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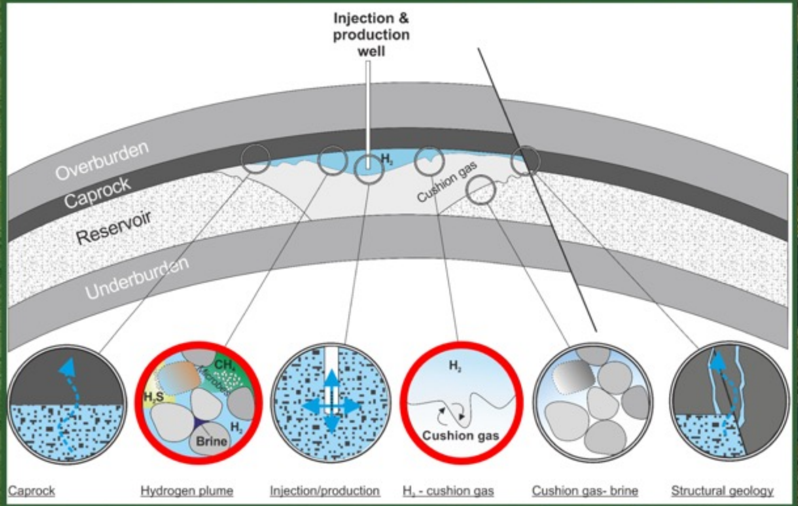
Webinar

Tuesday, 29 March 2022
12.00-13.00 GMT

Increasing confidence for hydrogen storage in porous rocks



HyStorPor team: Niklas Heinemann, Ali Hassanpouryouzband, Eike Thaysen, Stuart Haszeldine, Mark Wilkinson, Chris McDermott, Ian Butler, Julien Mouli-Castillo, Jonathan Scafidi, John Low (all UoE), Leslie Mabon (OU), Romain Viguier (SCCS), Gillian Pickup (HW), Sam Krevor (Imperial)

The University of Edinburgh | The Open University | Heriot Watt University | Imperial College London | EPSRC

EP/S027815/1

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Agenda

- 13:00-13:10 (10 mins) - Introduction, project overview and context. Chair: Katriona Edlmann
- 13:10-13:20 (10 mins) - Talk one - Site selection to minimize the risk for microbial growth and hydrogen consumption in geological hydrogen storage, Eike Thaysen
- 13:20-13:30 (10 mins) - Talk two - Physico-Chemical reactivity of hydrogen, Ali Hassanpouryouzband
- 13:30-13:40 (10 mins) - Talk three - Understanding the role of cushion gas in subsurface hydrogen storage, Niklas Heinemann
- 13:40-14:00 (20 mins) - Q&A

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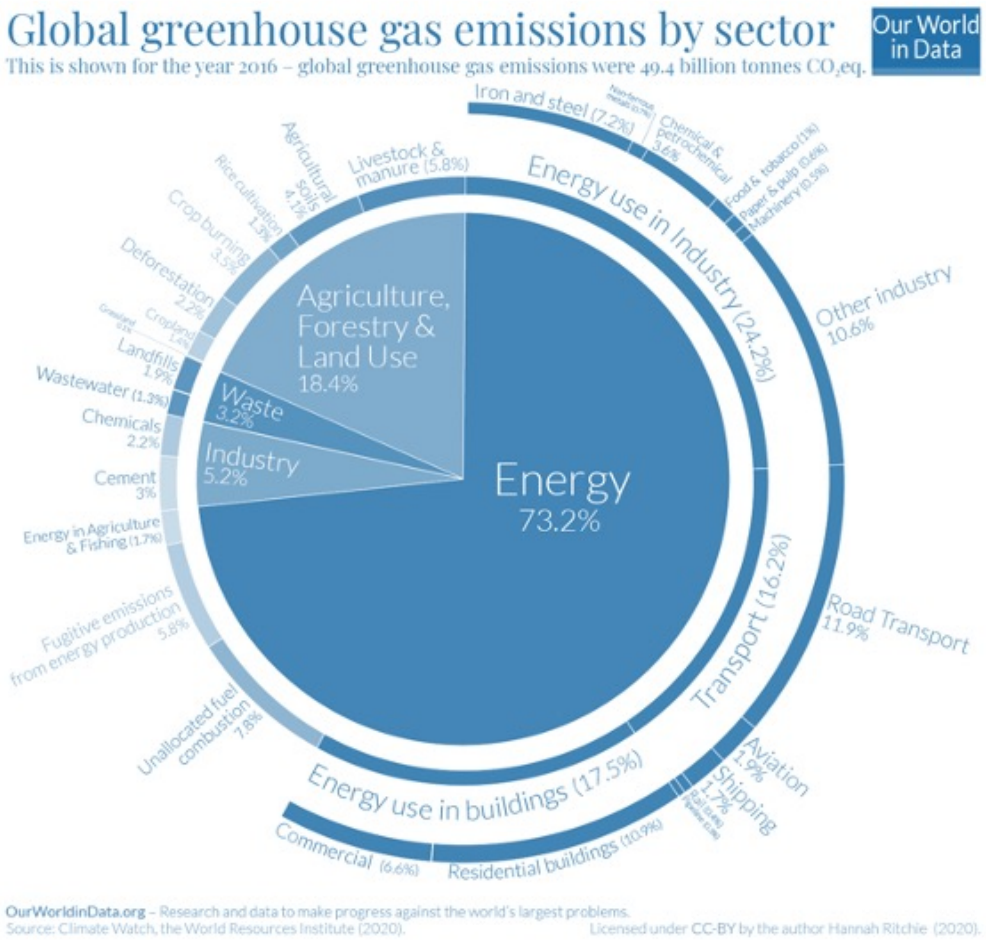
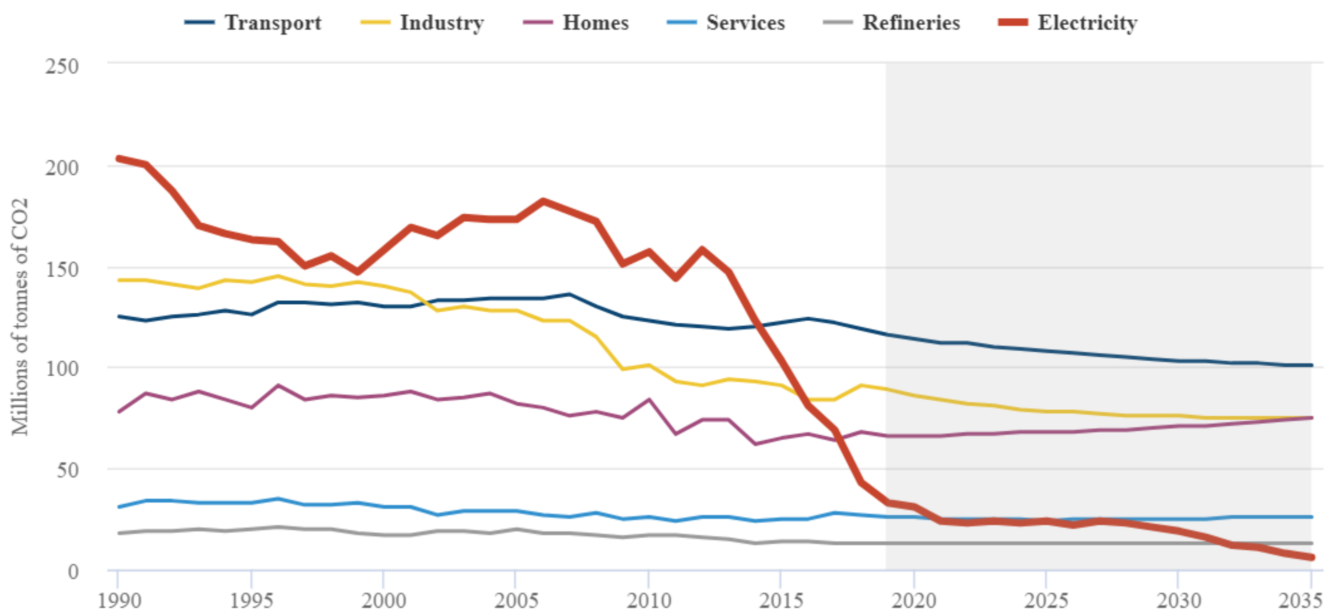


