Finding Synergy between CCS and Large-scale Hydrogen Storage

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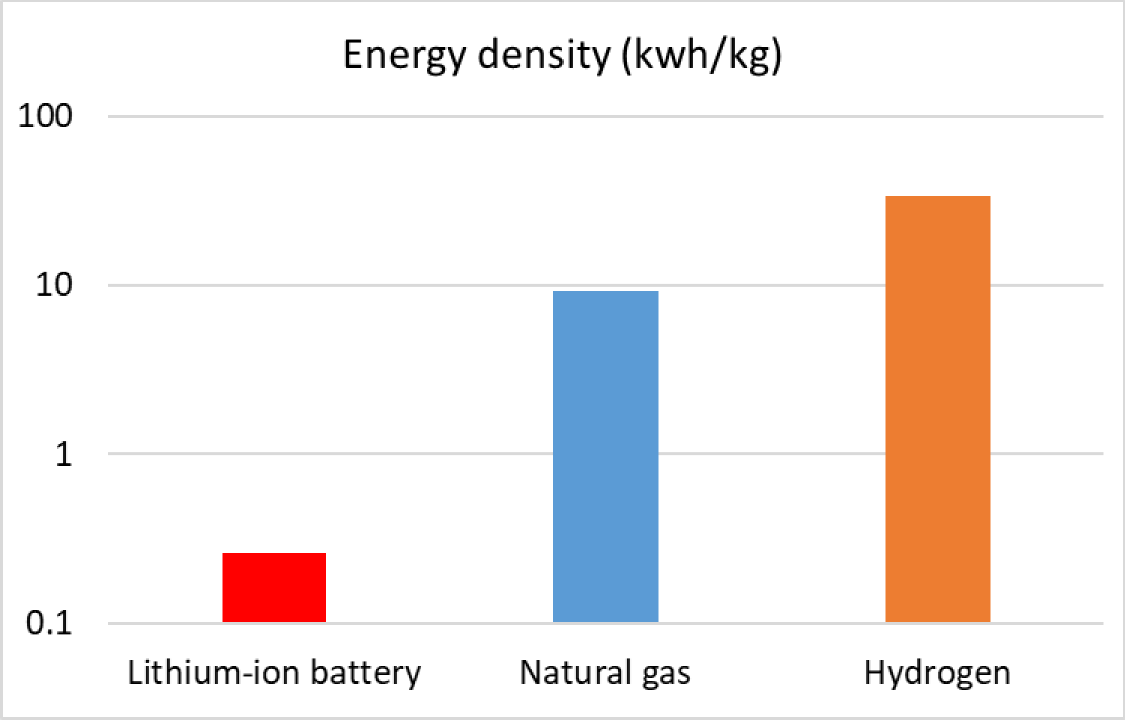
Outline

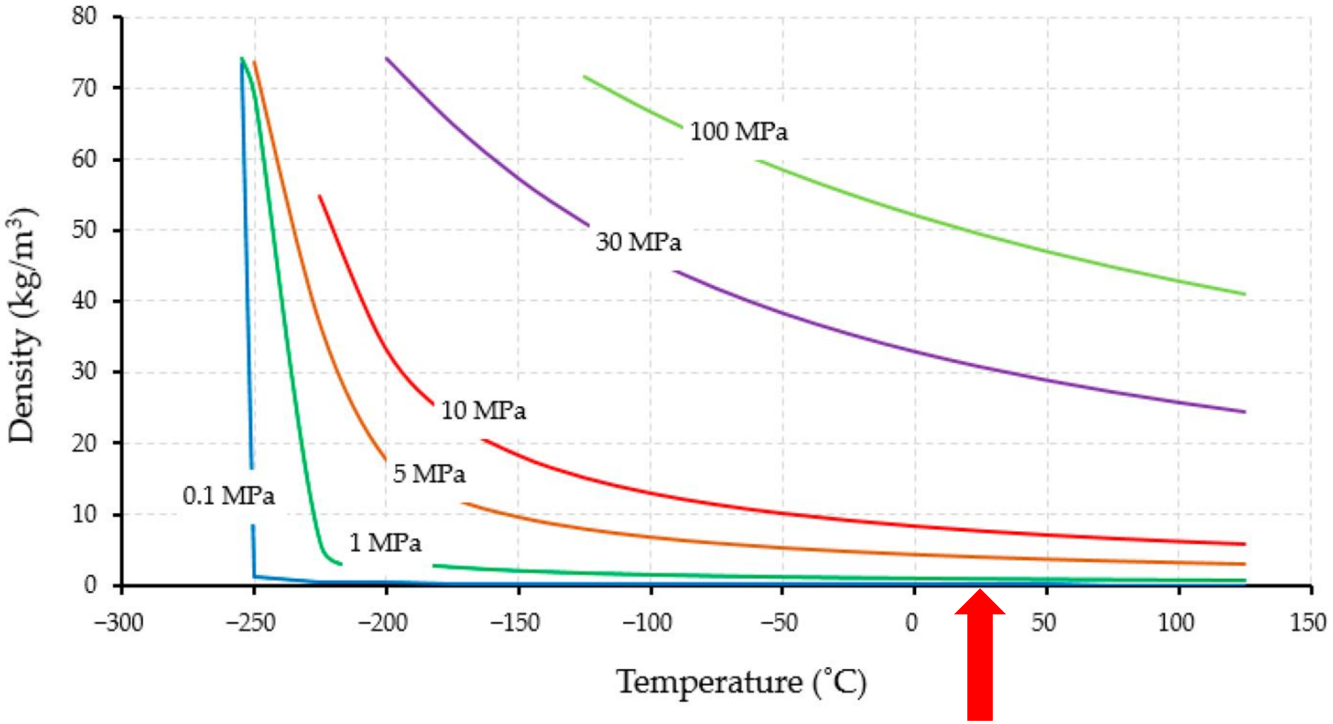
- Role of H_2 storage in the energy transition
- Driving factors for H_2 storage/withdrawal performance
- A field example: Repurposing natural gas storage field for hydrogen storage
- Conclusions

