
U.S. salt domes

A B S T R A C T

Hydrogen (H_2) has the potential to become a clean fuel alternative to replace hydrocarbons in a low-carbon economy with H_2 storage representing a key component of the emerging H_2 value chain. However, the use of H_2 for bulk power management and other industrial applications will require significant upscaling of geological storage. While geological H_2 storage can take place in both porous media and salt caverns within salt formations, salt caverns are considered the best option for underground H_2 storage for their large storage capacity, their sealing integrity, and their flexible operation with large injection and withdrawal rates. This study collects a comprehensive database of 569 salt domes located in the onshore and the offshore regions of the Gulf of Mexico Basin in the United States. This work filters the database by selecting onshore domes with no pre-existing caverns and a suitable depth range for salt cavern construction. As a result, we select and analyze 98 onshore salt domes suitable for H_2 storage in the states of Texas, Louisiana, and Mississippi. We perform H_2 storage capacity calculations for three scenarios: low, base, and high cases. For the base scenario, we estimate that these salt domes can accommodate a total of 2550 caverns, with a total working gas potential of 130 Gsm^3, equivalent to a total energy stored potential of 368 TWh. According to our base scenario, a 10 % replacement of the natural gas consumption in the United States, could require a H_2 storage capacity of 28 Gsm^3. This number implies the construction or repurposing of more than 556 salt caverns with a geometric volume of 0.75 Mm^3 per cavern. This study is the first of its kind, providing a breakdown of H_2 storage potential by state, county, and individual salt dome in the states of Texas, Louisiana, and Mississippi. The findings from this study provide valuable information for assessing the H_2 storage potential of salt domes in the United States, useful to assist in the definition of strategies to develop future H_2 infrastructure. Finally, we provide the readers with an interactive map that displays the results of this study.

1. Introduction

1.1. Motivation for underground hydrogen storage (UHS) in salt domes

The shift from fossil-based fuels to renewable energy is driving a major transformation in our energy systems, reshaping the way we consume energy. As part of this transition, H_2, a known carbon-free energy carrier, will play a vital role in bridging the gap between fossil fuels and renewables. However, to establish a successful H_2 economy, it is essential to develop several key components across the entire value chain including feedstock, production methods, storage, transportation, and marketability. For instance, to replace 10 % of the U.S. current natural gas consumption, which is equivalent to 915 Gsm^3 [1], could require a H_2 storage capacity of 28 Gsm^3. To reach this storage capacity, approximately 1000 salt caverns, each with a capacity of 28 Msm^3, would need to be either leached or adapted for H_2 storage. This estimate assumes a storage-to-consumption ratio of 10 % [2] and the energy content of H_2, measured in terms of its volumetric lower heating value, is one-third of natural gas. This simple calculation highlights the urgent need to scale up the H_2 storage capacity to unprecedented levels in order to achieve the goal of a net-zero economy within the next couple of decades. Currently, there are a limited number of salt cavern sites for H_2 storage in the United Kingdom (Teesside), and in the United States, including Clemens Dome, Spindletop, and Moss Bluff [3,4]. Clemens Dome has been in operation since 1983, while Moss Bluff began its operations in 2007 [4]. These long-standing projects have consistently shown the technical feasibility of underground H_2 storage. However, these subsurface H_2 storage facilities were not designed for bulk power management, industrial purposes (feedstock for steel and cement), or for

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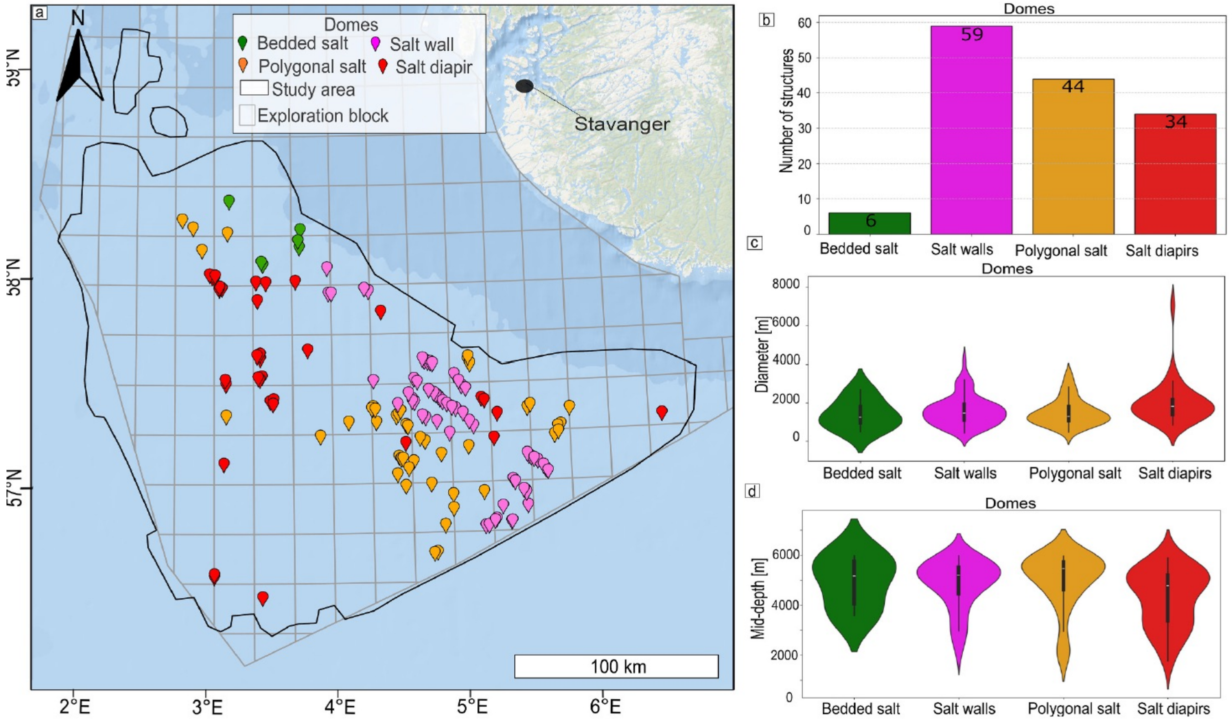
Available online 25 January 2024

Salt Domes Offshore Norway: Hydrogen Storage Potential



- Collected data of 241 offshore salt domes.
- 143 salt domes suitable for energy storage.
- Low, base, high storage scenarios.
- Results breakdown: block and salt dome.

Journal of Energy Storage 128 (2025) 117032

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/est

Research Article

Assessing hydrogen storage potential in Zechstein salt caverns of the Norwegian North Sea

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[b] Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin, United States of America

ARTICLE INFO

Keywords:
Zechstein
Salt structures
H2 storage
Salt caverns
Energy security
Energy transition

ABSTRACT

Underground hydrogen storage (UHS) in salt caverns offers a viable solution for balancing intermittent renewable energy sources like wind and solar. This study evaluates UHS potential in the southern Norwegian North Sea, focusing on Upper Permian Zechstein salt structures. Using well log and seismic data, we characterize the salt structures and identify those suitable for cavern development. Through a GIS-based analysis and the $GeoH_2$ tool, we estimate storage capacity across low, base, and high scenarios. In the base case, ~8700 caverns across 143 salt domes could store ~11,164 Bscf of hydrogen, equating to ~900 TWh of energy. After accounting for 22 % non-halite content estimated from well logs, this is reduced to 699 TWh—about three times Norway's annual energy consumption. The alignment of UHS in salt caverns with ongoing and planned CO_2 storage and wind energy projects, could transform the Norwegian Continental Shelf into a hub for low-carbon energy, supporting Europe's transition to a sustainable energy system.

1. Introduction

Hydrogen (H_2) is a high-energy-density carrier that generates power without greenhouse gas emissions. While exploration for naturally occurring subsurface hydrogen (white H_2) is in its infancy [1], global demand is rising steadily [2]. This demand may be met through green H_2—produced via electrolysis powered by renewables—or blue H_2, generated through steam methane reforming with carbon capture and storage.

Large-scale H_2 production requires equally large-scale, cost-effective storage solutions to meet both short- and long-term needs. Underground hydrogen storage (UHS) is one of the most promising options, offering scalable capacities to balance the variable supply and demand from renewable energy sources [3].

Currently, three main types of UHS options are considered [4]: (1) depleted hydrocarbon reservoirs, (2) deep saline aquifers, and (3) man-made salt caverns. Among these, salt caverns are especially attractive due to their impermeability, mechanical stability, and ability to handle high injection and withdrawal rates [5]. Constructed through solution mining [6], salt caverns act as large "subsurface batteries," managing daily and seasonal fluctuations in renewable energy [7–9].

Salt's unique properties—particularly halite's low permeability and chemical inertness—make it ideal for gas storage. Several countries have already deployed UHS in salt caverns, including the Teesside project in the UK [10,11] and sites in the U.S. like Moss Bluff, Spindletop and Clements [12,13]. However, these sites mainly serve as strategic reserves with infrequent cycling, in contrast to the frequent injection and withdrawal cycles required for power generation [14]. In addition, there is a need for upscaling both H_2 production and storage to meet future demands [15].

Despite growing interest, several technical challenges remain. Salt heterogeneity—including non-halite facies like anhydrite, carbonates, and clastics—can affect cavern stability, permeability, and integrity [14,16,17]. These factors are critical for long-term operation and efficient cycling [18]. Additionally, seismic imaging of salt bodies remains complex due to internal deformation and contrasting velocities [19].

Interest in UHS is growing rapidly across Europe and North America [20,21], with Germany, the Netherlands and the UK leading in European exploration [22–25]. Caglayan et al. [20] estimate the UHS potential of European salt basins at ~84,800 TWh, with the Norwegian North Sea alone accounting for ~7500 TWh.

