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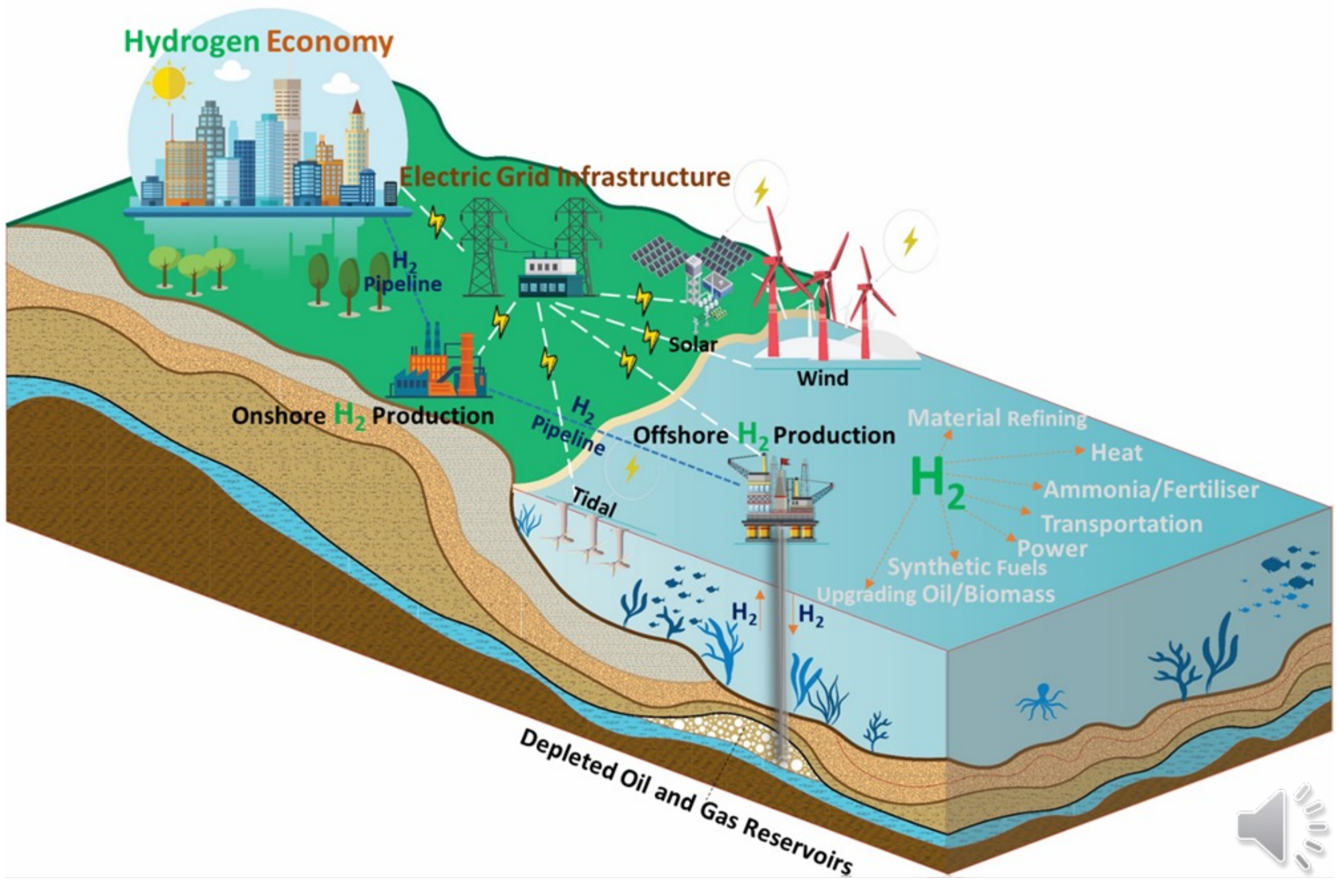
Implications of Hydrogen's Physical and Chemical Reactivity for Geological Storage