H_2 as an energy vector

High energy density by **mass**



Difficult to compress



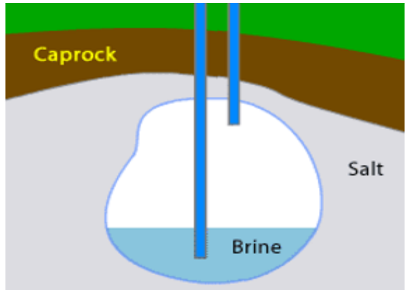
(Aziz,2021) Liquid Hydrogen: A Review on Liquefaction, Storage, Transportation, and Safety

Central concern- storage capacity of hydrogen

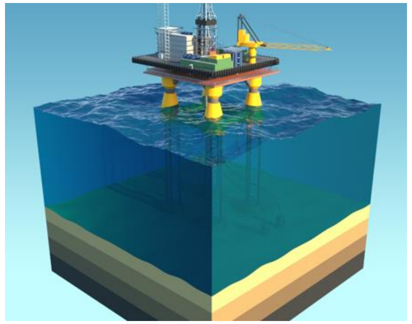
82 TWH to heat Scotland (2019)

app. 2,400,000 metric tones hydrogen

- ❑ > **120,000** Olympic swimming pool sized tanks @ 100 bar 25 °C



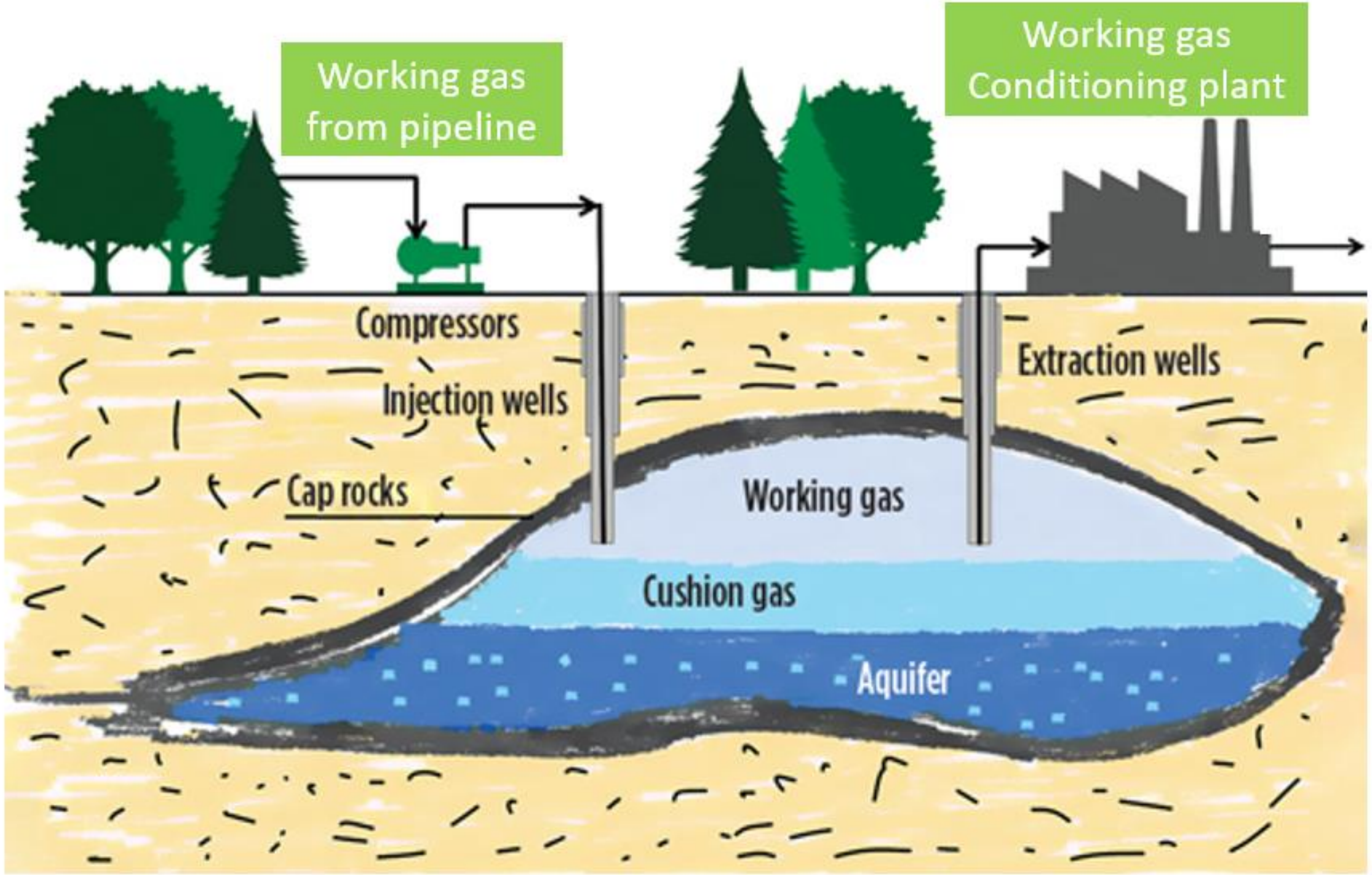
- ❑ > **400** salt caverns



- ❑ < **10** depleted hydrocarbon reservoirs

Calculations are for scale demonstration only.

Schematic of operation site (concept of cushion gas)