Historically, the prosperity of North Sea countries—especially

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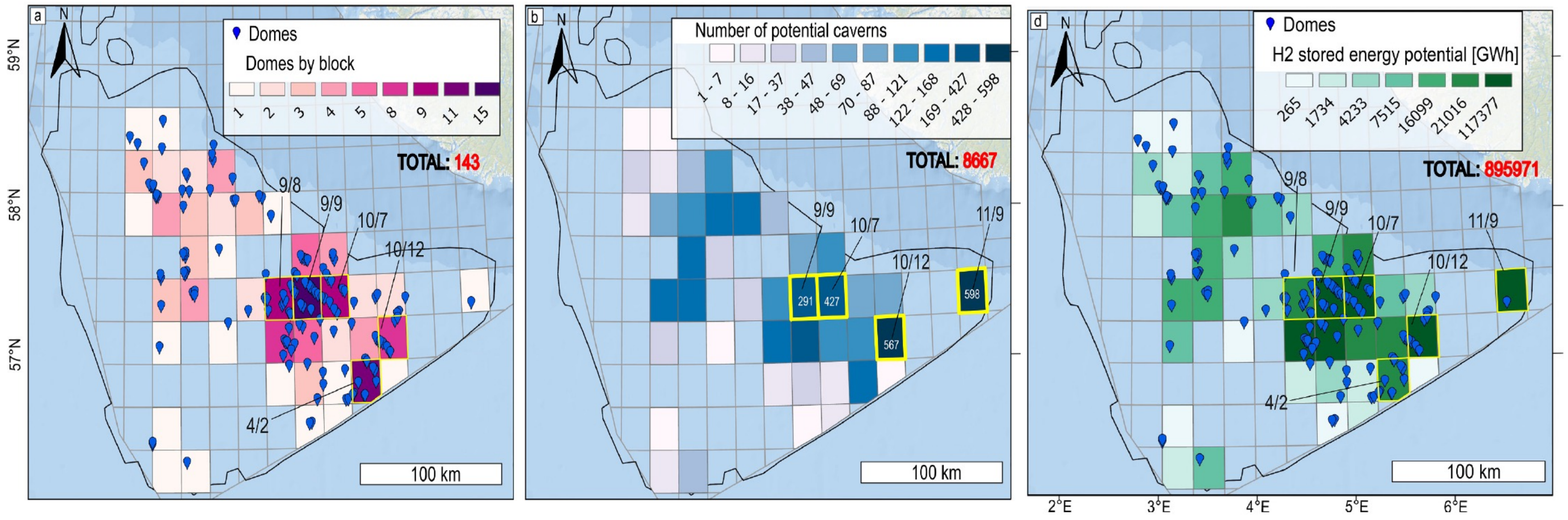
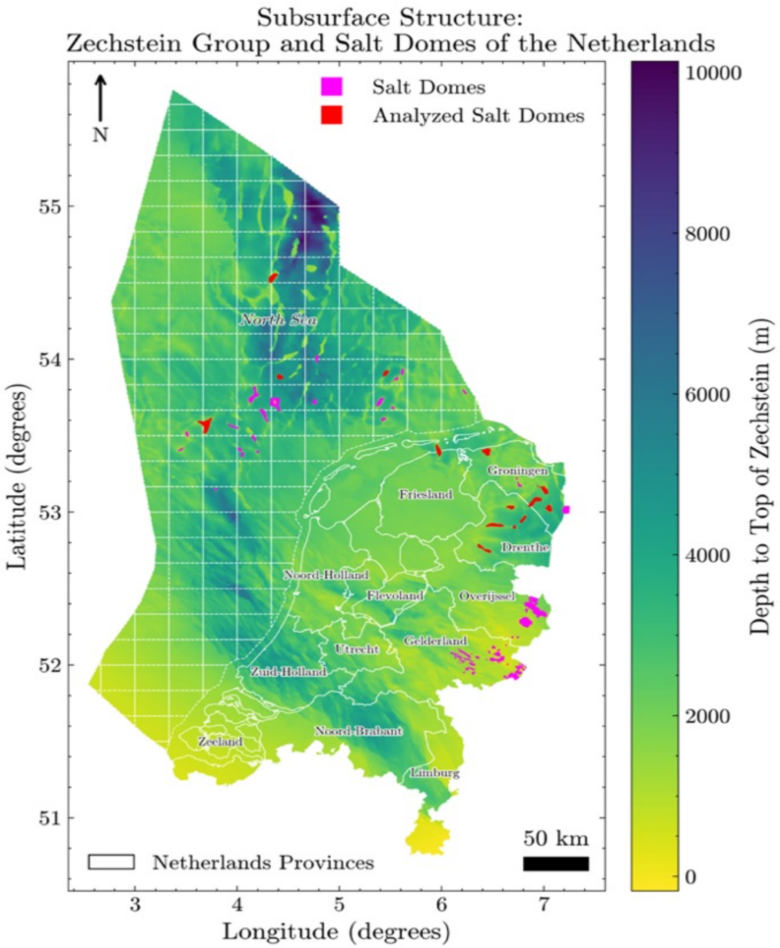
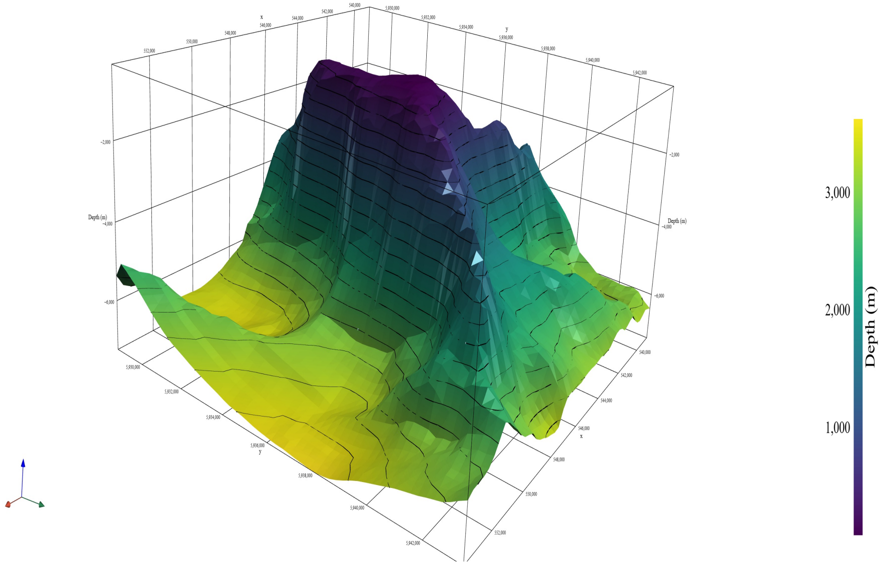
Available online 27 May 2025

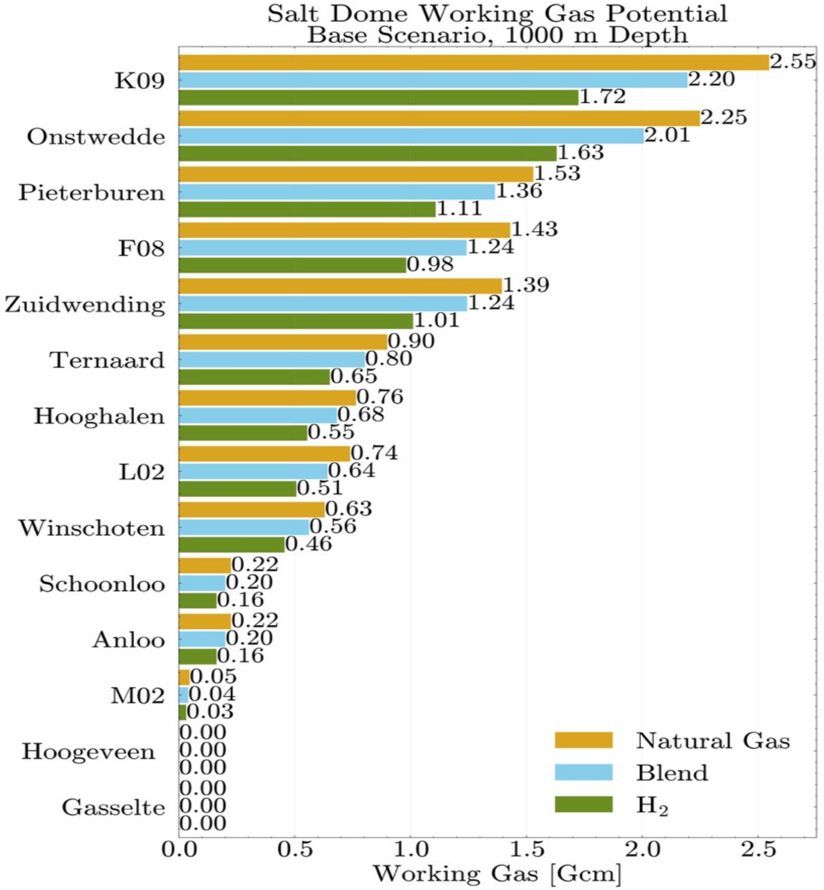


Salt Domes in The Netherlands: **Energy Storage Potential**



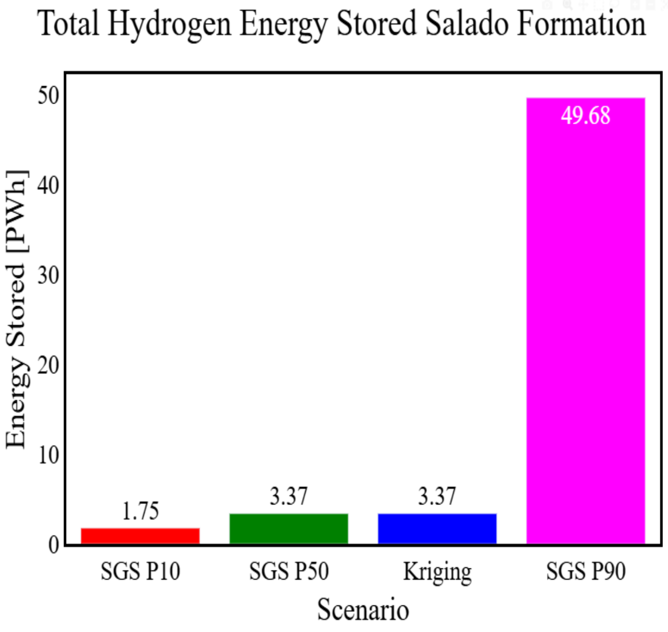
3-D model K09 Offshore Dome

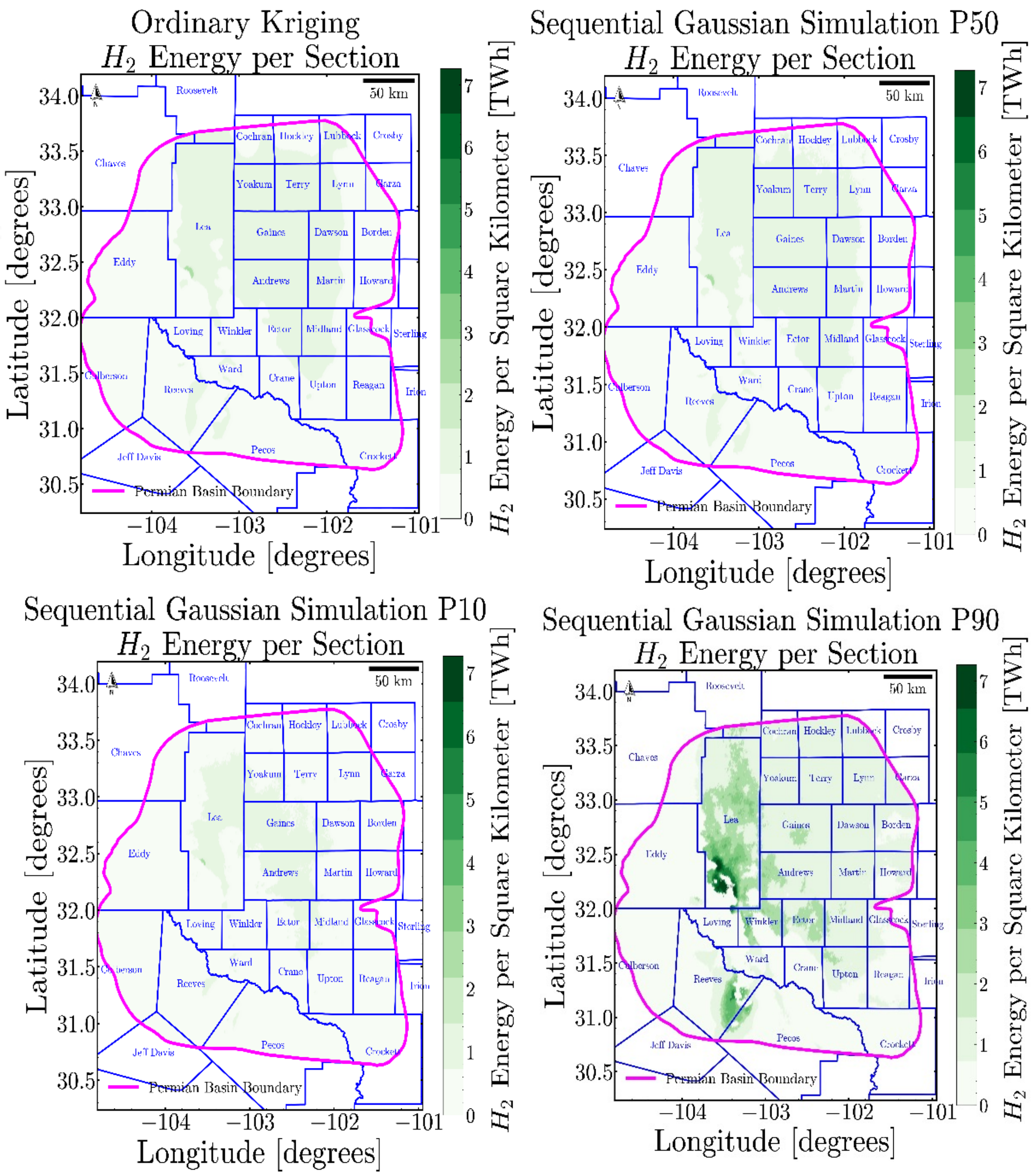




- Collected data of 14 offshore/onshore domes.
- 3-D modeling of Netherlands domes.
- Hydrogen, natural gas, and blend estimations
- Low, base, high storage scenarios.
- Results breakdown: province, block and salt dome.

U.S. Permian Basin Salado Bedded Salt Formation: Hydrogen Storage





- Collected data of 30k well logs.
- Depth and electrofacies for 2k logs.
- Kriging and SGS for properties.
- Results breakdown: county and block

International Journal of Hydrogen Energy 144 (2025) 496–512

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journal homepage: www.elsevier.com/locate/he

Hydrogen storage potential of Salado Formation in the Permian Basin of West Texas, United States

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ARTICLE INFO

Keywords:
Hydrogen geologic storage
Bedded salt
Salado Formation
West Texas Permian Basin
Uncertainty quantification
Geoscience and engineering integration

ABSTRACT

Hydrogen (H_2) has the potential to become a cleaner fuel alternative to increase energy mix versatility as part of a low-carbon economy. Geological H_2 storage represents a key component of the emerging H_2 value chain since large-scale energy generation linked to energy generation and large-scale industrial applications will require significant upscaling of geological storage. Geological H_2 storage can take place in both salt domes and bedded salt formations. Bedded salt formations offer a significant advantage for H_2 storage over salt domes because of their widespread availability. This research focuses on evaluating the H_2 storage potential of the Salado Formation, a bedded salt deposit in the Permian Basin of West Texas in the United States. Using data from 3268 well logs, this study analyzes an area of 136100 km^2 to identify suitable depth and net halite thickness for H_2 storage in salt caverns. In addition, this work applies a novel geostatistical workflow to quantify the uncertainty in the formation's storage potential. The H_2 working gas potential of the Salado Formation ranges from 0.62 to 17.53 Tsm^3 (1.75–49.68 PWh of stored energy) across low-risk to high-risk scenarios, with a median potential of 1.19 Tsm^3 (3.37 PWh). The counties with the largest storage potential are: Lea in New Mexico, and Gaines and Andrews in Texas. These three counties account for more than 75 % of the formation's total storage potential. This is the first study to quantify uncertainty in H_2 storage estimates for a bedded salt formation while providing a detailed breakdown of results by county and 1 km^2 grid sections. The findings of this work offer critical insights for developing H_2 infrastructure in the Permian Basin. The Permian Basin of West Texas has the potential to become an important hub for H_2 production from both natural gas and/or renewable energy. Estimating H_2 storage potential is an important contribution to assess the feasibility of the entire H_2 value chain in Texas. An interactive map accompanies this work, allowing the readers to explore the results visually.