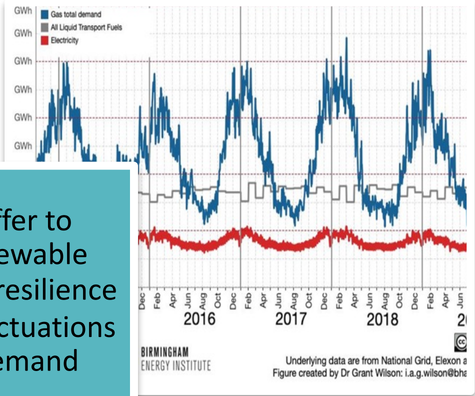


https://www.carbonbrief.org/analysis-half-uks-electricity-to-be-renewable-by-2025

An energy decarbonisation option... Hydrogen

Hydrogen for Net Zero

~75% of all greenhouse gas emissions are related to energy use in transport, buildings and industry



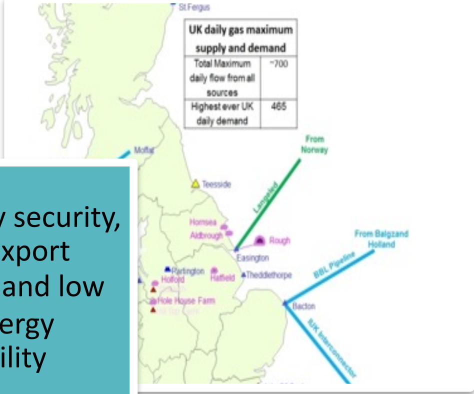
Act as a buffer to increase renewable energy supply resilience to seasonal fluctuations in energy demand

Enable large scale renewable energy integration and power generation

Decarbonise heat by replacing methane in the gas grid

Decarbonise aviation, road freight, rail & shipping

Replace hydrocarbon based Industrial feedstock



Increase energy security, economic export opportunities and low carbon energy sustainability

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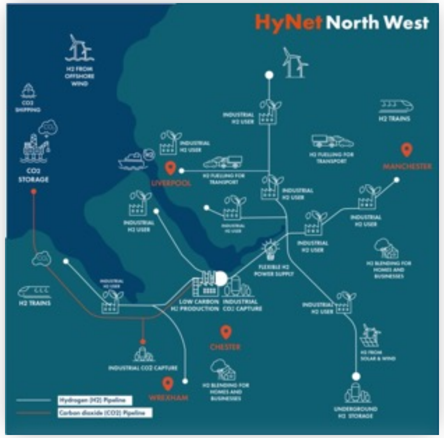
- All our climate-neutrality scenarios to meet Net Zero by 2050 include a growing reliance on hydrogen:
  - UK Hydrogen Strategy
  - Scottish Hydrogen Policy Statement
  - Ten Point Plan for a Green Industrial Revolution.
  - North Sea transition deal.
- UK and Scottish Governments have committed to 5GW of low carbon hydrogen production capacity by 2030.



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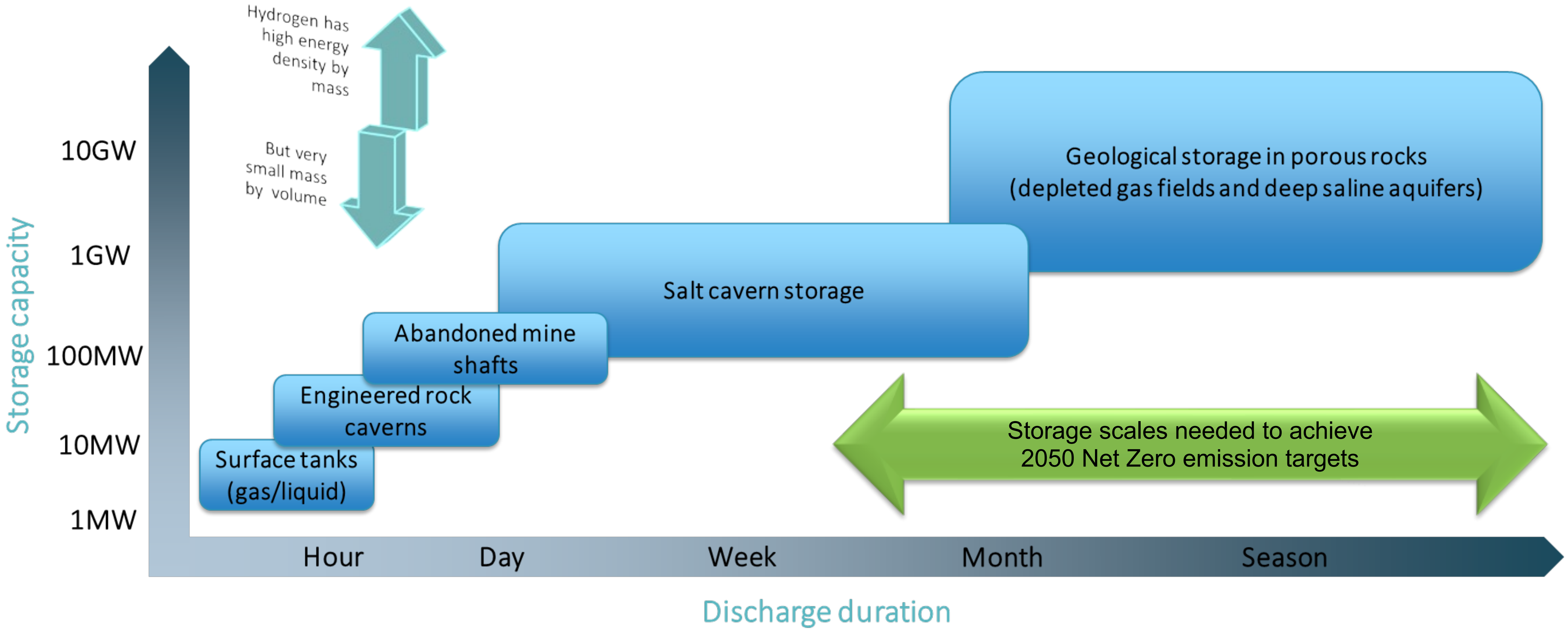
Scales and deliverability of hydrogen storage



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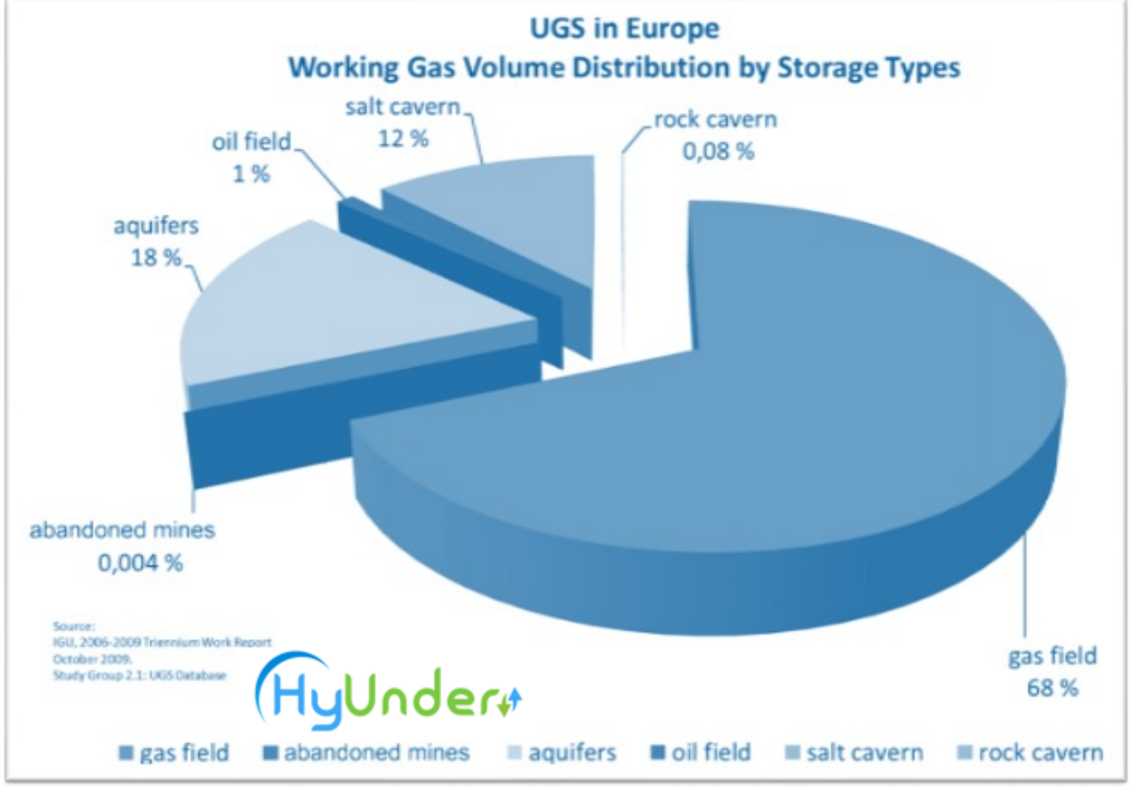
Underground gas storage



