Hydrogen injectivity and recovery in porous media

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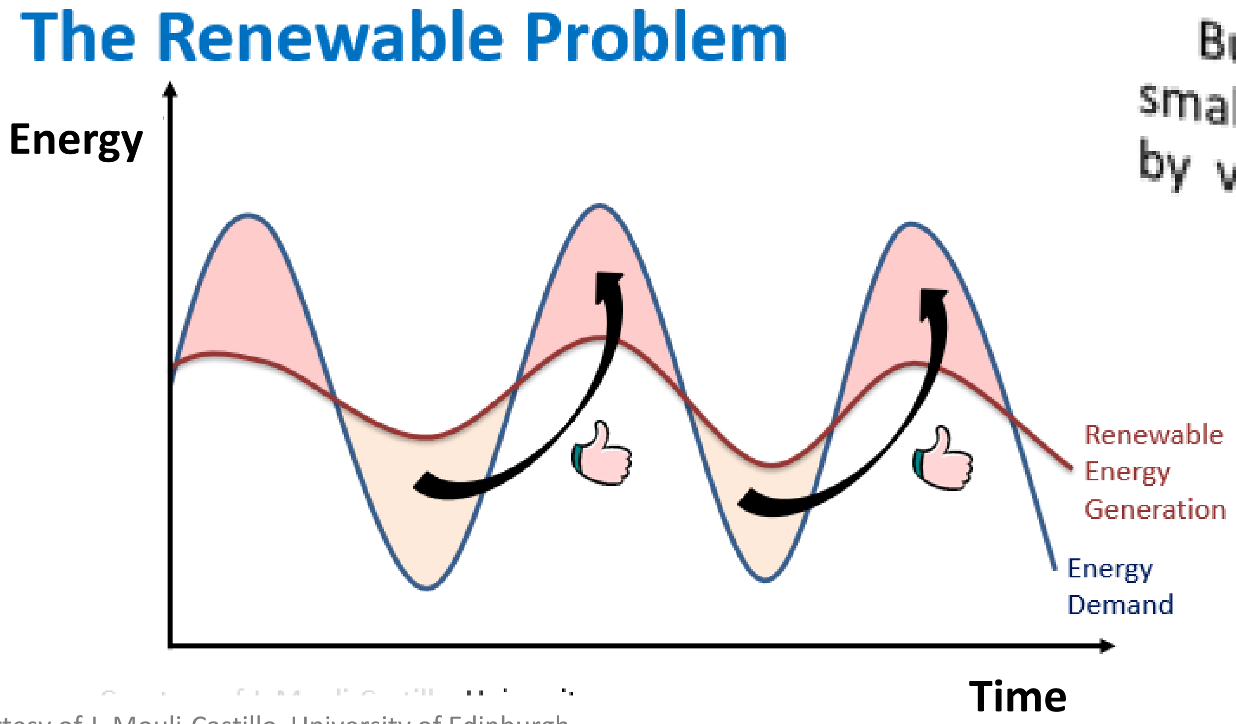
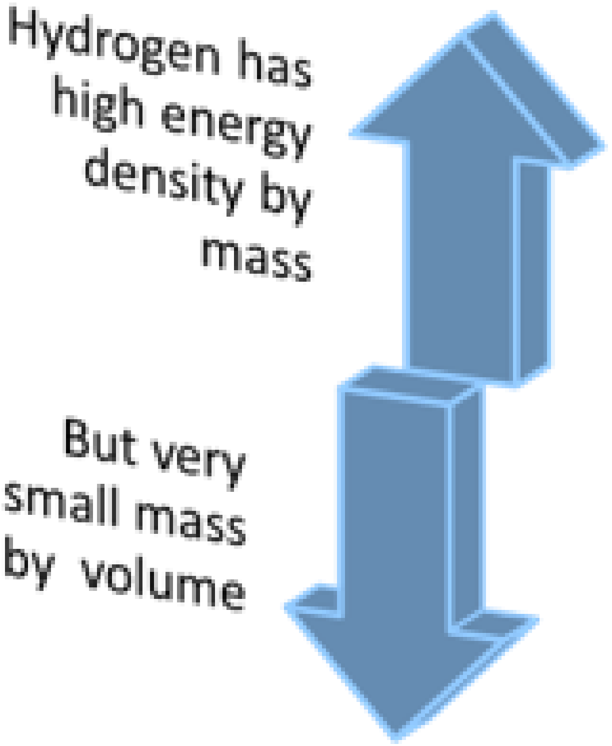
Why porous media storage of hydrogen?

If electricity is fully renewable by 2050, the UK will need 60 TWh storage

[Howard 2019]