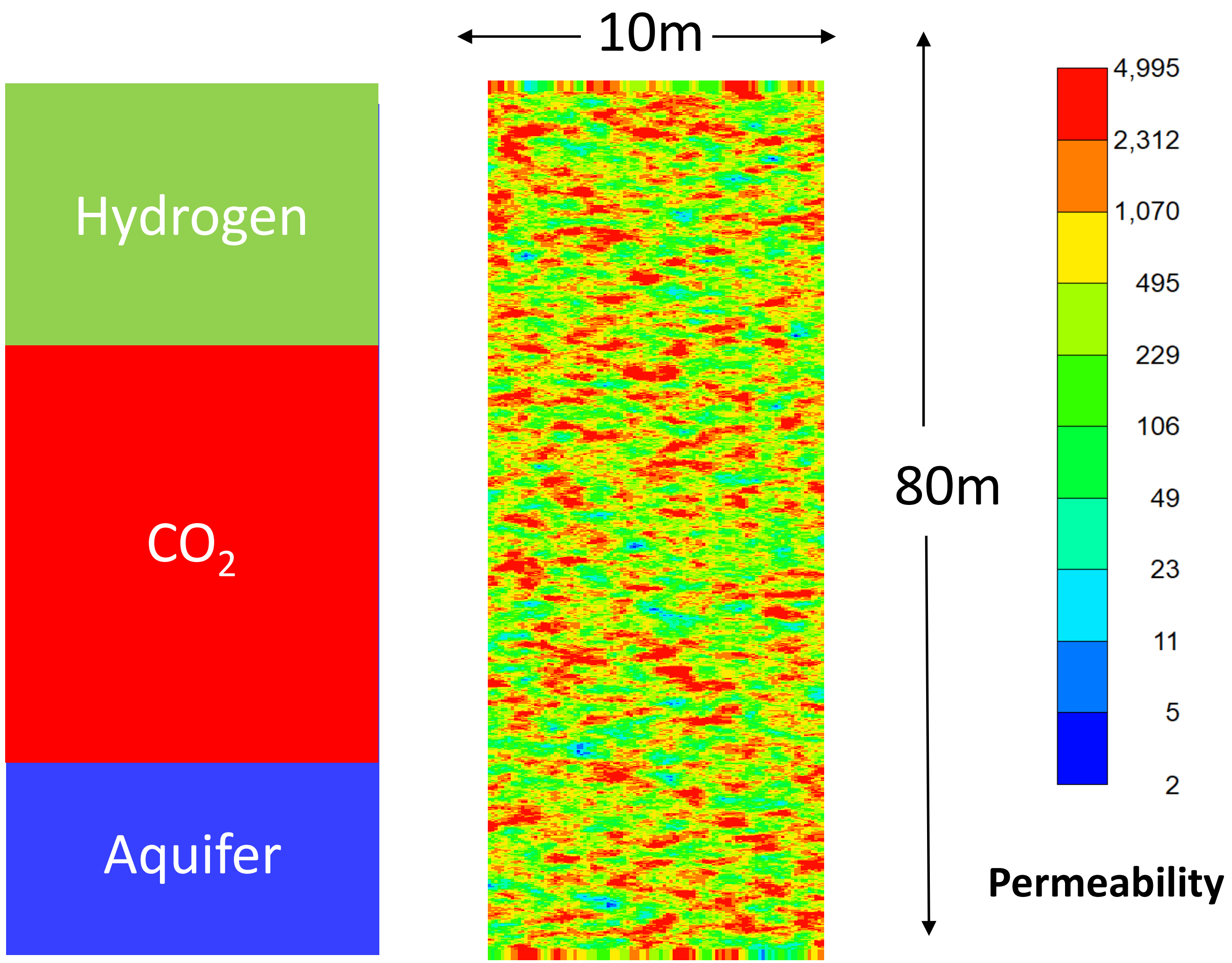
http://gasprocessingnews.com/features/202004/natural-gas-pipeline-systems-and-operations.aspx

Cushion gas (CO_2, CH_4 and H_2)

- **Pressure support**
- **Preventing water breakthrough**
- **Flow confinement**

Set-up of 2D flow simulations

Vdp= 0.6 ; Correlation range=1m*1m



Correlated and heterogeneous permeability field

T=53°C, P_r=15000 kPa

Dykstra-Parsons coefficient (V_{DP})	0.6
Horizontal correlation range	1m
Vertical correlation range	1m
K_v/K_h	0.1
Porosity	0.1

Operational strategy

Volume ratio of CO_2 to H_2 at reservoir conditions = 2 : 1

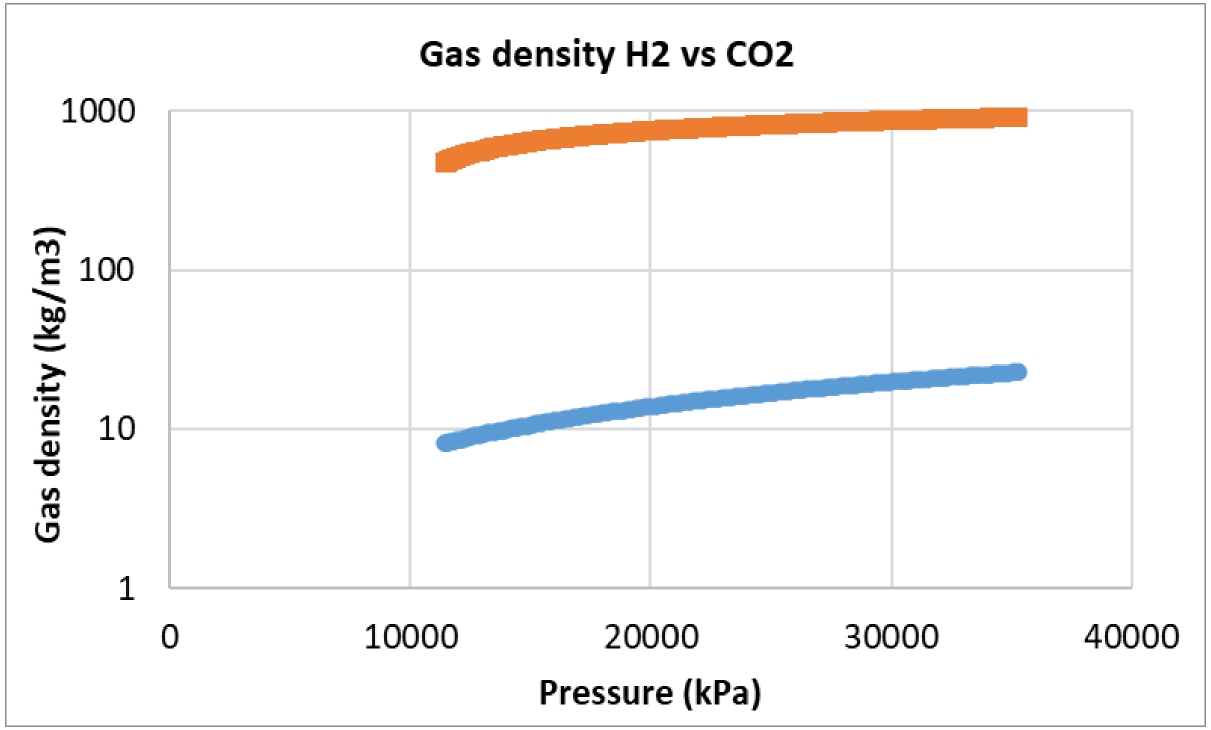
Case A_lowQ	0-130 days	130-180 days	180-280 days	280-330 days
	CO_2 injection	H_2 injection	Shut in	gas production