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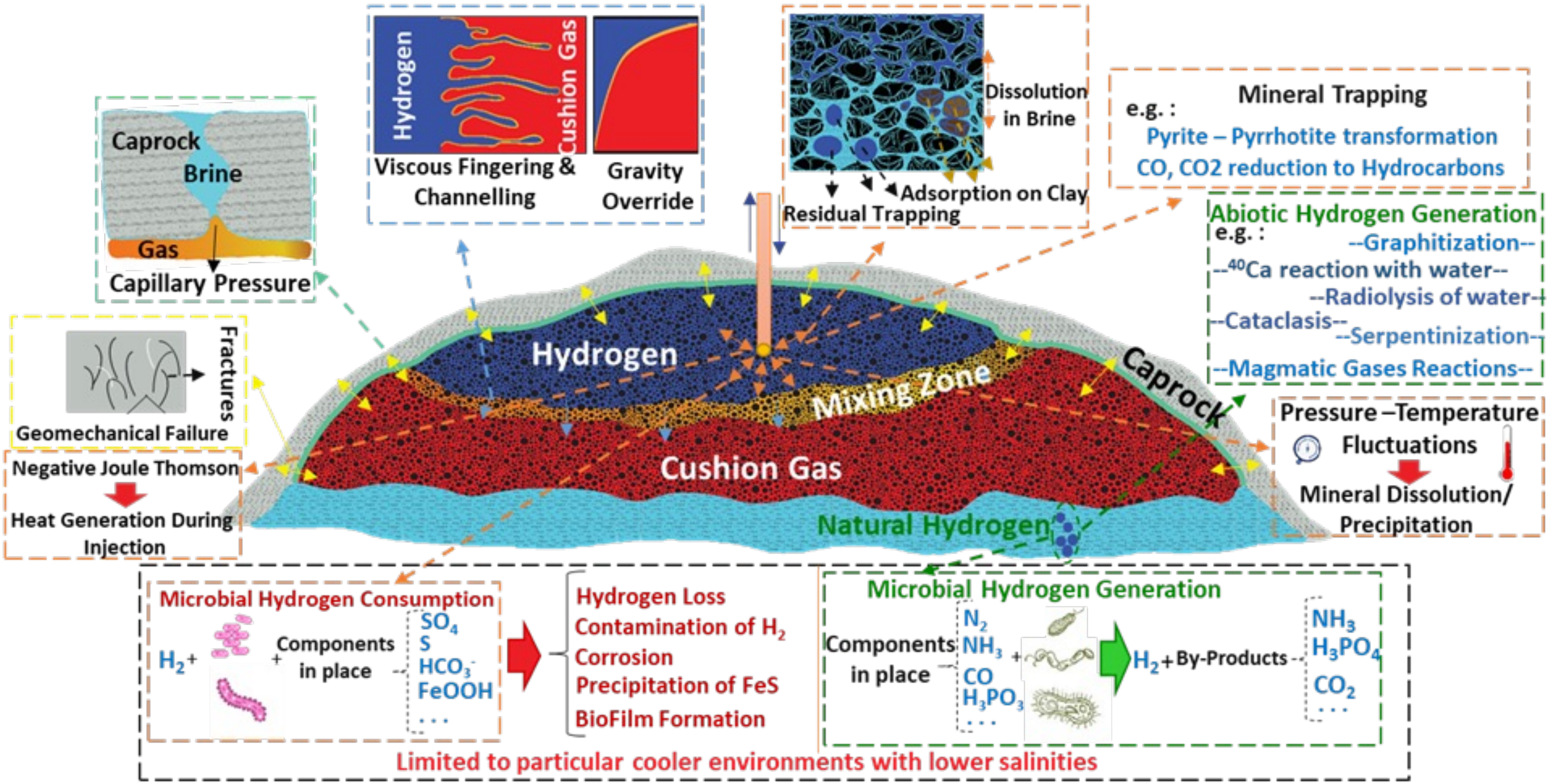
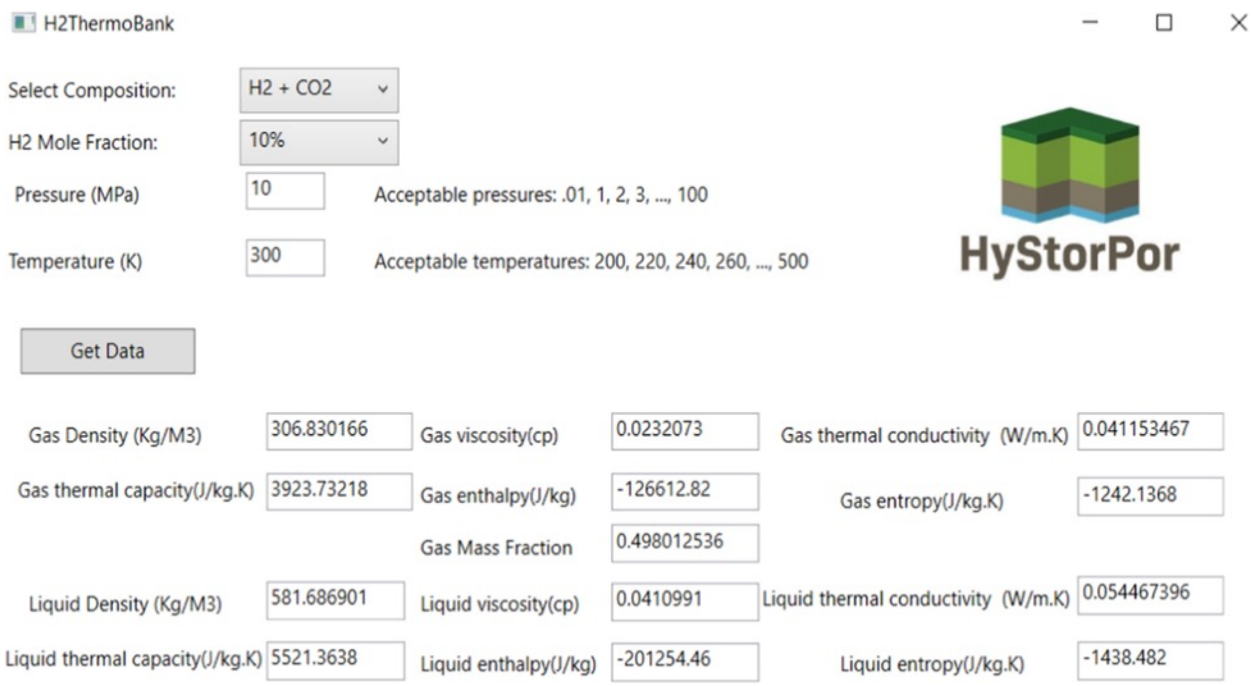
What Processes Will Impact Geological H_2 Storage?



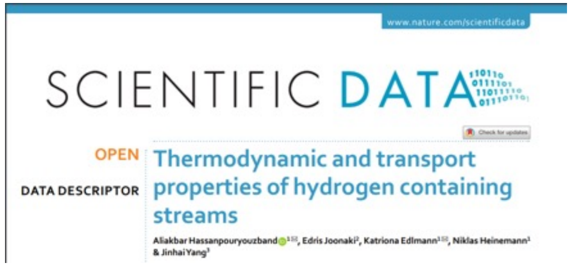
Modified after: Hassanpouryouzband et al. "Offshore Geological Storage of Hydrogen: Is This Our Best Option to Achieve Net-Zero?." ACS Energy Letters 6 (2021): 2181-2186. doi.org/10.1021/acsenergylett.1c00845

H2Thermobank: Thermodynamics of Hydrogen Gas Streams

- Thermodynamic properties of hydrogen mixtures, including CO_2, N_2, CH_4 and a typical UK North Sea Natural Gas.
- Mole fractions of hydrogen from 10-90 mole %.
- Pressure from 0.01 – 100 Mpa.
- Temperatures from 200-500 K (-73C to 227C).



Hassanpouryouzband et al. "Thermodynamic and transport properties of hydrogen containing streams." Scientific Data 7.1 (2020): 1-14. doi.org/10.1038/s41597-020-0568-6
https://github.com/aliakbarhssnpr/H2ThermoBank

