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The #H2IQ Hour

Today's Topic:

Subsurface Hydrogen Assessment, Storage, and Technology Acceleration (SHASTA)

This presentation is part of the monthly H2IQ hour to highlight hydrogen and fuel cell research, development, and demonstration (RD&D) activities including projects funded by U.S. Department of Energy's Hydrogen and Fuel Cell Technologies Office (HFTO) within the Office of Energy Efficiency and Renewable Energy (EERE).

Housekeeping

This webinar is being recorded.

This webinar is being recorded and will be available on the H2IQ webinar archives.

Technical Issues:

- If you experience technical issues, please check your audio settings under the "Audio" tab.
- If you continue experiencing issues, direct message the host, Kyle Hlavacek

Questions?

- There will be a Q&A session at the end of the presentation
- To submit a question, please type it into the Q&A box; **do not** add questions to the Chat

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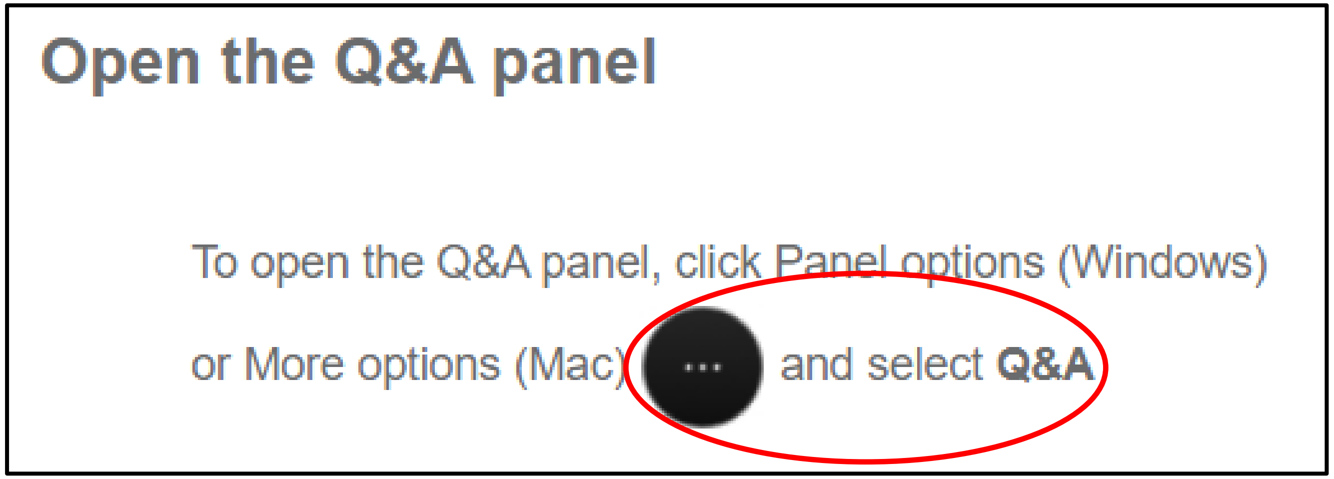
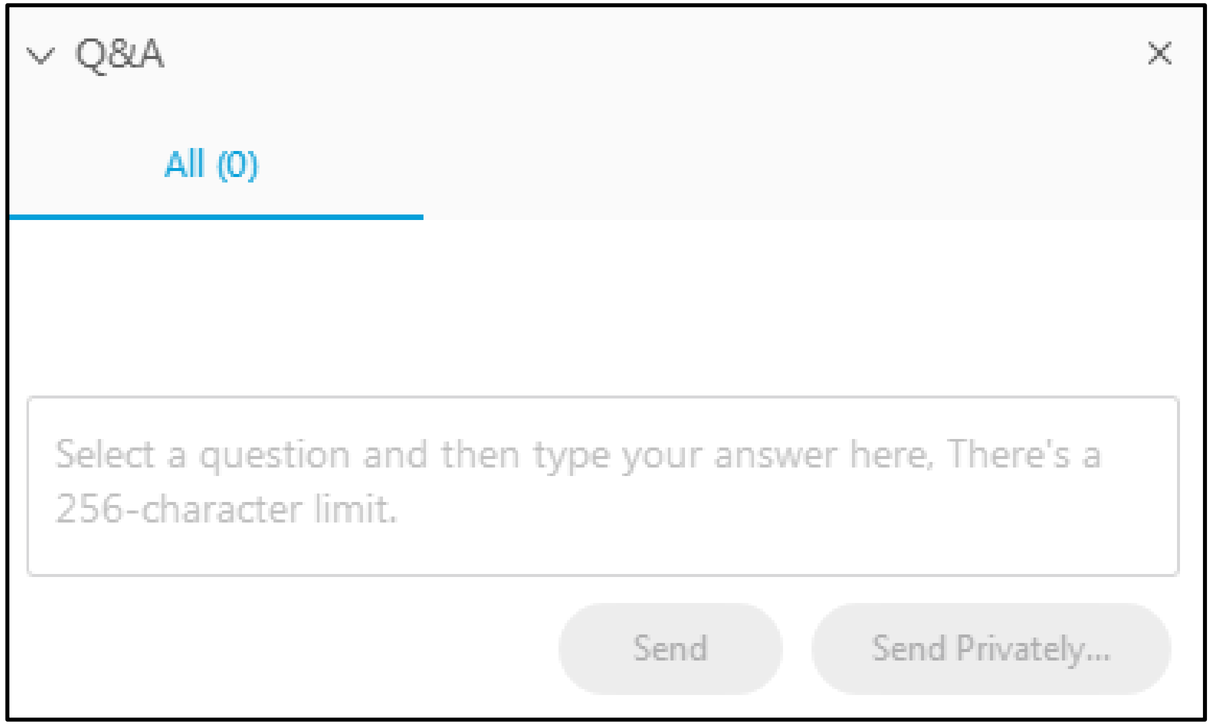
The #H2IQ Hour Q&A

Please type your questions into the Q&A Box



Open the Q&A panel

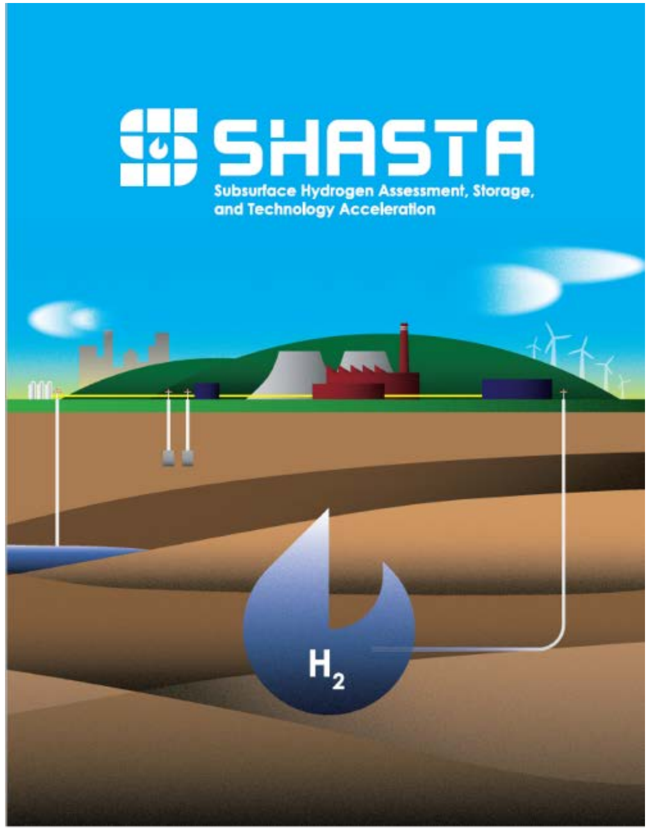
To open the Q&A panel, click Panel options (Windows) or More options (Mac) ··· and select **Q&A**



Select a question and then type your answer here. There's a 256-character limit.

SHASTA

Subsurface Hydrogen Assessment, Storage, and Technology Acceleration



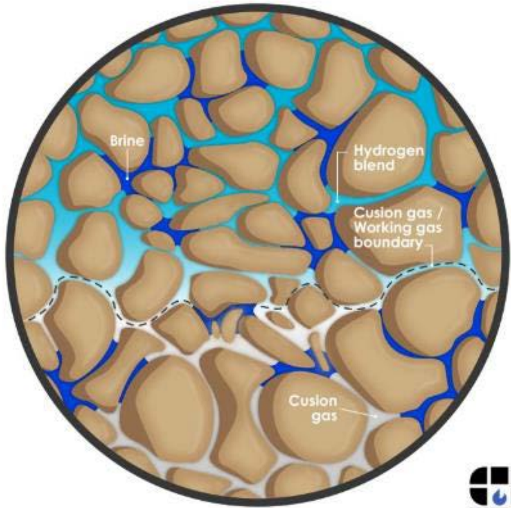
Project Overview

Dr. Nicolas Huerta, PNNL

Dr. Angela Goodman, NETL

H_2IQ Hour Webinar

December 15th, 2023



SHASTA Project Objective and Goals

Identify and **address key technological hurdles** and **develop tools and technologies** to enable broad public acceptance for **subsurface storage** of pure hydrogen and hydrogen/natural gas mixtures

Project Goals:

- ✓ Quantify operational risks
- ✓ Quantify potential for resource losses
- ✓ Develop enabling tools, technologies, and guidance documents
- ✓ Develop a collaborative field-scale test plan in partnership with relevant stakeholders

SHASTA

Subsurface Hydrogen Assessment, Storage, and Technology Acceleration

NATIONAL ENERGY TECHNOLOGY LABORATORY

Pacific Northwest NATIONAL LABORATORY

Sandia National Laboratories

Lawrence Livermore National Laboratory

Project Organization

Research Focus

Research Thrusts

- Risk Quantification (Experiment & Simulation)
- Enabling Technologies to Manage Hydrogen Storage
- Recommended Practices and Industry Engagement

S&T Outcomes

- Core- to reservoir-scale performance
- Materials compatibility
- Role of microbial interactions
- Simulation and monitoring tools
- Scientifically informed pilot test plan(s)

Structure

Project Direction

- DOE-FECM
- NETL-Program

Project Advice

- Stakeholder Group

Project Execution

- PNNL
- NETL-RIC
- LLNL
- SNL
- Industry Partner(s)

Project Organization

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- DOE-FECM
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- Stakeholder Group

April 2- 4, 2024
Resource Sustainability Project Review Meeting at the Wyndham Grand Hotel in Pittsburgh, PA

Project Execution

- PNNL
- NETL-RIC
- LLNL
- SNL
- Industry Partner(s)

SHASTA

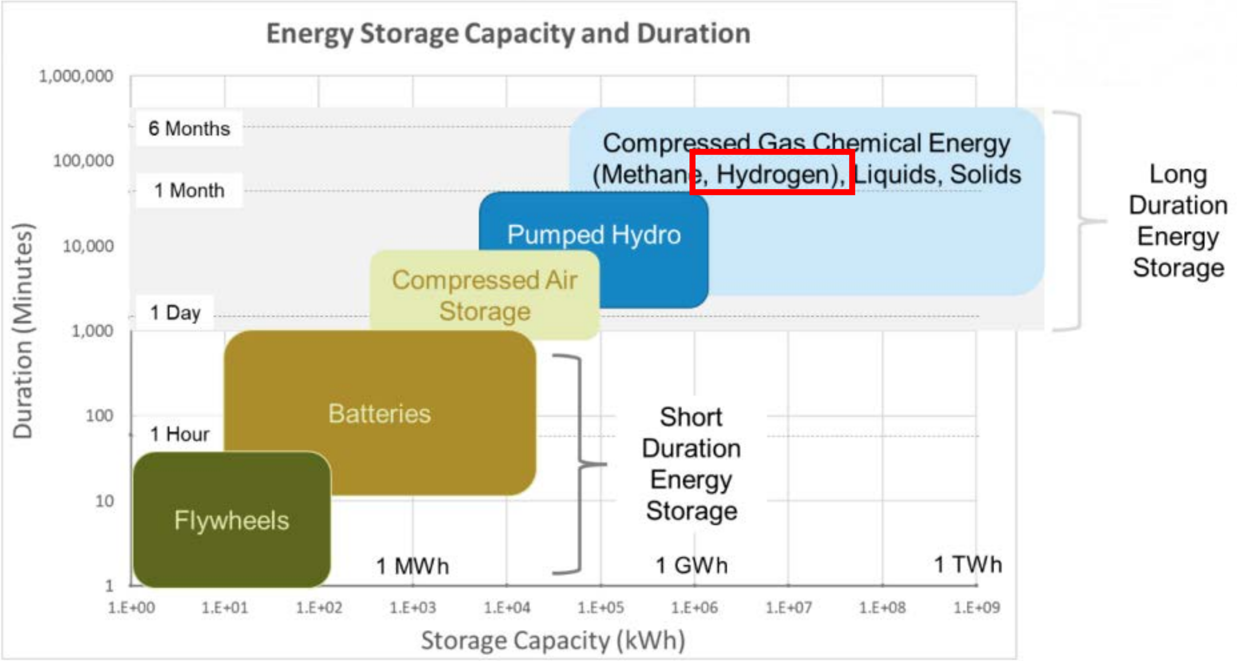
Hydrogen as an Enabler to a Low-Carbon Future

Significant potential

- **A flexible fuel with many end uses**
- **Potential for very large-scale energy storage**

Need

- **Provide long-term, safe, effective regional subsurface storage to ensure reliability of hydrogen energy supply**



Advantages of Underground Gas Storage (vs. Tank)

✓ Storage capacity

- Reservoirs and caverns can accommodate long-duration (seasonal) storage
- Gas can be stored at greater pressure and mass density than in storage tanks

✓ Storage cost

- Geologic structure is the containment vessel
- Construction costs are primarily those associated with the injection/withdrawal well infrastructure, which are less than the cost of storage tanks

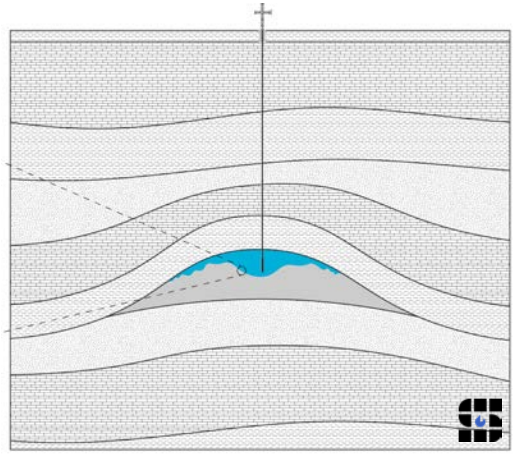
✓ Surface footprint

- Land area occupied by well pads and pipelines is smaller than that of storage tanks

✓ Storage safety

- Storage formation is physically separated from risk factors, such as oxygen, ignition sources and floods, which reduces the vulnerability to fire, extreme climate events, and sabotage

~300 – 10,000 kg H_2

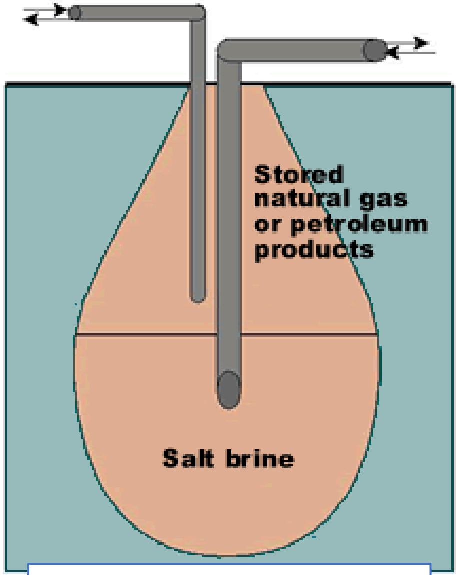


~3,000,000 – 30,000,000 kg H_2

Storage Reservoir Types

4 main types of underground gas storage

Salt Cavern

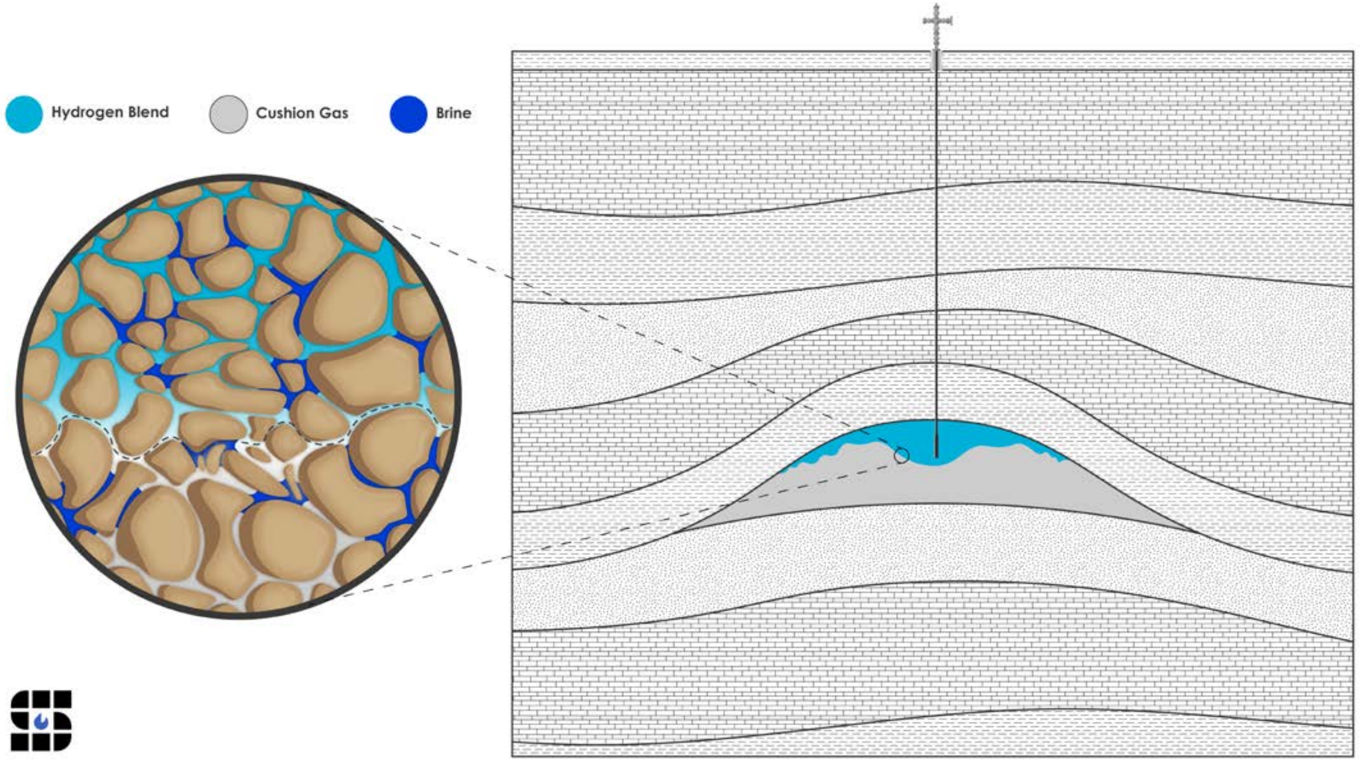


https://www.phmsa.dot.gov/pipeline/underground-natural-gas-storage/fact-sheet-underground-natural-gas-storage-caverns