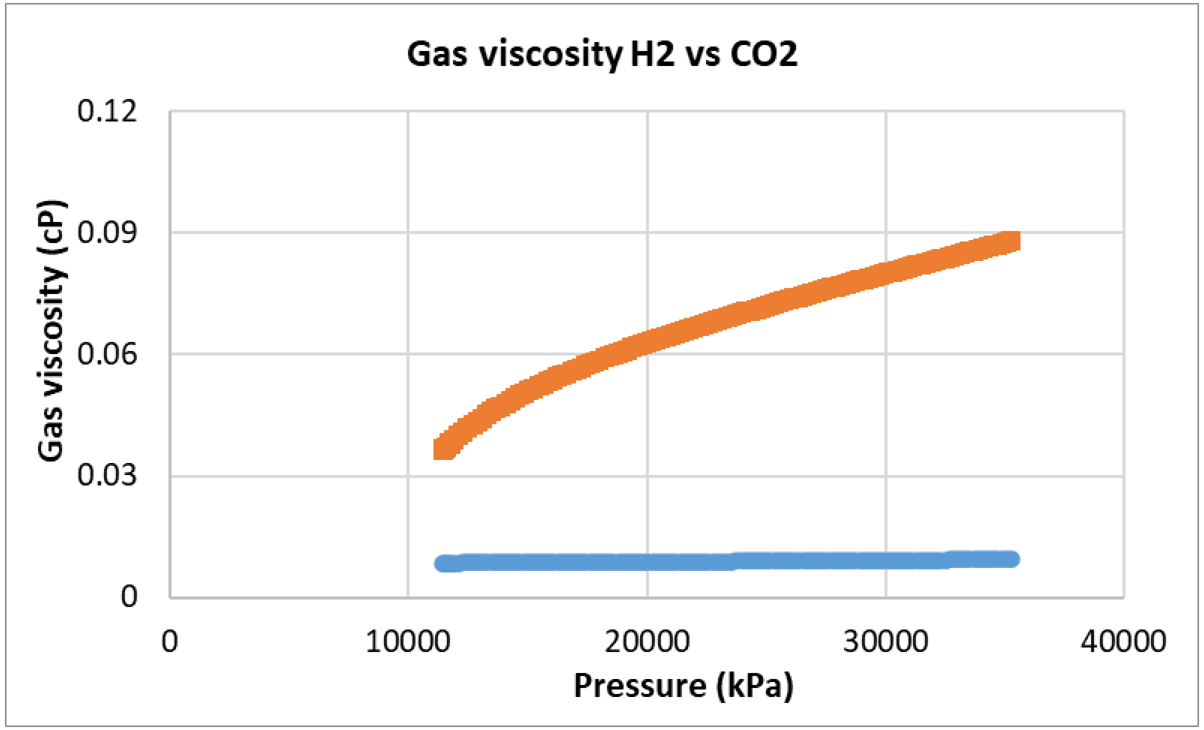
Case B_highQ	0-13 days	13-18 days	113-118 days	118-123 days
	10 × Q	10 × Q	Shut in	10×Q

Balance between gravity and viscous forces

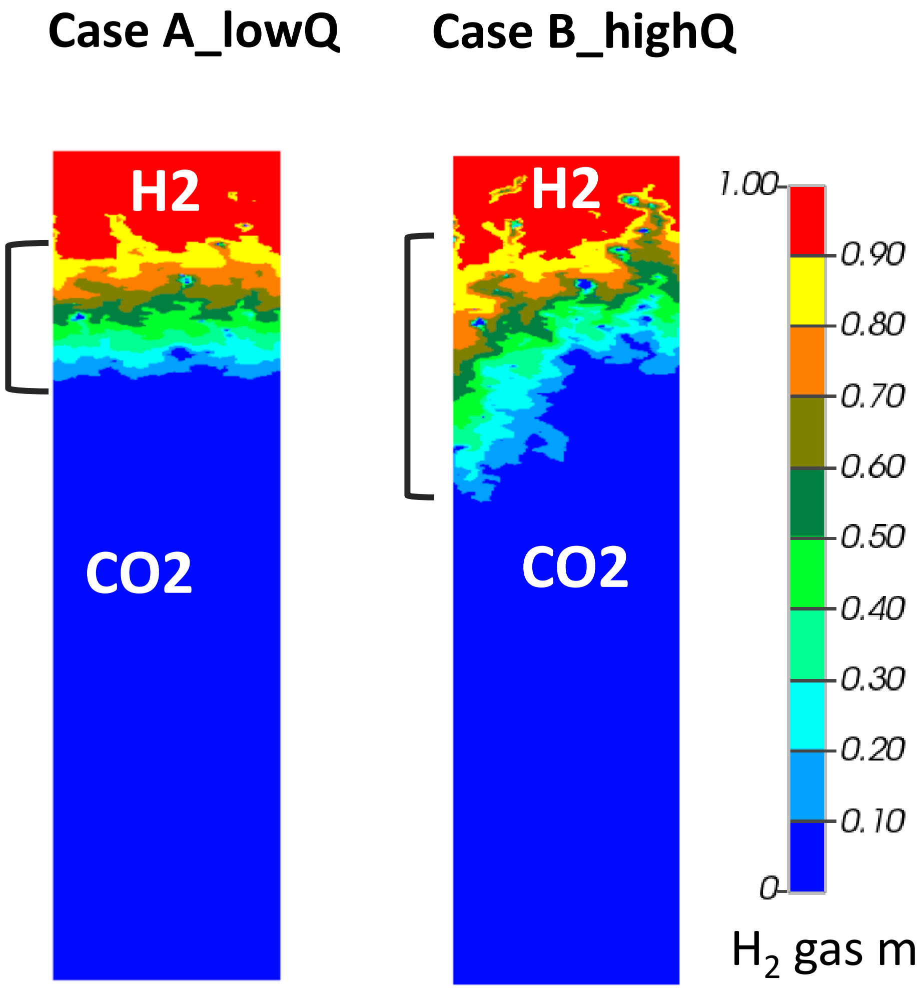
Comparisons of gas properties between CO_2 and H_2