Curtesy of J. Mouli-Castillo, University of Edinburgh



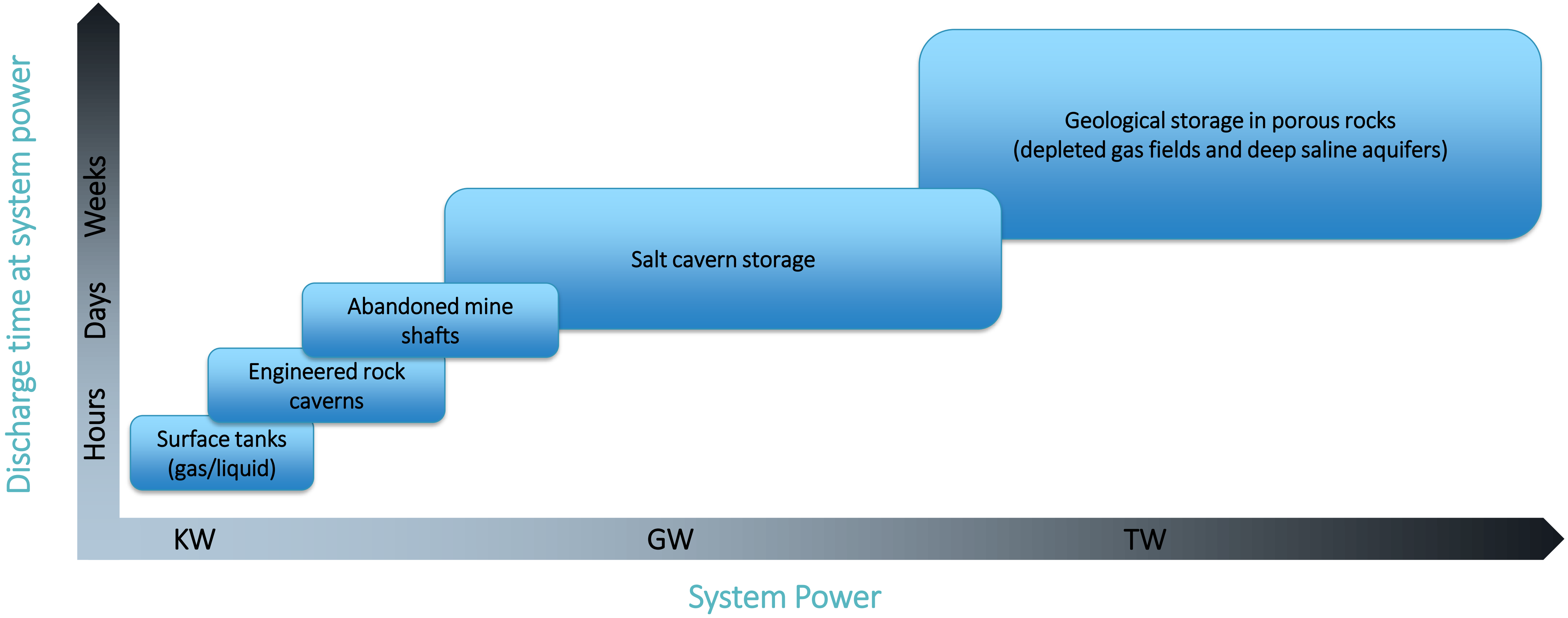
To store the same amount of energy with H_2 we need **3x** more space than for CH_4

Large scale storage is required

Compressing or liquifying H_2 @ -252.9℃ increases the volumetric energy density

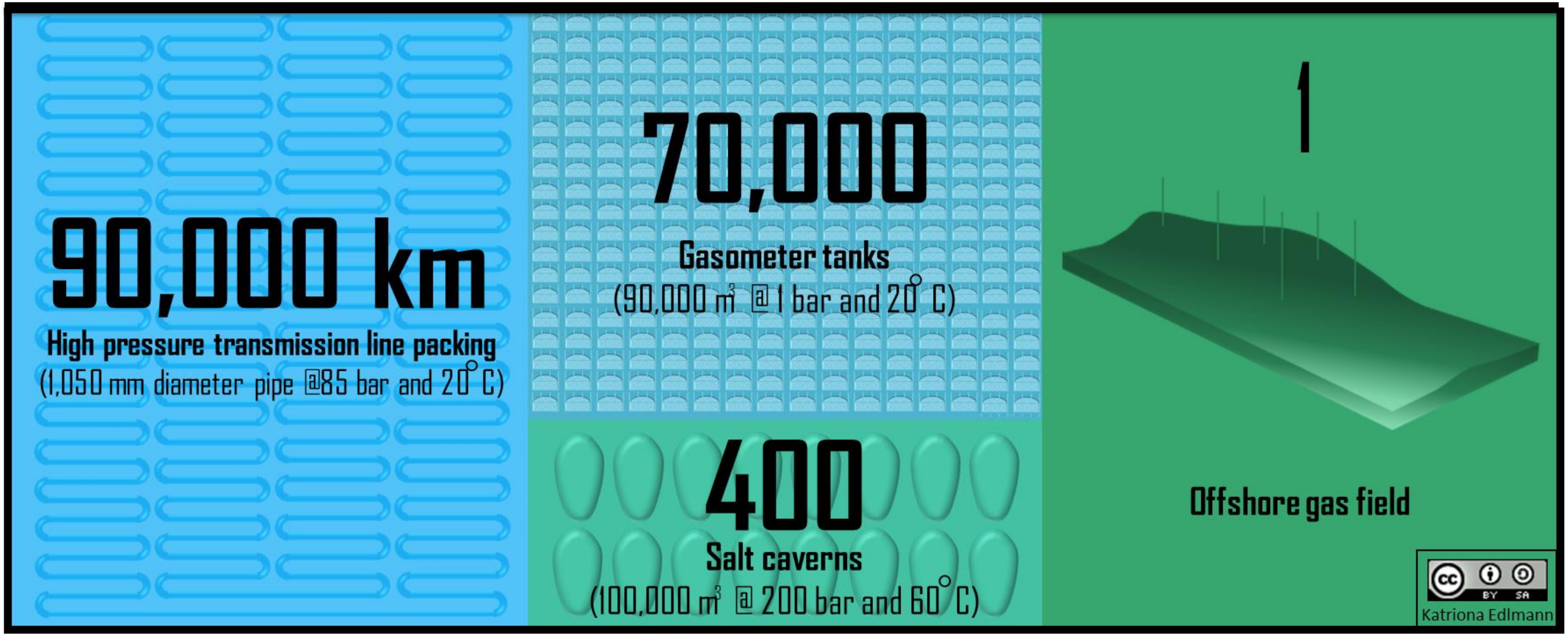
Howard, R. (2019). *2050 perspective – Future European power system and strategic implications*. Aurora Energy Research