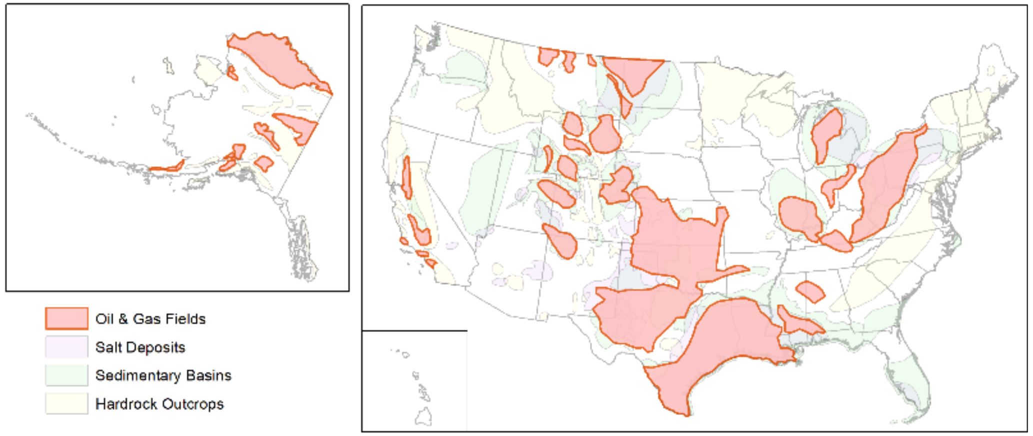
Hard Rock Cavern

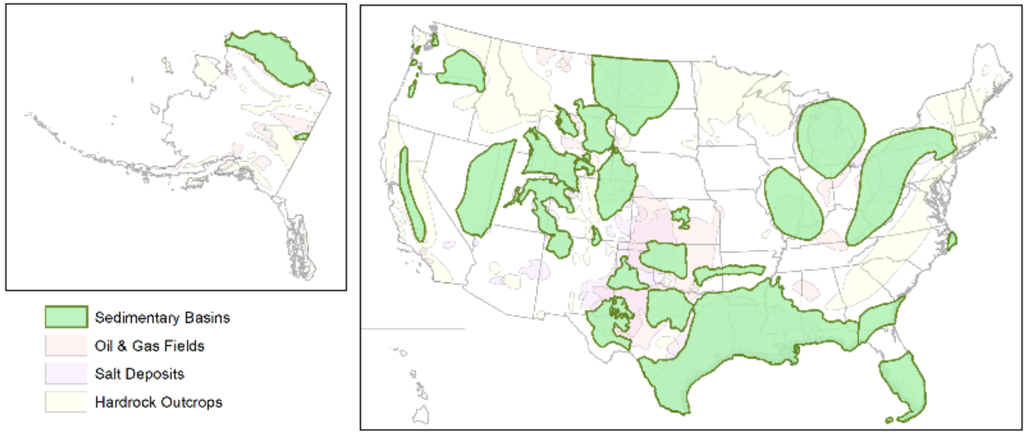
https://www.encyclopedie-environnement.org/en/soil/underground-storage-gas-and-hydrocarbons-prospects-for-energy-transition/

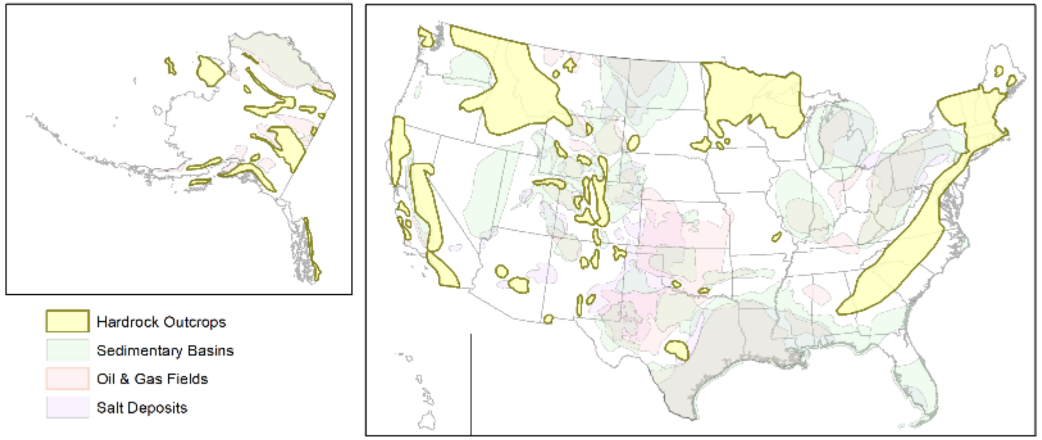
Depleted Reservoirs & Brine Aquifers

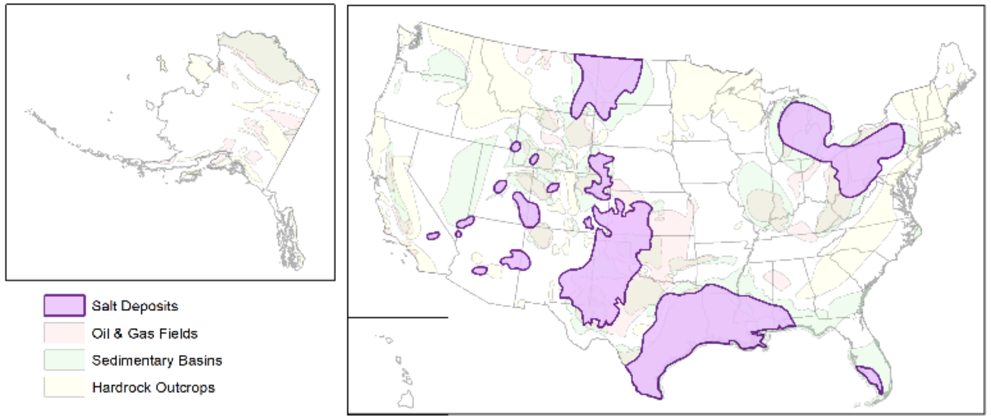


Storage Reservoir Types Across the U.S.


Oil and Gas Fields in the United States

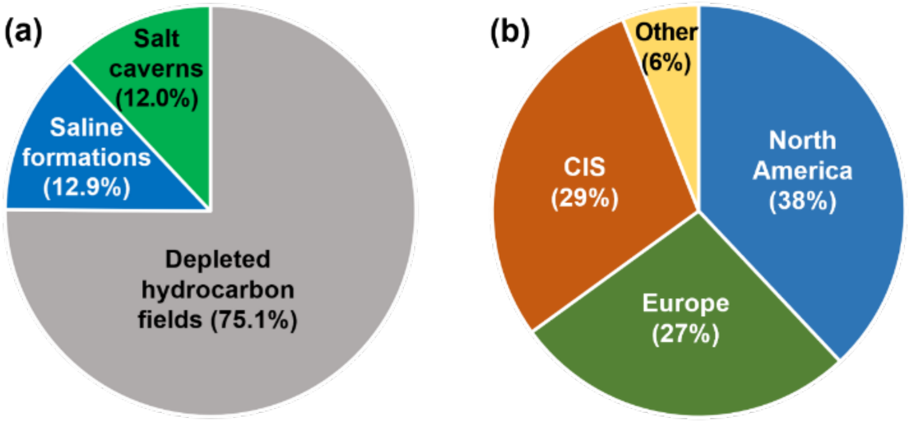

Sedimentary Basins in the United States


Hardrock Outcrops in the United States


Salt Deposits in the United States

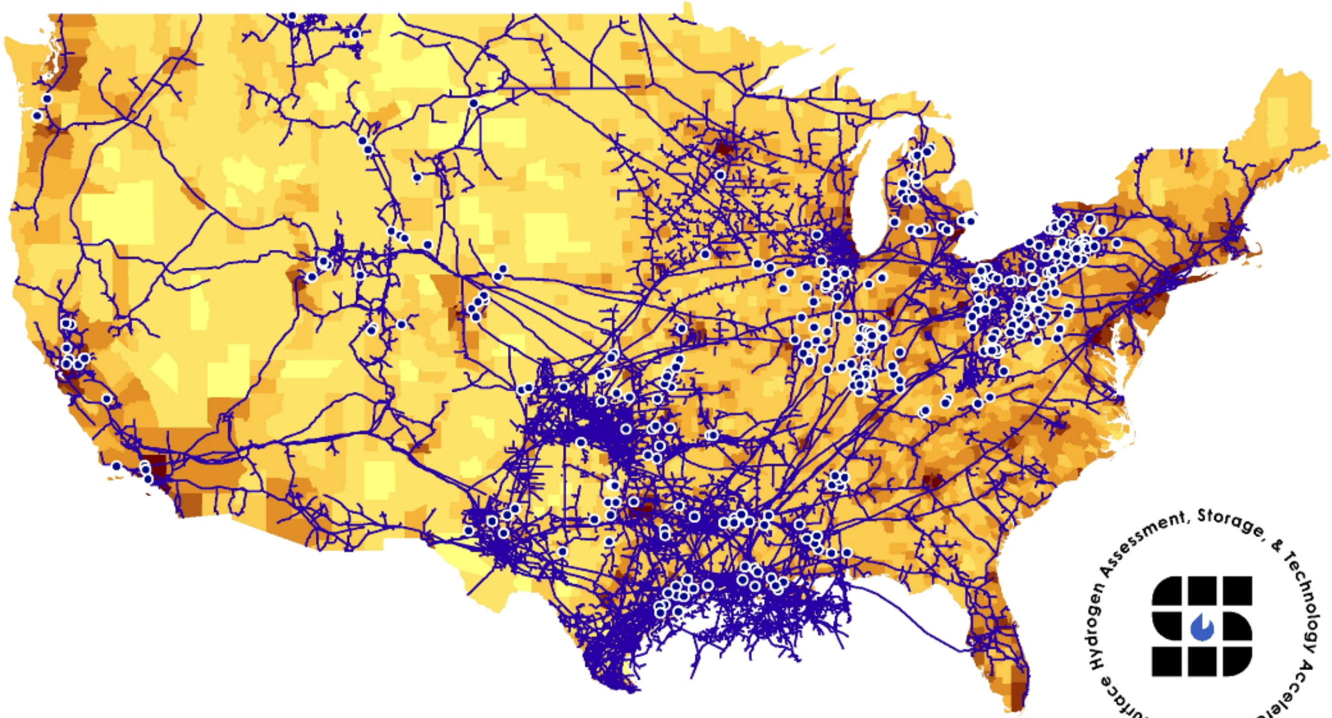
Underground Natural Gas (UGS) Storage Infrastructure

- UGS has provided long-duration storage for more than 100 years, primarily to meet seasonally-variable heating demand.
  - What is the impact of H_2 blending on underground energy storage?
  - Can existing UGS facilities be converted to underground hydrogen storage (UHS) to sufficiently buffer prospective H_2 demand?



Breakdown of UGS storage volumes by storage types (a) and by region (b)

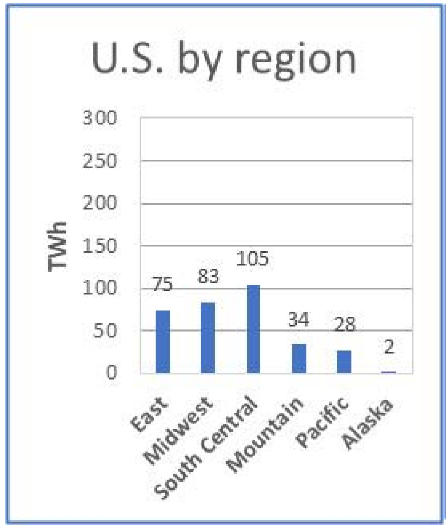
- UGS sites are distributed throughout the United States and are often located near large population centers, where NG gas demand is greatest.

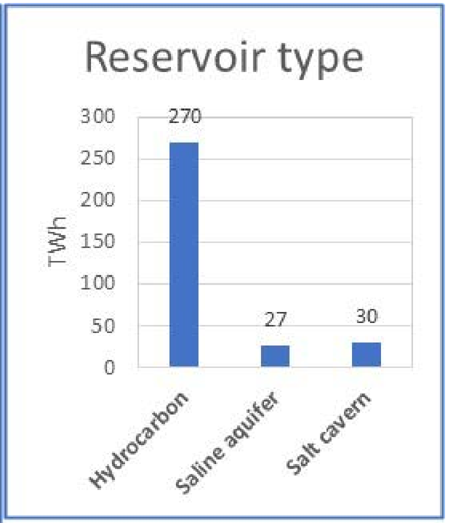


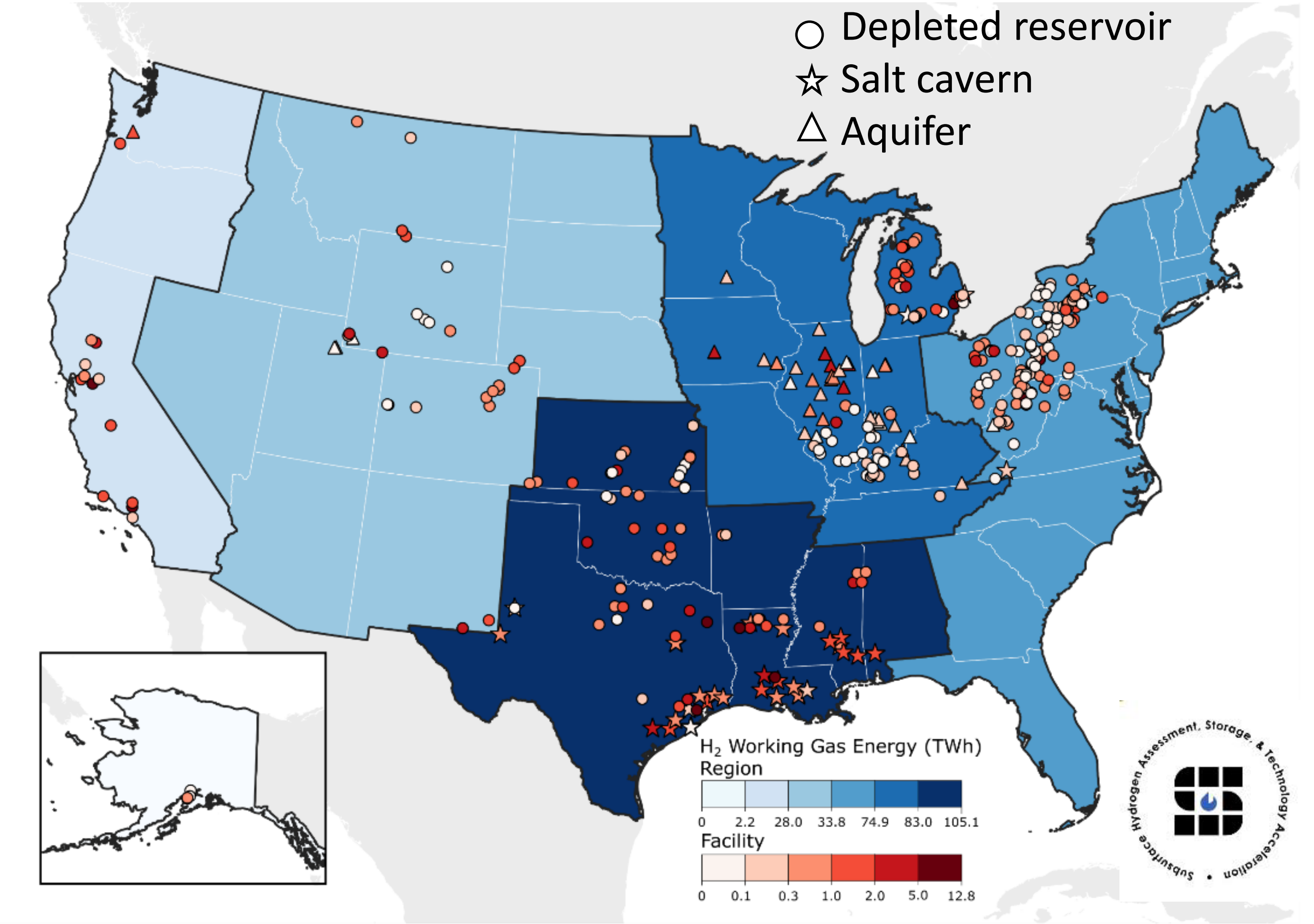
H_2 Energy Storage Potential in Existing UGS Facilities

Conversion of working gas energy (WGE) for natural gas to hydrogen results in a 75% reduction of 1,282 TWh (92.3 MMT) to 327 TWh (9.8 MMT)

Assuming 100% H_2



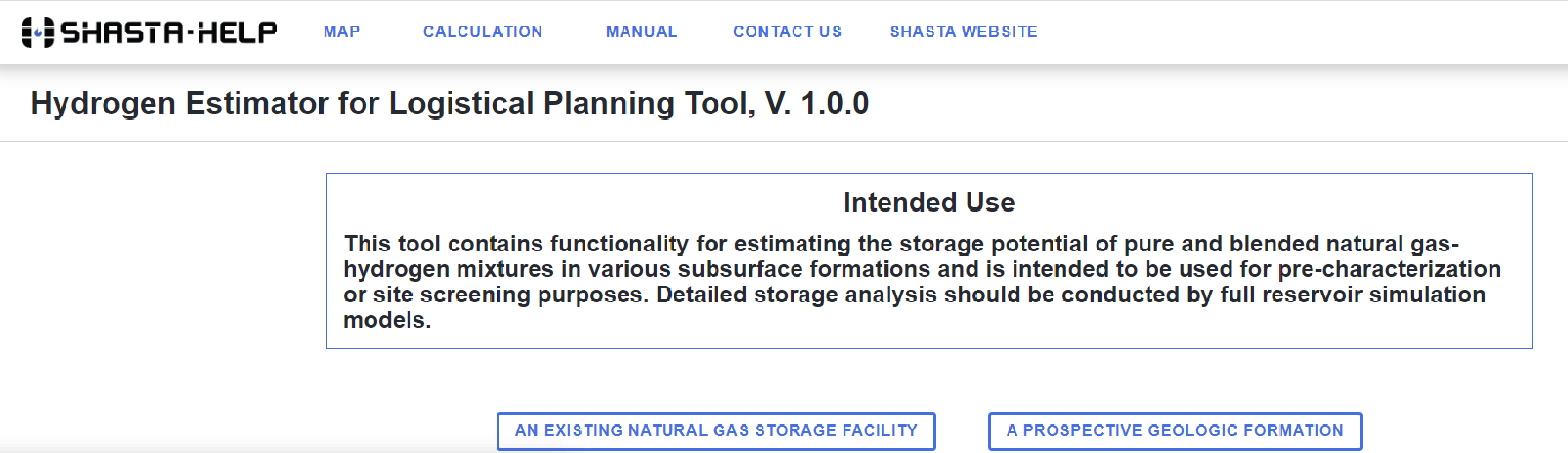




- ✓ Lots of interest in blended storage (H_2 + natural gas)
- ✓ Many facilities operating below their max volume
- ✓ May need new sites depending on demand scenario

Lackey et al., 2023 (https://doi.org/10.1029/2022GL101420)

SHASTA-HELP Tool



Hydrogen Estimator for Logistical Planning Tool, V. 1.0.0

Intended Use

This tool contains functionality for estimating the storage potential of pure and blended natural gas-hydrogen mixtures in various subsurface formations and is intended to be used for pre-characterization or site screening purposes. Detailed storage analysis should be conducted by full reservoir simulation models.