CO_2 vs H_2





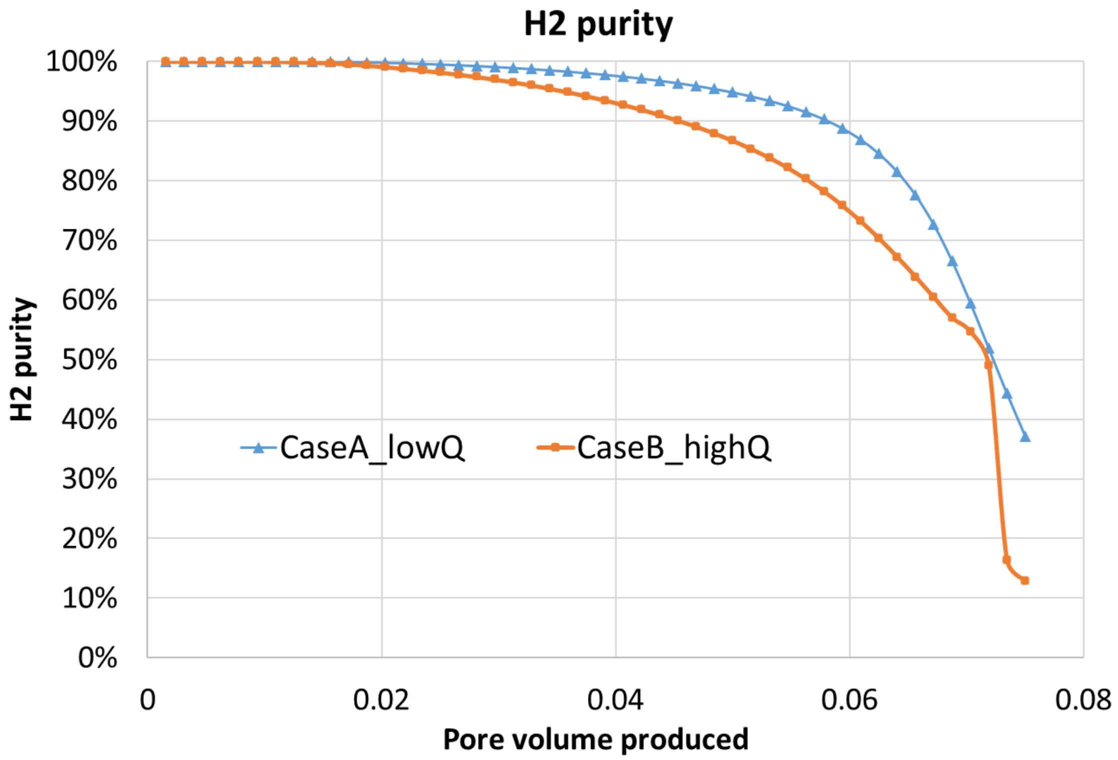
Gas mixing



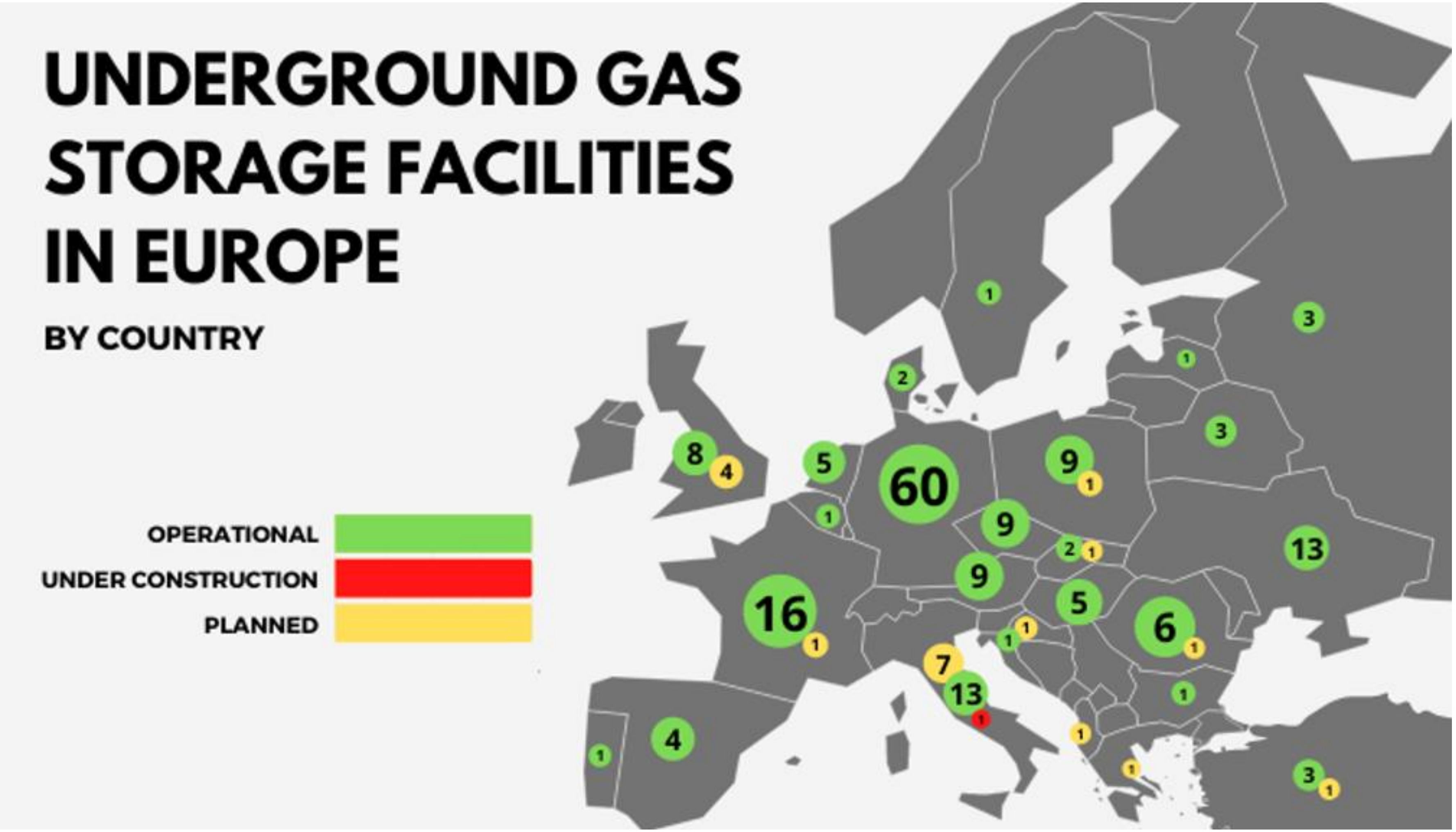
H_2 gas mole fraction

End of H_2 injection

Decreasing H_2 purity



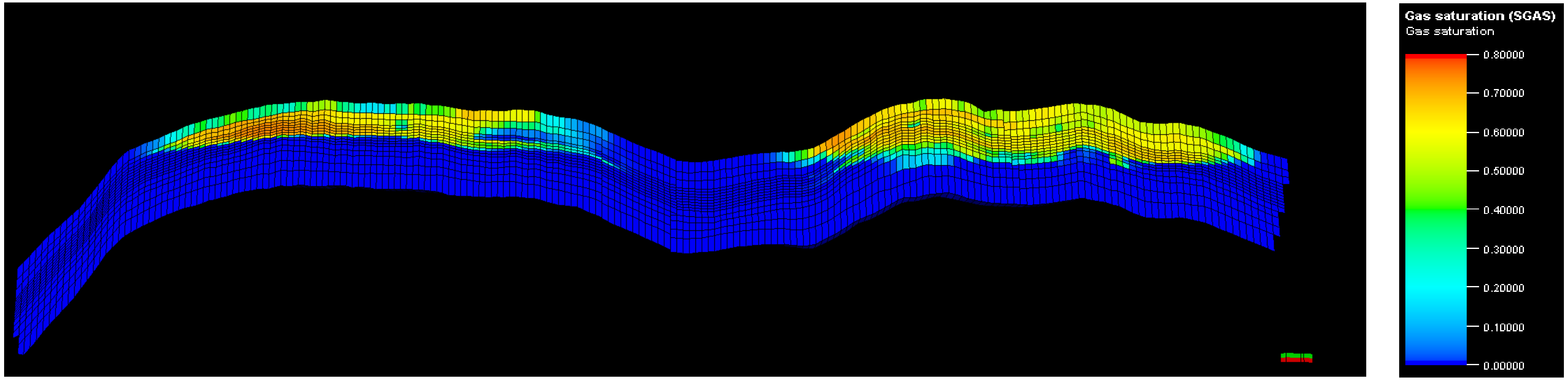