Aquifer storage of hydrogen

- Ketzin, Germany (62% hydrogen town gas – now closed)
- Beynes, France (50% hydrogen town gas from 1956-1972)
- Lobodice, Czech Republic (50% hydrogen town gas from 1965, now used for natural gas storage)

Salt cavern storage of hydrogen

- Teeside, UK (active since 1959 storing 95% hydrogen)
- Kiel, Germany (62% hydrogen, now operating with natural gas)
- Spindletop, US (95% hydrogen storage)
- Clemens Dome, US (95% hydrogen storage)
- Moss Bluff, US (95% hydrogen storage)

Hydrogen storage for biomethane production

- Hychico, Argentina (10% hydrogen storage in a depleted gas reservoir)
- Underground Sun Storage, Austria (10% hydrogen storage in a depleted gas reservoir from 2015)

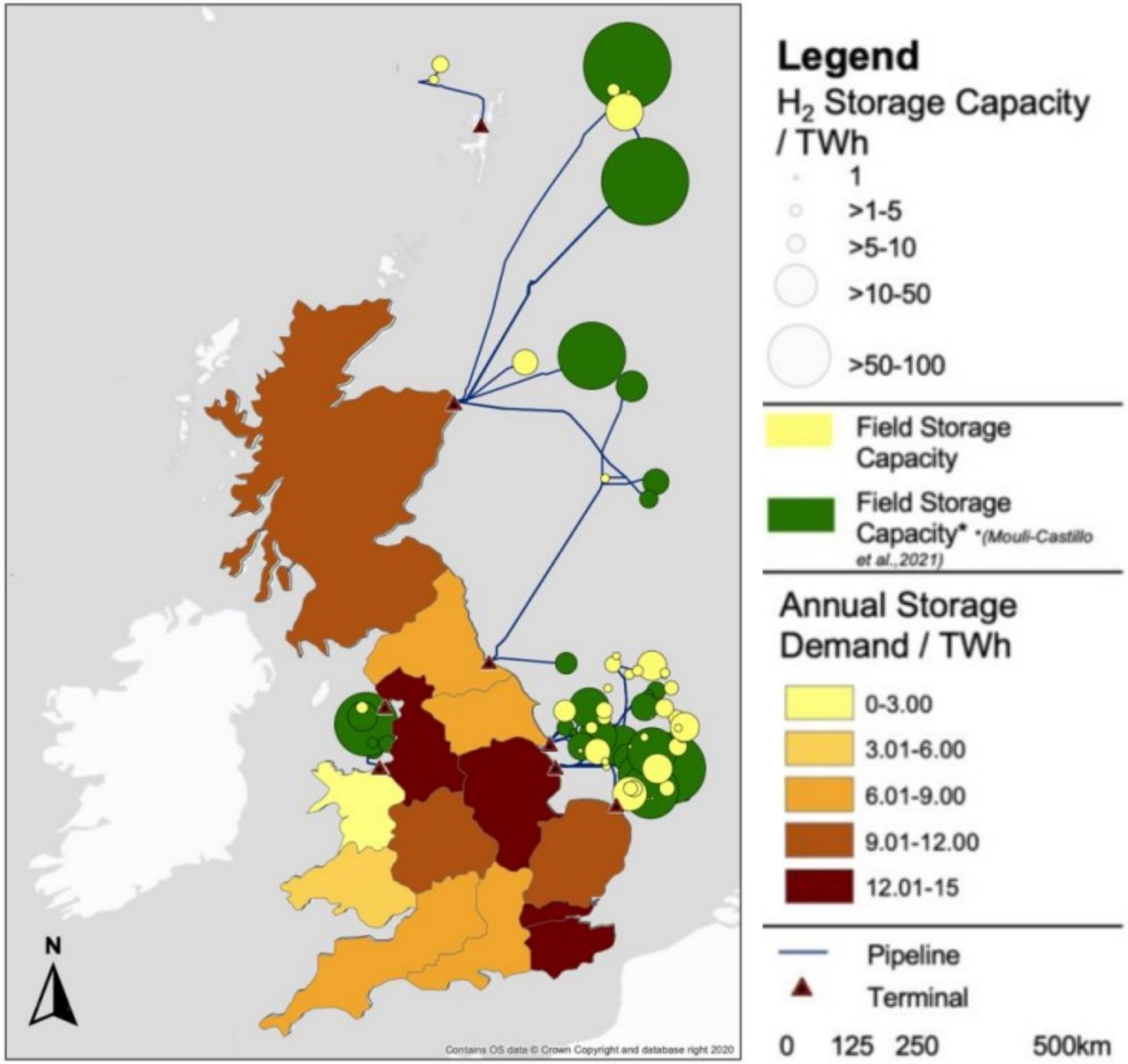
Hydrogen storage in engineered rock caverns

- HYBRIT, Sweden for 100% decarbonised steel production

Julien Mouli-Castillo (julien.moulicastillo@ed.ac.uk) and Anna Peecock (a.r.o.peecock@sms.ed.ac.uk)
https://doi.org/10.1016/j.apenergy.2020.116348

UK gas field capacities

- 100-150 TWh hydrogen storage capacity required to meet the seasonal variation if all current natural gas demand was met with hydrogen.
- We estimate 1000's of TWh of storage capacity in North Sea depleted gas fields.
- One large gas field may be sufficient to balance the entire seasonal demand for UK domestic heating: feeds into the debate around centralised or distributed energy storage.
- These are volumetric capacity estimates. Accurate estimations of hydrogen storage capacity will only be achieved when matched against operational data during active geological hydrogen storage projects.