Characterizing Hydrogen Storage Potential in U.S. Underground Gas Storage Facilities

Greg Lackey, Gerad M. Freeman, Thomas A. Buscheck, Foad Haeri, Joshua A. White, Nicolas Huerta, Angela Goodman

First published: 10 February 2023 | https://doi.org/10.1029/2022GL101420

https://shasta-help.pnnl.gov/

SHASTA-HELP

SHASTA-HELP Tool Overview

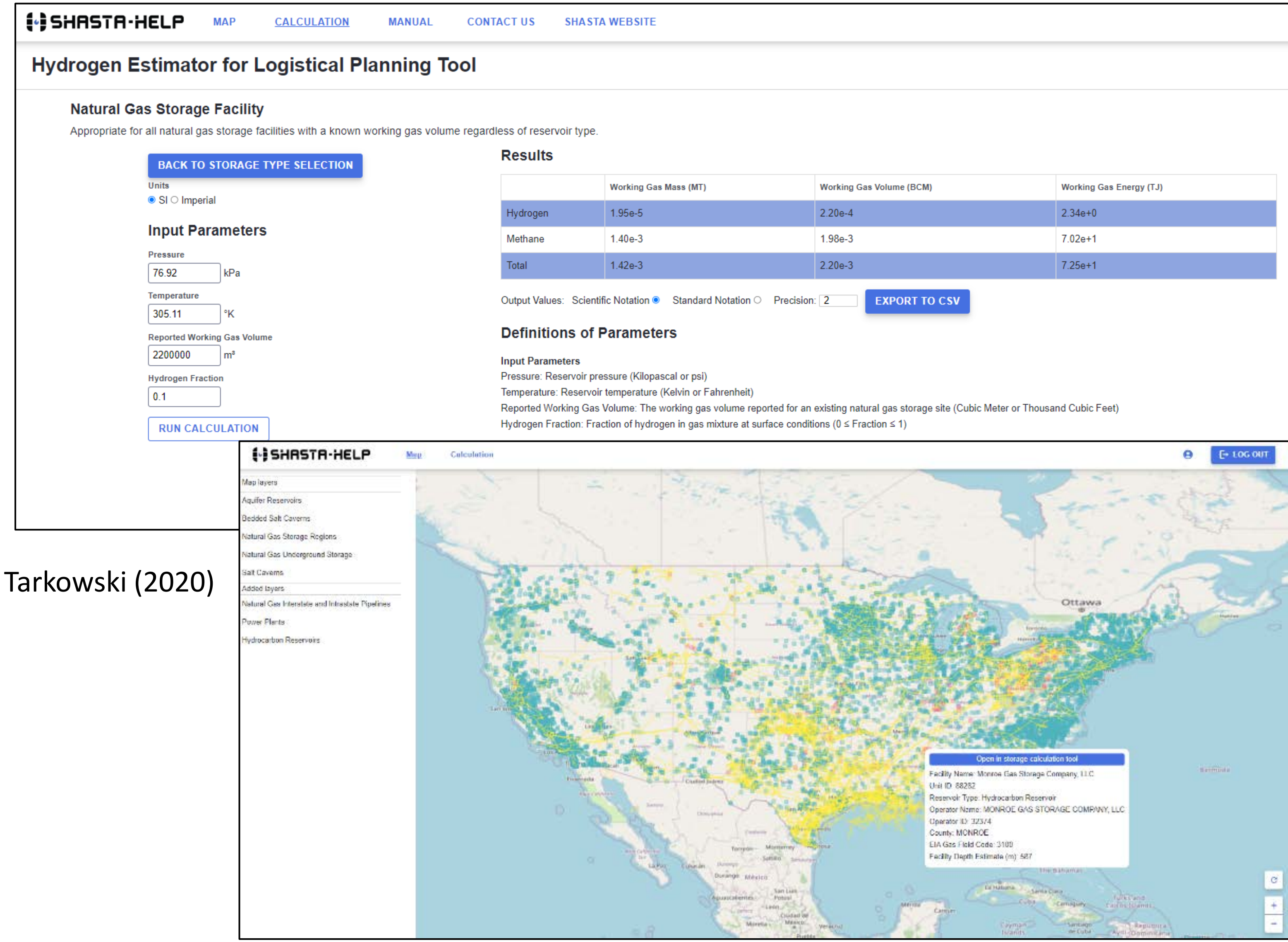
Volumetric approach

$$WGE_{H_2,a} = WGV_{CH_4,a}\left(\frac{\rho_{CH_4,a}}{\rho_{CH_4,r}}\right)\rho_{H_2,r}\ LHV_{H_2}$$

WGE = working gas energy
WGV = working gas volume
ρ = gas density
LHV = lower heating value

Other references

Mouli-Castillo et al. (2021), Chen et al. (2023), and Lankof and Tarkowski (2020)



Hydrogen Estimator for Logistical Planning Tool

Natural Gas Storage Facility

Appropriate for all natural gas storage facilities with a known working gas volume regardless of reservoir type.

Units
● SI ○ Imperial

Input Parameters

Pressure: 76.92 kPa
Temperature: 305.11 °K
Reported Working Gas Volume: 2200000 m³
Hydrogen Fraction: 0.1

Results

	Working Gas Mass (MT)	Working Gas Volume (BCM)	Working Gas Energy (TJ)
Hydrogen	1.95e-5	2.20e-4	2.34e+0
Methane	1.40e-3	1.98e-3	7.02e+1
Total	1.42e-3	2.20e-3	7.25e+1

Output Values: Scientific Notation ● Standard Notation ○ Precision: 2

Definitions of Parameters

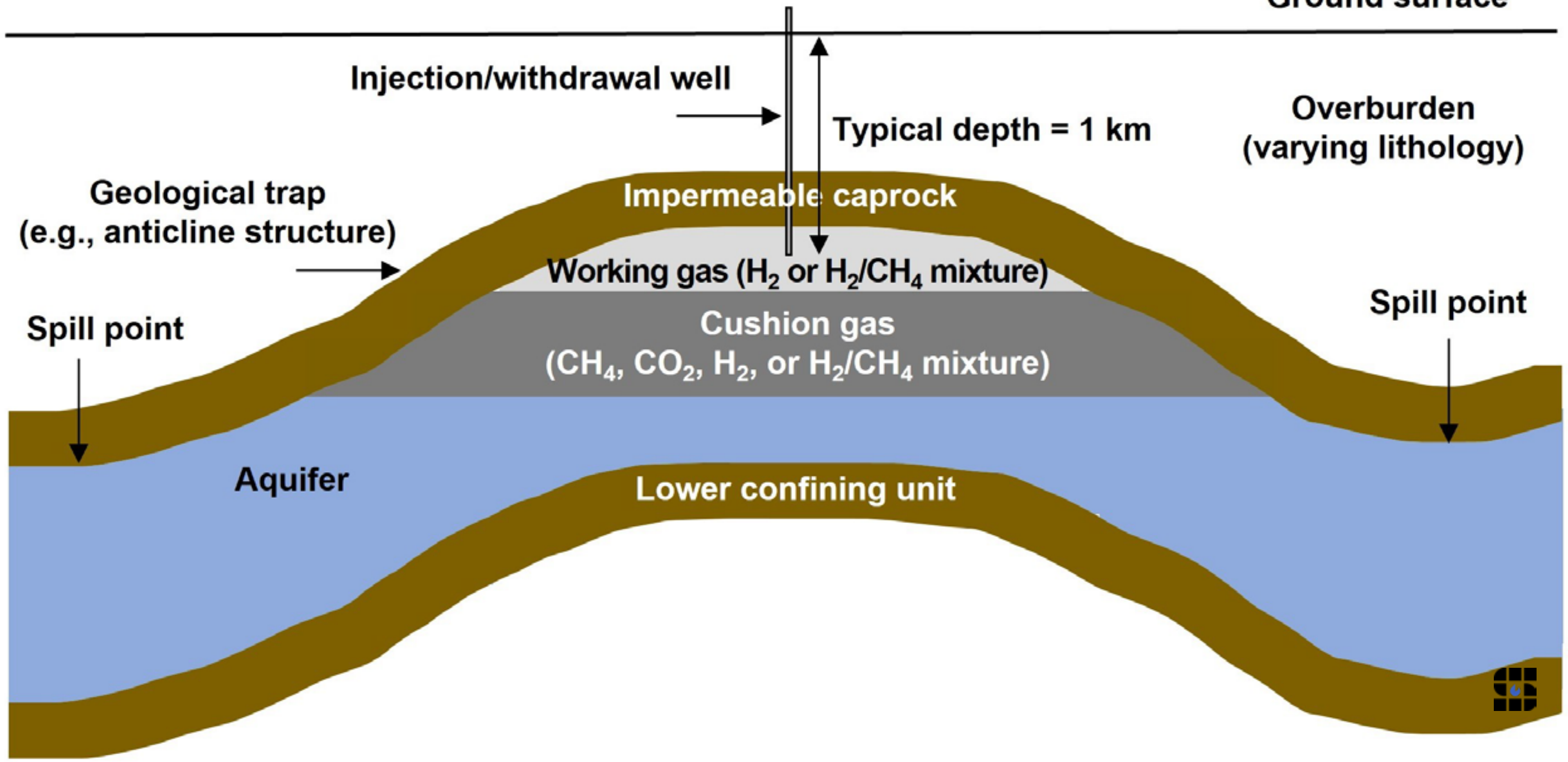
Input Parameters
Pressure: Reservoir pressure (Kilopascal or psi)
Temperature: Reservoir temperature (Kelvin or Fahrenheit)
Reported Working Gas Volume: The working gas volume reported for an existing natural gas storage site (Cubic Meter or Thousand Cubic Feet)
Hydrogen Fraction: Fraction of hydrogen in gas mixture at surface conditions (0 ≤ Fraction ≤ 1)

Facility Name: Monroe Gas Storage Company, LLC
Unit ID: 88282
Reservoir Type: Hydrocarbon Reservoir
Operator Name: MONROE GAS STORAGE COMPANY, LLC
Operator ID: 32374
County: MONROE
EIA Gas Field Code: 3100
Facility Depth Estimate (m): 587

SHASTA-HELP
Hydrogen Estimator for Logistical Planning Tool

Considerations for Subsurface H_2 Storage

Underground Hydrogen Storage (UHS)



Key considerations

- ✓ Well integrity
- ✓ Microbiology & geochemistry
- ✓ Managing reservoir flow dynamics
- ✓ Techno-economics

Well Integrity

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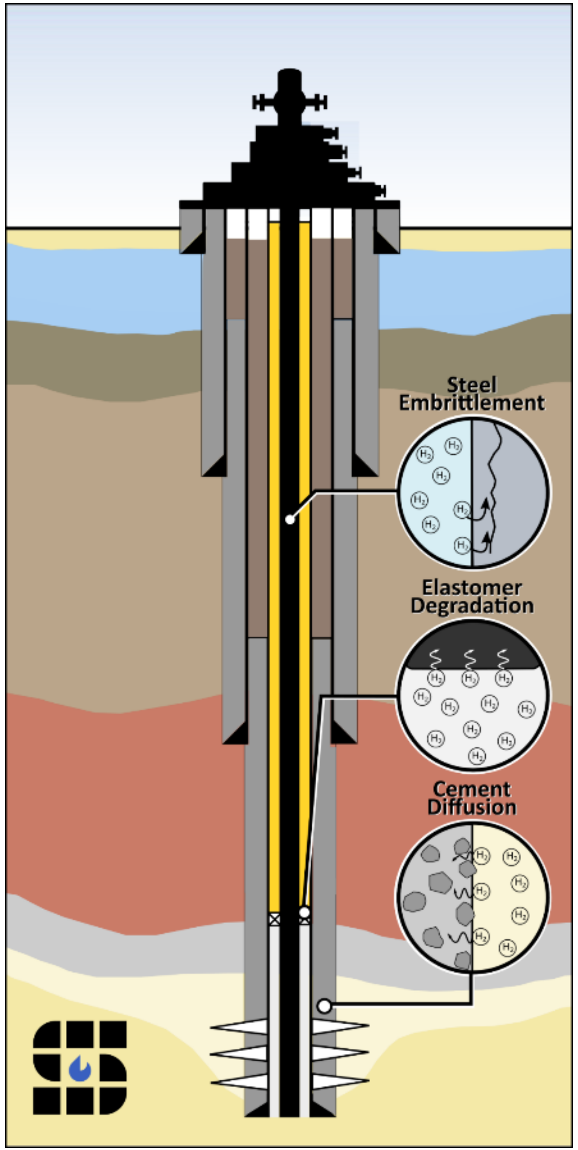
Subsurface Hydrogen Assessment, Storage, and Technology Acceleration



Well integrity is an important source of risk and liability for UHS

- Well integrity loss has been the source of most leakage events at natural gas storage sites
- H_2 is highly mobile in the subsurface and will potentially leak through faulty wells
- Well integrity must be maintained in injection, monitoring, and legacy wells

Steel embrittlement

- H_2 moves into the atomic structure of steel causing premature cracking and failure
- Commonly used low-carbon steels are susceptible
- Occurs when H_2 concentrations are high

Elastomer degradation

- Damage can result from permeation of H_2 into the material followed by rapid decompression
- Other failure mechanisms may include temperature and chemical degradation, extrusion and nibbling, compression set, wear, and spiral failure

Cement diffusion

- H_2 is the smallest molecule and has a high diffusivity
- H_2 diffusivity in cement is expected to be more of a challenge than reactivity

Well Integrity: Permeability and Diffusivity

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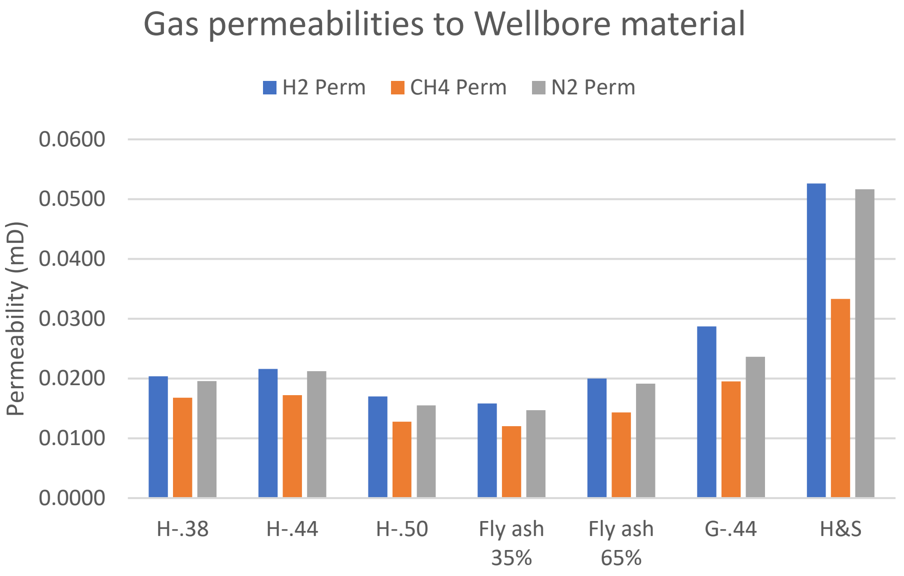
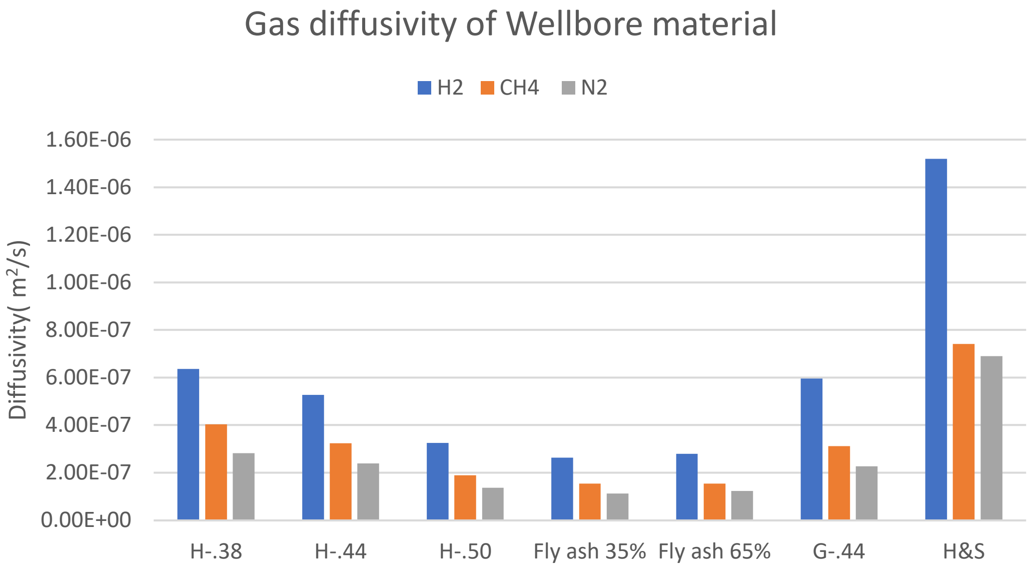
Subsurface Hydrogen Assessment, Storage, and Technology Acceleration

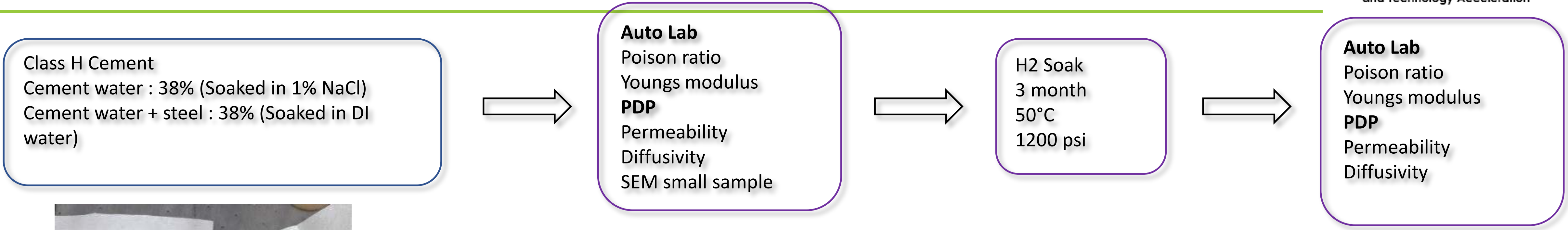
Cement Type	Water/Solids Ratio	Additives	Slurry Density lb/gal (g/cm^3)
Class H	0.38		16.6 (2.00)
Class H	0.44		16.0 (1.91)
Class H	0.50		15.4 (1.84)
Class H	0.52	Fly Ash 35%	14.8 (1.76)
Class H	0.56	Fly Ash 65%	13.9 (1.68)
Class G	0.44		15.9 (1.91)





U.S. DEPARTMENT OF ENERGY | Fossil Energy and Carbon Management | NATIONAL ENERGY TECHNOLOGY LABORATORY | Pacific Northwest NATIONAL LABORATORY | Lawrence Livermore National Laboratory | Sandia National Laboratories

Well Integrity: Mechanical Properties



Class H Cement
Cement water : 38% (Soaked in 1% NaCl)
Cement water + steel : 38% (Soaked in DI water)

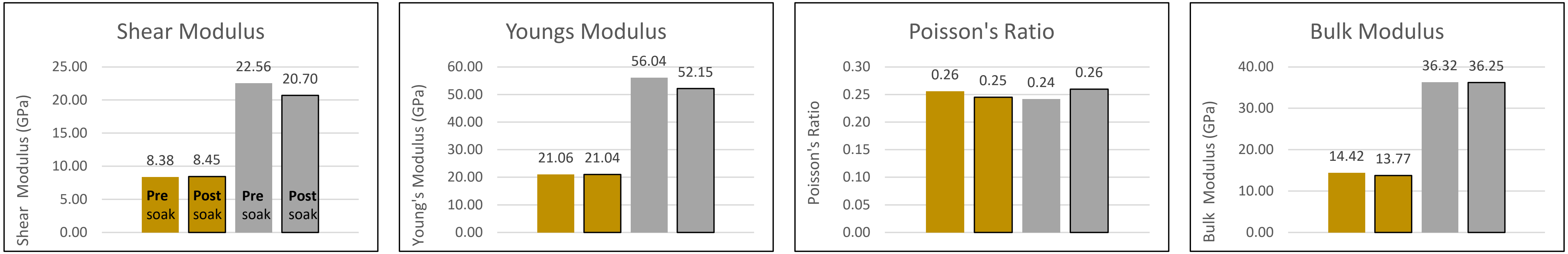
Auto Lab
Poison ratio
Youngs modulus
PDP
Permeability
Diffusivity
SEM small sample