Scales and deliverability of hydrogen storage

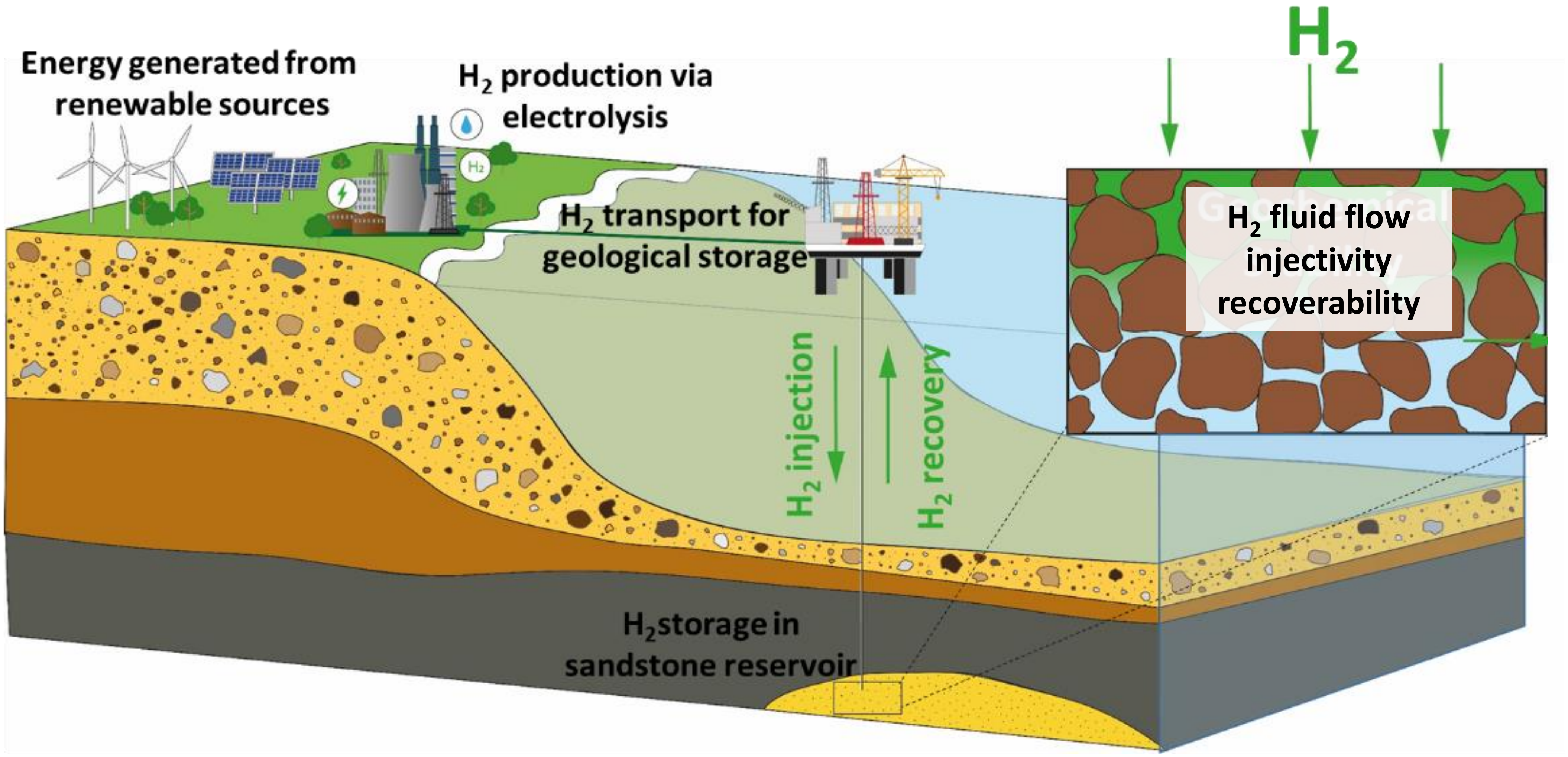


Curtesy of K. Edlmann, University of Edinburgh

Where can we store 20 TWh of H_2?

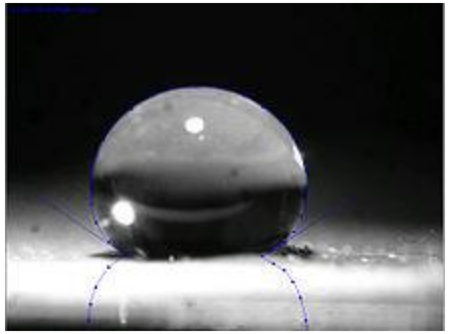


Interseasonal porous media H_2 storage– a technology in its infancy shoes



Parameters that affect H_2 injectivity and recovery

Key parameter: Wettability (contact angle between H_2, brine and rock)

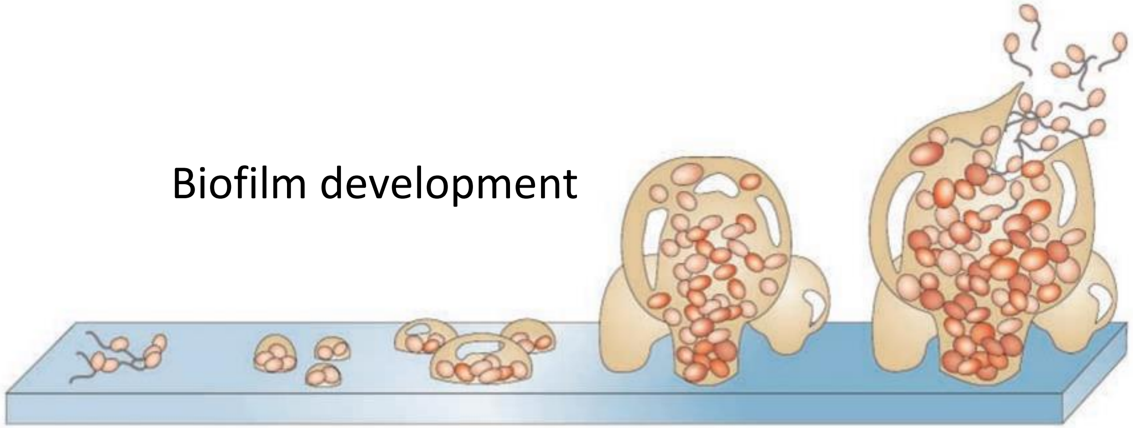


organic acids, oil and biofilm coating affect the wettability and, depending on measurement technique (buoyancy, capillary and gravitational forces acting) salinity, temperature, pressure