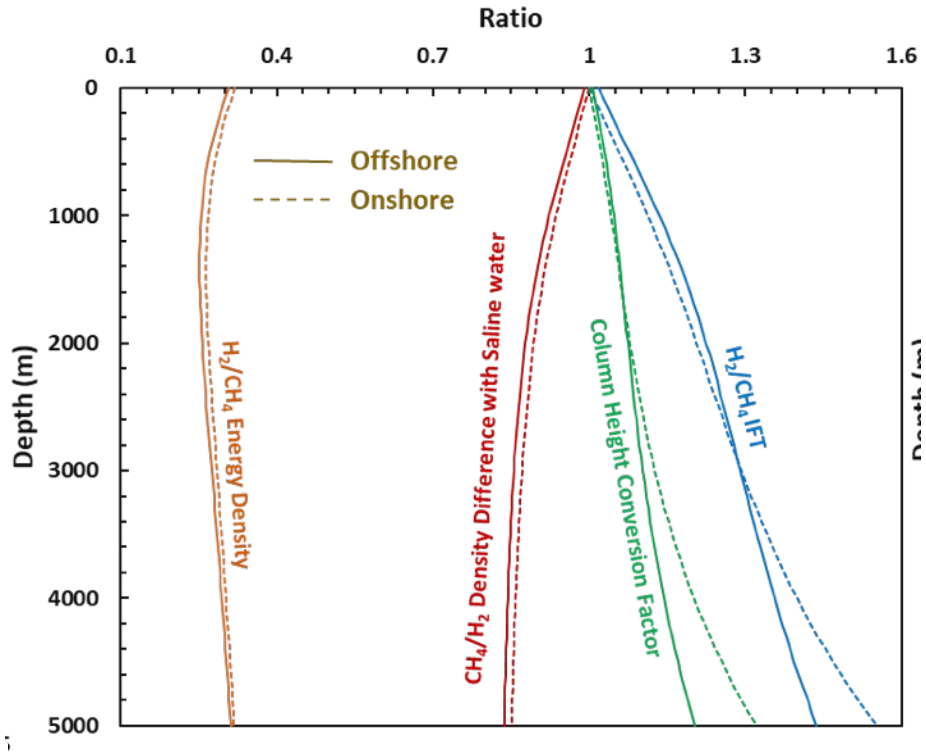

SCIENTIFIC DATA
OPEN
DATA DESCRIPTOR
Thermodynamic and transport properties of hydrogen containing streams

Hydrogen Caprock Sealing

- Column heights reflect the sealing capacity of any caprock.
- Column height conversion factor calculated to convert known natural gas column heights to hydrogen column heights.
- Hydrogen can be stored at a higher pressure in the reservoir than methane.

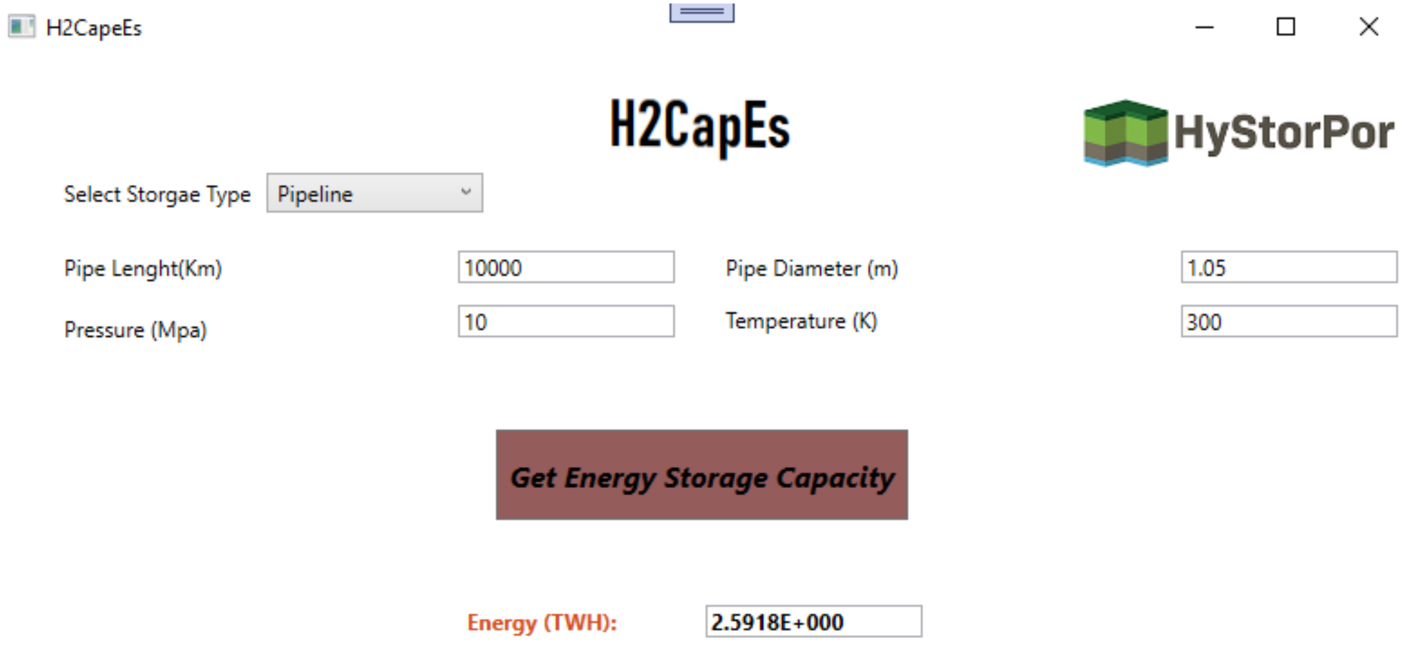
Density difference *IFT* *Wettability contact angle*

$$\Psi_{CH_4/H_2} = \frac{\Delta\rho_{CH_4/water}}{\Delta\rho_{H_2/water}} \frac{\gamma_{H_2/water}}{\gamma_{CH_4/water}} \frac{\cos\theta_{H_2/water}}{\cos\theta_{CH_4/water}}$$