1. Introduction

1.1. Motivation for underground hydrogen storage in bedded Salt Formations

The ambition to transition from fossil fuels to renewable energy is challenging our vision of how energy systems should look like in the future, and it can potentially change how we consume energy. Hydrogen, an established energy carrier, can play a crucial role in bridging the gap between the use of fossil fuels and renewables. To build a successful H_2 economy, we must develop critical components across the value chain, including feedstock, production methods, storage, transportation, and marketability [1,2]. For example, replacing just 10 % of the U.S. current natural gas consumption of 915 Gsm^3 would require a H_2 storage capacity of 28 Gsm^3 [3]. This estimate underscores the urgent need to scale up H_2 storage capacity to unprecedented levels to achieve our ambition to reach a net-zero economy. For this reason, developing underground H_2 storage will play a crucial role to meet the demands of a viable H_2 economy.

Underground H_2 storage (UHS) can take place in different geological settings including salt caverns, porous media (depleted hydrocarbon reservoirs and aquifers), and lined rock caverns. Among these options, salt caverns are the most viable option for storing H_2 due to their integrity, compatibility with H_2, flexibility in withdrawal and injection rates, and cost-effectiveness [4–6]. Salt caverns can be built in both salt domes and bedded salt formations. The widespread geographical availability of bedded salt formations makes them best suited for H_2 storage [7]. Although large-scale H_2 storage in bedded salt formations is

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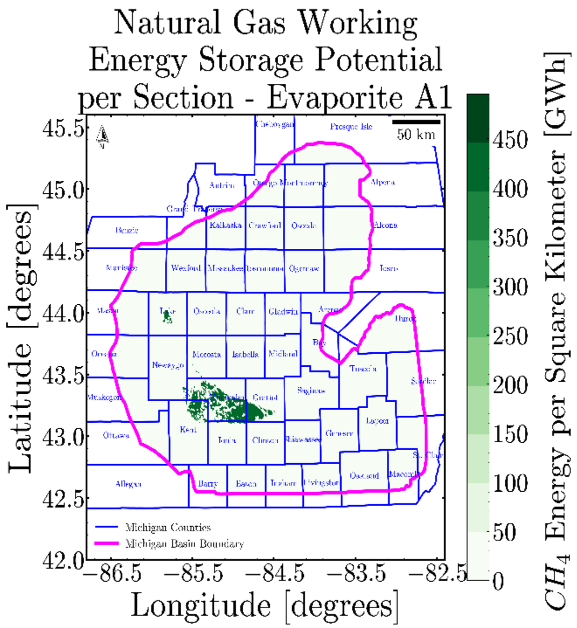
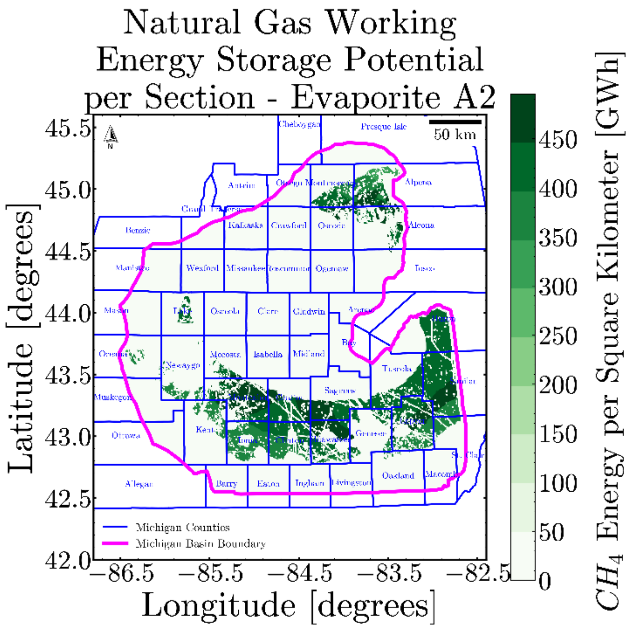
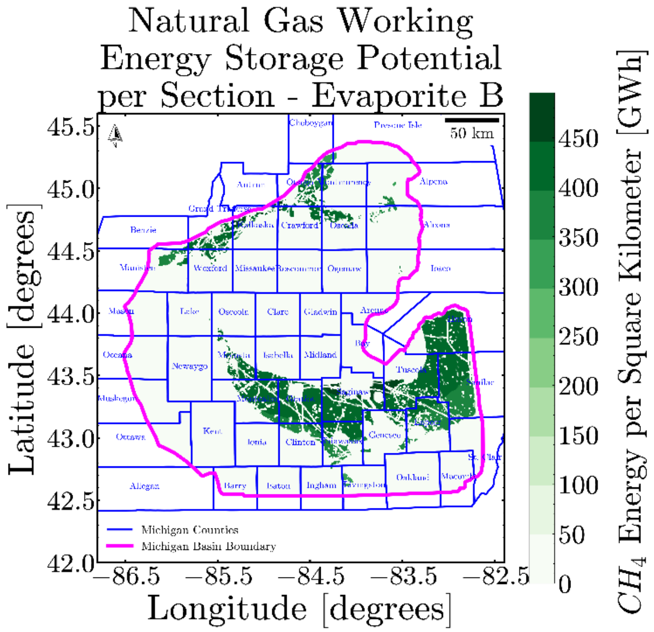
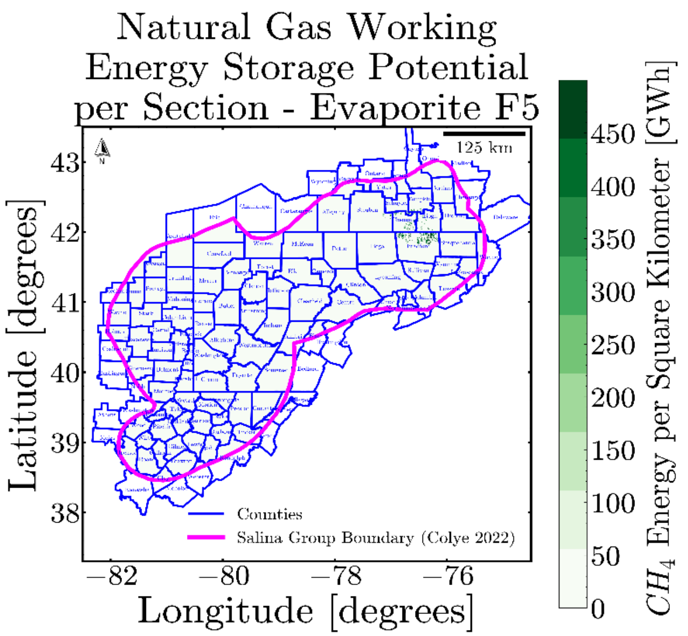
Available online 10 June 2025

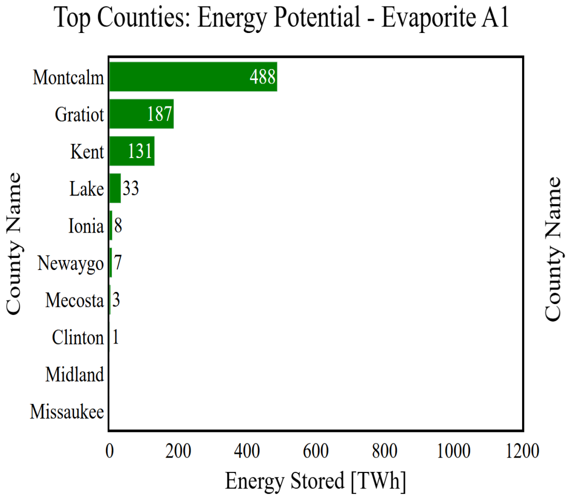
Michigan/Appalachian: Natural Gas Working Energy Evaporites: A1, A2, B, F5