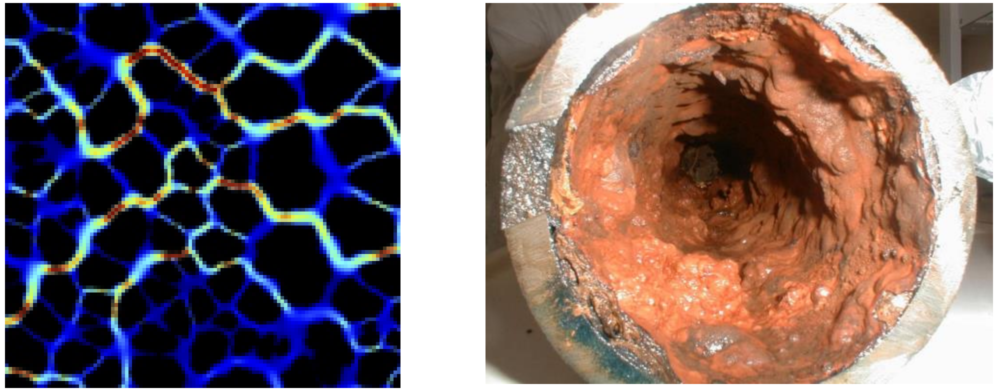
- Porosity, permeability, tortuosity, pore network connectivity also important descriptors for H_2 fluid flow

  beware microorganisms!
- Cushion gas

Biofilm development



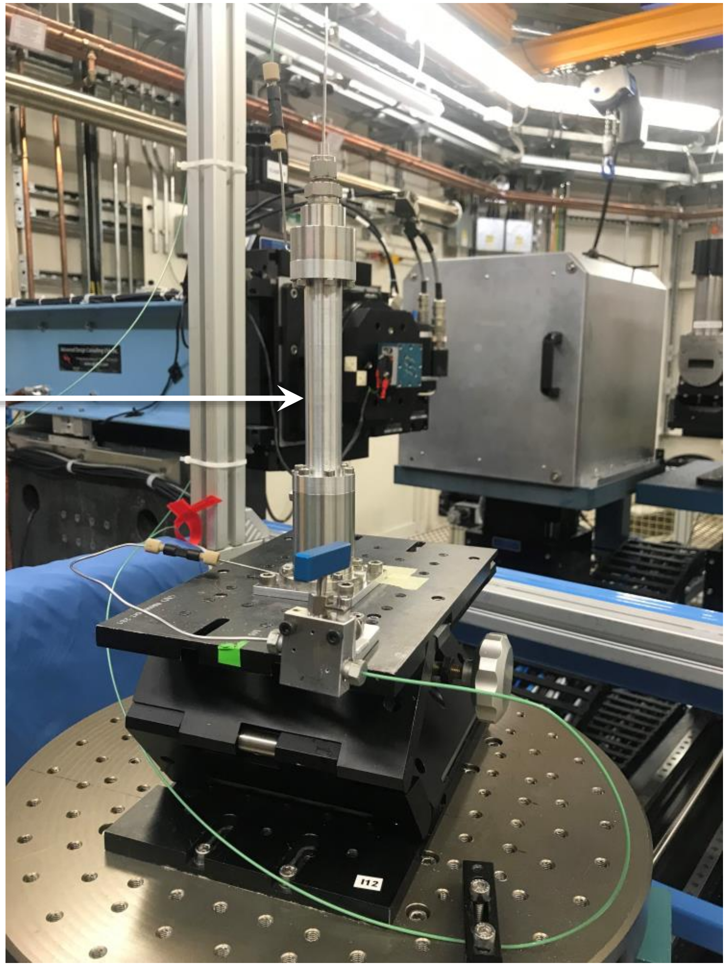
Davies, D. (2003). Understanding biofilm resistance to antibacterial agents. *Nature Reviews Drug Discovery (2),* 114–122