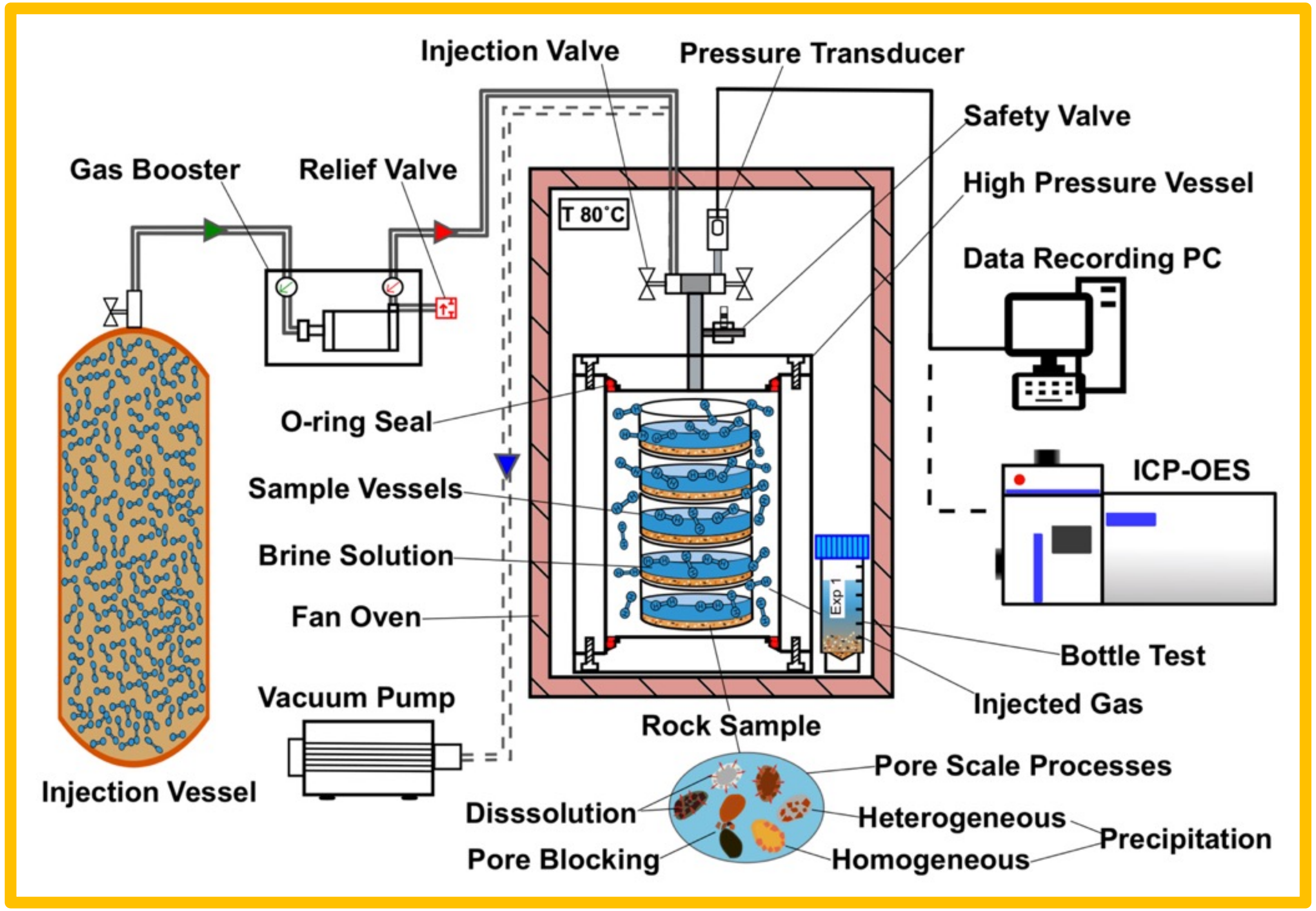
Hassanpouryouzband et al. "Offshore Geological Storage of Hydrogen: Is This Our Best Option to Achieve Net-Zero?." ACS Energy Letters 6 (2021): 2181-2186. doi.org/10.1021/acsenergylett.1c00845

Storage Capacity Estimation



Hassanpouryouzband et al. ACS Energy Letters (2021)
https://github.com/aliakbarhssnpr/H2CapEs

Geo-Chemistry Experiments



Over 500 experiments

- 8 Different Sandstones
  - Temperatures: 50-80 ° C
  - Pressures: 0.01-20 Mpa
  - Salinities: 0-25 weight% NaCl
  - Different Rock Sizes
  - Different Water/Rock Ratios
  - …
- 12 Different Samples from gas fields
  - Experiments at Reservoir Condition
- 4 Caprock Sample
- 3 Cement Samples

Pure Minerals

Gypsum, Calcite, Dolomite, and Pyrite

Hassanpouryouzband et al. "Geological hydrogen storage: geochemical reactivity of hydrogen with sandstone reservoirs" ACS Energy Letters, 2022, doi.org/10.1021/acsenergylett.2c01024

HyStorPor

Geo-Chemistry Experiments

Temperature

- Experiments undertaken in an thermostatically controlled oven where temperatures up to 80°C are reliable and repeatable due to precise temperature regulation and monitoring which limited any potential temperature-dependent effects on potential geochemical reactions.

Pressure

- Bottle tests undertaken in sealed atmospheric plastic containers with no injected gas accounted for any pressure-dependent effects on mineral reactions in each experiment. Therefore, experiments at pressures between 1 - 20 MPa were validated and deemed repeatable.

Salinity

- Experiments at salinities up to 250 ppt are reliable and repeatable.

Sample sterilization

- No effect on the results were observed due to sample sterilisation. Sterilisation is an essential preparation step for the rock samples to minimise the potential occurrence of biotic reactions that may influence component concentrations, particularly the gas composition.

Rock to water ratio

- Each sample was examined at different rock-water ratios to evaluate the rate-dependent effect of mineral phase concentration on hydrogen associated geochemical reactions.

Disaggregated grain size

- Grain sizes from 0.335 to 4 mm are suitable however, larger grain sizes must be balanced by a higher rock to water ratio. Smaller grain sizes increase mineral reactive surface areas resulting in higher concentrations of dissolved components. Uniform grain size across all experimental conditions for an individual rock type was implemented to ensure a more robust analysis of sample reactivity.

Reaction vessel

- High-pressure/temperature, 316 stainless steel, static batch reactor with O-ring seals and high tensile cap screws. No degradation or blistering was observed on the steel or O-rings under this range of parameters.

Sample vessel

- Tested with steel - contamination identified - changed to glass bottles, self-standing plastic centrifuge bottles used for atmospheric tests

Oxygen removal

- Nitrogen flow through and vacuum pumping was utilised on all experiments to remove free oxygen from the vessels before gas injection, controlling the redox-sensitive nature of anoxic subsurface environments.

Control experiments

- All samples were run with hydrogen and nitrogen at pressure and temp and with just brine at experimental temperature but ambient pressure to ensure any reactions observed could be directly attributable to hydrogen rather than say pressure or brine.

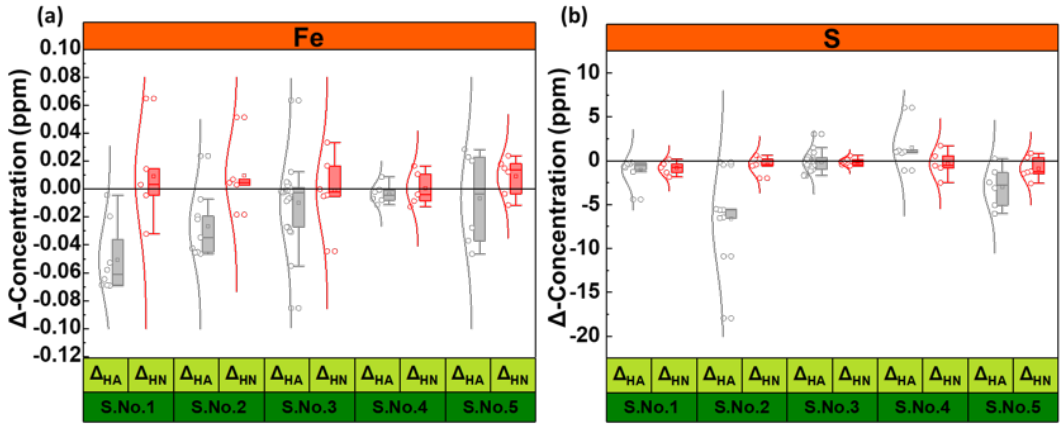
NaCl/brine quality

- The sensitivity of our equipment is such that it will pick up on even the smallest variations in the composition of the NaCl that we used to make the brine..