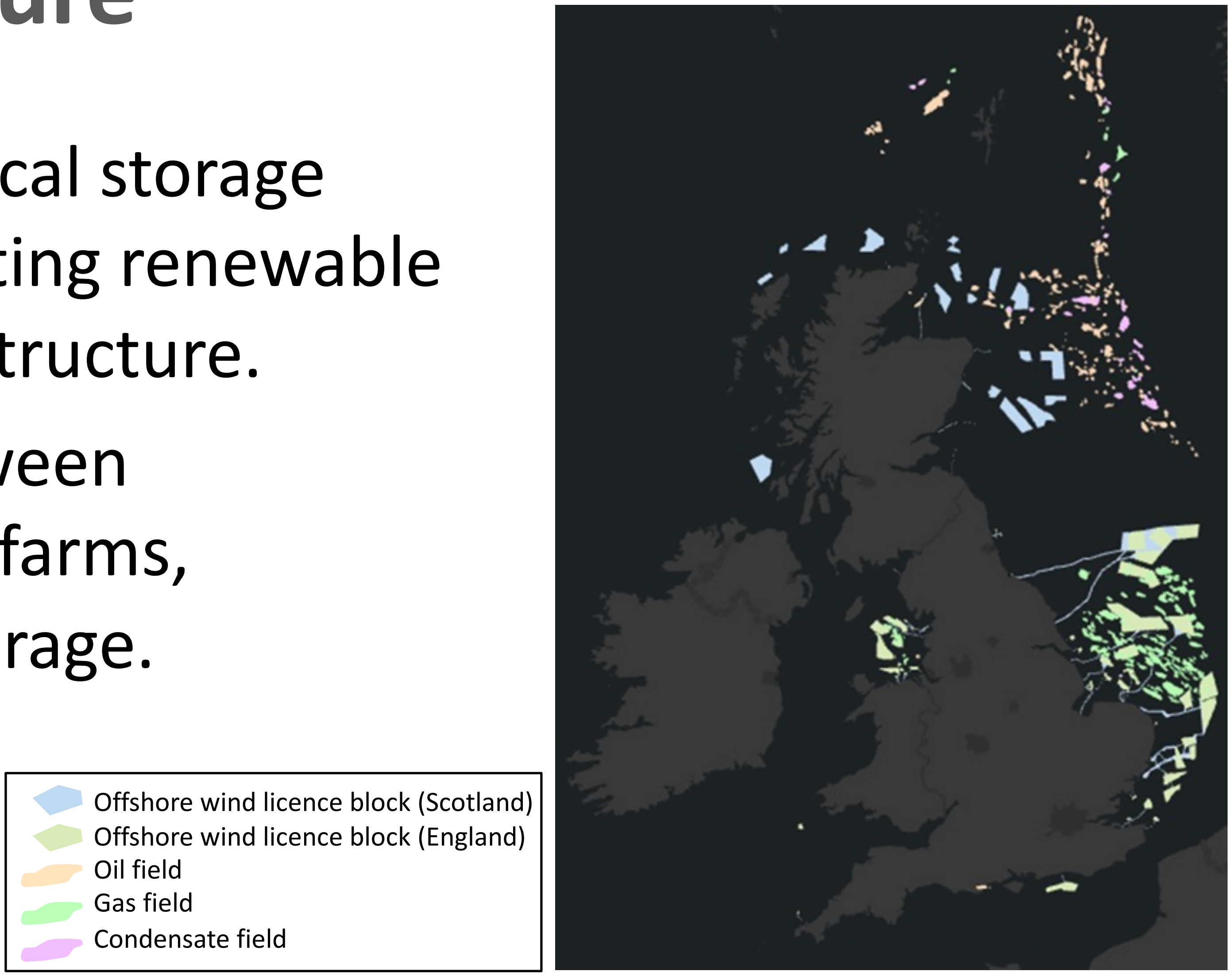


SGN funded open access GIS based “Hydrogen Storage Database” project: Tim Armitage tim.armitage@ed.ac.uk

Storage and infrastructure

- GIS database to map geological storage location and capacity to existing renewable energy and oil and gas infrastructure.
- Highlight any mismatch between infrastructure between windfarms, hydrogen generation and storage.

Planned and developed wind farms and infrastructure Crown Estate and Crown Estate Scotland land overlain by the location for oil and gas fields offshore UK.



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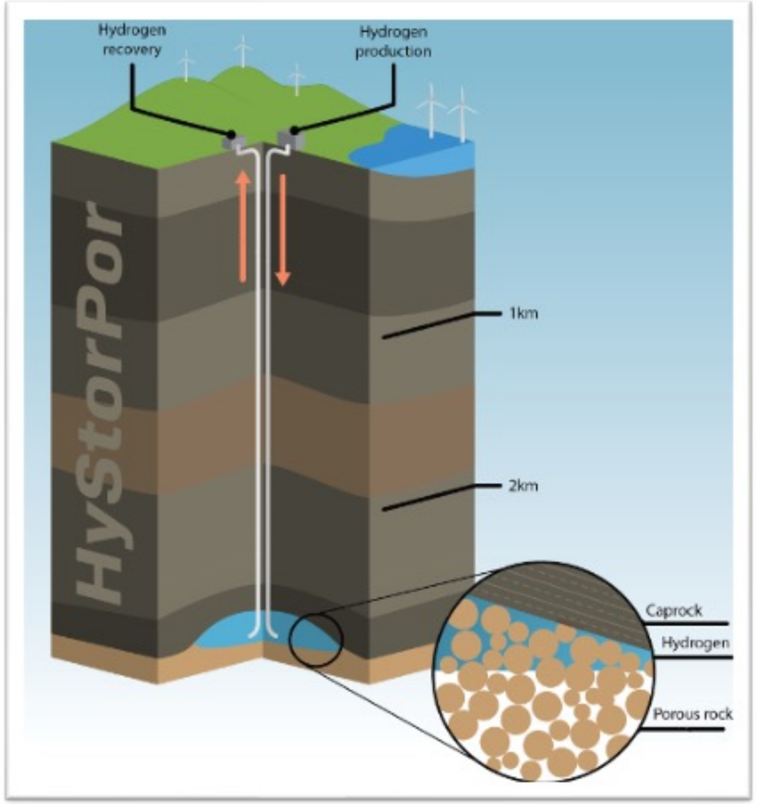
HyStorPor Goals: Fundamental understandings

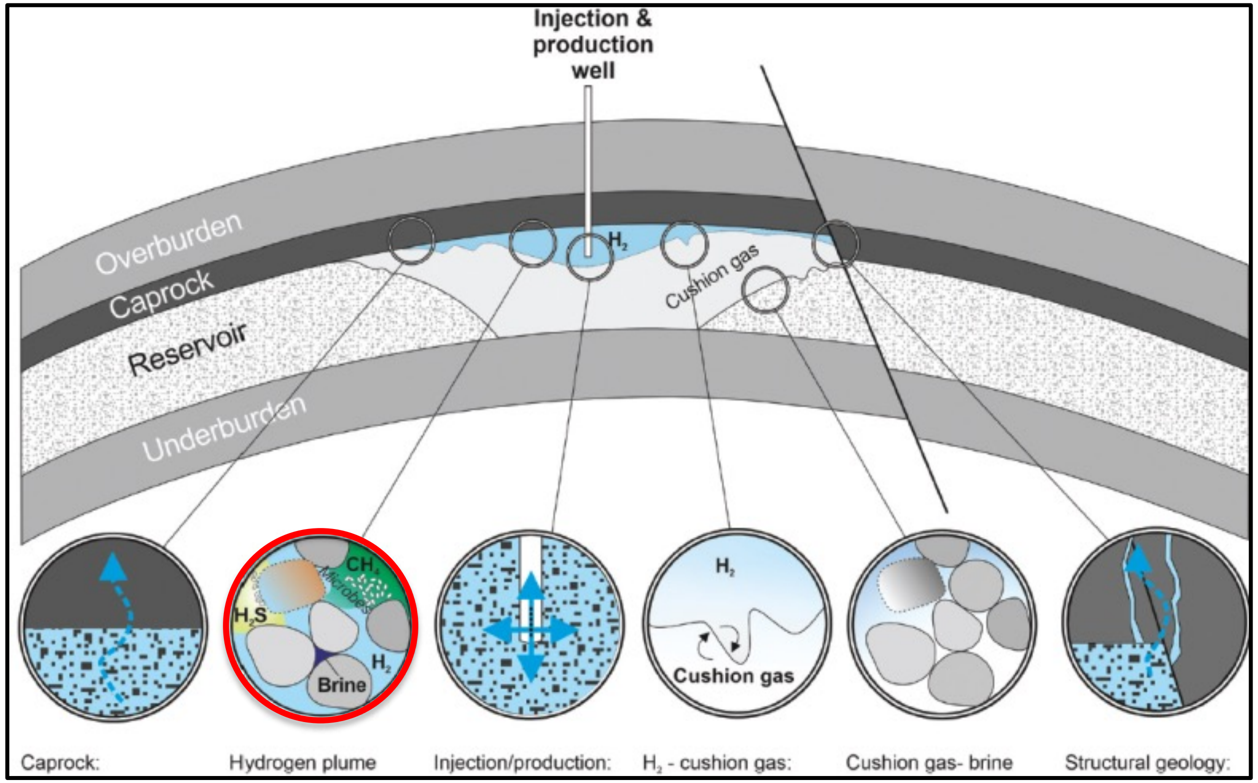


- To identify if **microbial and geochemical reactions** between the rock, fluids, cushion gas and hydrogen could compromise storage.
- To determine what **flow processes** will influence hydrogen migration and trapping during injection and withdrawal.
- **Reservoir simulations to estimate what volumes of hydrogen can be stored and recovered** from storage sites of varying scales.
- To **clarify what citizens and opinion shapers think about hydrogen storage.**

https://blogs.ed.ac.uk/hystorpor/ (katriona.edlmann@ed.ac.uk)