H2 Soak
3 month
50°C
1200 psi

Auto Lab
Poison ratio
Youngs modulus
PDP
Permeability
Diffusivity

Class H with steel

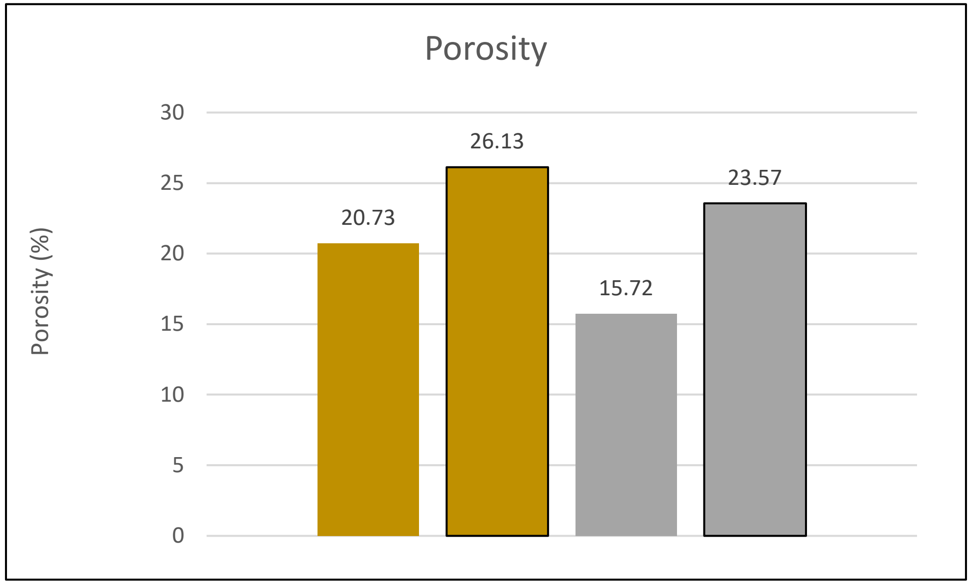
Class H cement

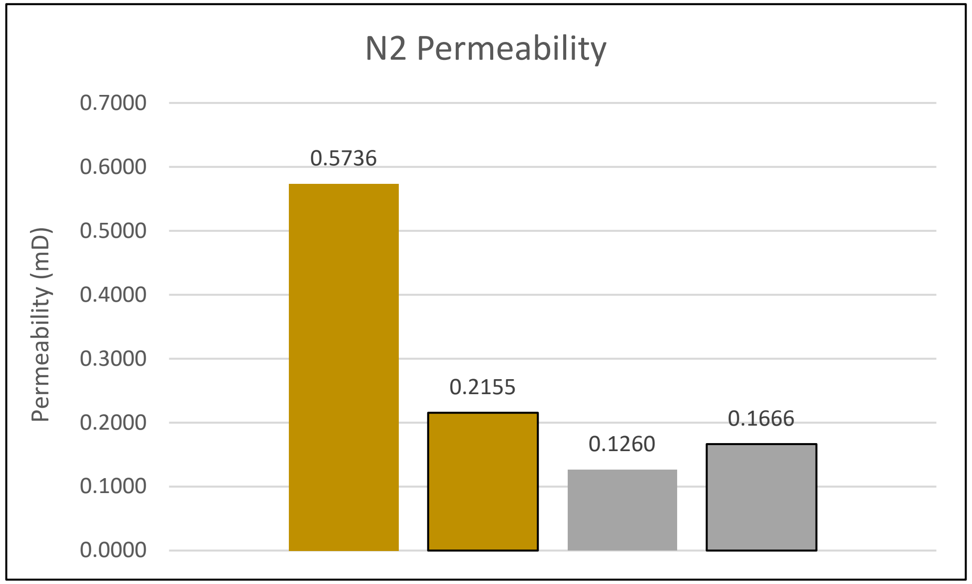


Pre and Post 3 months H_2 Batch exposure @ 1,200 psi and 50°C

Well Integrity: Porosity & Permeability

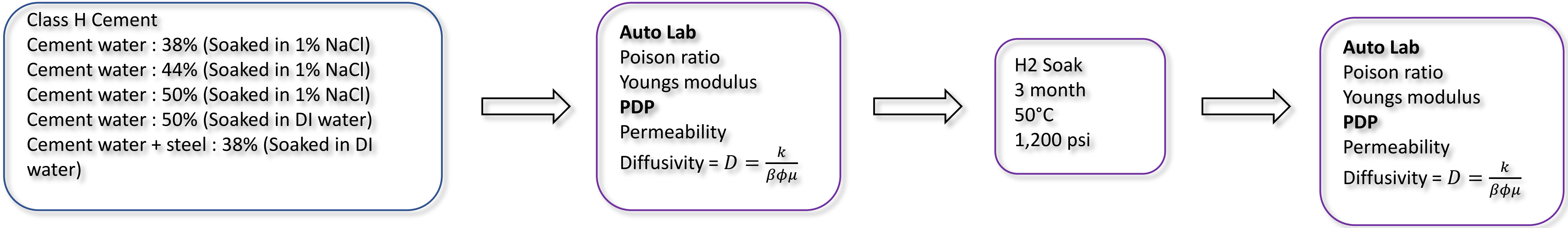
Pre and Post 3 months H_2 Batch exposure @ 1,200 psi and 50°C





🟨 Class H cement

⬜ Class H with steel



Class H Cement
Cement water : 38% (Soaked in 1% NaCl)
Cement water : 44% (Soaked in 1% NaCl)
Cement water : 50% (Soaked in 1% NaCl)
Cement water : 50% (Soaked in DI water)
Cement water + steel : 38% (Soaked in DI water)

Auto Lab
Poison ratio
Youngs modulus
PDP
Permeability
Diffusivity = $D = \frac{k}{\beta\phi\mu}$

H2 Soak
3 month
50°C
1,200 psi

Auto Lab
Poison ratio
Youngs modulus
PDP
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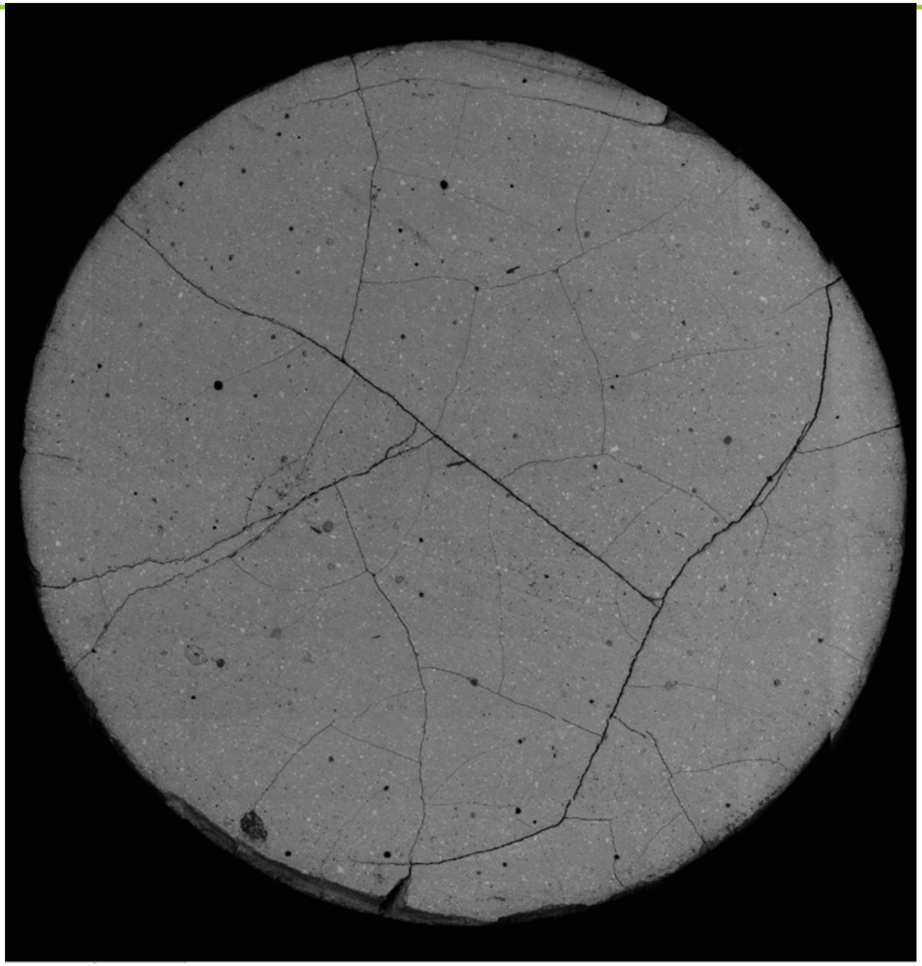
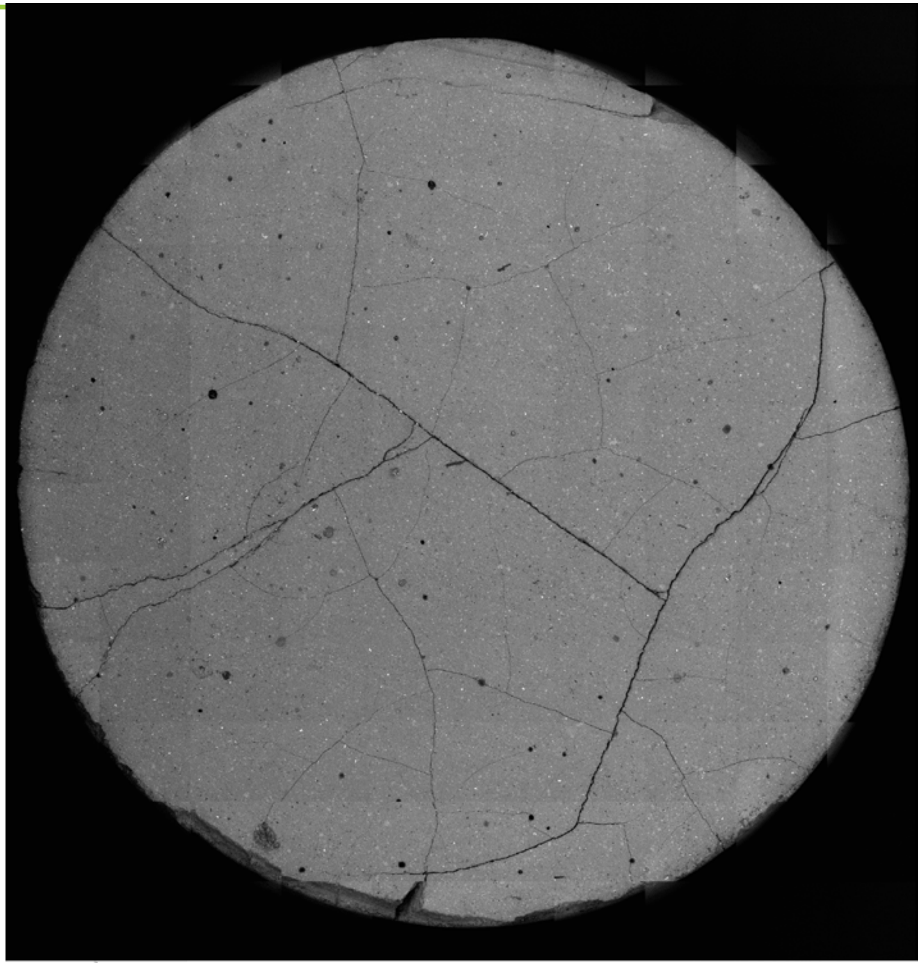
Well Integrity

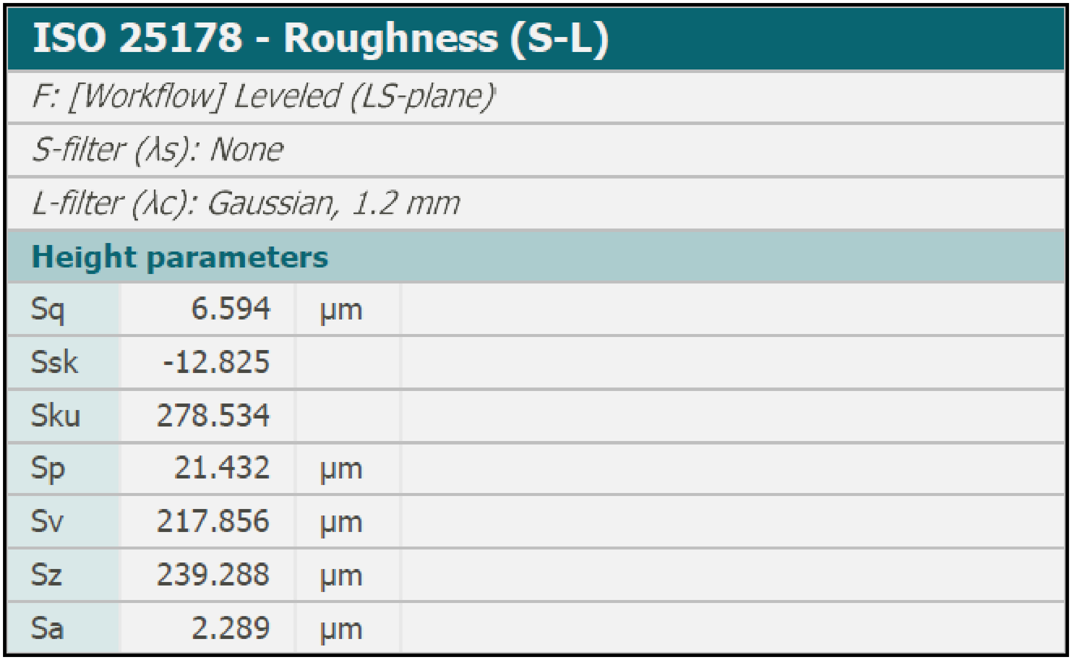


pre-H_2 soak



post-H_2 soak

Well Integrity



ISO 25178 - Roughness (S-L)

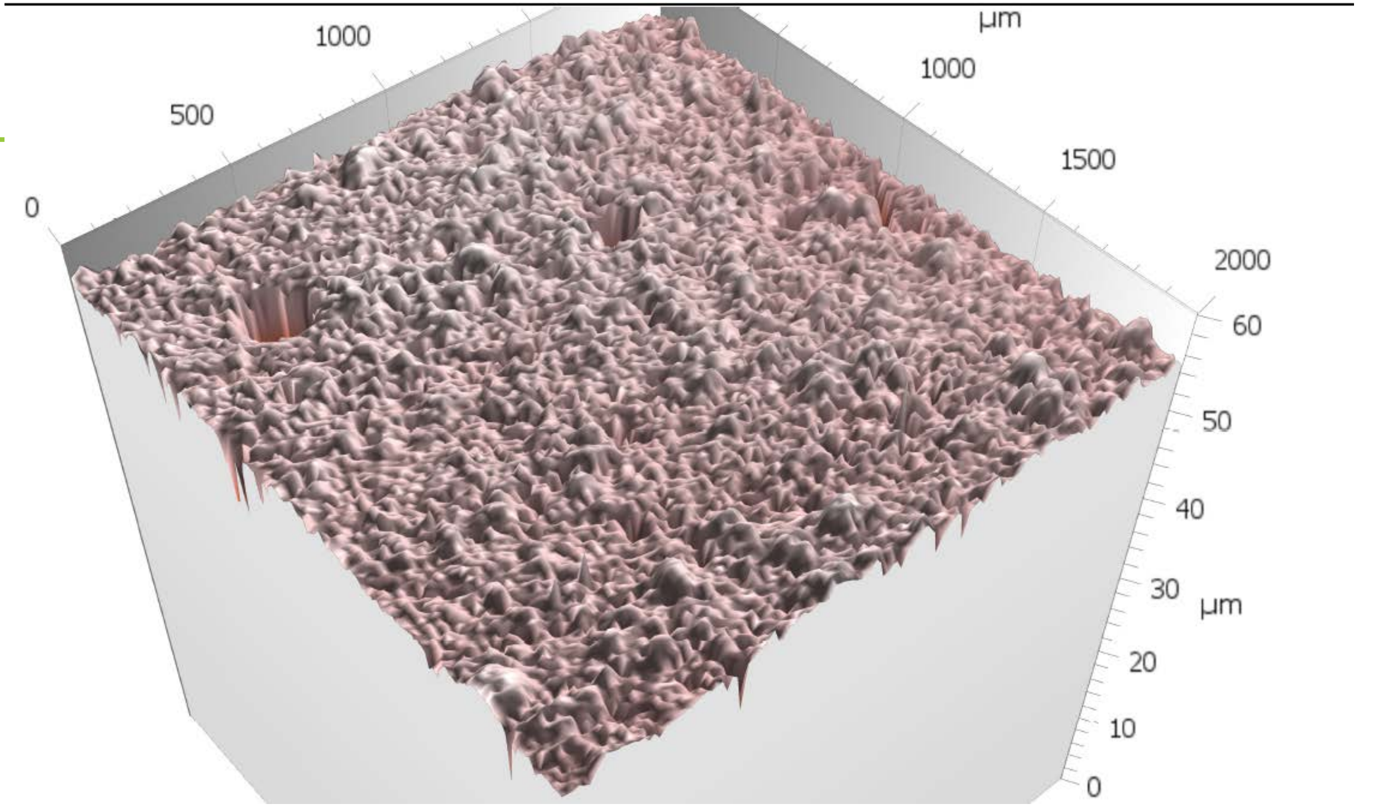
F: [Workflow] Leveled (LS-plane)