Repeatability

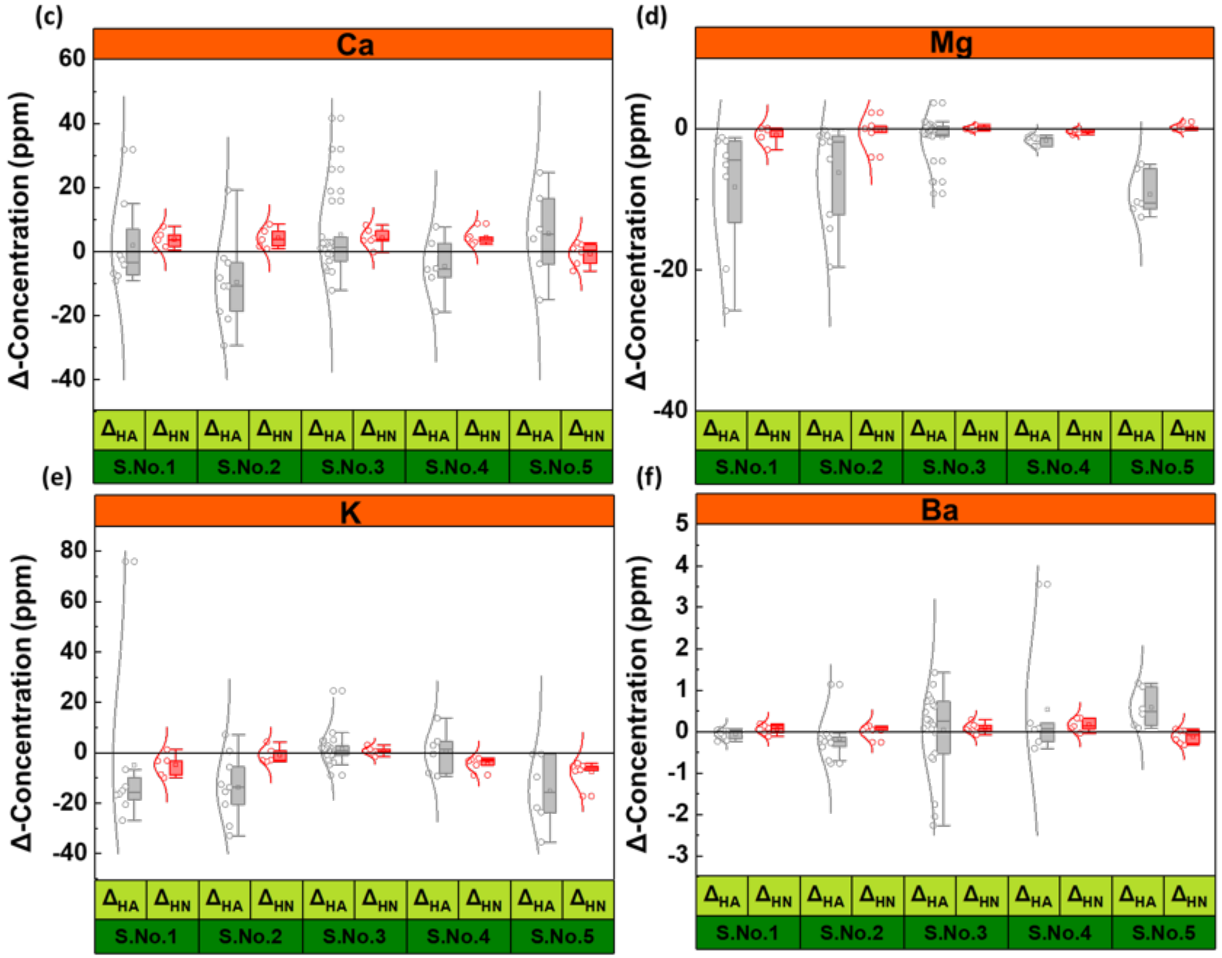
- Overall experimental repeatability is high with robust results produced across 253 experiments including 40 repeats covering all conditions. Replacement of batch reactor O-ring seals after each experimental cycle.

Results: Element Fluid Concentrations On Exposure To Hydrogen (From Icp-oes)



ΔHN: concentration of the element after experiment with H_2 deducted from the concentration of the same element after experiments with the N_2 control test under the same conditions (focus on impact of hydrogen).

ΔHA: concentration of the element after the experiment with H_2 deducted from the concentration of the same element after the bottle control test (focus on impact of pressure).