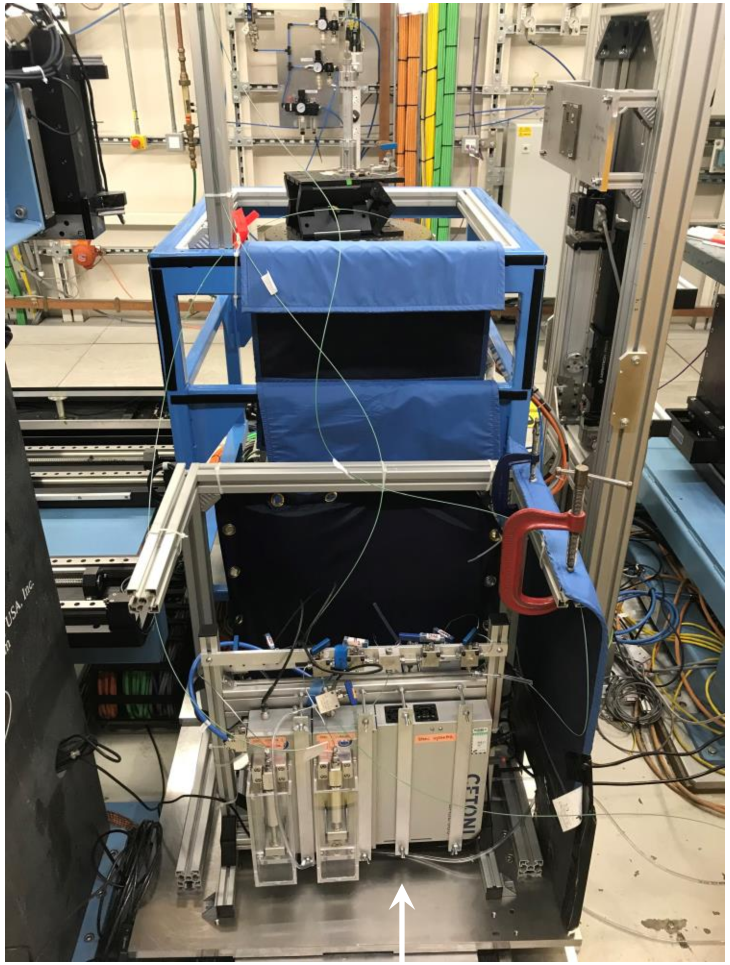


Clogging of pores and pipes

Experiments on H_2 injectivity and recovery at Diamond Light Source, UK

pressure vessel





Rock sample inside X-ray transparent pressure vessel

Pumps for injecting H_2 and brine
and for the confining pressure and backpressure

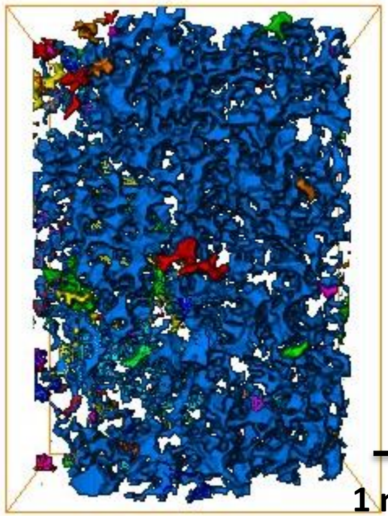
Residual H_2 saturation increases with pore fluid pressure

(all at constant confining pressure of 8 MPa)

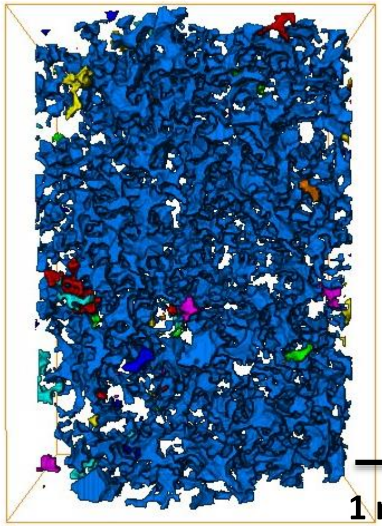
2 MPa | **5 MPa** | **7 MPa**

H_2 saturation after injection into brine saturated rock

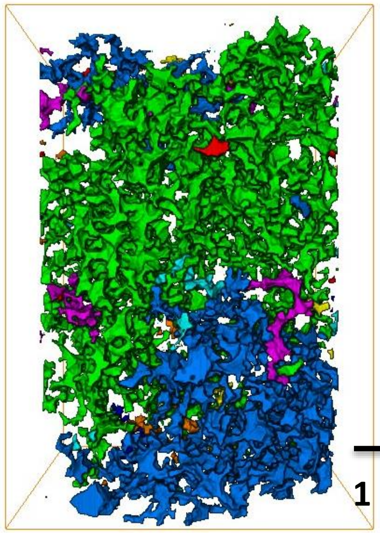
@C_a= 1.7*10^{-8}



49.8 ±0.01%



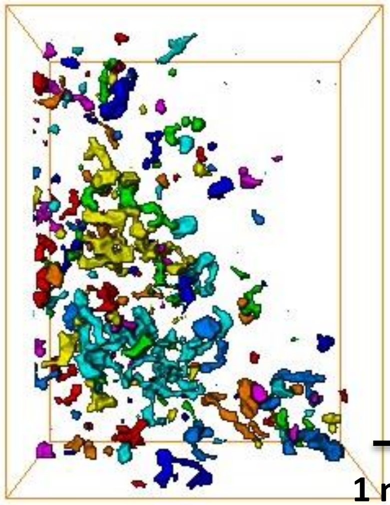
51.7 ±0.66%



49.5 %

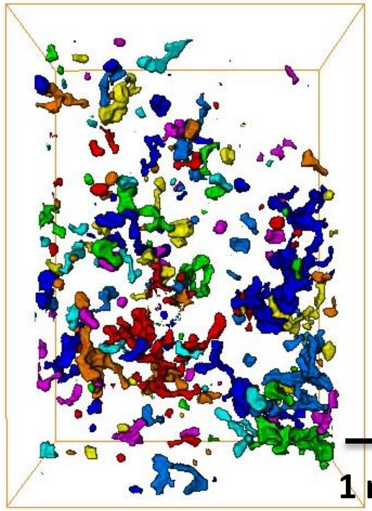
Residual H_2 saturation after brine imbibition

@C_a= 2.4*10^{-6}



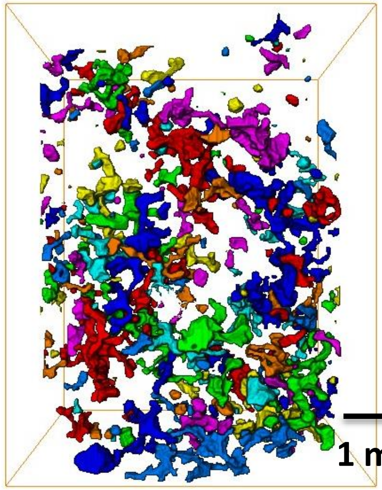
Total: 10.0 ± 0.02%

Percentage of injected: 20 %



Total: 11.5 ± 0.64%

Percentage of injected: 24%



Total: 21.4 %

Percentage of injected: 43%

Thaysen et al., Pore-scale imaging of hydrogen displacement and trapping in porous media, Int J Hydrogen J, in press, 2022