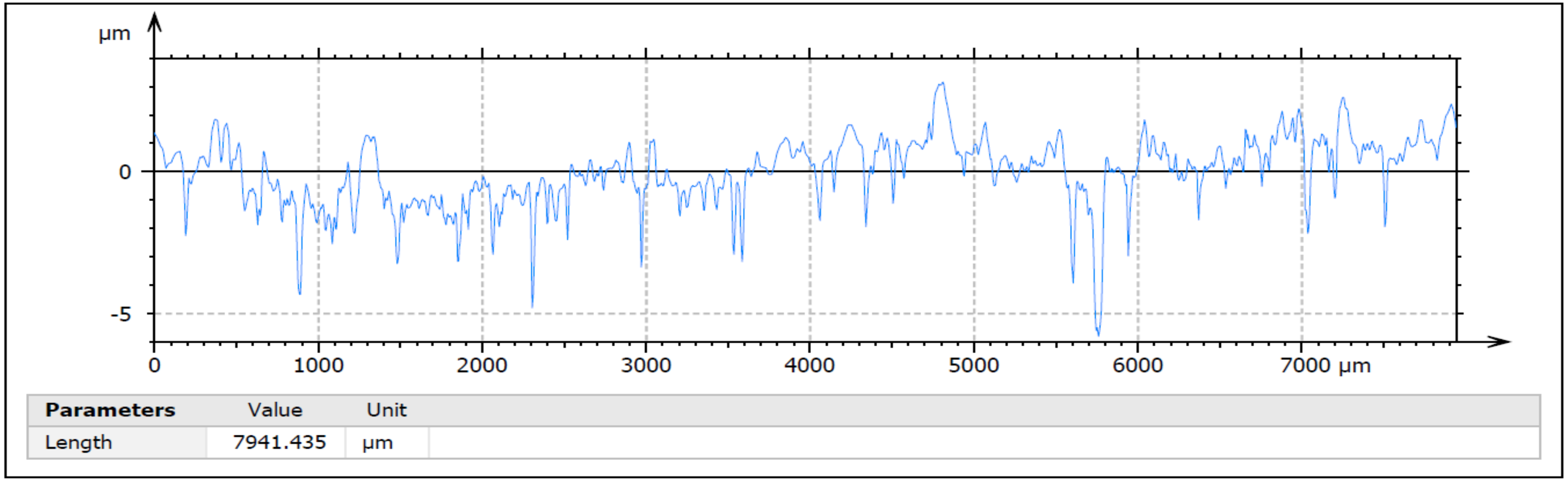
S-filter (λs): None

L-filter (λc): Gaussian, 1.2 mm

Height parameters

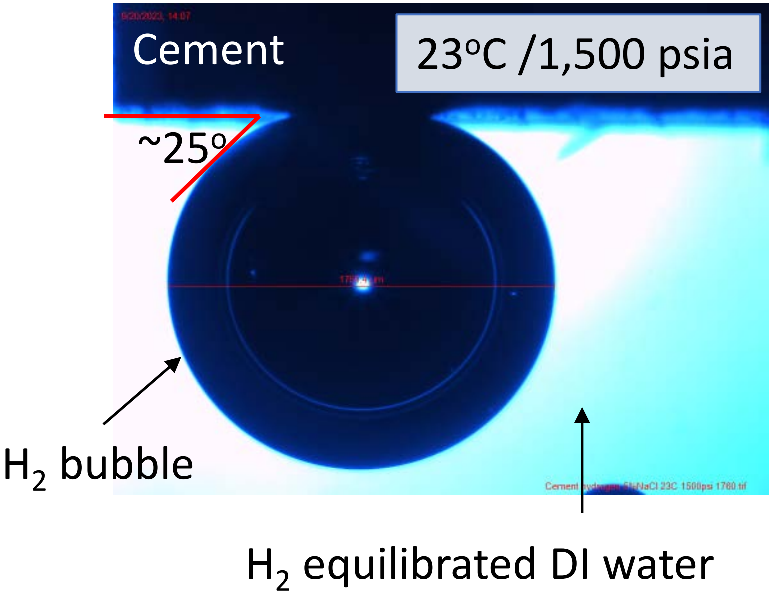
Sq	6.594	µm
Ssk	-12.825	
Sku	278.534	
Sp	21.432	µm
Sv	217.856	µm
Sz	239.288	µm
Sa	2.289	µm

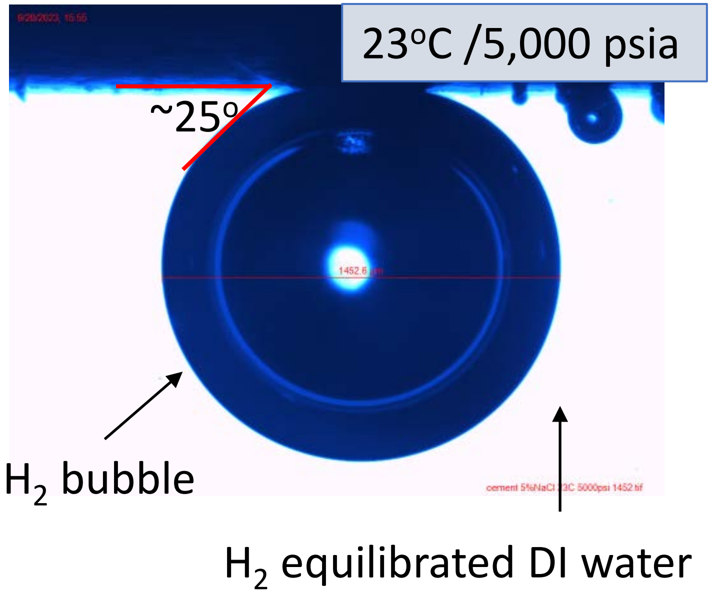


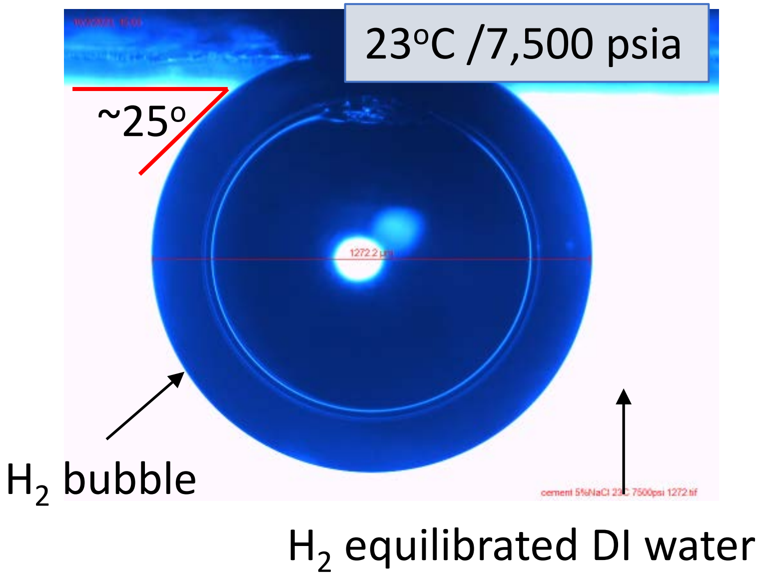


Parameters	Value	Unit
Length	7941.435	µm

Well Integrity: Multiphase Flow Properties



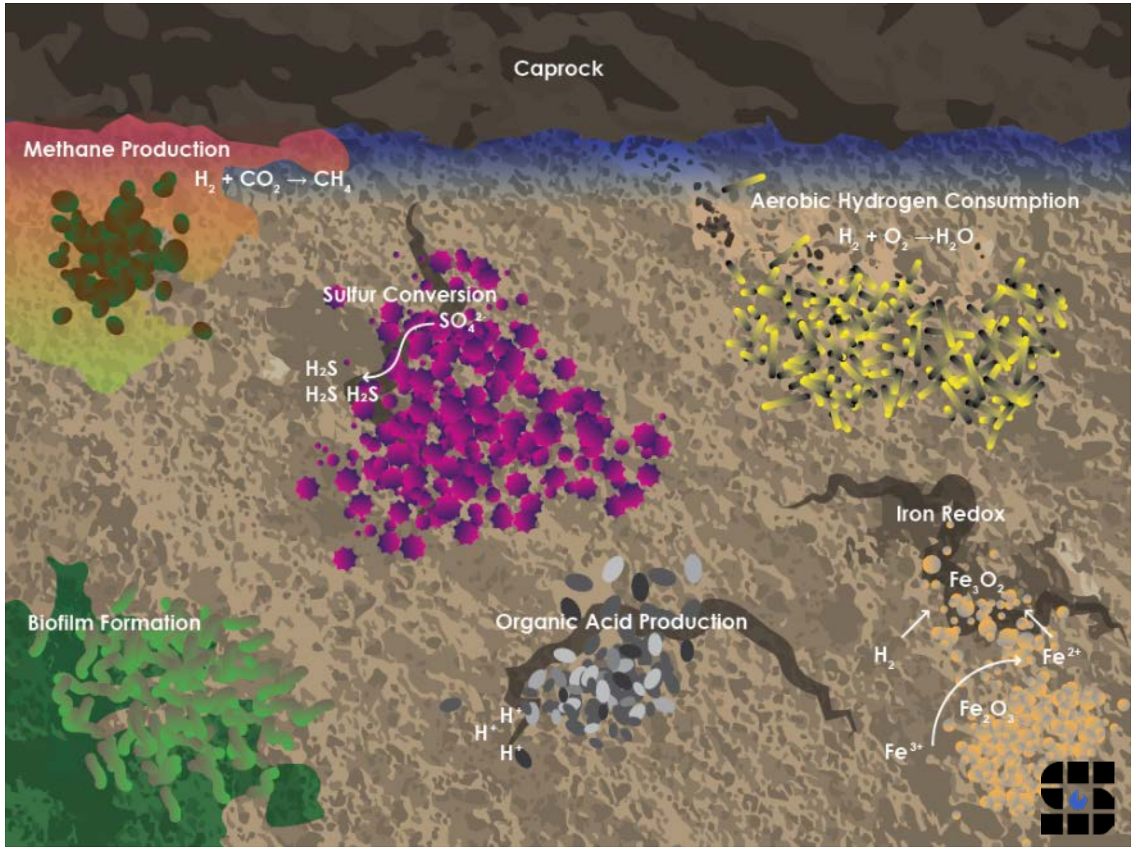




- Measured wetting properties of H_2 with cement (contact angles ~ 25°)
- Results show no significant change in contact angle with pressure, temperature, and H_2 bubble size

✓ **Conclude that H_2 will remain non-wetting in subsurface storage conditions and will not lead to leakage by imbibition into the cemented annulus or caprock**

Microbiology and Geochemistry Fundamentals

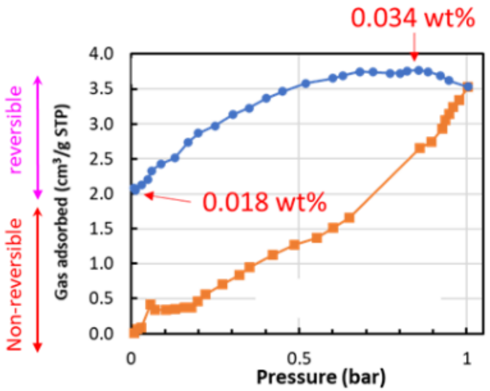


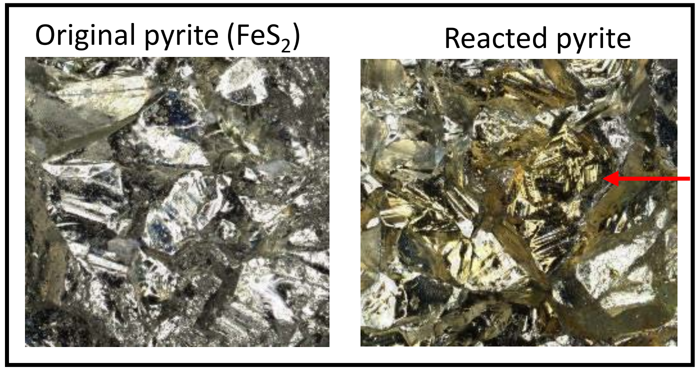
Microbial activity can affect subsurface energy storage through:

- Methanogenesis
- Hydrogen Sulfide Production
- Acid Production
- Microbiological Corrosion Pathways

Geochemical reactions between H_2, formation fluids, and rock mineralogy may lead to:

- Loss of H_2
- Contamination of stored H_2 by wanted gas generation (e.g., H_2S)
- Mineral dissolution/precipitation

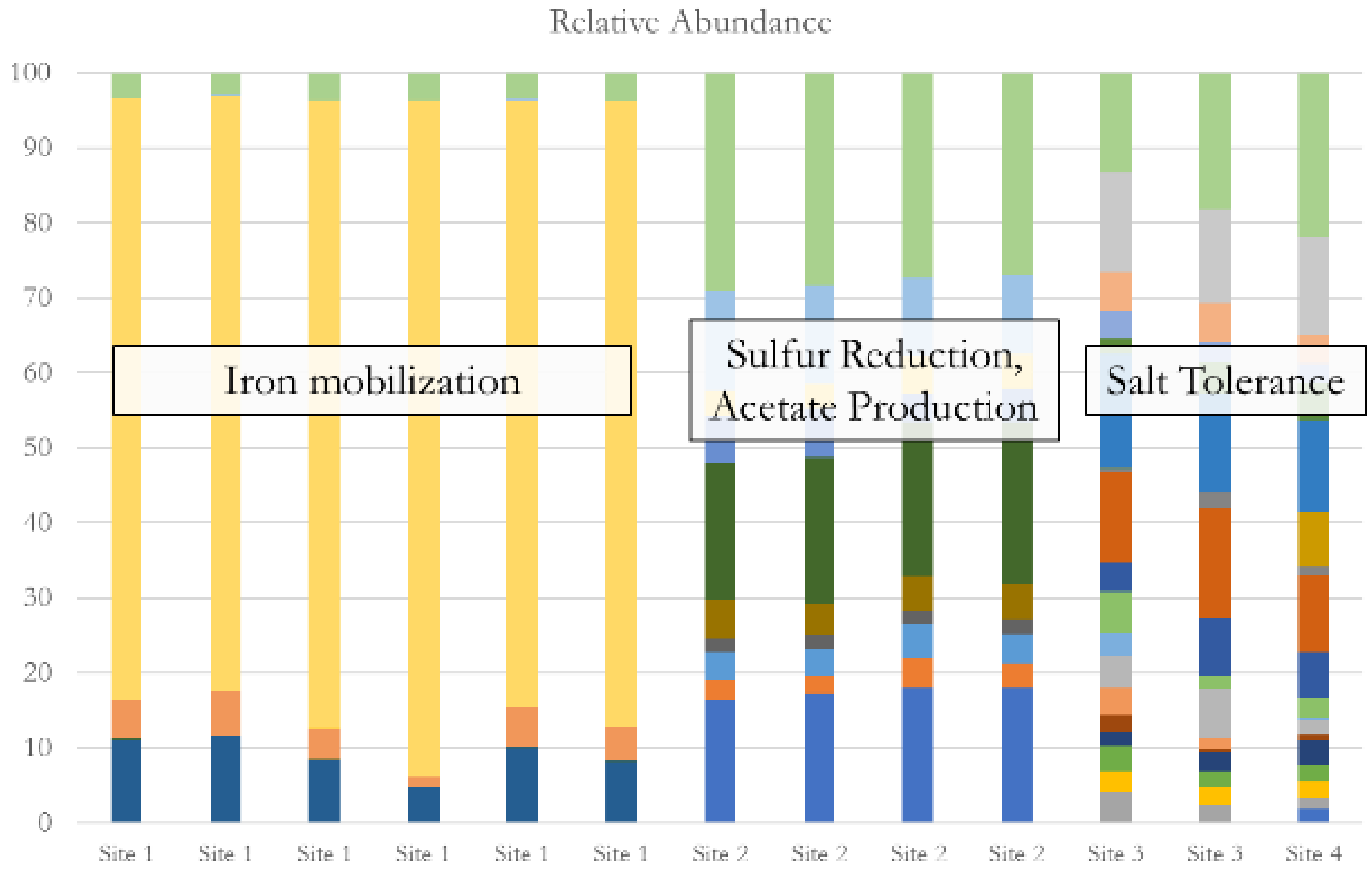



Original pyrite (FeS_2)

Reacted pyrite

Microbiology – Field Characterization and Lab Testing

- **Goal:** Identify and characterize potential reservoir reactions that may occur after hydrogen storage
- Examining four field sites (Midwest and West)
- Diverse microbial community (Metagenomic and 16S rRNA Sequencing characterization)
- Identified microorganisms capable of sulfur reduction, iron reduction, and acetogenesis in the initial microbial community
  - Suggests native microorganisms are capable of driving hydrogen consumption reactions resulting in organic acid production, hydrogen sulfide production, and metal mobility



Microbiology – Field Characterization and Lab Testing

- Conducting exposure testing with fluids (containing microbial community and abiotic) and H_2/CH_4 blends at reservoir pressure & temperature conditions

			B^A	Ba^A	Ca^A	Fe^A	K^A	Li^A	Mg^A	Mn^A	Na^A	P^A	Sr^A	Cl^B	SO_4^B	Br^B	PO_4^B
	Field Sample	**DST Fluid**	3.25	0.28	2730	BDL	215	5.97	808	1.03	11480	0.44	70	30857	3280	BDL	BDL
With Sediment	**Biotic**	**Day 1**	2.98	0.34	2351	BDL	201	5.71	775	1.02	10650	0.45	64	30917	2217	BDL	BDL
		Day 2	3.45	0.34	2568	BDL	232	6.38	871	1.37	11960	0.43	72	30480	2244	BDL	BDL
		Day 7	3.24	0.35	2700	BDL	228	6.18	868	1.16	11820	BDL	72	26523	2475	BDL	BDL
		Day 21	3.14	1.30	2491	BDL	222	6.37	865	2.91	12080	0.39	71	33760	2689	BDL	BDL
	Biotic Replicate	**Day 1**	3.22	0.32	2591	BDL	217	6.14	822	1.23	11290	0.42	69	33930	2128	BDL	BDL
		Day 2	3.28	0.31	2484	BDL	217	5.94	828	1.05	11200	0.44	68	28360	1979	BDL	BDL
		Day 7	2.96	0.38	2332	BDL	201	5.52	769	1.07	10540	BDL	63	23973	2876	BDL	BDL
		Day 21	3.38	0.34	2629	102	227	6.39	861	1.35	11950	0.53	72	29860	2399	BDL	BDL

Initial results:

- Production of H_2S (both biotic and abiotic)
- Decrease of sulfate in the fluid phase
- Some selection of microbes as reaction progresses

Pressure: ~1800 psia

Temperature: 47°C

90mL fluid / 10 g sediment

15% H_2/85% CH_4

Reservoir Performance

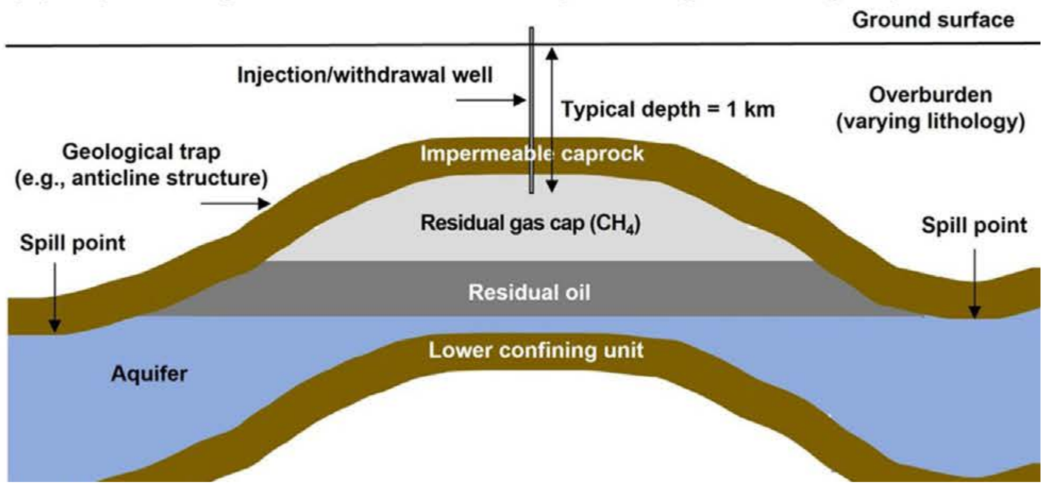
Goal

- Investigate reservoir behavior when converting existing natural gas storage fields to UHS or creating new storage from depleted field or aquifer

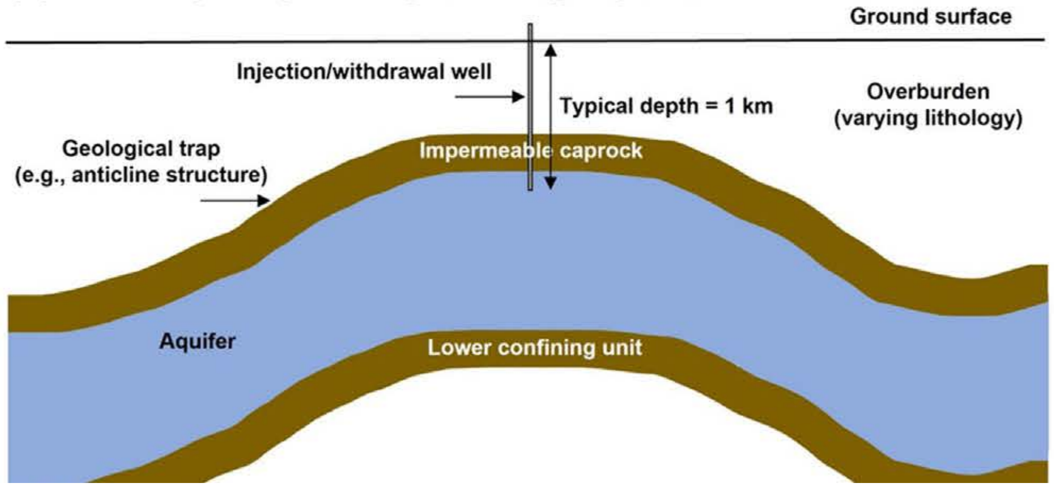
Key questions

- What is the impact of rock and fluid properties on storage efficiency and energy availability?
- How can H_2 / NG / brine flow dynamics be managed?
- What mechanisms could lead to resource loss?
- To what extent can existing industrial workflows be re-used for H_2 projects?