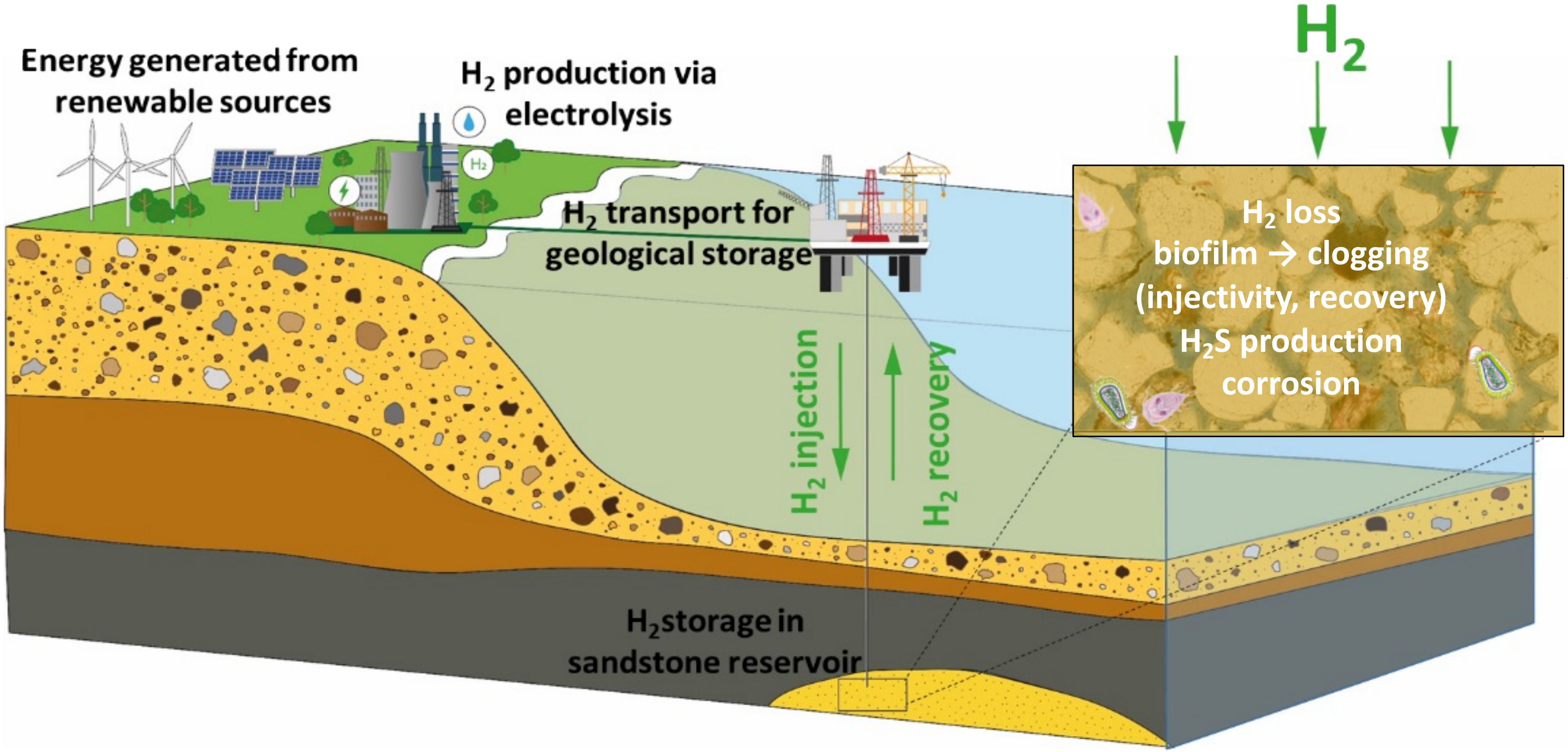
Site selection to minimize the risk for microbial growth and hydrogen consumption in geological hydrogen storage

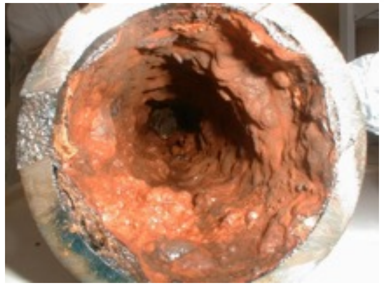
Dr Eike Marie Thaysen
School of GeoSciences
University of Edinburgh



Heinemann et al. 2021: https://doi.org/10.1039/D0EE03536J

Motivation



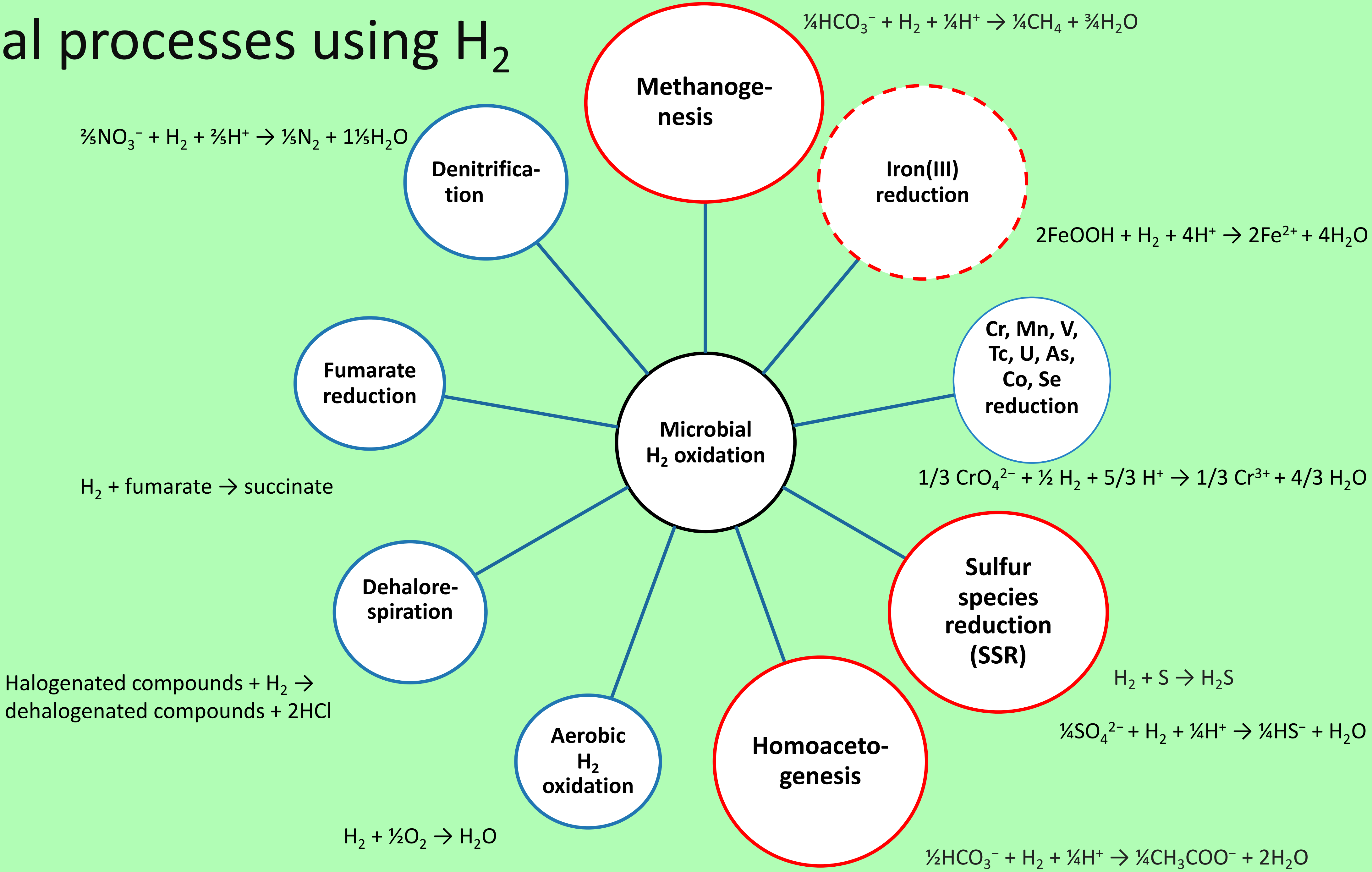


clogging and corrosion

corrosion

Hassanpouryouzband et al. "Geological hydrogen storage: Geochemical reactivity of hydrogen with sandstone reservoirs“ Under-review

Microbial processes using H_2



Optimum and critical growth conditions for 520 cultivated strains from the major H_2-oxidizing groups

along with physicochemical data for 42 depleted oil and gas fields (DOGF) and 5 H_2 storage test sites