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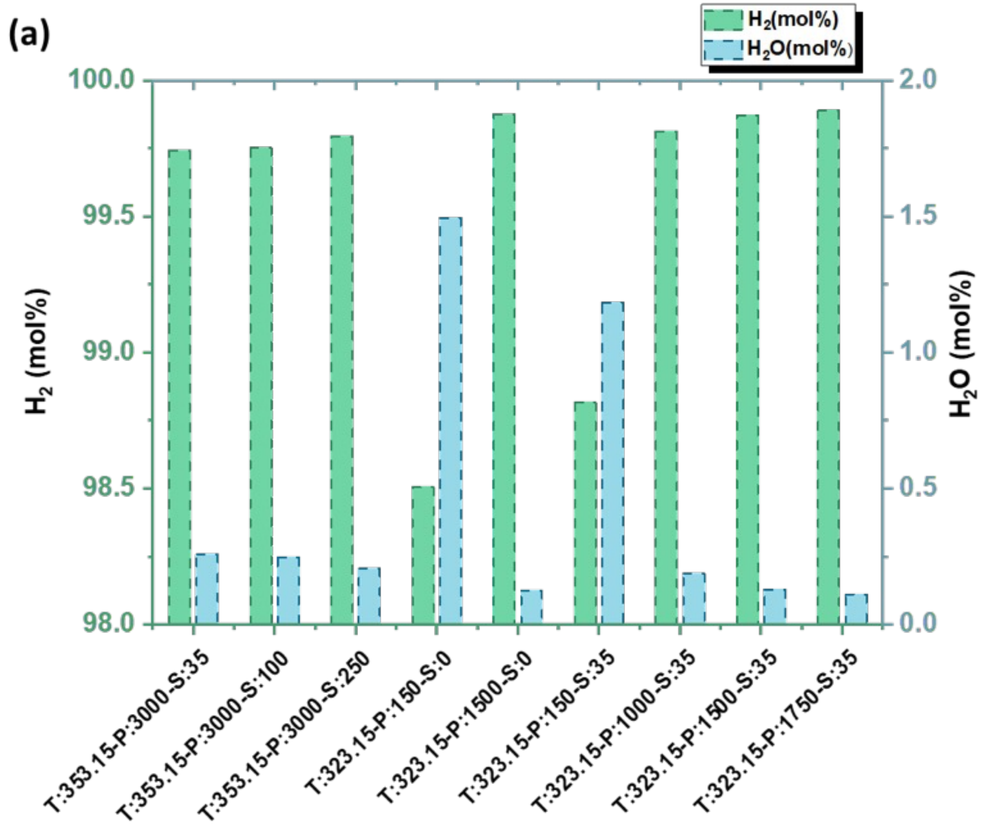
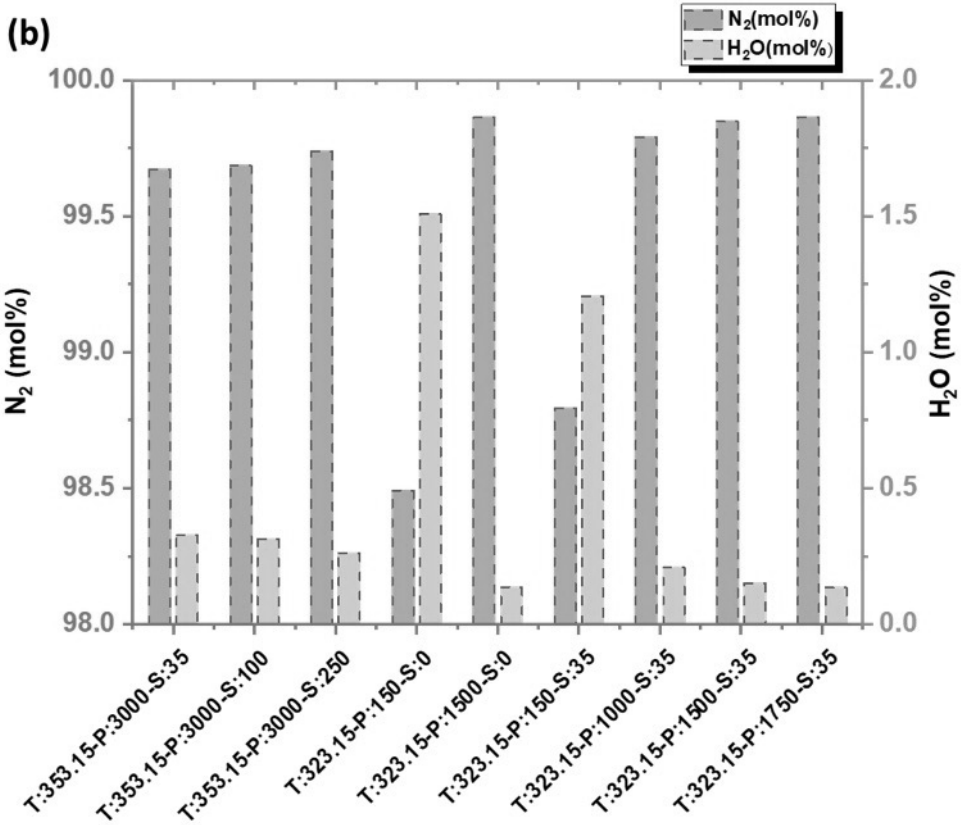
Results: Gas Composition



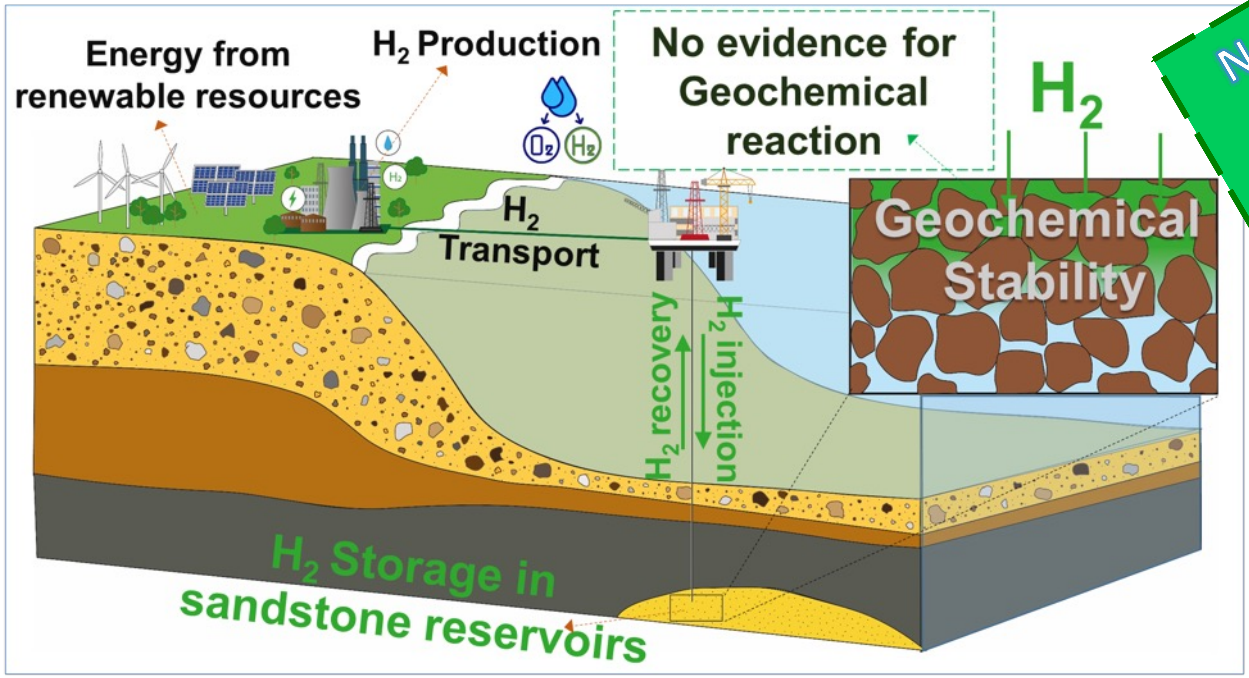
Hydrogen gas purity experiments



Nitrogen gas purity experiments

Hassanpouryouzband, et al. "Geological Hydrogen Storage: Geochemical Reactivity of Hydrogen with Sandstone Reservoirs." ACS Energy Letters 7 (2022): 2203-2210. https://doi.org/10.1021/acsenergylett.2c01024

Geo-Chemistry Experiments



Hassanpouryouzband et al. "Geological hydrogen storage: geochemical reactivity of hydrogen with sandstone reservoirs" ACS Energy Letters, 2022, doi.org/10.1021/acsenergylett.2c01024

No evidence of significant geochemical reactions so far….