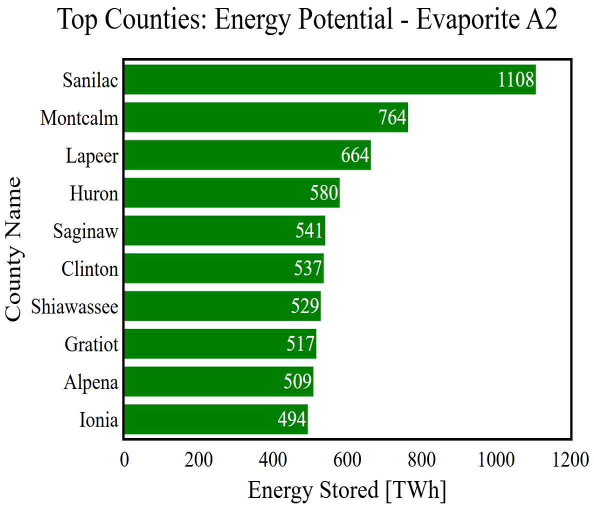


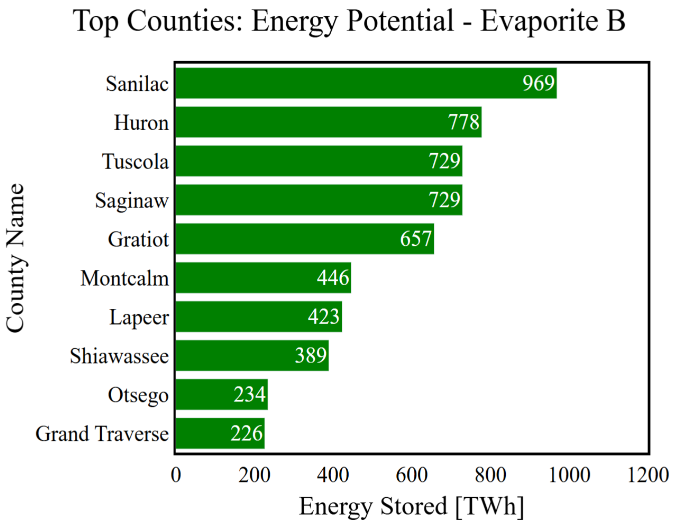


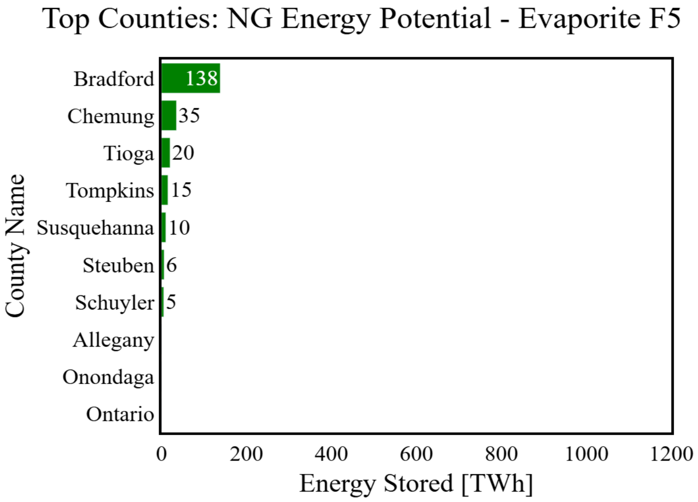




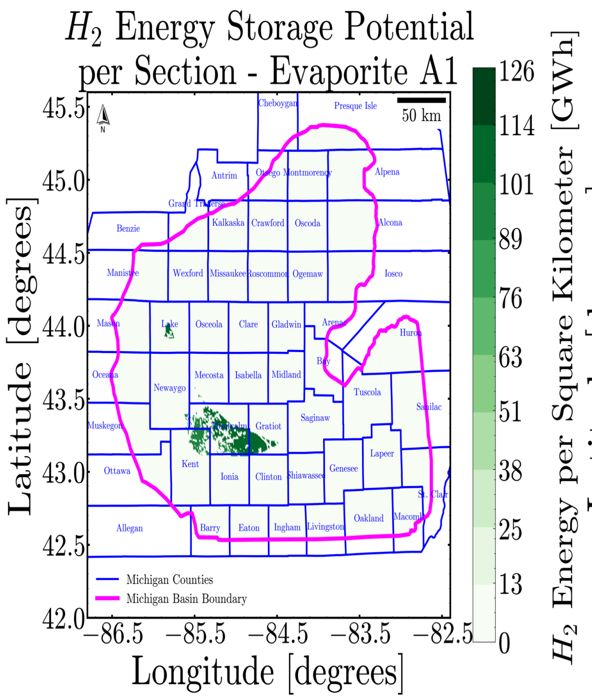


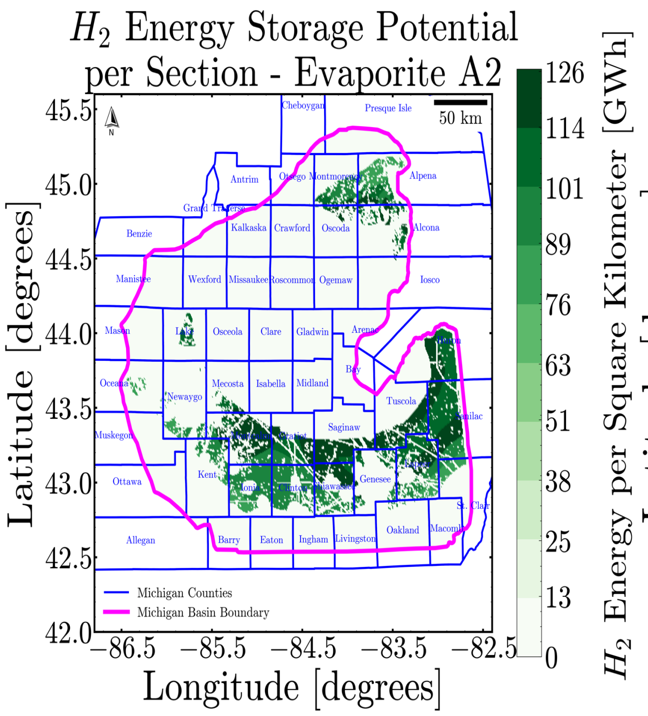


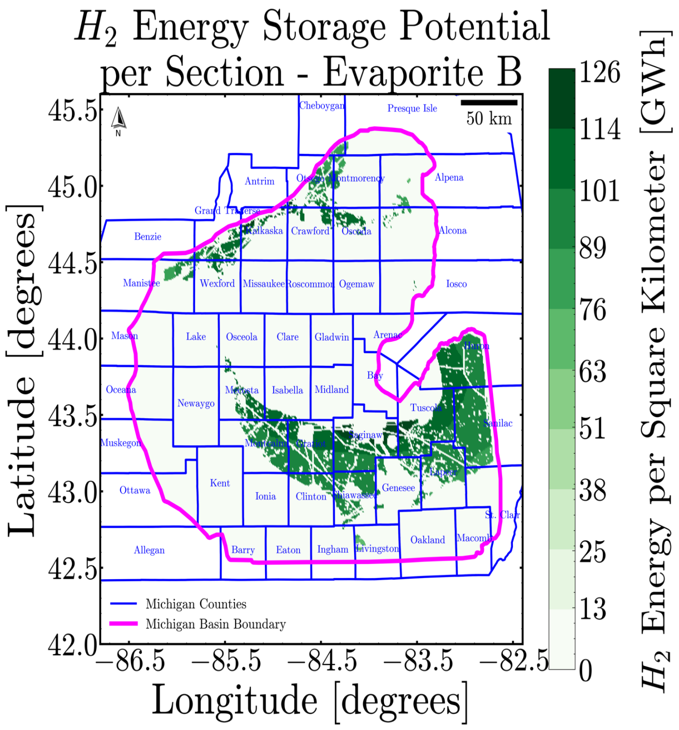


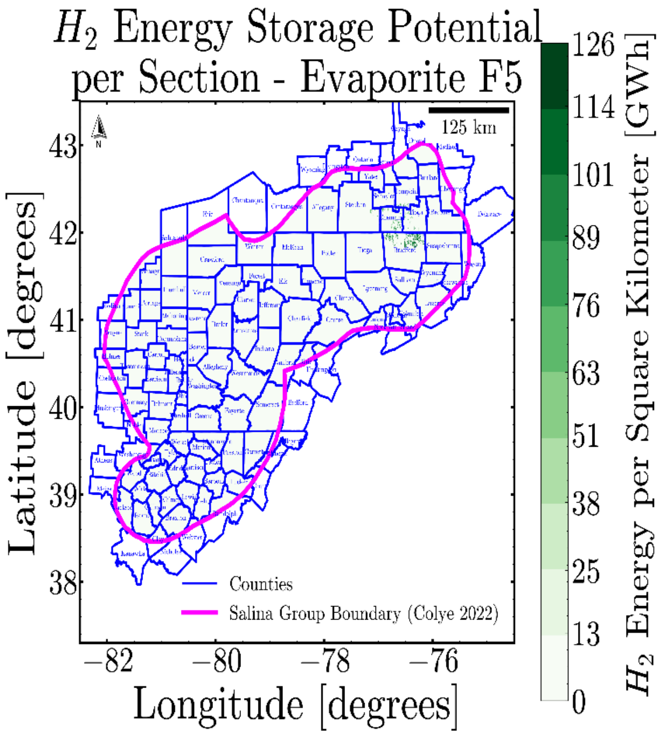


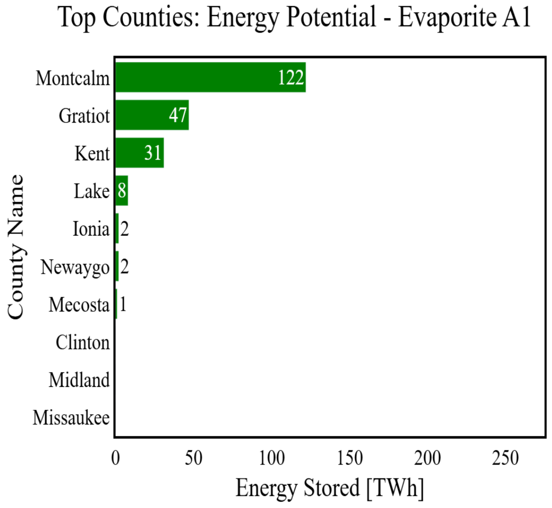
Michigan/Appalachian: **Hydrogen** Working Energy Evaporites: A1, A2, B, F5

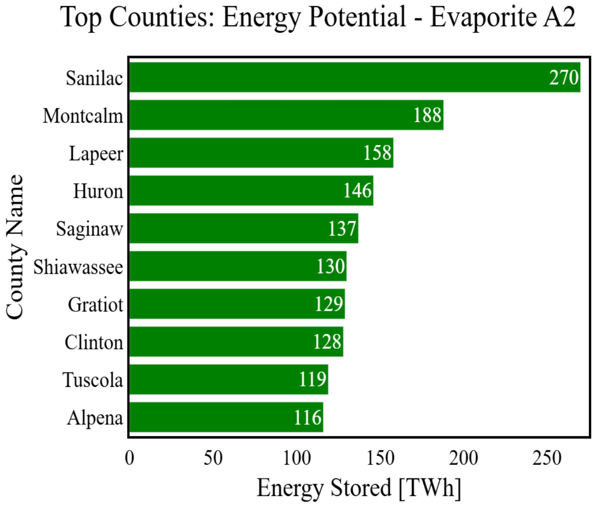


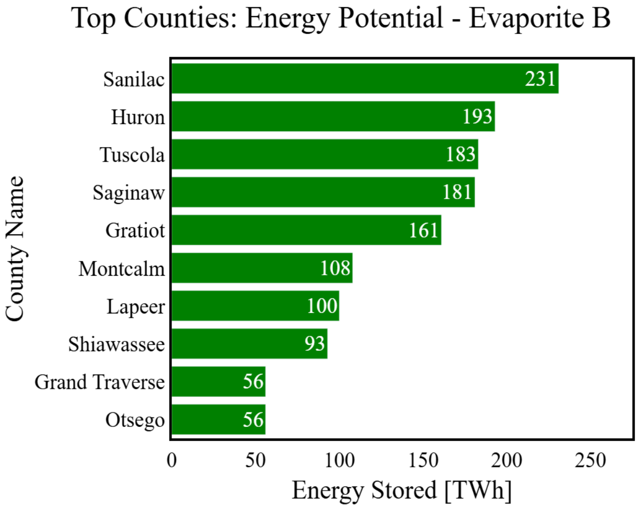


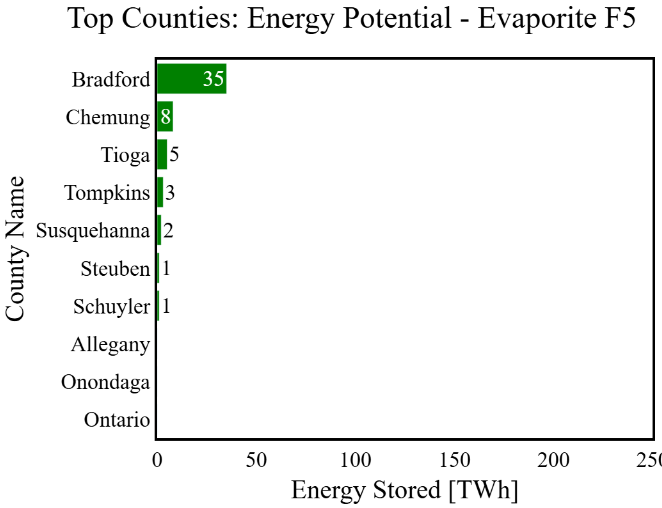






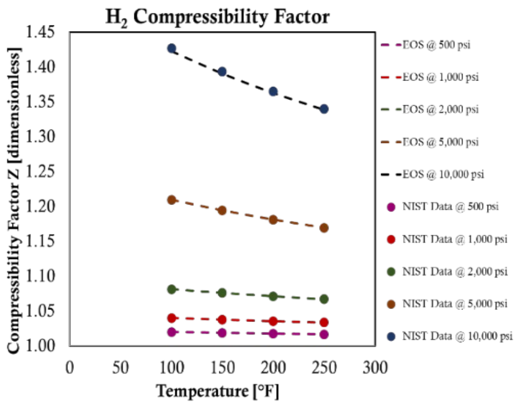




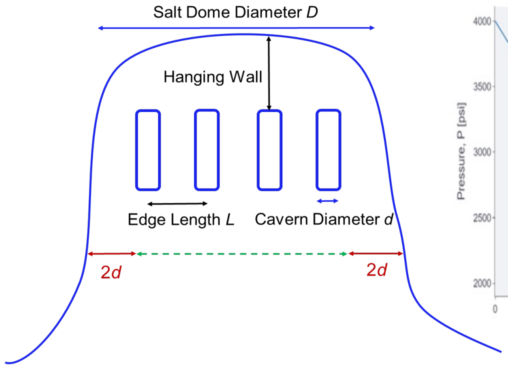


$GeoH_2$ Salt Storage and Cycling Web App: Features and Modules

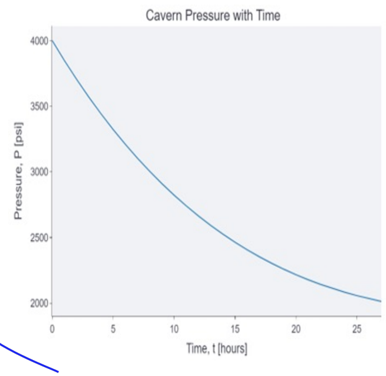
Fluid Properties

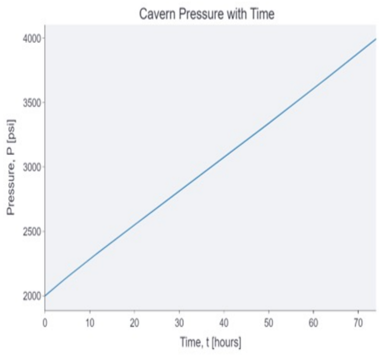


Salt Storage Capacity



Injection/Withdrawal





- Open-source web app.
- Consists of 6 modules.
- Handles H_2, CH_4 and blends.
- First of its kind in salt energy storage

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Modeling hydrogen storage capacities, injection and withdrawal cycles in salt caverns: Introducing the $GeoH_2$ salt storage and cycling app

Leopoldo M. Ruiz Maraggi, Lorena G. Moscardelli*

Bureau of Economic Geology, The University of Texas at Austin

HIGHLIGHTS

- Open-source web application for modeling hydrogen storage and cycling processes in salt caverns.
- Hydrogen real gas thermodynamic simulator.
- Modeling capabilities include: physical properties, volumetric, withdrawal, injection, and cycling processes.