A field example- repurposing natural gas storage field for hydrogen storage



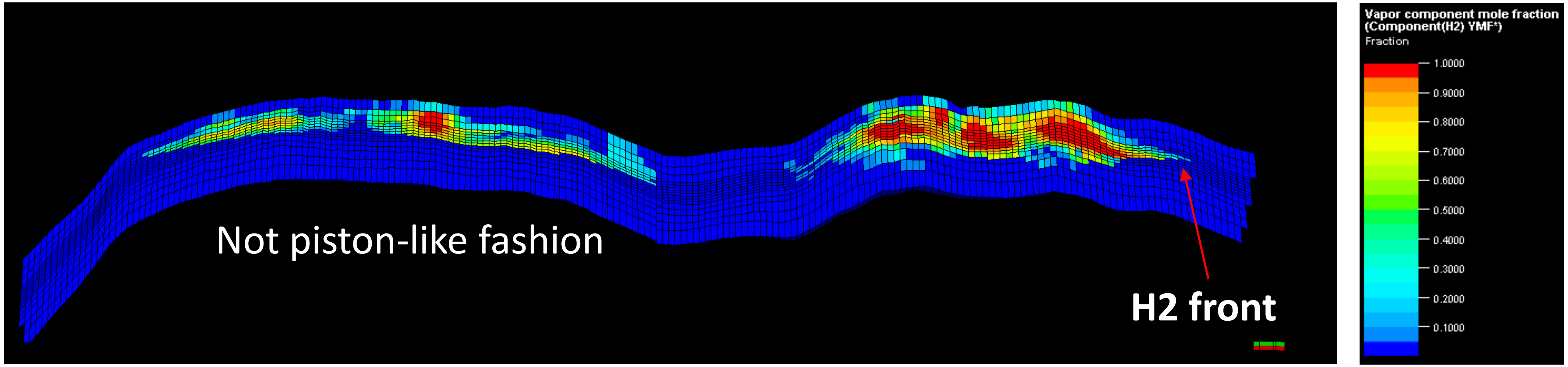
https://www.prosperoevents.com/europes-underground-gas-storage-sites-2/