(a) Depleted hydrocarbon reservoir prior to gas-storage operations



(b) Saline aquifer prior to gas-storage operations



Buscheck et al. (2023)
https://doi.org/10.1016/j.ijhydene.2023.07.073

Compositional Reservoir Simulation, GEOS

Tracking the evolution of

1. One or more components (H_2, CH_4, H_2O, CO_2, …)
2. One or more fluid phases (gas, aqueous, oil, …)

Satisfying

1. Component-wise mass conservation
2. Phase and component summation constraints
3. Multiphase Darcy’s law
4. Thermodynamic equilibrium (i.e., flash calculations)
5. Various constitutive models: density, viscosity, relative permeability, capillary pressure, etc.

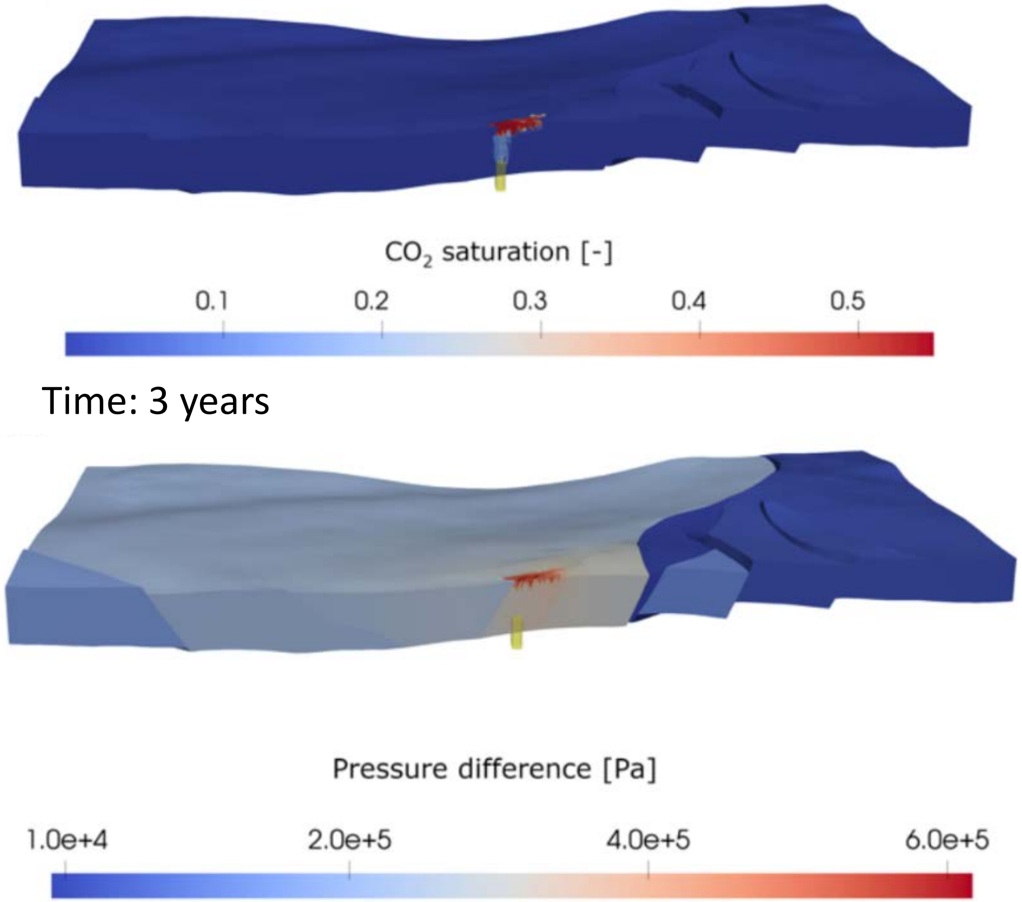
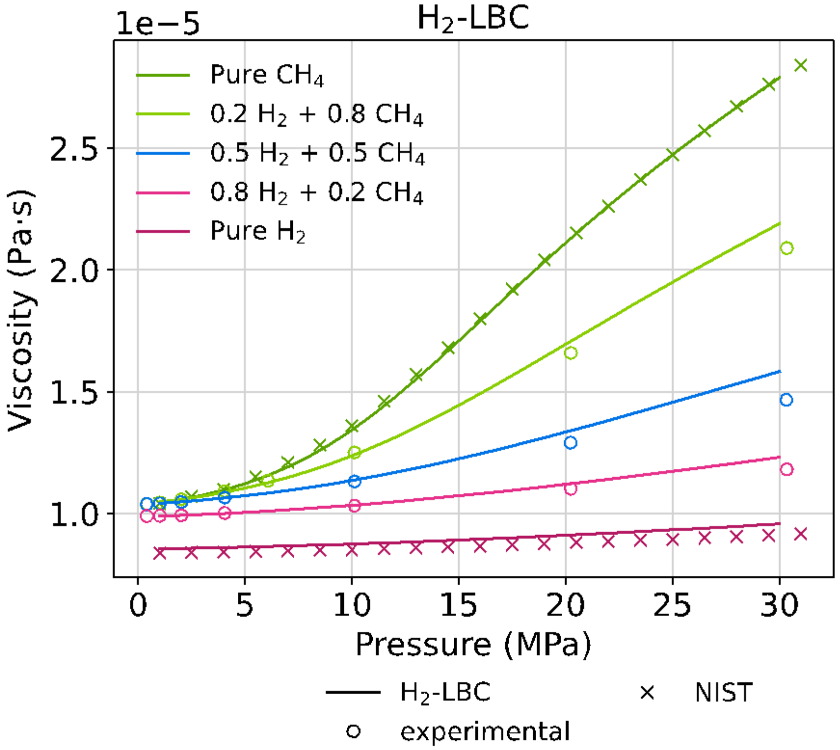


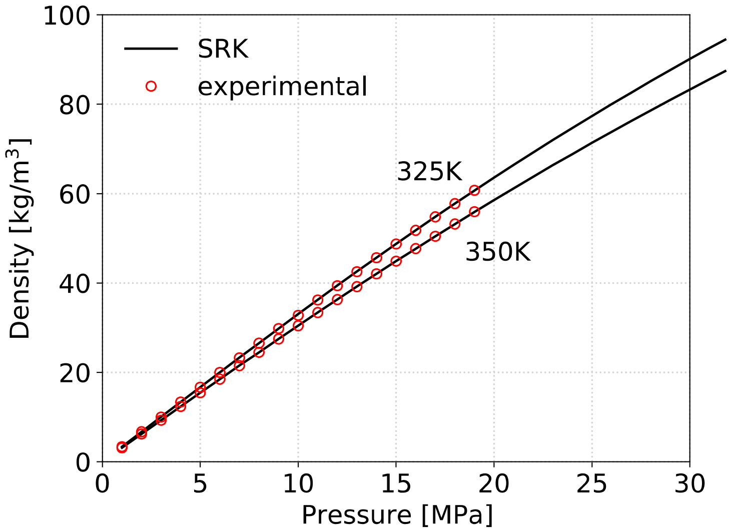
Figure: Side view of a two-phase, two-component model of CO_2 injection into a saline aquifer.

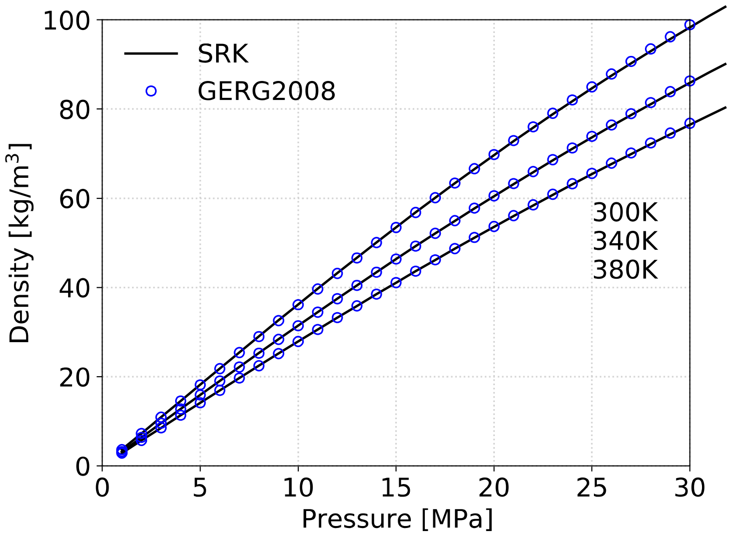
[Camargo et al., GHGT-16, 2022. http://dx.doi.org/10.2139/ssrn.4296637]

Mixture Density and Viscosity Capability Upgrades

Upgrades to GEOS to enable H_2 simulations



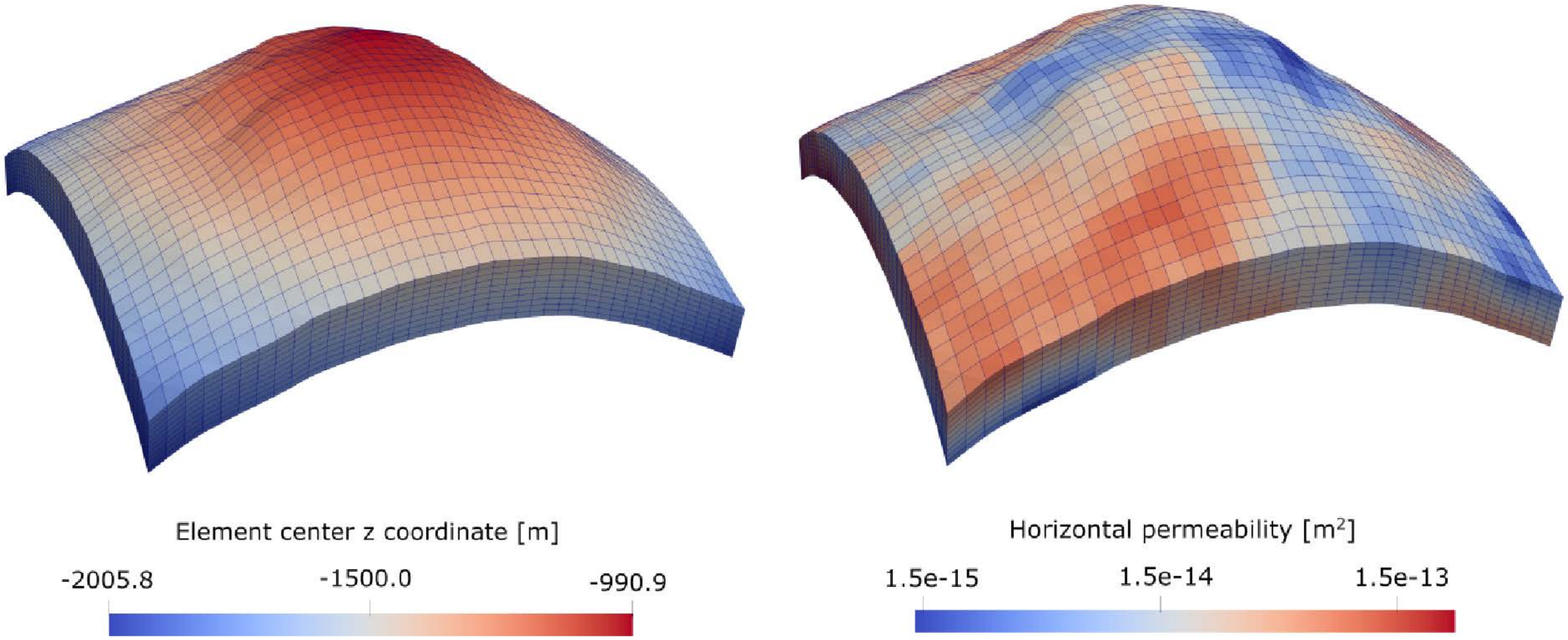




* SRK = Soave-Redlich-Kwong Cubic Equation of State

Field-Scale Simulations for a Simple System

Synthetic Hydrogen Storage Reservoir Model



(a)

(b)

Table 1: Rock properties

Parameter	Units	Min – Max	Mean
Porosity	fraction	0.05 – 0.25	0.15
Permeability	mD	1.4 - 265	51

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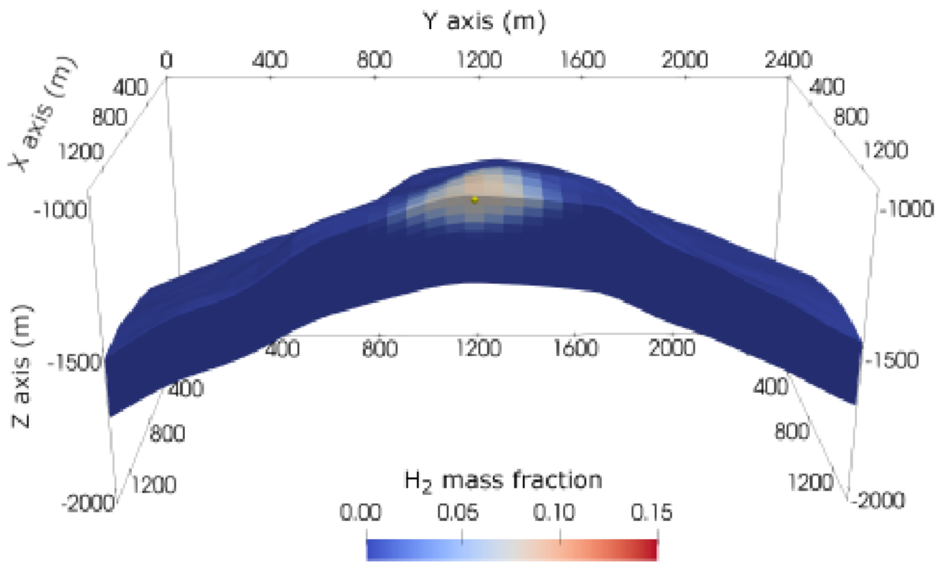
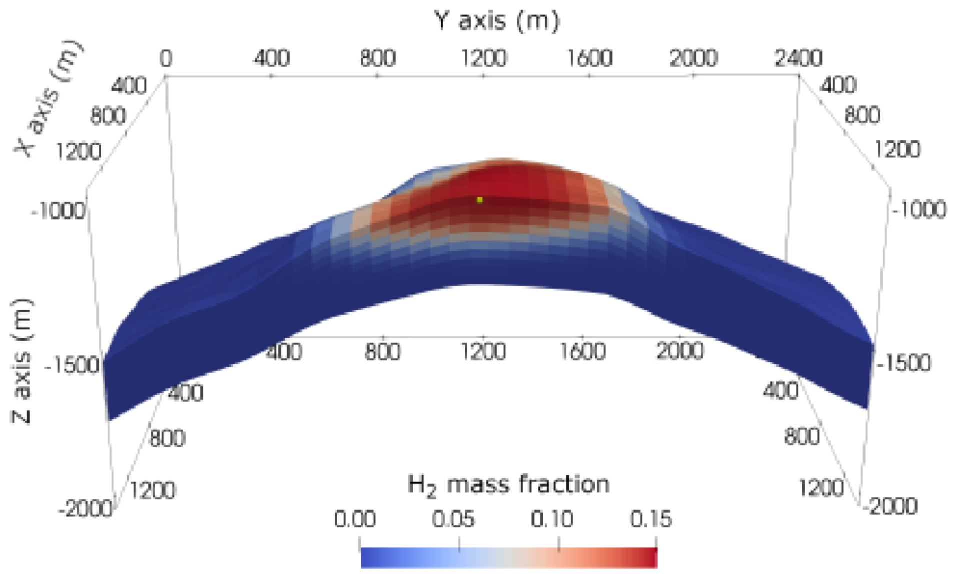
Field-Scale Simulations, Operational Scenario

Seasonal Storage & Delivery Scenario

- Field is initially saturated with CH_4
- H_2 (pure or blended) is cyclically injected in various design configurations
- Gas-water contact dynamics ignored for the moment (single-phase, two-component system)



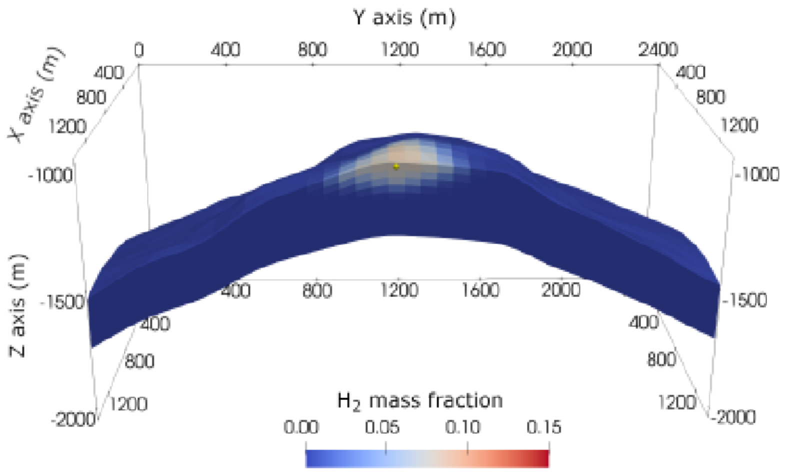
(a) After the first withdrawal cycle when injecting at the top of the reservoir.



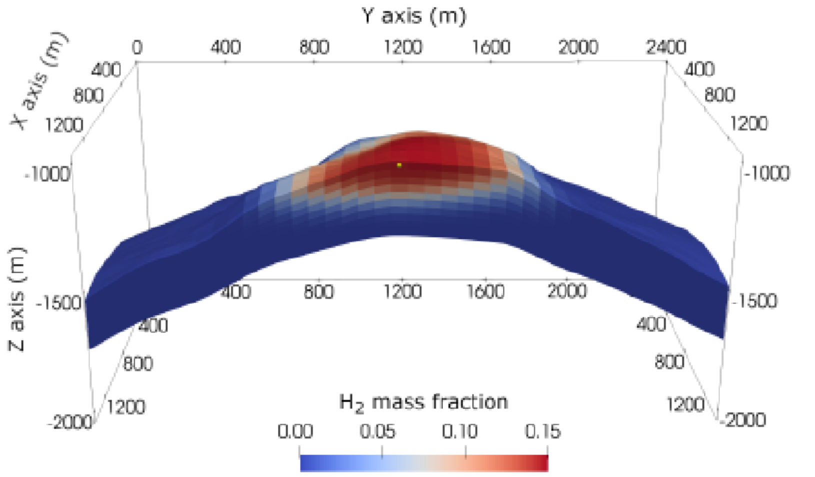
(b) After the last (15th) withdrawal cycle when injecting at the top of the reservoir.