- Temperatures of 20-40 °C are preferred

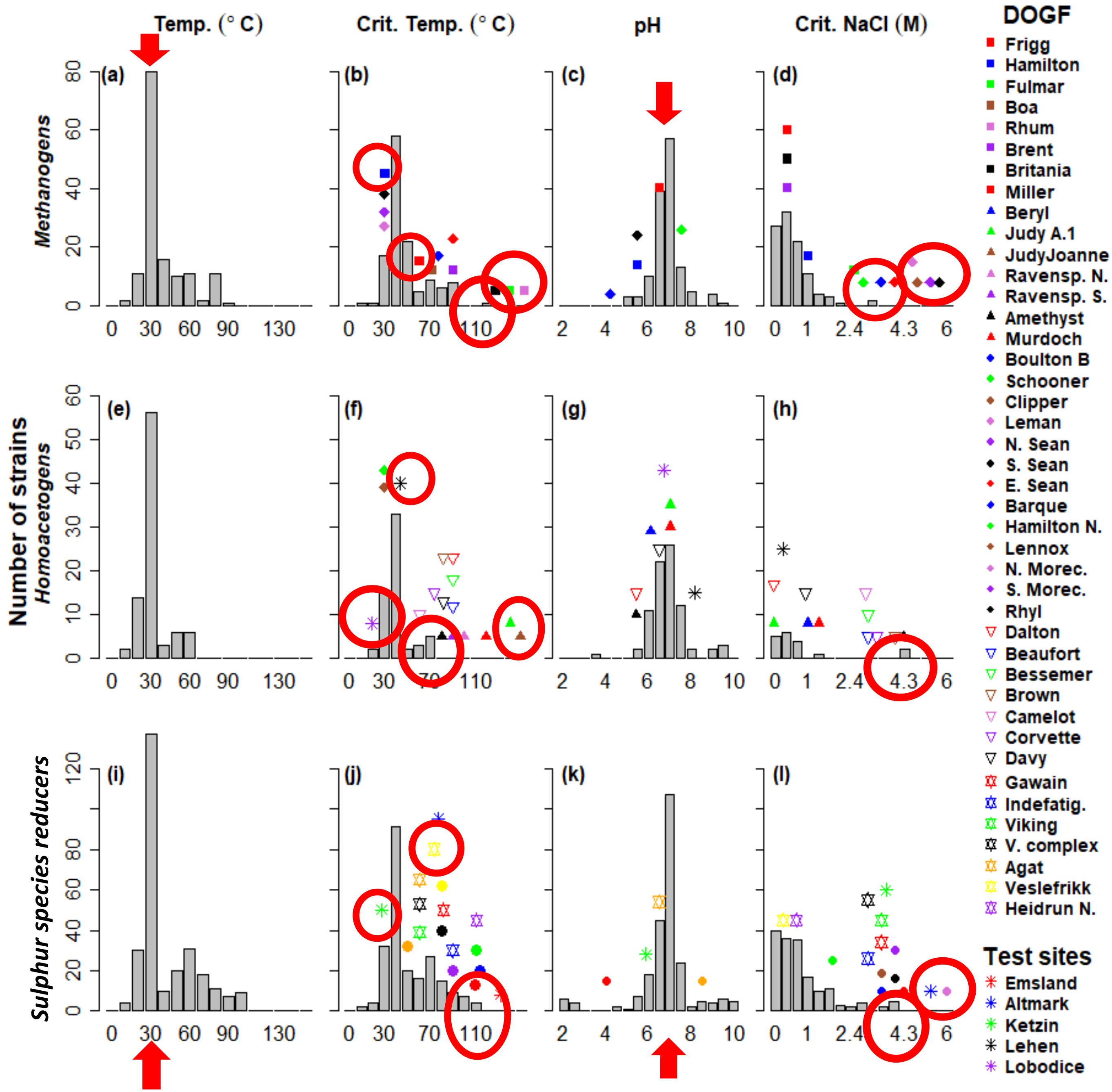
- Methanogens grow up to 122 °C
- Homoactogens grow up to 72 °C
- Sulphur species reducers grow up to 113 °C

- pH values of 6-7.5 are preferred

- Methanogens grow up to 3.4 M
- Homoactogens grow up to 4.4 M
- Sulphur species reducers grow up to 4.2 M

Of the 47 sites, 12 can be considered at reduced risk for adverse microbial effects

Only 6 sites allow the growth of all investigated microorganisms



Optimum= highest growth occurs here
Crit.= condition beyond which no growth is possible

Thaysen et al., 2021

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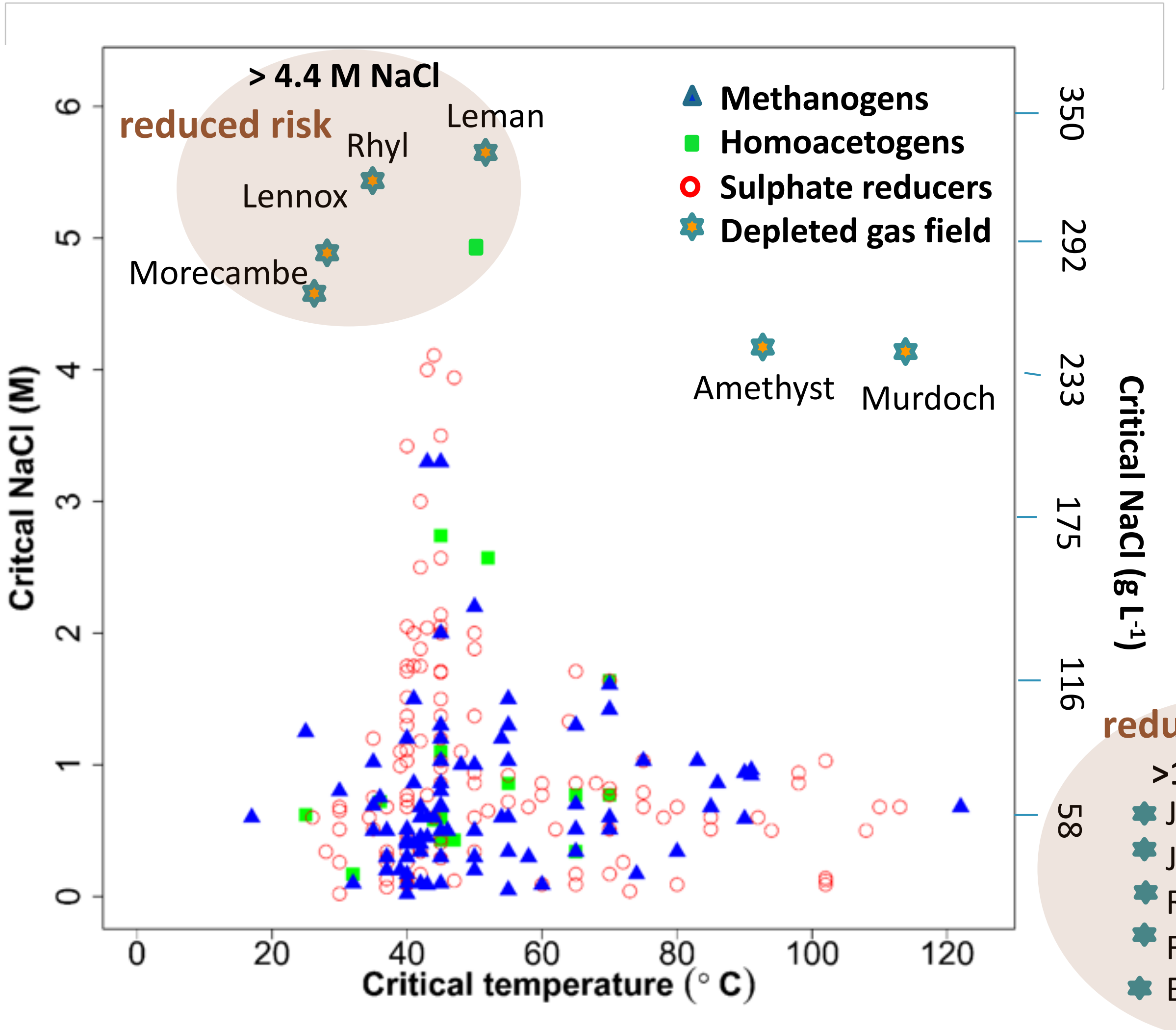
Site selection for H_2 storage



reduced risk/sterility

>122 °C

- Judy/Andrew1
- Judy/Joanne
- Rhum
- Fulmar
- Britannia

Site selection may be based on the most important factors for controlling microbial growth: salinity and temperature