A field example- repurposing natural gas storage field for hydrogen storage

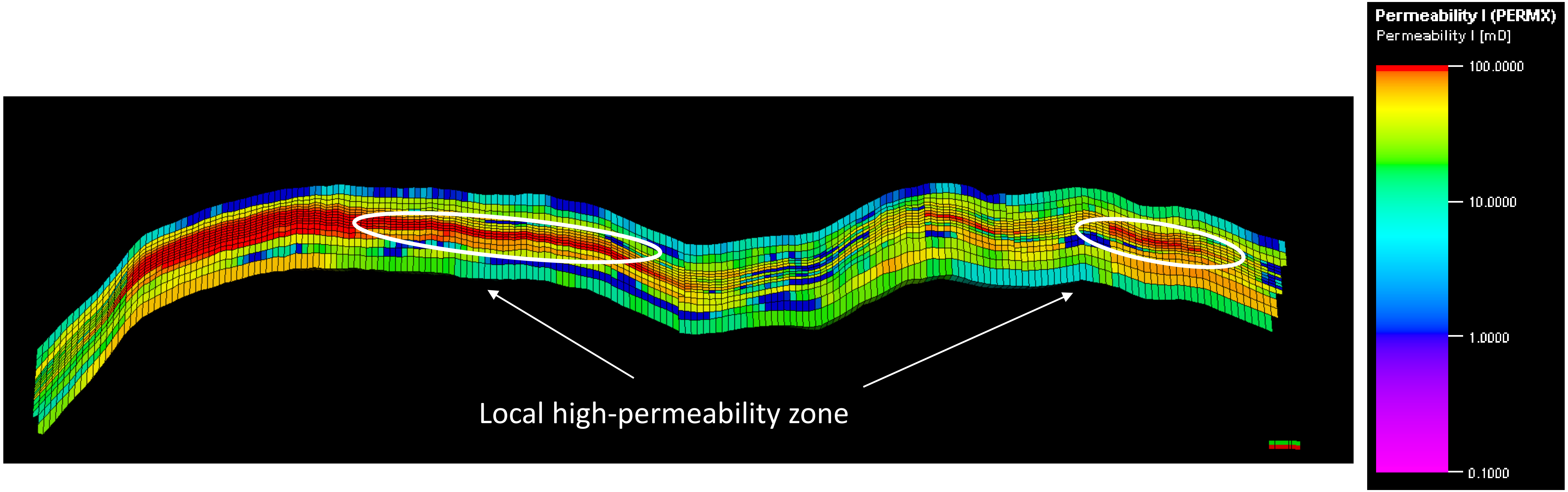
Gas saturation after first-year H_2 injection



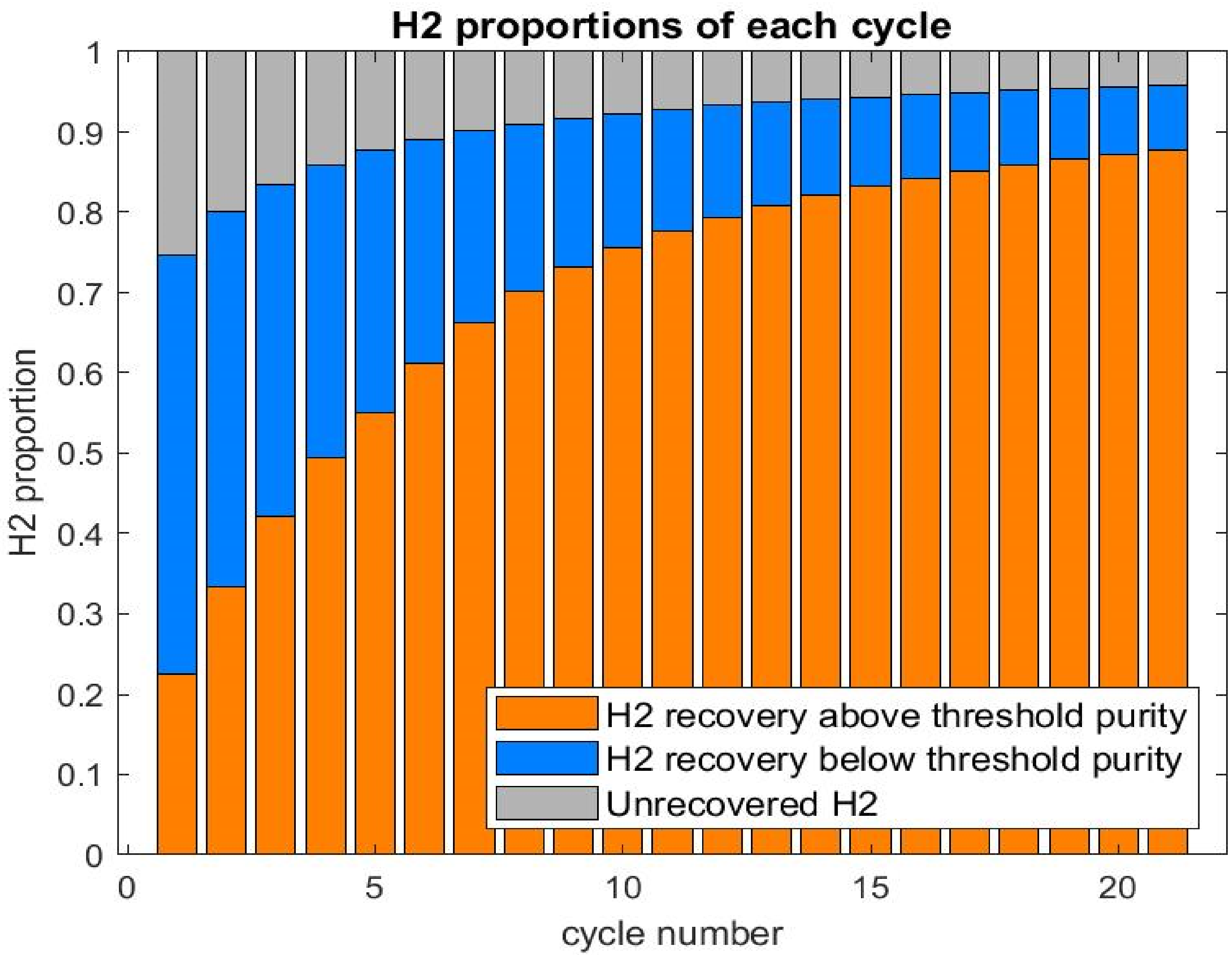
H_2 gas mole fraction after first-year H_2 injection