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Thermodynamic simulator
Storage capacities
Cycling operations

ABSTRACT

Salt caverns have been used as hydrogen (H_2) storage solutions in four locations worldwide with refineries and the petrochemical industry relying on these supplies as strategic back-up. The viability of storing H_2 within salt caverns is advantageous given their large volumetric capacities, their flexible operation with large injection and withdrawal rates, and for being a proven technology for the underground storage of a wide variety of gases and liquids. However, to our knowledge, there are no open-source web-based software tools to assess the technical potential of salt caverns for H_2 storage. This work aims to fill that gap by introducing the $GeoH_2$ Salt Storage and Cycling App, a computer program that models H_2 storage capacities, and injection/withdrawal cycles in salt caverns.

The $GeoH_2$ Salt Storage and Cycling App is a web-based thermodynamic simulator, which consists of the following modules: (a) H_2 physical properties, (b) volumetric, (c) production, (d) injection, and (e) cycling. The physical properties module provides the user with the main thermodynamic, transport, and thermal properties of H_2. The volumetric module allows the user to estimate H_2 storage capacities in salt caverns. The production and the injection modules simulate the withdrawal and the injection of H_2, respectively. Finally, the cycling module models sequential withdrawal and injection processes.

This study validates the results of the physical properties and the volumetric modules with real data. We validate the results of the production and the injection modules for synthetic cases using an open-source thermodynamic simulator.

This work presents a novel tool suitable to assess the technical potential of H_2 storage, injection, withdrawal, and cycling operations in salt caverns. This application can also be used, along with subsurface geological information, as a first order screening tool to assess H_2 storage capacity at a regional or hub scale.

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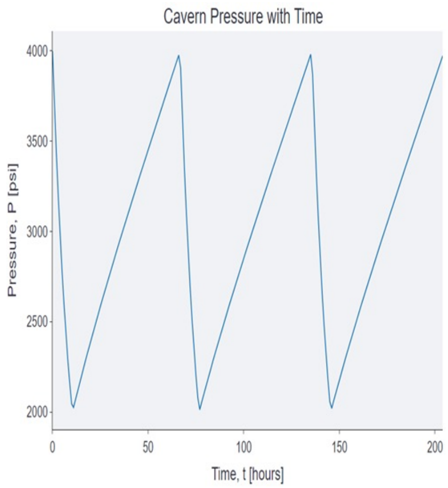
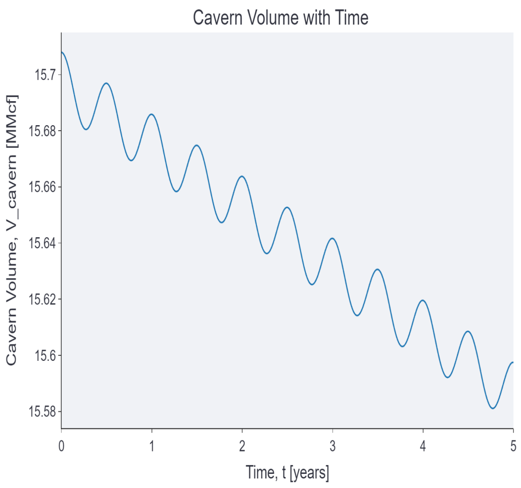
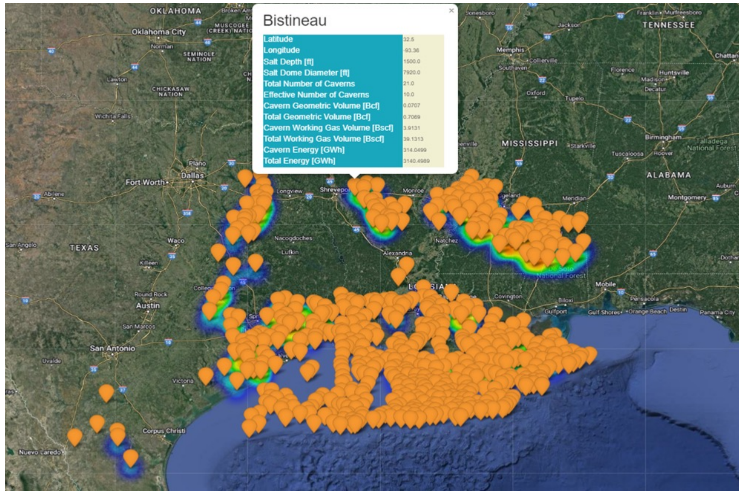
Cycling



Geomechanics



GIS of Domes and Bedded Salt



HyFive 2.0

A Research-Rooted Tool Supports Commercial Decisions

GeoH2

Ning Lin, Mariam Arzumanyan, Edna Rodriguez Calzado

Public webinar | July 2026

Bureau of Economic Geology

What HyFive does: three decisions, one workflow

Hydrogen only works at scale if you can store it underground. Before anyone commits capital, three questions have to be answered — and they have to be answered in this order.

1 WHERE?
Screening Tool

2 WHAT COST?
Cost Tool

3 WORTH IT?
Valuation (NPV) Tool

Ranks locations against pipelines, demand centers, announced projects and the geology itself — weighted by the priorities *you* set.

Decision: where to look first.

Engineering-grade capital and operating cost for a specific site: salt dome, bedded salt or depleted reservoir, from 250 MMcf to 15 Bcf of working gas.

Decision: whether the design is feasible.

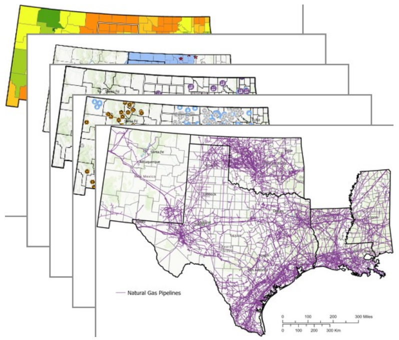
Turns cost, location and market price spreads into a cash-flow model across the life of the project.

Decision: invest or walk away.

All three run in a web browser — nothing to install. Built by the $GeoH_2$ consortium at the Bureau of Economic Geology, UT Austin.

Under the hood: how the screening tool ranks a location

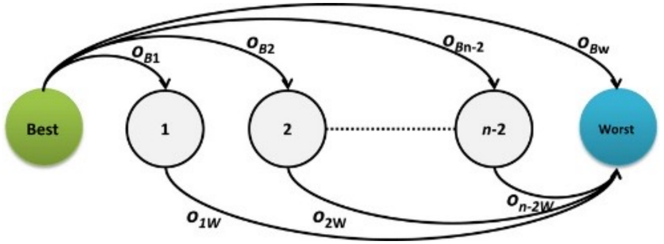
1 Five criteria, as GIS map layers



- Production and supply
- Transportation
- Market
- Environment
- Announced projects

2 Your ranking becomes weights

You rank the criteria best to worst. The **Best-Worst Method** solves for the weights that fit your ranking most consistently — and scores how consistent it was.



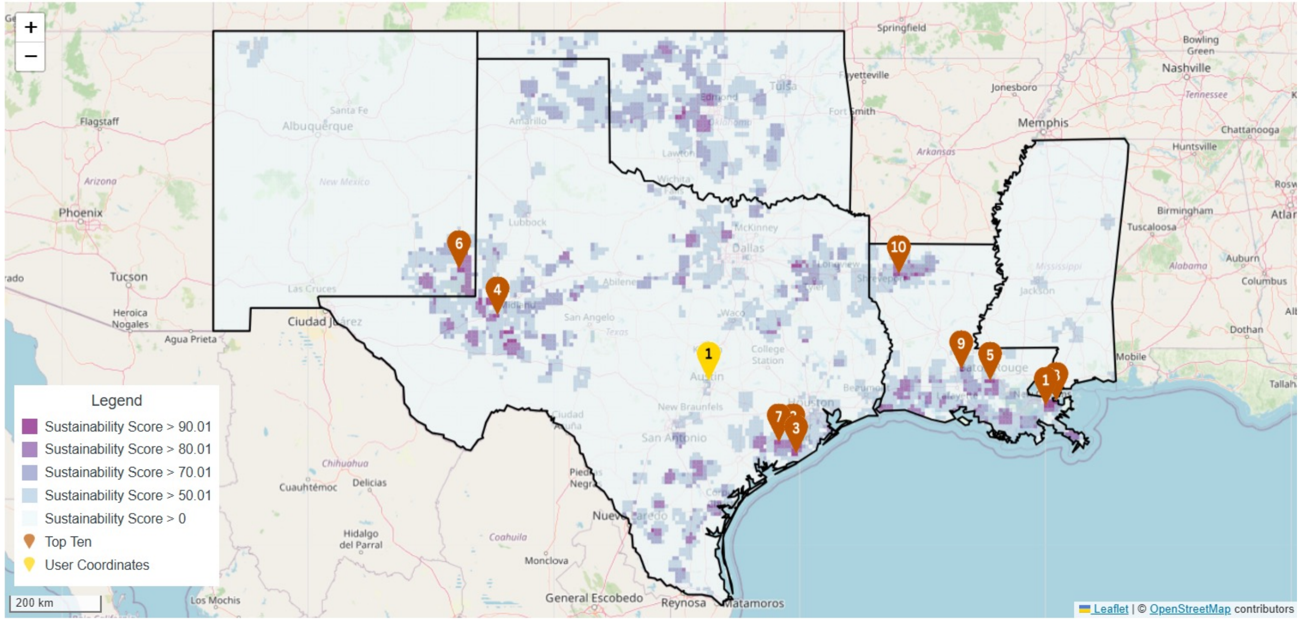
$$\min_j \max \left\{ \left| \frac{w_B}{w_j} - a_{Bj} \right|, \left| \frac{w_j}{w_W} - a_{jW} \right| \right\}$$

s.t.

$$\sum_j w_j = 1$$

$$w_j \geq 0, \text{ for all } j$$

3 Aggregate, reclassify — and rank the map



Weighted layers are aggregated into one suitability surface, reclassified into score bands, and the ten highest-scoring locations are returned with coordinates.

Re-rank the criteria and the whole map re-solves. It is not our ranking — it is customized based on the user's preference and made explicit and reproducible.

Method: Rodriguez Calzado, Razm & Lin (2025), *Int. J. Hydrogen Energy* 111, 171–182.