ACS Energy Letters
http://pubs.acs.org/journal/aelccp
LETTER

Geological Hydrogen Storage: Geochemical Reactivity of Hydrogen with Sandstone Reservoirs

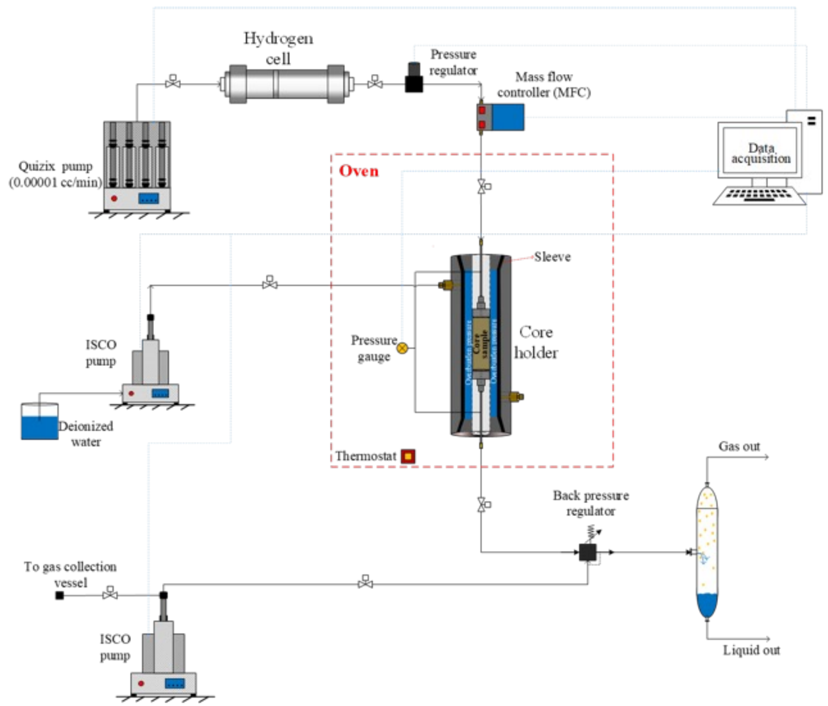
Aliakbar Hassanpouryouzband,* Kate Adie, Trystan Cowen, Eike M. Thaysen, Niklas Heinemann, Ian B. Butler, Mark Wilkinson, and Katriona Edlmann*

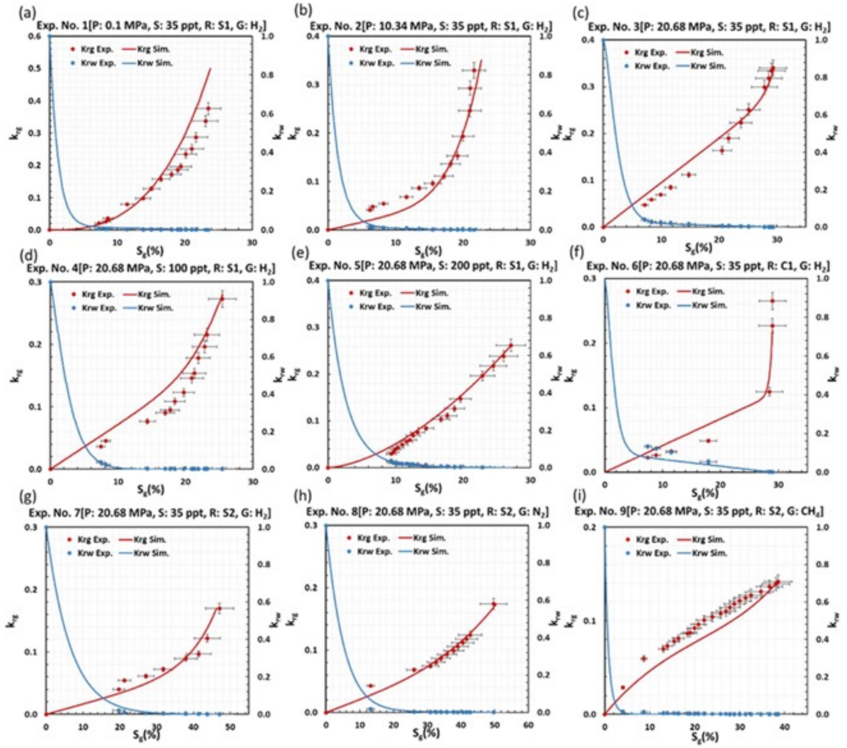
Environmental Science & Technology Letters
pubs.acs.org/journal/estlcu
Letter

Geochemical Integrity of Wellbore Cements during Geological Hydrogen Storage

Adnan Aftab, Aliakbar Hassanpouryouzband,* Abby Martin, Jackie E. Kendrick, Eike M. Thaysen, Niklas Heinemann, James Utley, Mark Wilkinson, R. Stuart Haszeldine, and Katriona Edlmann*

Unsteady State Relative Permeability Experiments





2 Different Sandstone Cores from Gas Reservoir

Temperatures: 80 ° C
Pressures: 0.01, 10, 20 Mpa
Salinities: 3.5, 10, 20 weight% NaCl
Using Different Gas for Comparison: N2, CH4