➡ Aquifers with **temperatures >122 °C and salinities > 4.4 M may be considered at reduced risk** with respect to H_2-oxidizing microorganisms

➡ **Storing H_2 >55 °C and >2 mol L^{-1} NaCl reduces the risk of H_2 loss**

uncertainty: not cultivable microbes

Geographical location of gas fields with reduced risk

Southern North Sea- Leman, Amethyst, Murdoch

Central North Sea- Judy Andrew1, Judy Joanne

Northern North Sea- Rhum, Fulmar, Britannia

Irish Sea – Rhyl, Morecambe, Lennox

First order approach to estimation of microbial growth and H_2 consumption in DOGF with favourable environmental conditions

Microbial growth

$$\text{Cell growth} = \frac{\text{[nutrient] in aquifer}}{\text{microbial cell content of nutrients}}$$

Results:

Cell numbers in the order of 10^7-10^8 cells ml^{-1}

Assumptions

- No nutrient replenishment by inflow/weathering/cell decay

Associated H_2 consumption

% H_2 consumed =

$$100 * \frac{\text{cell specific } H_2 \text{ consumption} * \text{microbial cell count}}{[H_2] \text{ in aquifer}}$$

Results:

H_2 consumption: <0.01-3.2 % of the stored H_2

the time, *T*, for when the microbial cell count is reached: actively growing cells need 0.1-19.1 days, resting cells need between 2.5 months and 6.6 years

Assumptions

- equal volumes of H_2 and water in the aquifer
- No H_2 consumption beyond the time it takes to reach the maximum cell count (maintenance).

Testing and verification of the calculated predictions are necessary

Please read more here

Renewable and Sustainable Energy Reviews 151 (2021) 111481

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Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Check for updates

Estimating microbial growth and hydrogen consumption in hydrogen storage in porous media

Eike M. Thaysen [a,*], Sean McMahon [a,c], Gion J. Strobel [b], Ian B. Butler [a], Bryne T. Ngwenya [a], Niklas Heinemann [a], Mark Wilkinson [a], Aliakbar Hassanpouryouzband [a], Christopher I. McDermott [a], Katriona Edlmann [a]

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[b] Department of Petroleum Engineering, Clausthal University of Technology, Germany
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ARTICLE INFO

Keywords:
Hydrogen
Underground storage
Microbial hydrogen consumption

ABSTRACT

Subsurface storage of hydrogen, e.g. in depleted oil and gas fields (DOGF), is suggested as a means to overcome imbalances between supply and demand in the renewable energy sector. However, hydrogen is an electron donor for subsurface microbial processes, which may have important implications for hydrogen recovery, gas injec-

Queries or questions

eike.thaysen@ed.ac.uk

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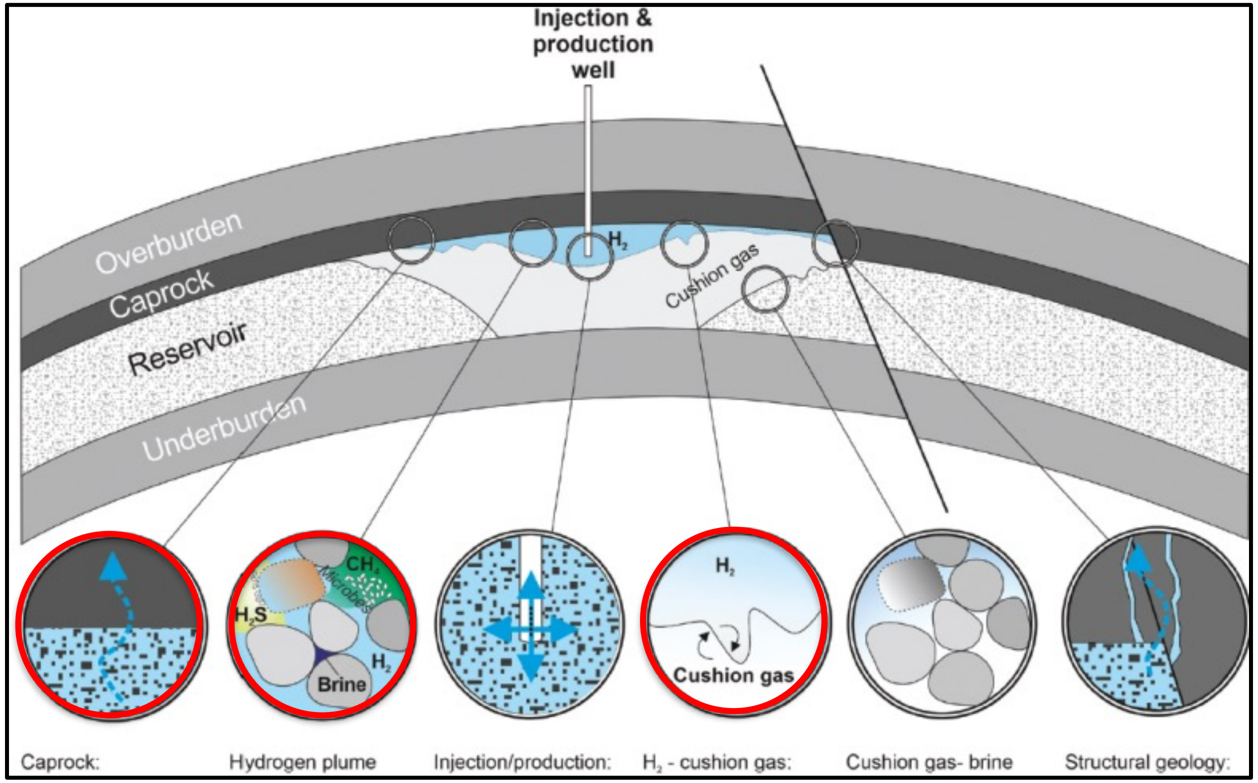
Physico-Chemical reactivity of hydrogen under geological conditions of hydrogen storage