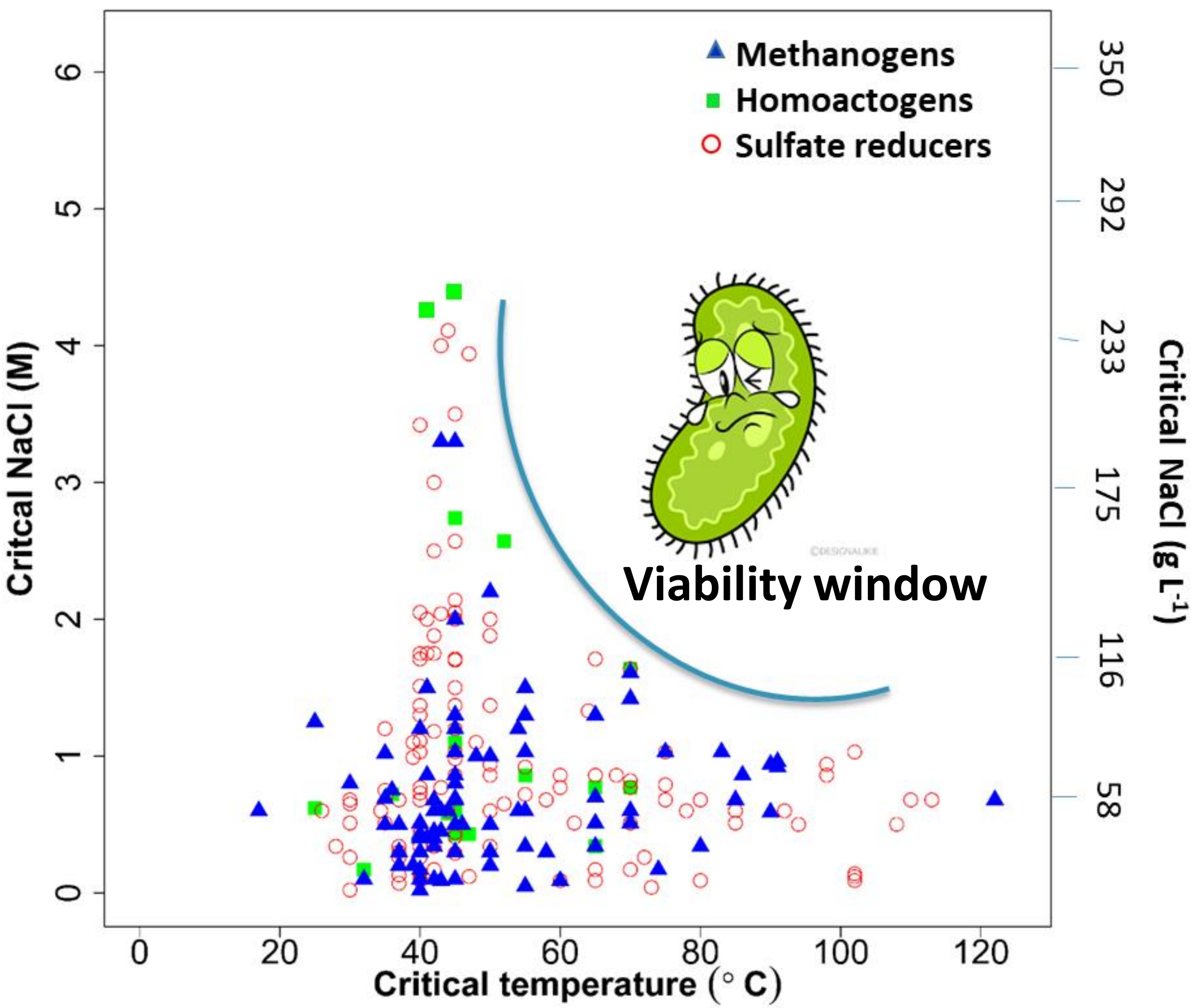
How do these numbers compare to other studies?

Rock dependency
Experimental condition
Methodology

H_2 Injectivity	Residual H_2 (recovery)	Rock material	Method	Reference
4 %	Less than 2 % trapped (more than 50 % recovered)	Fontainebleau sandstone	Nuclear Magnetic Resonance at 0.4 MPa and ambient temperature	Al-Yaseri et al. (2022)
65 %	41 % trapped (39 % recovered)	Gosford sandstone (very short sample**)	Micro-CT ambient temperature and pressure	Jha et al. (2021)
36 %	25 % trapped (30 % recovered)	Bentheimer sandstone	Micro-CT 10 MPa and 50°C	Jangda et al. (2022)
50 %	10-21 % trapped (57-80 % recovered)	Clashach sandstone	Micro-CT 2-7 MPa and ambient temperature	Thaysen et al. (2022)

How can we avoid reduced injectivity and withdrawal by clogging ?