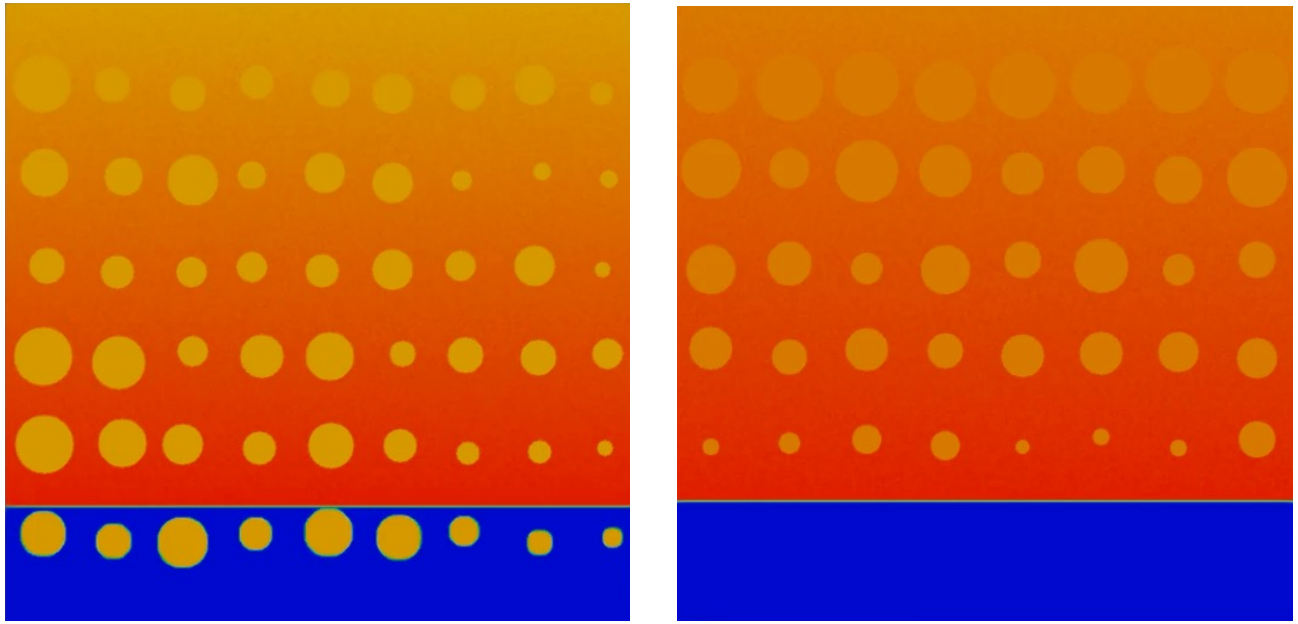
Carbonate Rock from Gas Reservoir

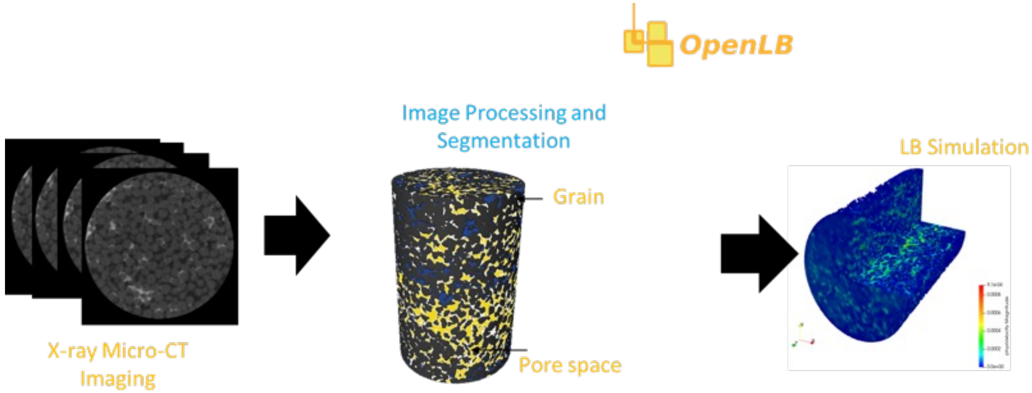
MICP, XRD, Centrifuge g-w drainage

Rezaei, et al. "Relative permeability of hydrogen and aqueous brines in sandstones and carbonates at reservoir conditions." Geophysical Research Letters (2022). doi.org/10.1029/2022GL099433

Pore-scale Simulation of Hydrogen Flow:

The Effect Of The Grain Arrangement

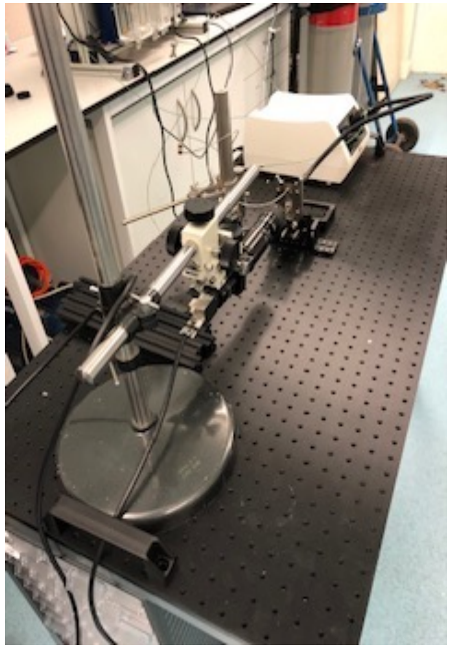


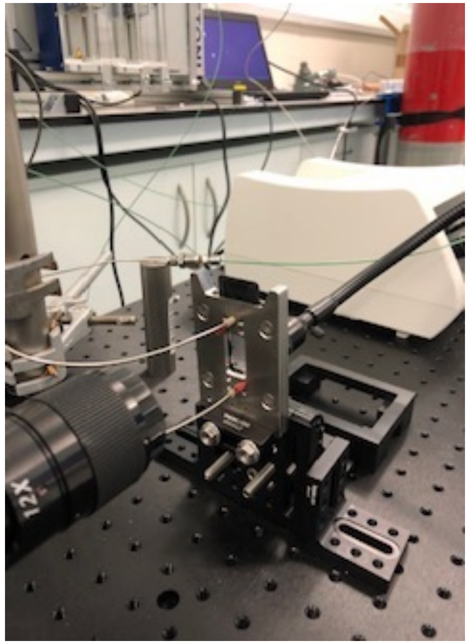


H_2

Water

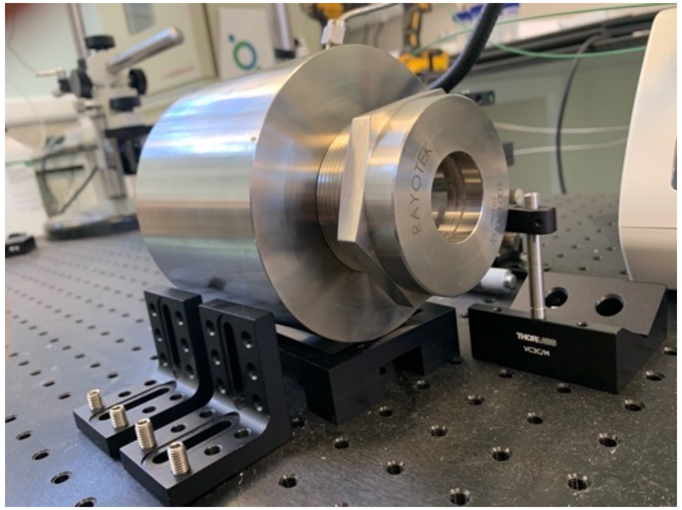
Glass Micromodel Hydrogen Flow Experiments





- Pressure range in existing cell up to 100 bar
- Multiphase flow
- Flow image recording
- Micromodels etched for any pore network
- Micromodels can have different wettability

High pressure and temperature visual cells



- Pressure range in existing cell up to 270 bar (27 MPa)
- Wettability measurements
- Image recording

Thank you for listening

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