A stable hydrogen cap (relative to perfs) is essential to stable production rates

Perforations at **top** of storage formation:

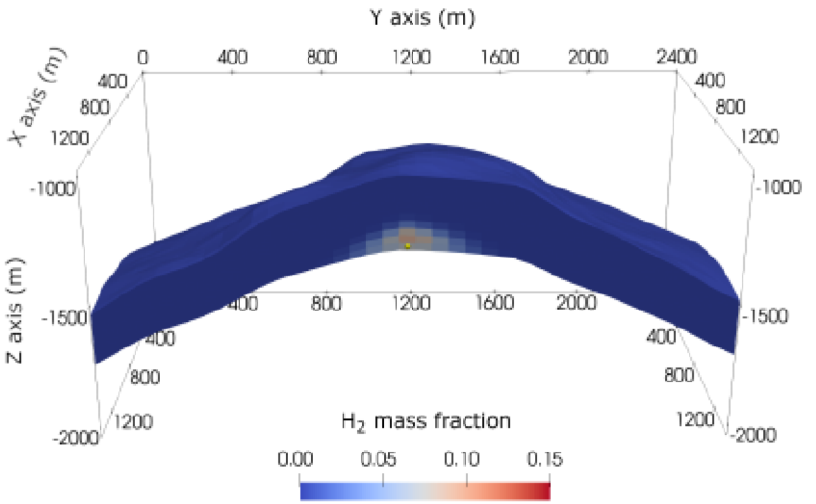


(a) After the first withdrawal cycle when injecting at the top of the reservoir.

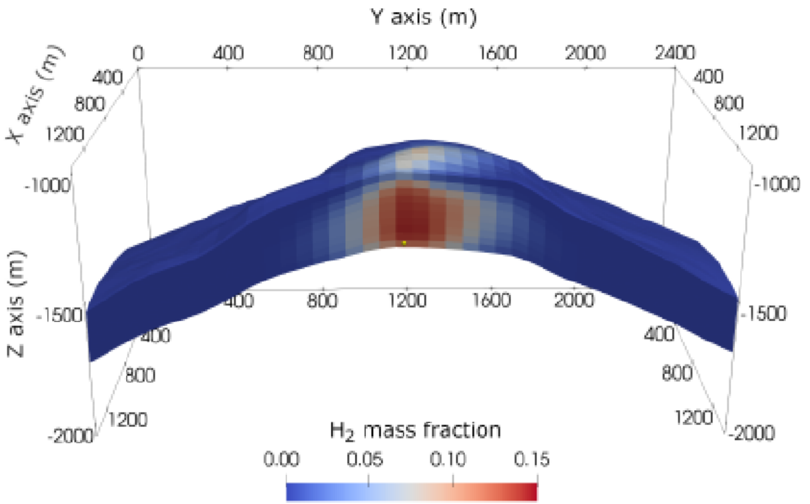


(b) After the last (15th) withdrawal cycle when injecting at the top of the reservoir.

Perforations at **bottom** of storage formation:

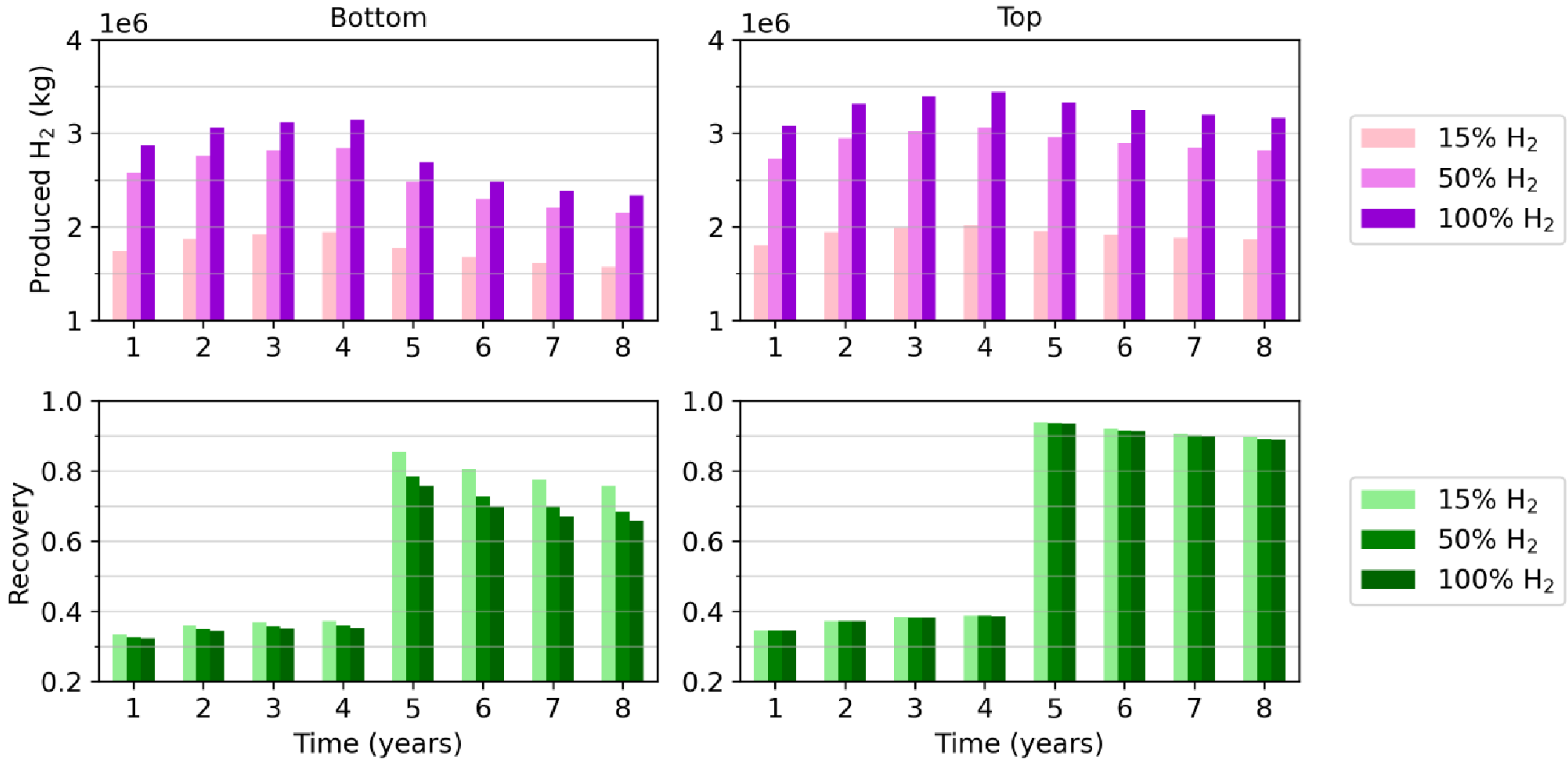


(c) After the first withdrawal cycle when injecting at the bottom of the reservoir.



(d) After the last (15th) withdrawal cycle when injecting at the bottom of the reservoir.

A stable hydrogen cap (relative to perfs) is essential to stable production rates



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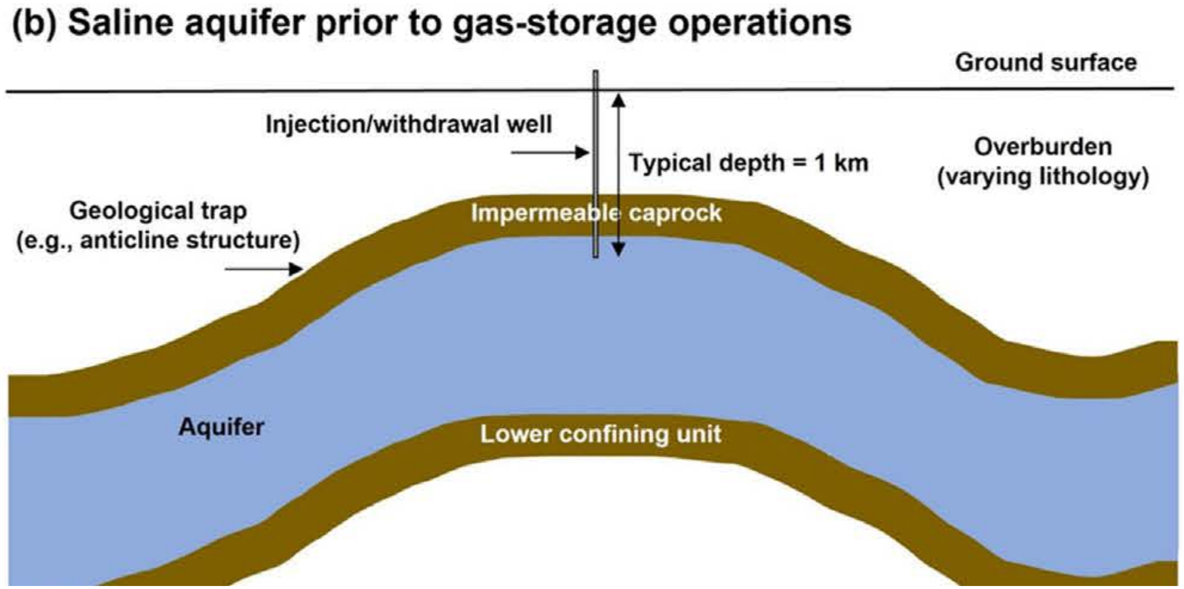
Reservoir Simulations Conclusions

1. Using NG instead of H_2 as a cushion could save significant build-out costs
   - NG is much cheaper than H_2
   - Circumvents viscous fingering problem in a new saline storage project

2. Standard reservoir simulators are well suited to H_2 simulations with modest upgrades (e.g. improved viscosity models)

3. A stable H_2 gas cap is essential to stable production rates

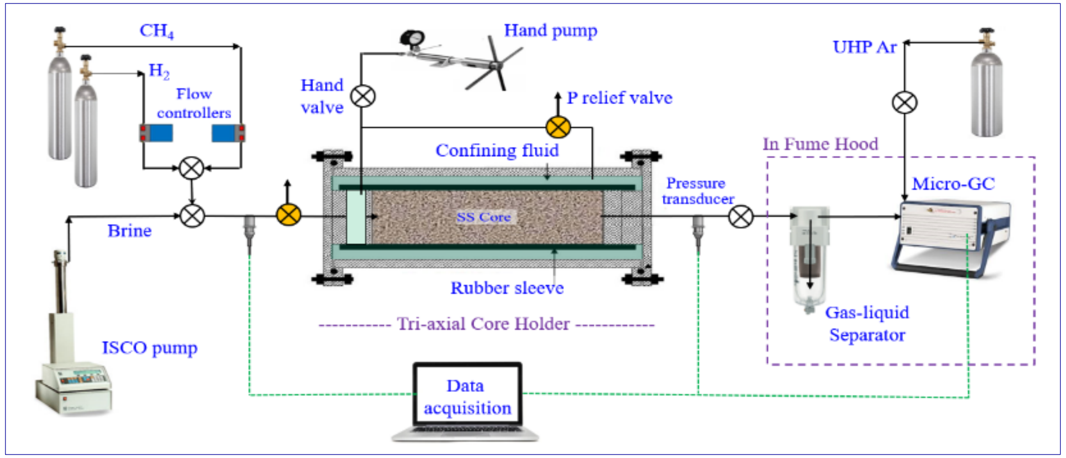
4. Stability is favored by:
   1. Good trapping structure
   2. Low vertical permeability and/or baffling
   3. Perforations near top of storage formation

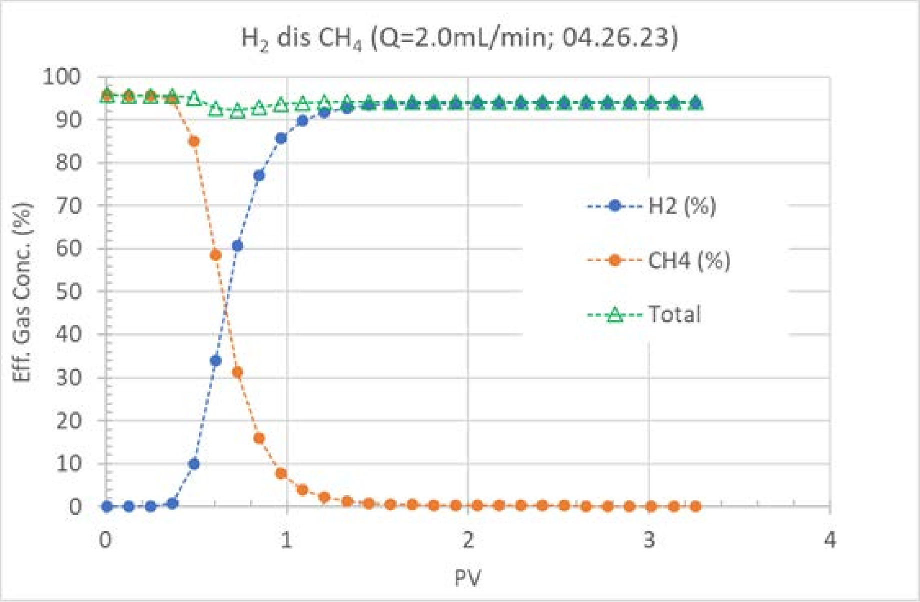


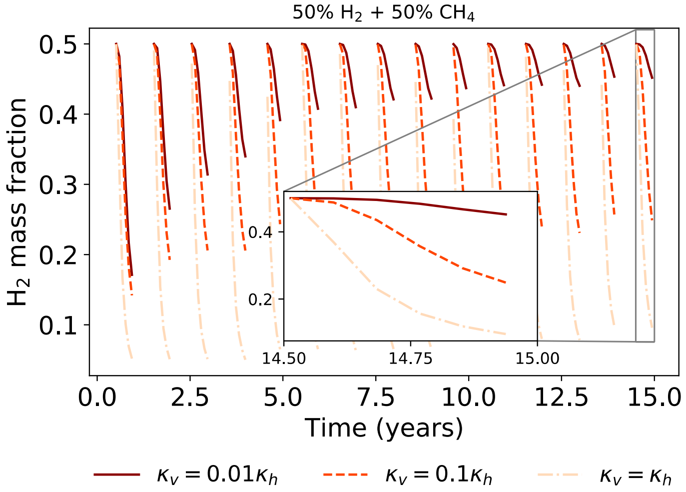
Buscheck et al., IJHE, 2023

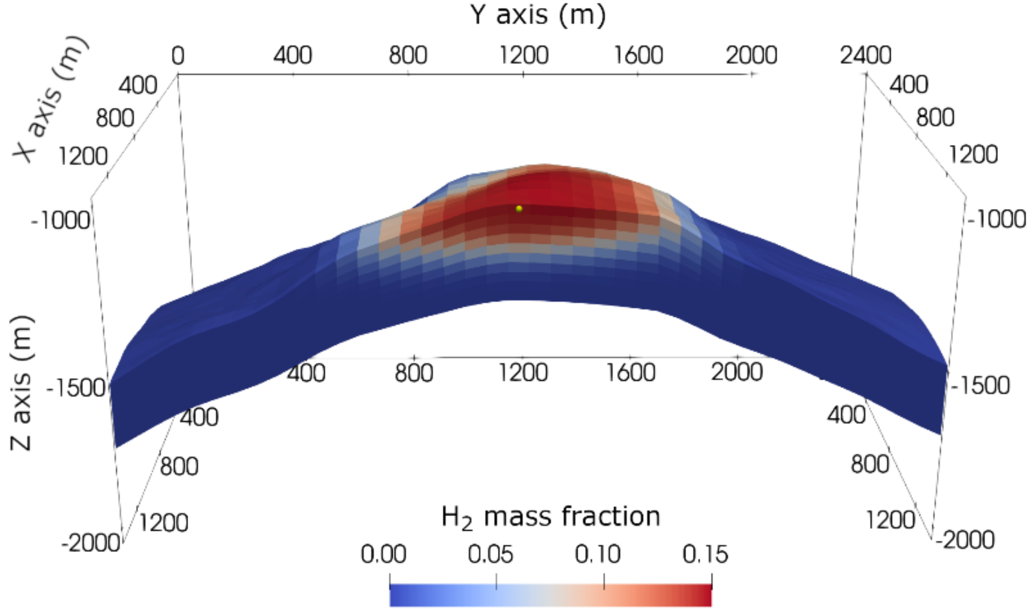
https://doi.org/10.1016/j.ijhydene.2023.07.073

Core to reservoir scale flow dynamics



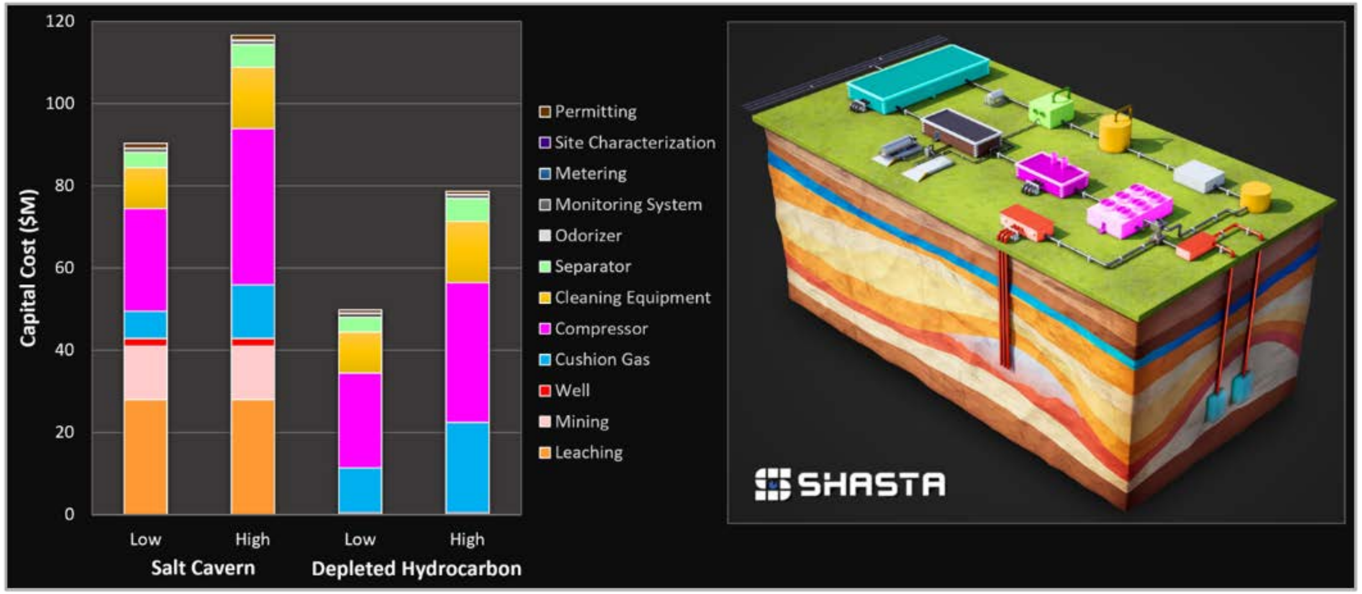


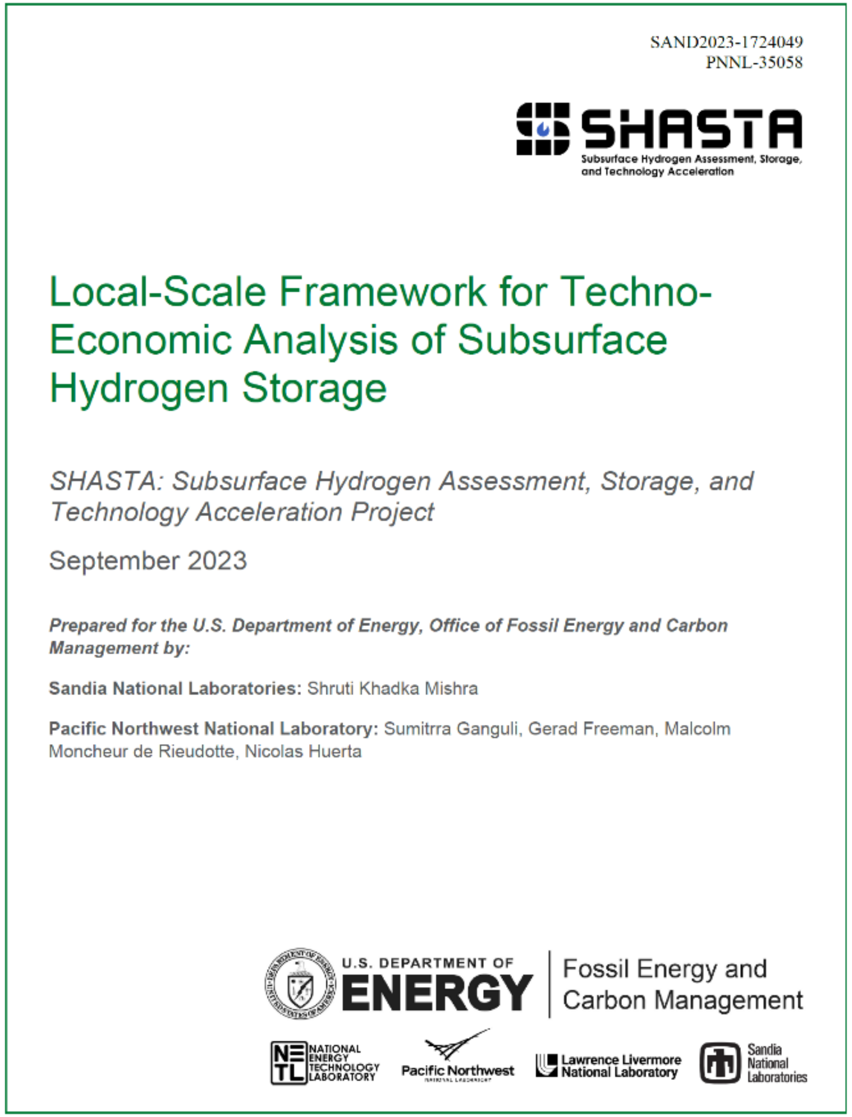




Local Scale Technoeconomic Analysis for UHS

- Framework for UHS cost estimation that reflects the granularity that an operator might use to assess their existing infrastructure or to identify opportunities to develop new facilities
  - ***https://www.osti.gov/servlets/purl/2202473***
- Present a hypothetical use case for Pennsylvania
- Working on a regional scale assessment methodology