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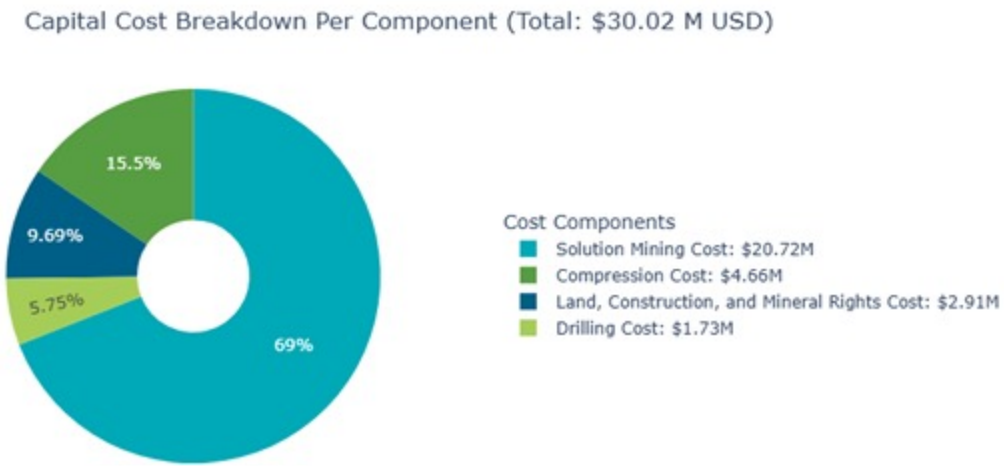
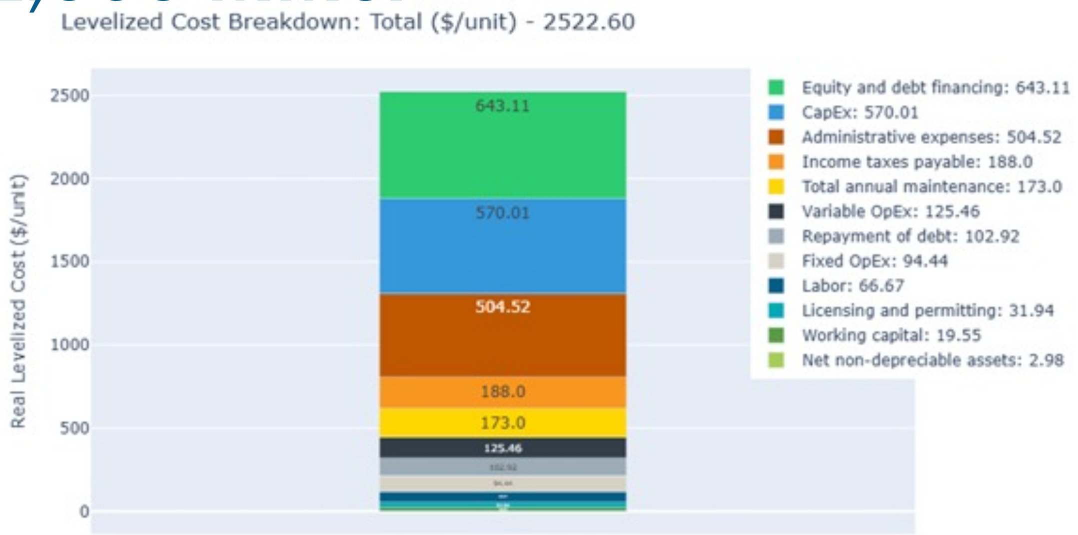
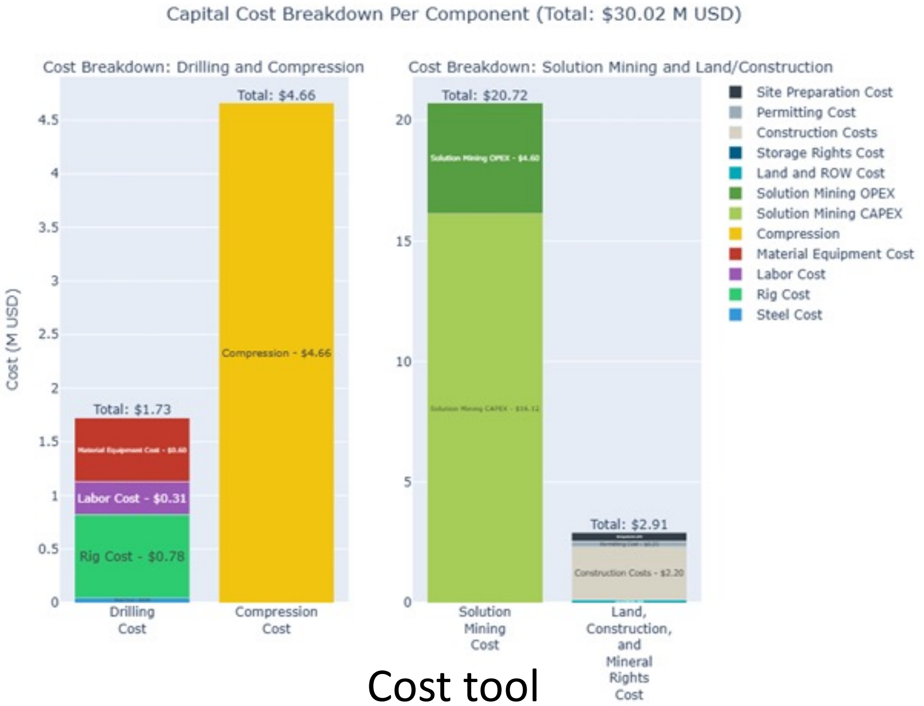
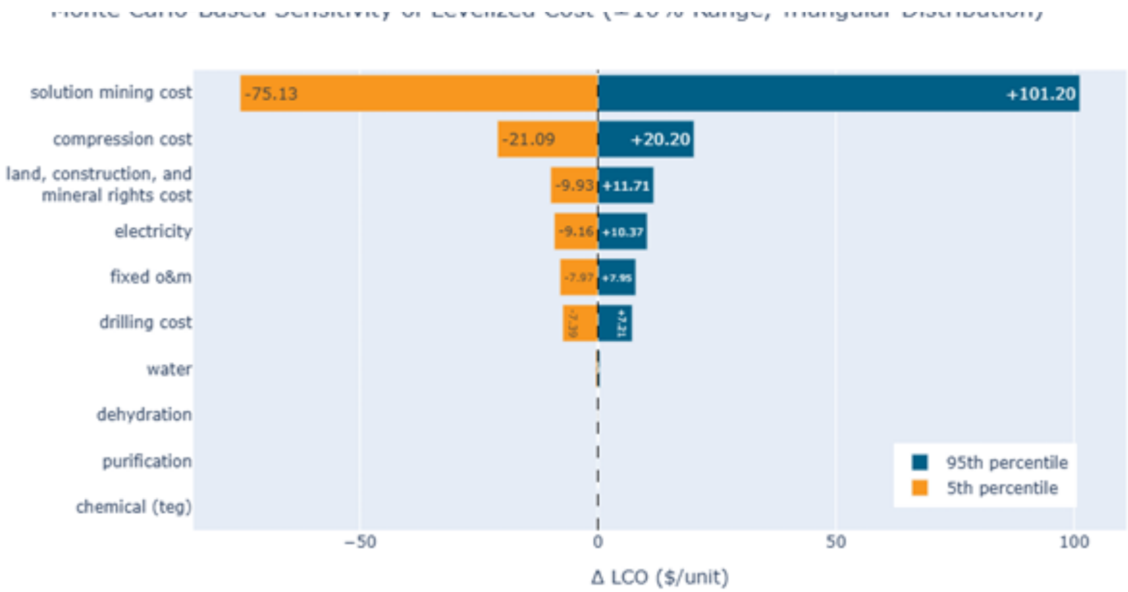
Case: Bedded Salt 1,000 MMcf







Cost tool

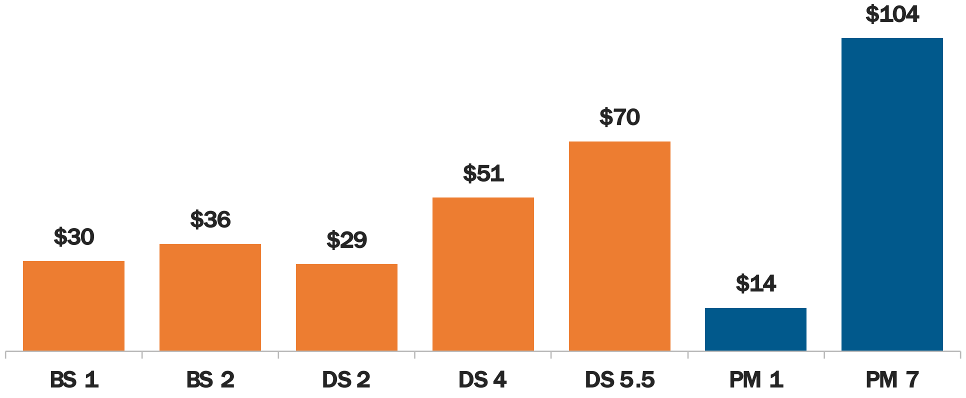


NPV tool

Cost and value: one method, seven scenarios

1 What it costs to build

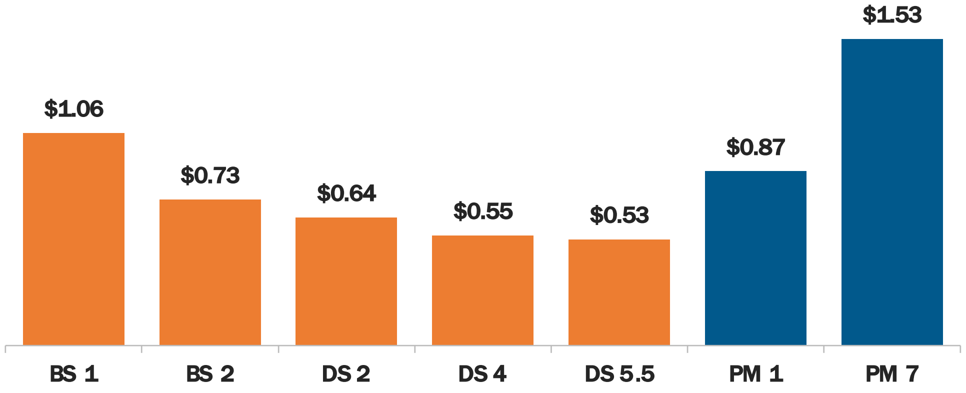
Total capital cost, million 2023 USD



The seven scenarios comparison: $14M for the smallest to $104M for a seven-well reservoir project.

2 Cost per kilogram stored

Levelized cost of storage, 2023 USD per kg



Cheapest storage is a **large domal salt cavern** at $0.53/kg. Compare with panel 2: PM 1 has the lowest capital cost of all seven and still is not the best value.

BS bedded salt **DS** domal salt **PM** porous media, i.e. depleted reservoir · number = Bcf of working gas · seven-scenario case study, HyFive model outputs

Source: Lin et al., "HyFive: Practical Techno-Economics and Valuation Tool for Geological Storage of Hydrogen," submitted to *Energy Storage* (Wiley), under review — Tables 7 and 8.

The result you cannot get from a rule of thumb: salt gets cheaper with scale ($0.64 → $0.53/kg), porous media gets **more expensive** ($0.87 → $1.53/kg) — because seven times the capacity was bought with seven times the wells.

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Why it matters — and where to see it for yourself

1 Not a black box. The screening method is published in the International Journal of Hydrogen Energy, the cost model is documented component by component, and the case study is in review.

2 Comparable across geologies. Salt domes, bedded salt and depleted reservoirs.

3 It keeps learning. v1.0 in July 2024. v2.0 added valuation in July 2025.

Future directions: natural hydrogen economics, hydrogen versus natural gas storage

Visit HyFive:

The tool and landing page
hyfive.beg.utexas.edu

HyFive 2.0 demo video
youtube.com/watch?v=oMkgXNsUigs

Agenda
GeoH$_2$ Summer Webinar
August 4, 2026

Times
US CDT

0800	**Introduction to GeoH2 (Shuster)**
	❑ Research Mission
	❑ Research Capability (people & capability)
	❑ Direction
0805	**Experimental Research (Dr. Toti Larson)**
	❑ Hydrogen generation (Dr. Tongwei Zhang)
	❑ Implications for geologic and stimulated hydrogen production (Dr. Toti Larson)
	❑ Hydrogen reactions and geomechanics: impacts on reservoir and seal (Dr. Peter Eichhubl)
	❑ Pore-scale flow (Dr. Ruichang Guo)
0825	**Modeling (Dr. Mojdeh Delshad)**
	❑ Reservoir (porous media) simulations (Dr. Mojdeh Delshad)
	❑ Storage capacity [salt cavern] (Dr. Leo Ruiz Maraggi)
	❑ Techno-economic analysis (Dr. Ning Lin)
0845	**Geologic hydrogen prospectivity (Dr. James Thompson)**
	❑ Texas study
	❑ Field-based reconnaissance studies
0855	**Close out/Q&A (Shuster)**

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Geologic Hydrogen Prospectivity in Texas

GeoH2

James Thompson, Gabriel Pasquet, Saad Saleh, Edna Rodriguez Calzado, C. Nur Schuba, Rama Chandrudu Arasada, Elizabeth Horne, Vincent Mow, Dane Kasperczyk, Jelena Markov, Andras Fall, Estibalitz Ukar, Shelby Short, Elliott Brent, Orsolya Gelencser, Shuvajit Bhattacharya, Toti Larson, Mark Shuster, Lorena Moscardelli, et al.