Site selection: Growth criteria of major cultivated H_2 consuming microbes



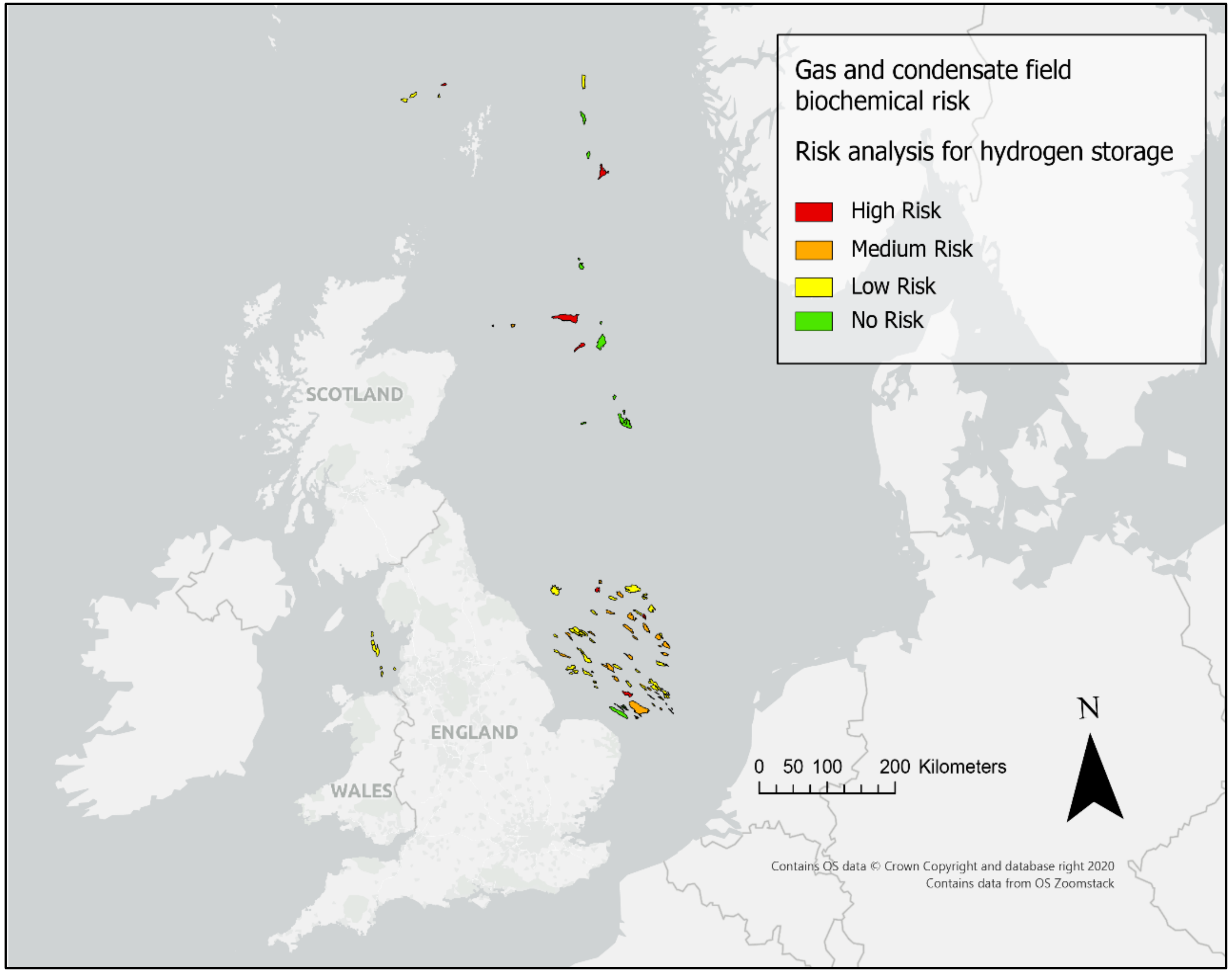
- Microbial life limits with regards to temperature, pH and salinity for four key hydrogen consuming bacteria:
  - ➢ **Methanogens** (consume hydrogen/produce methane)
  - ➢ **Homoactogens** (consume hydrogen/produce acetone)
  - ➢ **Sulphur species reducing** (consume hydrogen/produce hydrogen sulphide)

- Conditions are unfavourable to bacterial activity:
  - ➢ Above temperatures of 122°C
  - ➢ Above salinities of 4.4 M NaCl

Thaysen et al., 2022, Estimating microbial growth and hydrogen storage in porous media, Renew Sustain Energ Rev, 151(111481), 1-15

Microbial risk site screening of UKCS depleted gas fields and condensate fields

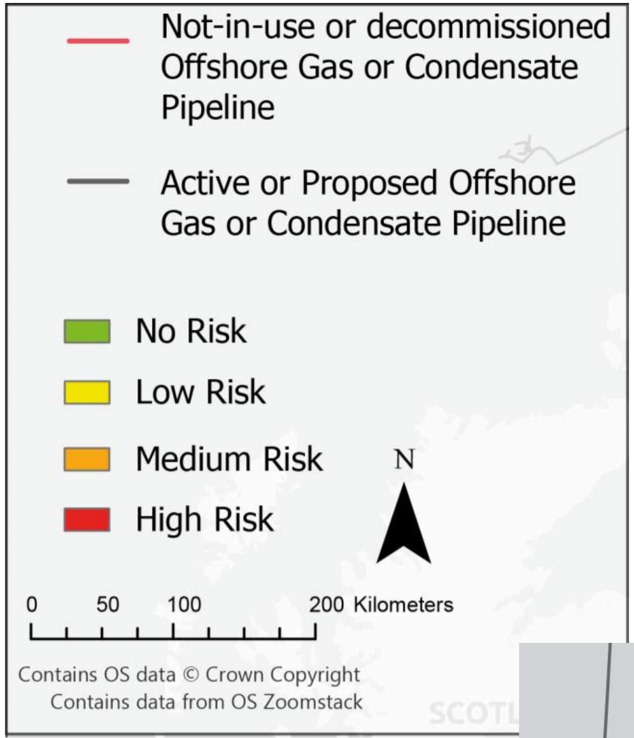
- **No risk**: fields with a temperature >122°C can be considered as sterile, as no H_2 consuming bacteria have been found above this temperature. **9 UKCS gas fields**
- **Low risk**: fields >90 °C are considered paleosterile. **35 UKCS gas fields**
- **Medium risk**: fields >55°C and a salinity > 1.7 mol L^{-1} NaCl, as no cultivated H_2 consuming bacteria can grow in this combination. **22 UKCS gas fields**
- **High risk**: fields <55°C and < 1.7 mol L^{-1} NaCl because these are conditions optimal for growth. **9 UKCS gas fields**