SAND2023-1724049
PNNL-35058

SHASTA
Subsurface Hydrogen Assessment, Storage, and Technology Acceleration

Local-Scale Framework for Techno-Economic Analysis of Subsurface Hydrogen Storage

SHASTA: Subsurface Hydrogen Assessment, Storage, and Technology Acceleration Project

September 2023

Prepared for the U.S. Department of Energy, Office of Fossil Energy and Carbon Management by:

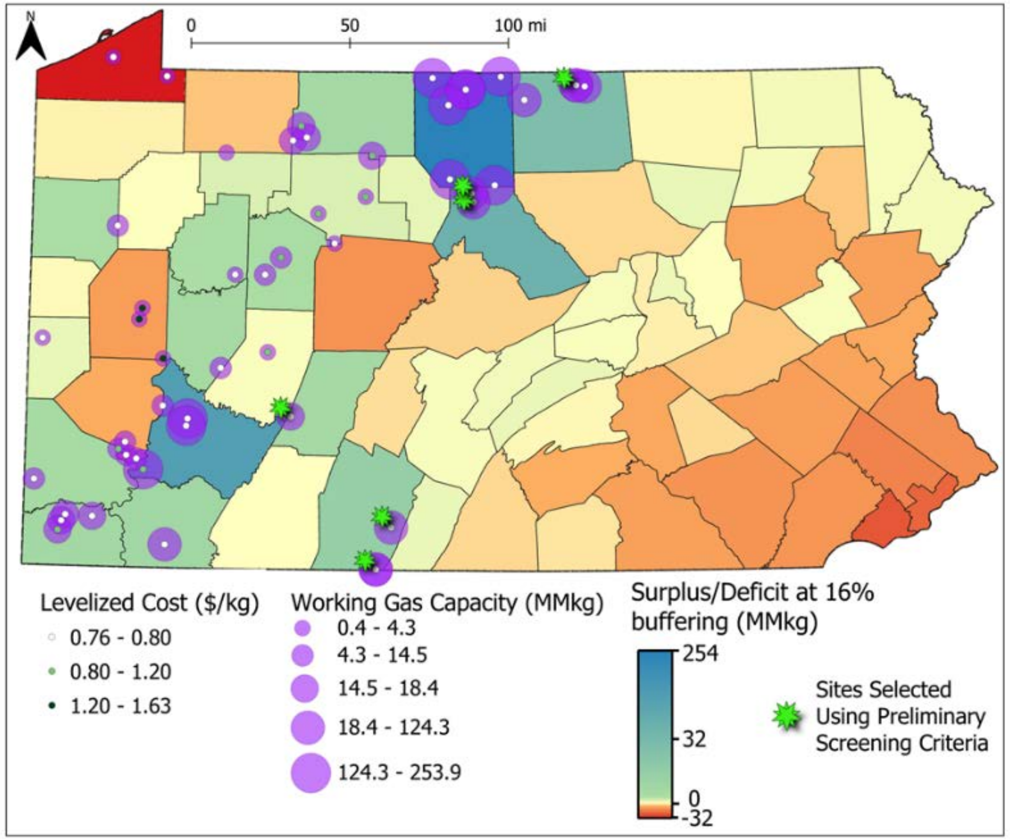
Sandia National Laboratories: Shruti Khadka Mishra

Pacific Northwest National Laboratory: Sumitrra Ganguli, Gerad Freeman, Malcolm Moncheur de Rieudotte, Nicolas Huerta

U.S. DEPARTMENT OF ENERGY | Fossil Energy and Carbon Management

NETL National Energy Technology Laboratory | Pacific Northwest | Lawrence Livermore National Laboratory | Sandia National Laboratories

Initial Technoeconomic Site Screening, PA



- **Initial screening criteria based on techno-economics:**
  - Working gas mass (favor large sites)
  - County-level demand (favor sites with surplus of working gas mass relative to demand)
  - Levelized cost of storage (favor sites with lower levelized costs)
- **If we consider a 100 km (62 mile) transportation distance, 43 of PA's 67 counties might be served by an existing UGS facility**

State of Knowledge (SOK) Report

SOK for subsurface H_2 and CH_4 storage

Delivered ***Subsurface Hydrogen and Natural Gas Storage: State of Knowledge and Research Recommendations Report*** April 2022

- Report covers:
    - Subsurface energy storage systems overview
    - Storage operations and key risks
    - Well integrity
    - Surveillance and monitoring
    - Social license to operate for subsurface hydrogen storage
    - Recommendations
- https://www.osti.gov/biblio/1846632/

DOE/NETL-2022/3236

SHASTA
Subsurface Hydrogen Assessment, Storage, and Technology Acceleration

Subsurface Hydrogen and Natural Gas Storage: State of Knowledge and Research Recommendations Report

SHASTA: Subsurface Hydrogen Assessment, Storage, and Technology Acceleration Project

April 2022

Prepared for the U.S. Department of Energy, Office of Fossil Energy and Carbon Management by:

National Energy Technology Laboratory: Angela Goodman, Barbara Kutchko, Greg Lackey, Djuna Gulliver, Brian Strazisar, Kara Tinker, Ruishu Wright, Foad Haeri

Pacific Northwest National Laboratory: Nicolas Huerta, Seunghwan Baek, Christopher Bagwell, Julia De Toledo Camargo, Gerad Freeman, Wenbin Kuang, Joshua Torgeson

Lawrence Livermore National Laboratory: Joshua White, Thomas A. Buscheck, Nicola Castelletto, Megan Smith

U.S. DEPARTMENT OF ENERGY | Fossil Energy and Carbon Management

NATIONAL ENERGY TECHNOLOGY LABORATORY · Pacific Northwest · Lawrence Livermore National Laboratory

Other Publications

1. **Managing reservoir dynamics when converting natural gas fields to underground hydrogen storage,** International Journal of Hydrogen Energy, 2023, ISSN 0360-3199. https://doi.org/10.1016/j.ijhydene.2023.09.165.
2. **Local-Scale Framework for Techno-Economic Analysis of Subsurface Hydrogen Storage,** 2023. "Local-Scale Framework for Techno-Economic Analysis of Subsurface Hydrogen Storage". United States. https://www.osti.gov/biblio/2202473.
3. **Underground storage of hydrogen and hydrogen/methane mixtures in porous reservoirs: Influence of reservoir factors and engineering choices on deliverability and storage operations,** (2023). Underground storage of hydrogen and hydrogen/methane mixtures in porous reservoirs: Influence of reservoir factors and engineering choices on deliverability and storage operations. International Journal of Hydrogen Energy. https://doi.org/10.1016/j.ijhydene.2023.07.073
4. **Characterizing Hydrogen Storage Potential in U.S. Underground Gas Storage Facilities,** (2023). Characterizing hydrogen storage potential in U.S. underground gas storage facilities. Geophysical Research Letters, 50, e2022GL101420. https://doi.org/10.1029/2022GL101420
5. **SHASTA Brochure** SHASTA, Subsurface hydrogen assessment, storage, and technology acceleration, 2022. https://edx.netl.doe.gov/dataset/shasta-brochure
6. **Subsurface Hydrogen and Natural Gas Storage: State of Knowledge and Research Recommendations Report,** DOE/NETL-2022/3236; NETL Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Morgantown, WV, 2022; p 77. DOI: https://doi.org/10.2172/1846632

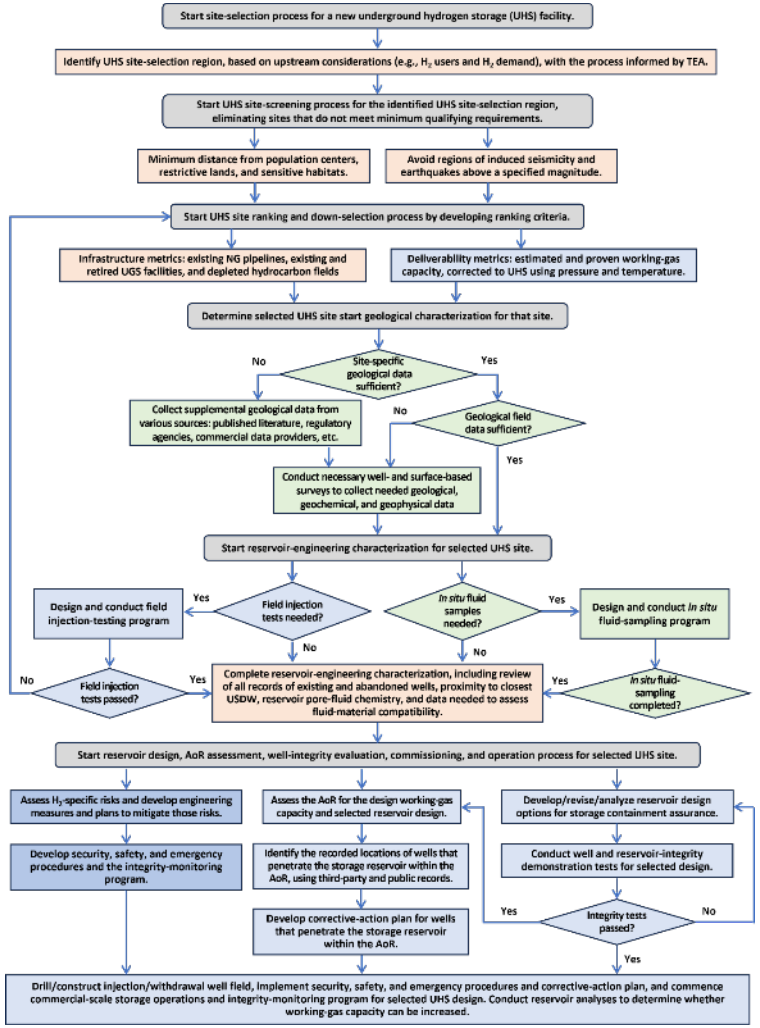
Resources

SHASTA research has resulted in a number of products including tools, publications, presentations, intellectual property, and datasets. These will be posted below as they become available.

edx.netl.doe.gov/shasta

Forward Look & Field Test

End of Project Deliverables



Start site-selection process for a new underground hydrogen storage (UHS) facility.

Identify UHS site-selection region, based on upstream considerations (e.g., H_2 users and H_2 demand), with the process informed by TEA.

Start UHS site-screening process for the identified UHS site-selection region, eliminating sites that do not meet minimum qualifying requirements.

Minimum distance from population centers, restrictive lands, and sensitive habitats.

Avoid regions of induced seismicity and earthquakes above a specified magnitude.

Start UHS site ranking and down-selection process by developing ranking criteria.

Infrastructure metrics: existing NG pipelines, existing and retired UGS facilities, and depleted hydrocarbon fields

Deliverability metrics: estimated and proven working-gas capacity, corrected to UHS using pressure and temperature.

Determine selected UHS site start geological characterization for that site.

Site-specific geological data sufficient?

No

Yes

Collect supplemental geological data from various sources: published literature, regulatory agencies, commercial data providers, etc.

Geological field data sufficient?

No

Yes

Conduct necessary well- and surface-based surveys to collect needed geological, geochemical, and geophysical data

Start reservoir-engineering characterization for selected UHS site.

Design and conduct field injection-testing program

Yes

Field injection tests needed?

No

In situ fluid samples needed?

Yes

No

Design and conduct *In situ* fluid-sampling program

No

Field injection tests passed?

Yes

Complete reservoir-engineering characterization, including review of all records of existing and abandoned wells, proximity to closest USDW, reservoir pore-fluid chemistry, and data needed to assess fluid-material compatibility.

Yes

In situ fluid-sampling completed?

Start reservoir design, AoR assessment, well-integrity evaluation, commissioning, and operation process for selected UHS site.

Assess H_2-specific risks and develop engineering measures and plans to mitigate those risks.

Develop security, safety, and emergency procedures and the integrity-monitoring program.

Assess the AoR for the design working-gas capacity and selected reservoir design.

Identify the recorded locations of wells that penetrate the storage reservoir within the AoR, using third-party and public records.

Develop corrective-action plan for wells that penetrate the storage reservoir within the AoR.

Develop/revise/analyze reservoir design options for storage containment assurance.

Conduct well and reservoir-integrity demonstration tests for selected design.

Yes

Integrity tests passed?

No

Yes

Drill/construct injection/withdrawal well field, implement security, safety, and emergency procedures and corrective-action plan, and commence commercial-scale storage operations and integrity-monitoring program for selected UHS design. Conduct reservoir analyses to determine whether working-gas capacity can be increased.

- Working on a recommended UHS project design and management workflow

- Consistent with API 1170 and 1171 RPs

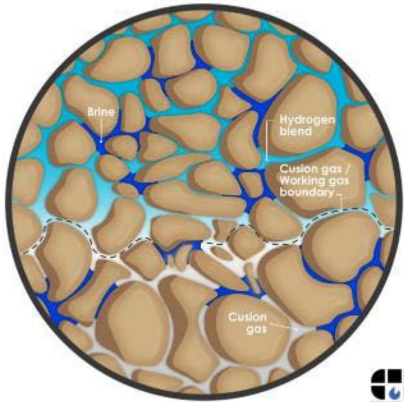
- *Key elements*
  1. Site selection
  2. Site characterization
  3. Engineering design
  4. Field testing and commissioning
  5. Operations
  6. Emergency response

- Will be used to structure final report deliverables
  - Geologic characterization & ranking of candidate sites
  - Risk assessment for UHS
  - Facility and regional-scale Technoeconomic framework

Forward Look & Field Test

End of Project Deliverables

- **Additional deliverables coming out of SHASTA**
  - Code comparison study for reservoir simulations
  - Geologic screening study for several locations (PA, AK)
  - Multiphase flow study in rocks
  - Material performance in H_2 environments (cement/steel)
  - Materials performance for reservoir and caprock under abiotic and biotic conditions
  - Continuous updates to SHASTA help tool (e.g., storage & delivery capability, GIS functionality)
  - Community engagement plan



SHASTA

Forward Look & Field Test

Field test planning

- SHASTA’s ultimate goal is to enable field tests
- Continue to build relationships with industry
  - Quantify asset and resource risks
  - Reduce uncertainty in operations
  - Characterize site-specific behavior
- Looking for site owners who may be interested in pilot-scale studies
  - Site characterization & risk assessment
  - Small pilot-scale demonstration at single well
  - Larger field-scale operations
- End of SHASTA deliverable is a plan for field test

Forward Look & Field Test

Completion of SHASTA 1.0

Subsurface Hydrogen Assessment, Storage, and Technology Acceleration – 2024 Workshop, **April 3, 2024, in-person**

- Present a dive into final SHASTA deliverables
- Invite complimentary efforts to present
  - International efforts
  - Complimentary R&D
    - HFTO projects
    - USGS
    - FOA-2400 projects
    - H_2 Hubs
  - Industry & regulatory perspective
- Discuss next step needs in UHS for research, industry, and regulators

Thank You

SHASTA

Subsurface Hydrogen Assessment, Storage, and Technology Acceleration

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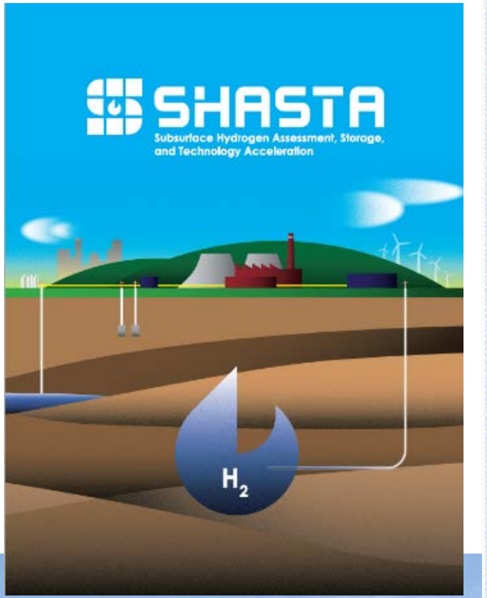

- Risk quantification (experiment & simulation)
  - Survey state of knowledge
  - Capabilities establishment
  - Fundamental work
  - Risks
- Enabling technologies to manage H_2 storage
  - Technology Transfer through Software Development
  - Advanced Technology Suite to support H_2 Subsurface Storage System
- Recommended practices and industry engagement
  - Knowledge transfer through Recommended Practices
  - Technoeconomics and the Business Case
  - Industry Engagement and Pilot Study Preparation

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Portions of this work were performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07-NA27344.
Portions of this work were performed under the auspices of the U.S. Department of Energy by Pacific Northwest National Laboratory under contract DE-AC05-76RL01830.
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The #H2IQ Hour

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This presentation is part of the monthly H2IQ hour to highlight hydrogen and fuel cell research, development, and demonstration (RD&D) activities including projects funded by U.S. Department of Energy's Hydrogen and Fuel Cell Technologies Office (HFTO) within the Office of Energy Efficiency and Renewable Energy (EERE).