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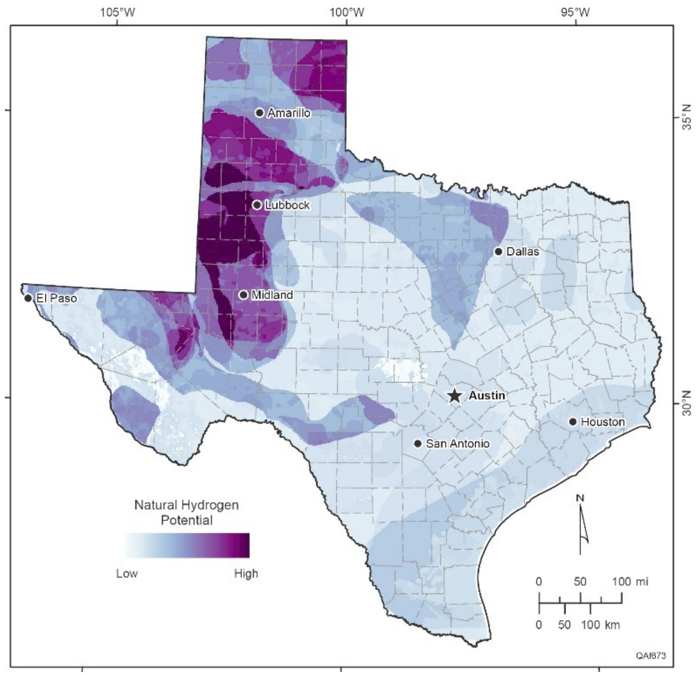
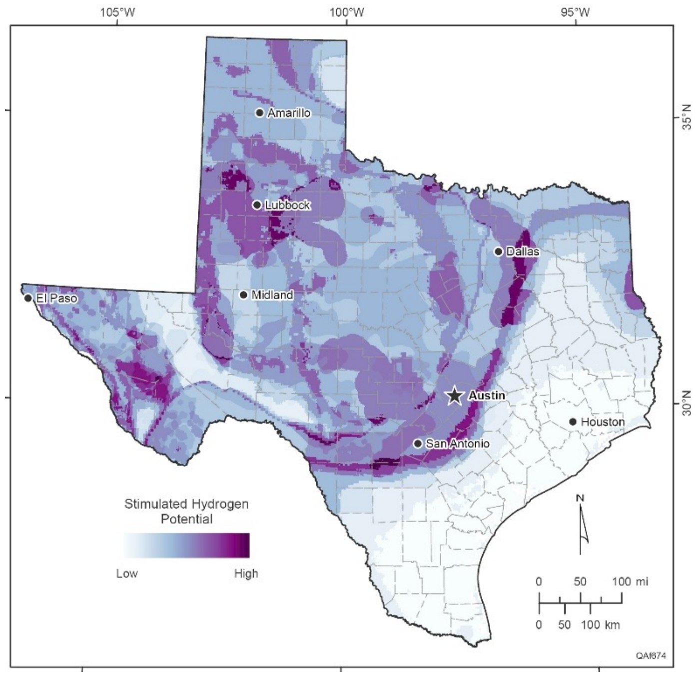
Prospectivity Maps / Sweet Spots

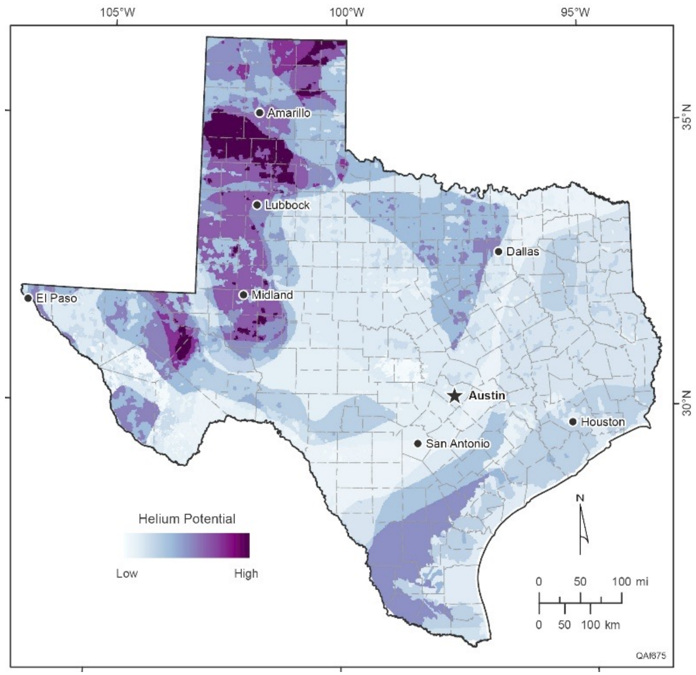
https://www.beg.utexas.edu/research/the-texas-imperative/sweet-spot-maps-for-geologic-hydrogen-and-helium-in-texas



Geological Hydrogen



Stimulated Hydrogen



Helium

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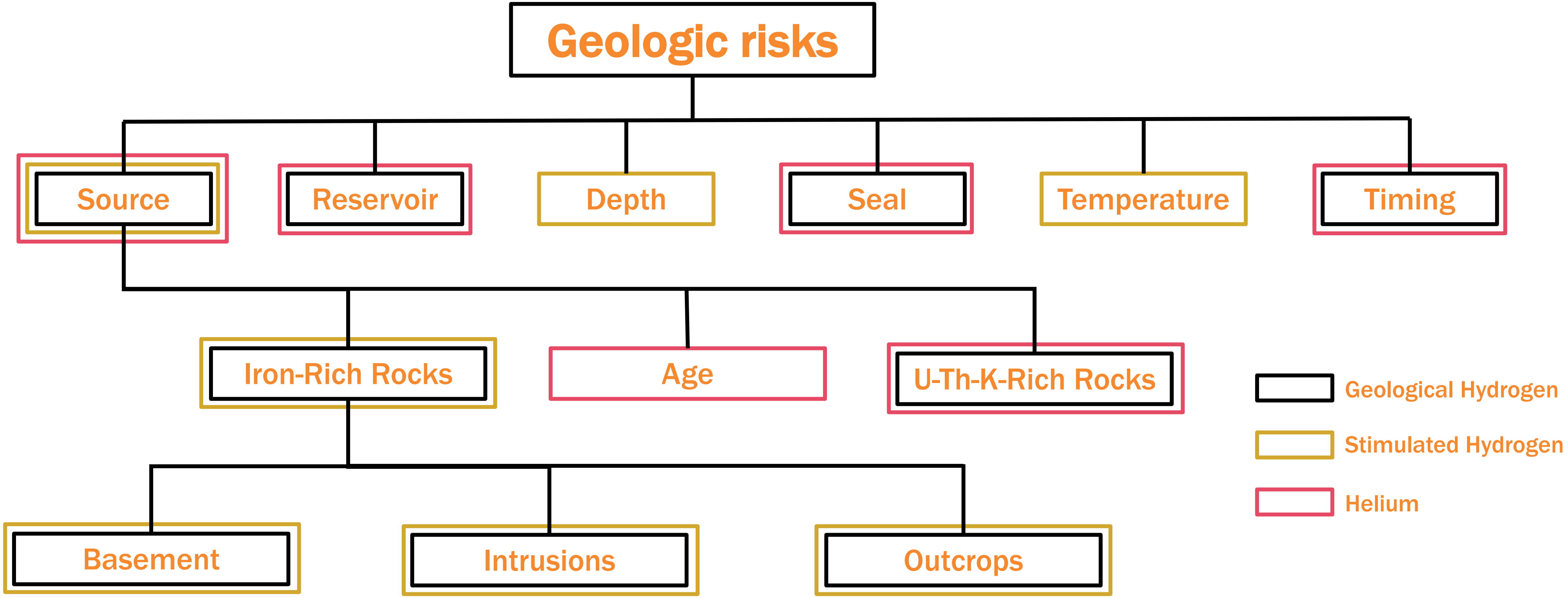
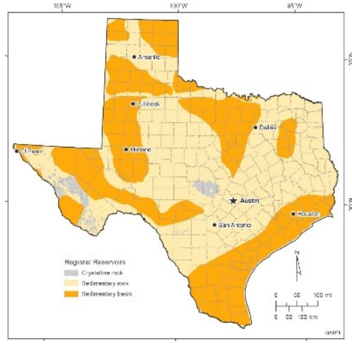
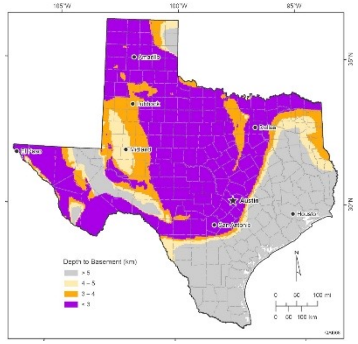
Methodology and Workflow



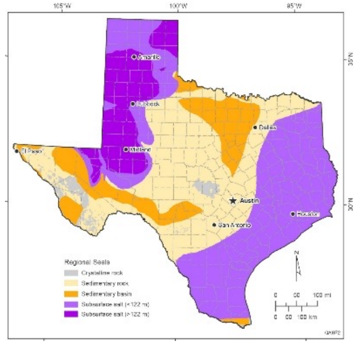
Conditions were integrated using Boolean logic and weighted subcomponent analysis



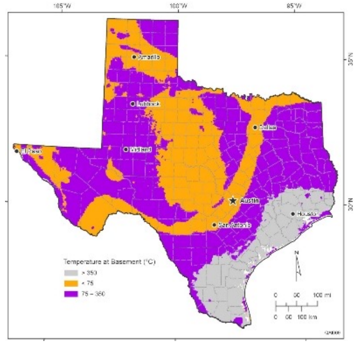
Reservoirs



Depth

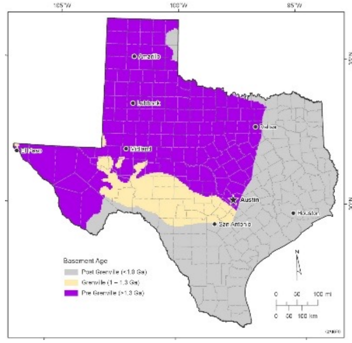


Seals

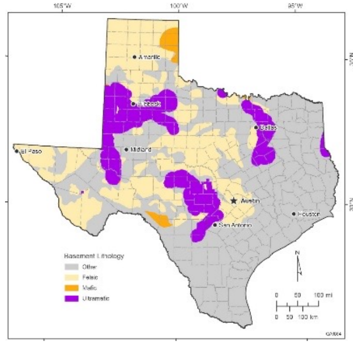


Temperature

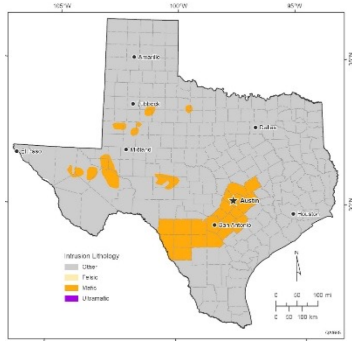
Iron-Rich Source Rock



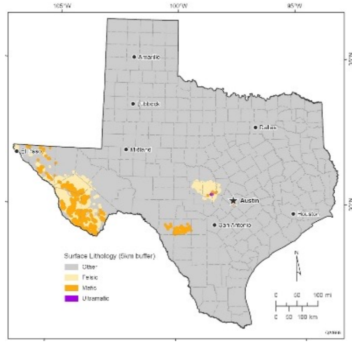
Basement Age



Basement Lithology

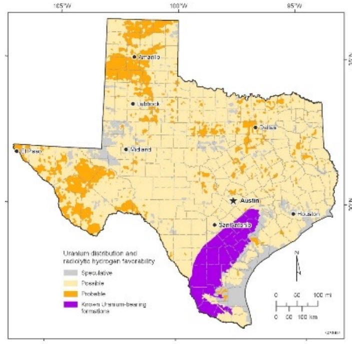


Intrusions



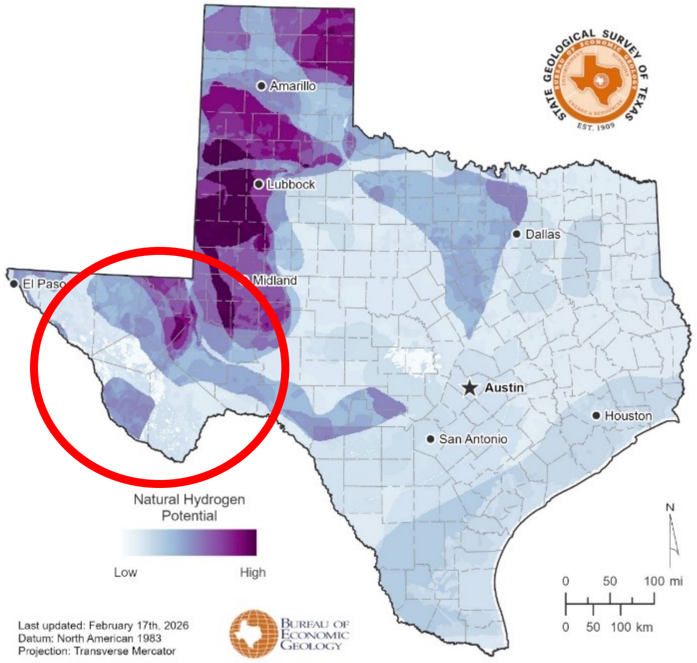
Surface Lithology

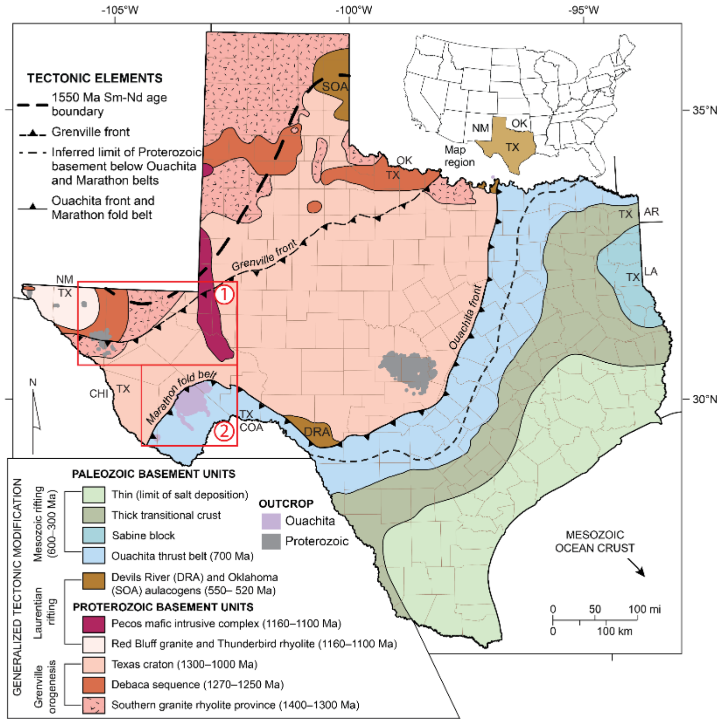
Uranium-Rich Source Rock



Local Scale

- **Focus on West Texas**
  - ✓ **Hydrogen emission detection and surface seep sensing**
  - ✓ **High-resolution gravity and magnetic data analysis**
  - ✓ **Rock and fluid sampling from outcrops and wells**