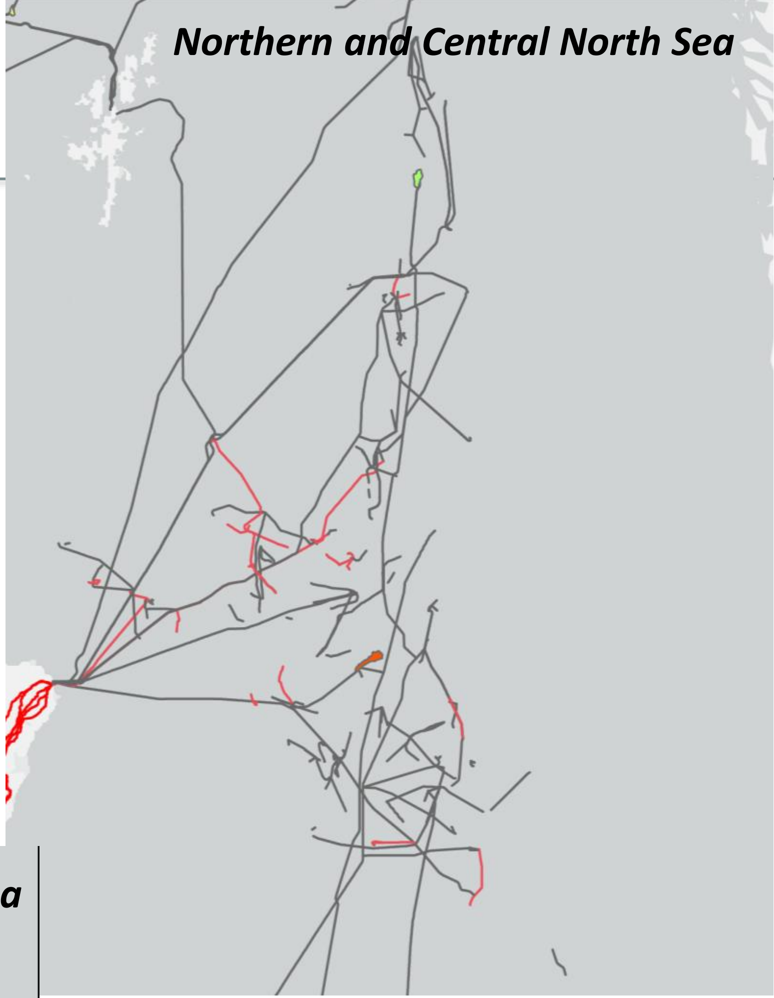


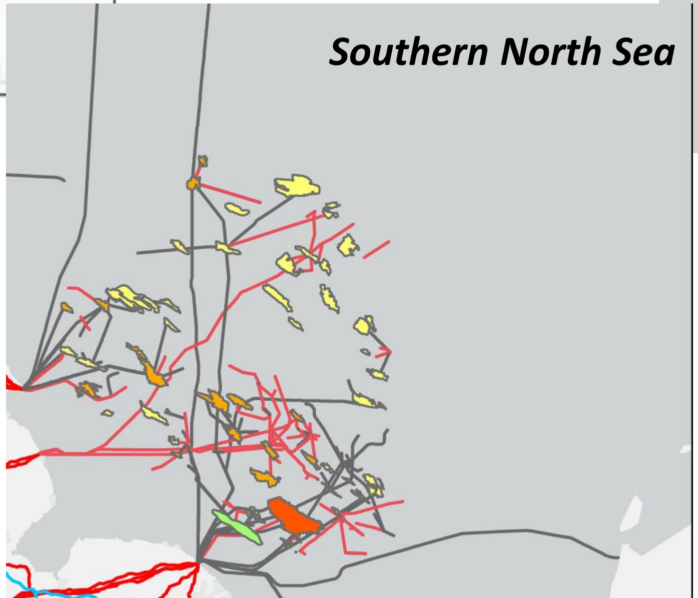
Thaysen et al., 2023, Microbial risk assessment for underground hydrogen storage in porous rocks, in review.

Microbial risk in depleted gas fields&not-in-use pipelines

Southern North Sea holds many not-in-use pipelines which could be repurposed for H_2 transport to ´no risk´ or ´low risk´ depleted gas fields







Thaysen et al., 2023, Microbial risk assessment for underground hydrogen storage in porous rocks, in review.

Summary

- H_2 injectivity ~4-65% of the pore space and independent of pore fluid pressure

- 30-80 % of the injected H_2 can be recovered making the H_2 storage operation feasible

- H_2 recovery decreases with pore fluid pressure, indicating that shallow reservoirs are more favourable for H_2 storage

- H_2 storage sites should be carefully selected with respect to temperature and salinity as microbial activity can reduce the injectivity and recovery (& consume H_2)

Thank you!

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HyStorPor

HyUSPRe Hydrogen Underground Storage in Porous Reservoirs

THE UNIVERSITY of EDINBURGH

No show stoppers… so far

- ✓ Perspective paper on enabling large-scale hydrogen storage in porous media – the scientific challenges https://doi.org/10.1039/D0EE03536J
- ✓ Biological site screening: We suggest that storage reservoirs over 122℃ or with salinities above 4.4 M NaCl equivalent will be less favourable to microbial growth https://authors.elsevier.com/c/1dYWP4s9Hw2Eu4
- ✓ No significant geochemical reactions have been observed in our reactive experiments https://pubs.acs.org/doi/full/10.1021/acsenergylett.2c01024
- ✓ Column height calculations indicate hydrogen will have a higher column height than methane and that this increases with increasing depth. https://doi.org/10.1021/acsenergylett.1c00845
- ✓ Developed a online tool to provide high accuracy thermodynamic property estimations of hydrogen mixtures (CO2, N2, CH4, natural gas) over a range of temperatures and pressures. https://www.nature.com/articles/s41597-020-0568-6
- ✓ Cushion gas will play an important role in controlling both injectivity and productivity during hydrogen storage. https://doi.org/10.1016/j.ijhydene.2021.09.174
- ✓ Significant storage capacity in depleted gas fields, minimising subsurface competition with other low carbon geoenergy applications such as CCS or CAES. https://doi.org/10.1016/j.apenergy.2020.116348 and https://doi.org/10.1021/acsenergylett.1c00845