Permeability heterogeneity



H_2 recovery performance



H_2 threshold purity: 90%

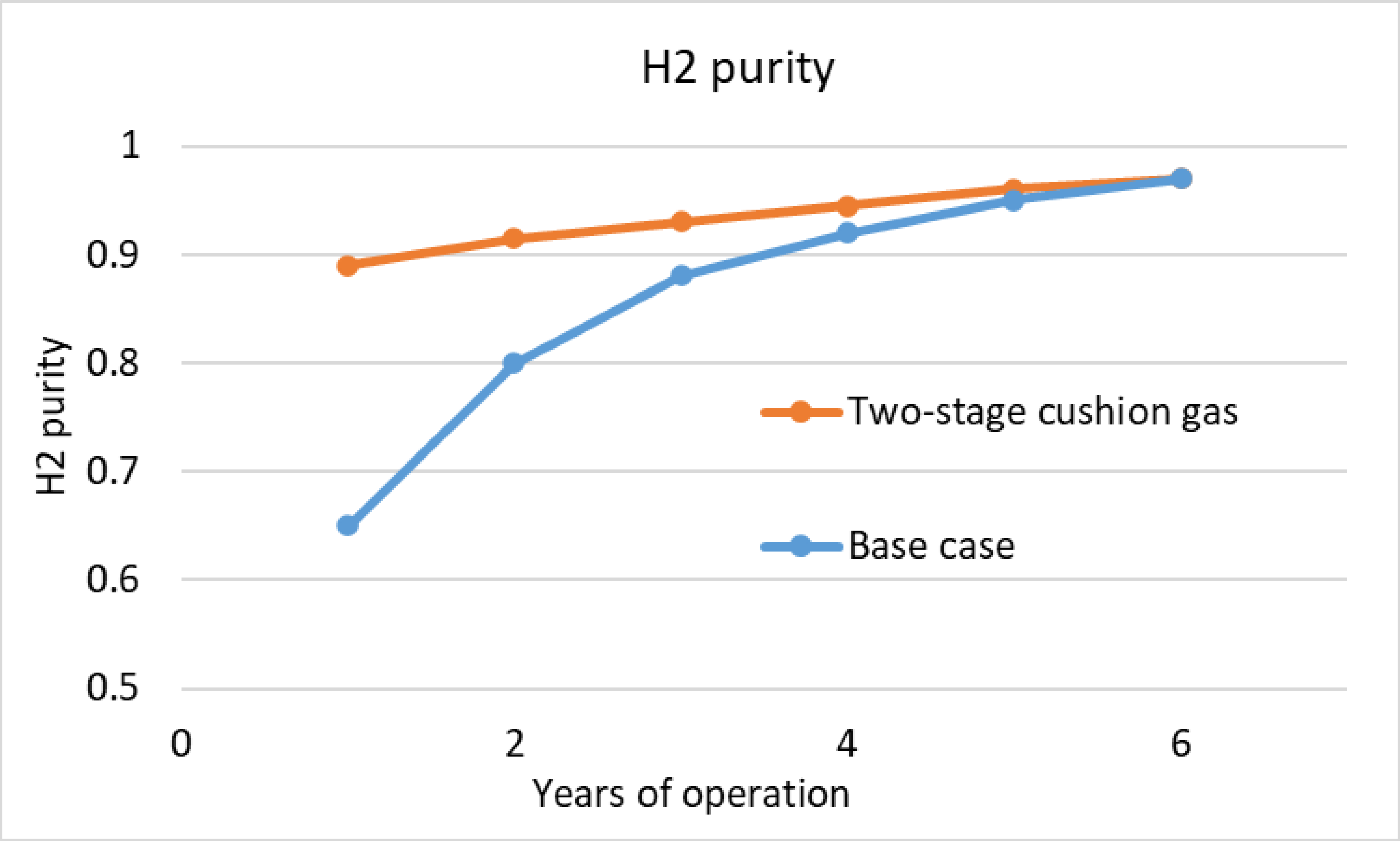
Practical concerns:

1. Gas quality

2. Production capacity

Design of cushion gas

Varying injection timing of H2



Two-stage cushion gas

1st stage: CO_2, CH_4 or N_2
2nd stage: H_2 (pre-injection)

The total volume of lifetime H_2 injections is the **same**.

A high concentration of H_2 accumulated in the near-wellbore zone is the key!

Conclusions

- **Interface between H_2 and cushion gas (CO_2, CH_4 or N_2)**

The low-viscosity H_2 may **infiltrate** the cushion gas in the proximity of the injectors, meaning that the cushion gas is not efficiently displaced away from the injectors in a piston-like fashion. This leads to an early and quick decrease in the H_2 purity during back production.

- **Reservoir heterogeneity**

Permeability heterogeneity and reservoir structure play a critical role in driving the flow behaviour of gases at the reservoir scale. Poor productivity at the top of the reservoir can lead to further degradation in recovery performance.

- **Design of cushion gas**

A two-stage cushion gas injection strategy improves the purity of produced H_2. A high concentration of H_2 accumulated in the near-wellbore zone is the key!

Publications on geological storage of H_2

Wang, G., Pickup, G. E., Sorbie, K. S. and Mackay, E. J. [2022], Scaling analysis of hydrogen flow with carbon dioxide cushion gas in subsurface heterogeneous porous media, *International Journal of Hydrogen Energy*, 47(3), pp. 1752-1764.

Wang, G., Pickup, G. E., Sorbie, K. S. and Mackay, E. J. [2022], Numerical modelling of H_2 storage with cushion gas of CO_2 in subsurface porous media: Filter effects of CO_2 solubility, *International Journal of Hydrogen Energy,* 47(67), pp. 28956-28968.

Wang, G., Pickup, G.E., Sorbie, K.S. ., de Rezende, J. R., Zarei, F. and Mackay, E.J, [2023], “Bioreaction coupled flow simulations: impacts of methanogenesis on seasonal underground hydrogen storage”, Under review.

Wang, G., Pickup, G.E., Sorbie, K.S. and Mackay, E.J, [2022], “Driving factors for the purity of withdrawn hydrogen: A numerical study of underground hydrogen storage with various cushion gases”, Proceedings of the 83rd EAGE Conference and Exhibition, 6 Jun. - 9 Jun. 2022, Madrid, Spain.

Wang, G., Pickup, G.E., Sorbie, K.S. and Mackay, [2021], “Compositional Simulation of Hydrogen Storage with Carbon Dioxide Cushion Gas in Subsurface Heterogeneous Porous Media”, Proceedings of the 2nd Geoscience & Engineering in Energy Transition Conference, 23 Nov. - 25 Nov. 2021, Strasbourg, France.

Acknowledgements

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Schlumberger