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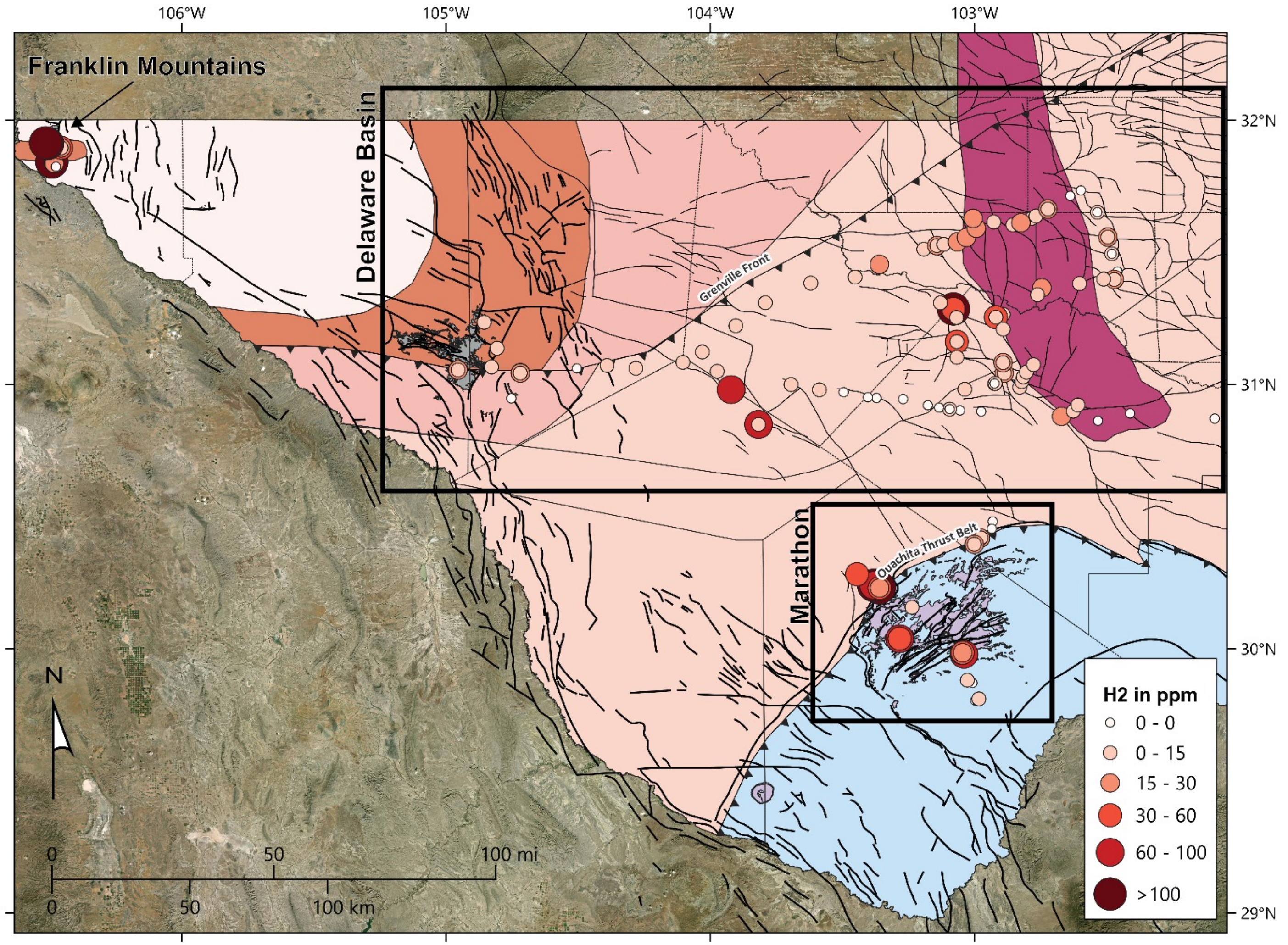
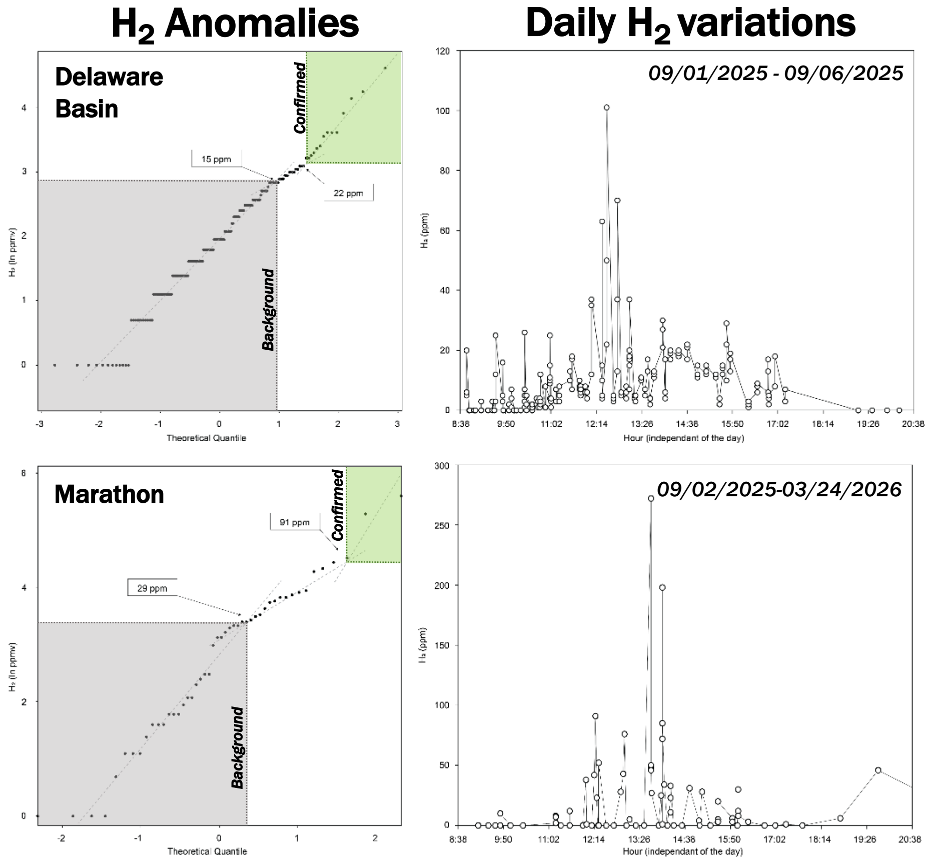
Geological H_2 – Texas : Soil Gas Survey



(modified after Horne et al., 2021, 2025, Horne 2024)



H_2 anomalies observed above major geological features :

- **Basement-rooted faults network**
  → rooted in the **Pecos intrusion**
  → where Salado fm. is the **thinnest**

- **Ouachita Thrust Belt**

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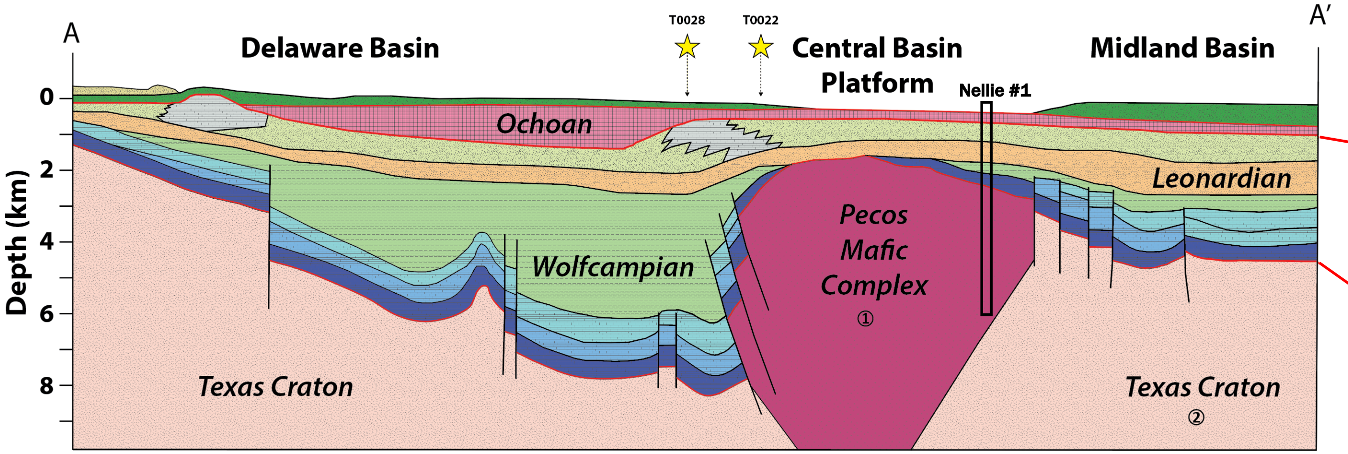
Geological H_2 – Texas : Generating Rocks



(modified after Fairhurst et al., 2021)

Seal :

- Ochoan series
- 300 - 1200m thick evaporite sequence

Reservoir :

- Wolfcampian & Leonardian series
- (Black-)Shale to sandstone formations
- Permian Hydrocarbon province

Source :

- **Pecos layered (ultra-)Mafic Intrusion (PMIC)**
- Texas Craton

- **Nellie #1 Well** → Pecos Mafic complex
  - Penetrated about 4,460 m of Precambrian (ultra-)mafic rocks
  - Olivine altered into serpentine + Opx and Cpx are fresh + Magnetite in fracture *(Kargi, 1993)*

Olivine + H_2O → Mg-Serpentine + Magnetite + H_2

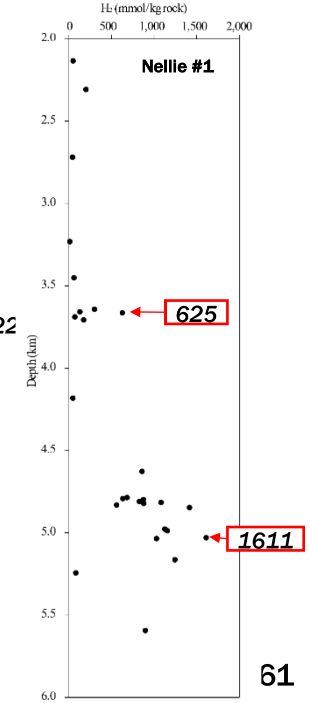
- **Estimate potential generation in H_2** (mmol.kg^{-1}) of PMIC: **616 mmol H_2 per kg** : Average **: 1.24 kg of H_2 per ton of rock**

$$H_2 = \frac{1000 \times m_{olivine} \times FeO_{olivine}}{3 \times M_{FeO}}$$

(modified after Pasquet et al., 2023; Geymond et al. 2022

- **PMIC :**
  - Volume : 3305 km^3 *(P90)* – 13700 km^3 *(P10)*
  - Total theoretical H_2 generation : **~11.49 Gt** *(P90)* + **~47.39 Gt** *(P10)* of H_2
  - If only 10% of rock volume and 10% of Fe^{2+} reacts : *P90* = **115 Mt H_2** & *P10* = **477 Mt H_2**
  - H2 demand in North America (2024) = **16 Mt H_2** → **PMIC** correspond to **7-30 years** of North America demand in H_2

(Arasada et al., in review)



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**If all bodies are the same as Nellie #1 well description*
**Only taking serpentinization of olivine into account*
**Complete reaction of olivine into serpentine+magnetite*
**Depending on fluid accessibility*

**H_2 might have been consumed, reacted or dissipated*
**Complete serpentinization does not mean the potential is exhausted*
**Other minerals can react*

Summary and Future

- Summary
  - ➢ A variety of conditions were incorporated to produce prospectivity maps
  - ➢ Anomalies observed above major geological features
  - ➢ Workflow is repeatable and scalable
- Future
  - ➢ Expand soil gas surveys and water well samples : with long-term deployments
  - ➢ Further evaluation of source volume potential and migration and seal systems
  - ➢ Integration remote sensing and AI for surface expression detection

Thank You !
Please Contact Us

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