Heinemann et al. 2021: https://doi.org/10.1039/D0EE03536J

Dr Aliakbar Hassanpouryouzband
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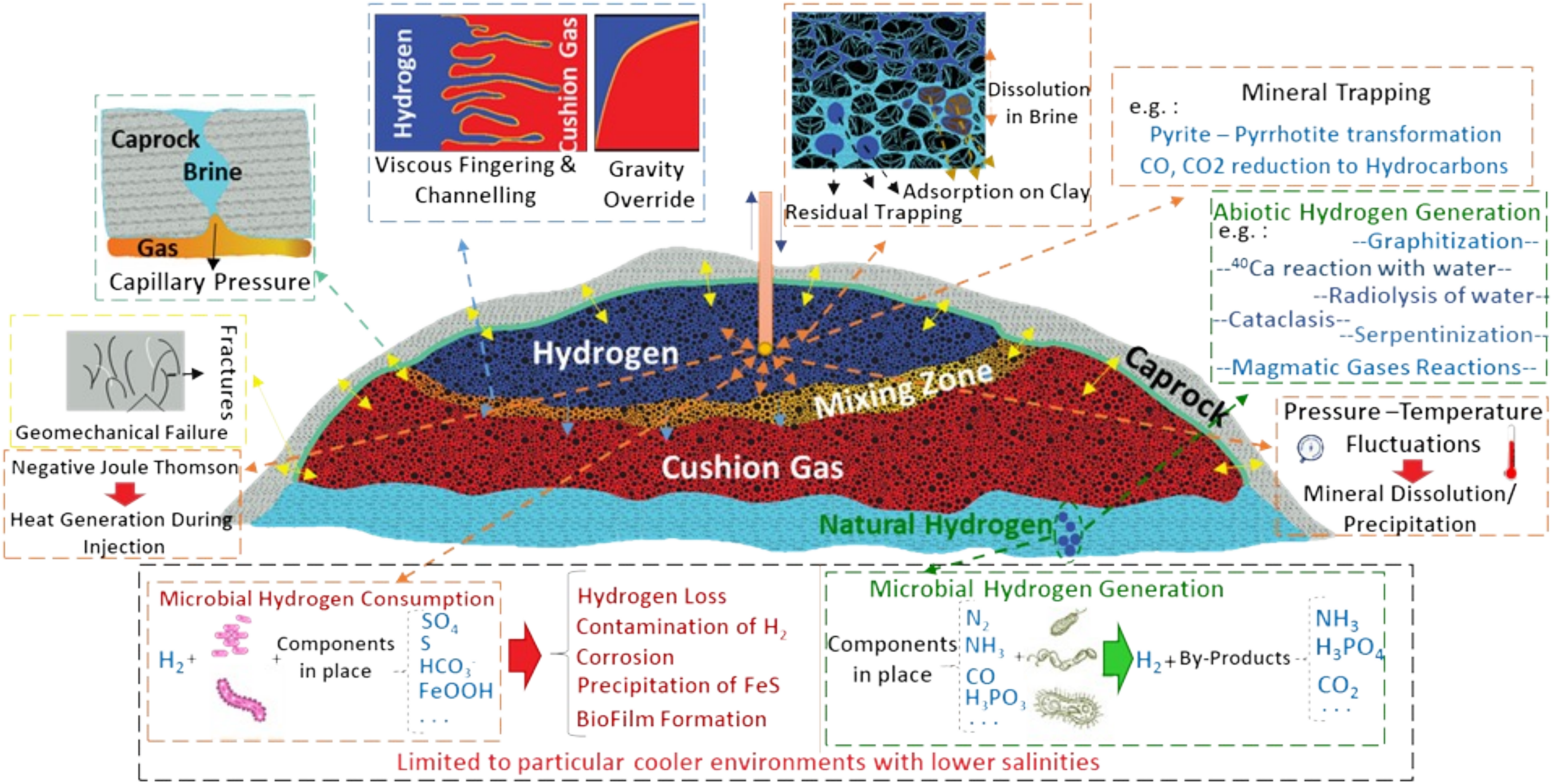
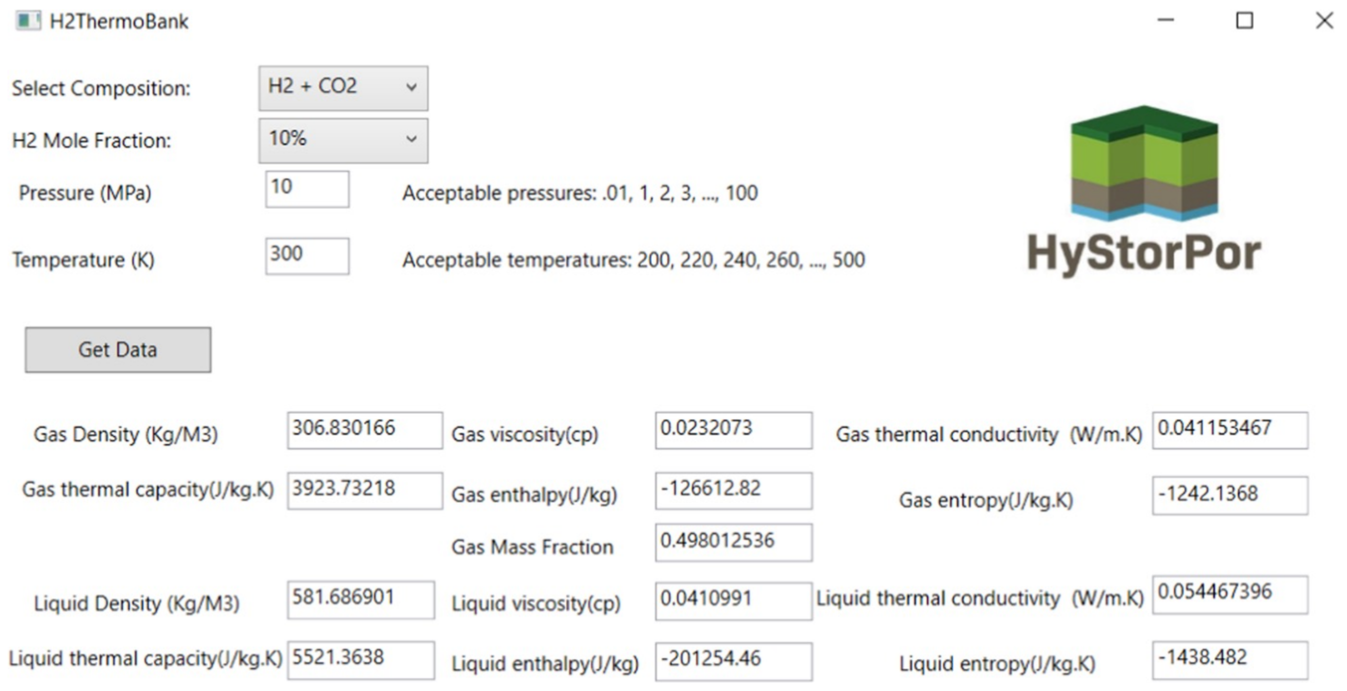
What Processes Will Impact Geological H_2 Storage?



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

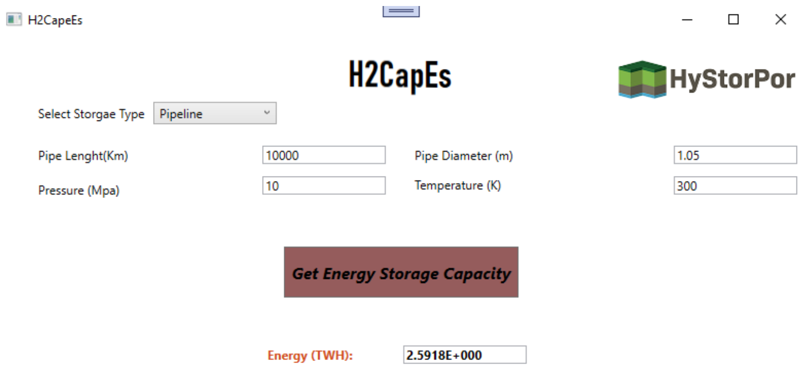
H2Thermobank: Thermodynamics of hydrogen gas streams

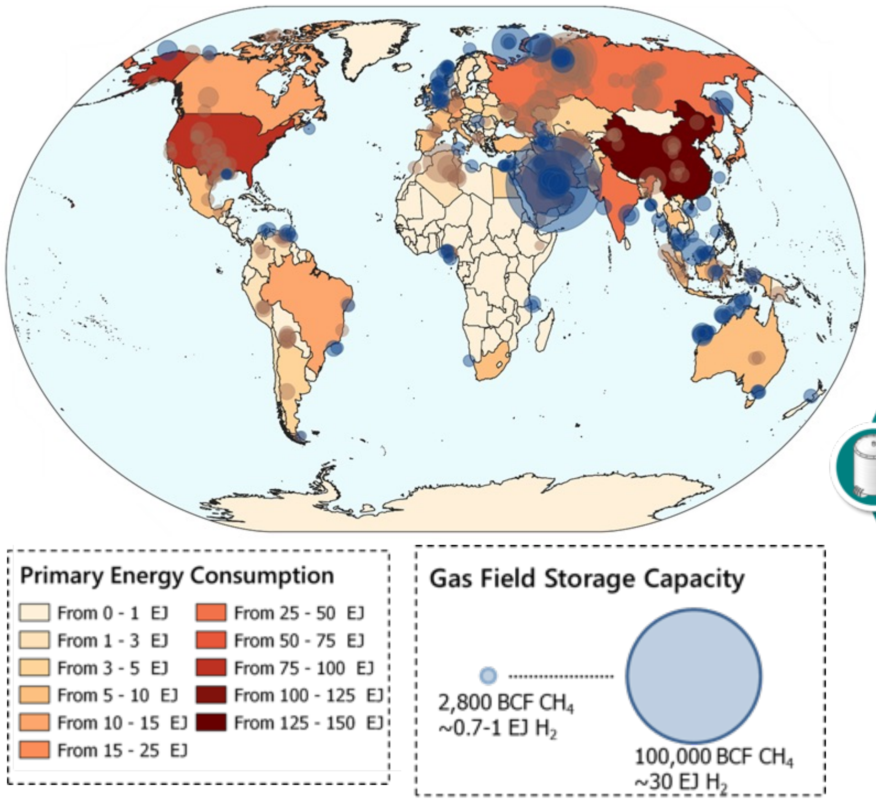
- **Thermodynamic properties of hydrogen mixtures, including CO_2, N_2, CH_4 and a typical UK North Sea Natural Gas.**
- **Mole fractions of hydrogen from 10-90 mole %.**
- **Pressure from 0.01 – 100 MPa.**
- **Temperatures from 200-500 K (-73°C to 227°C).**

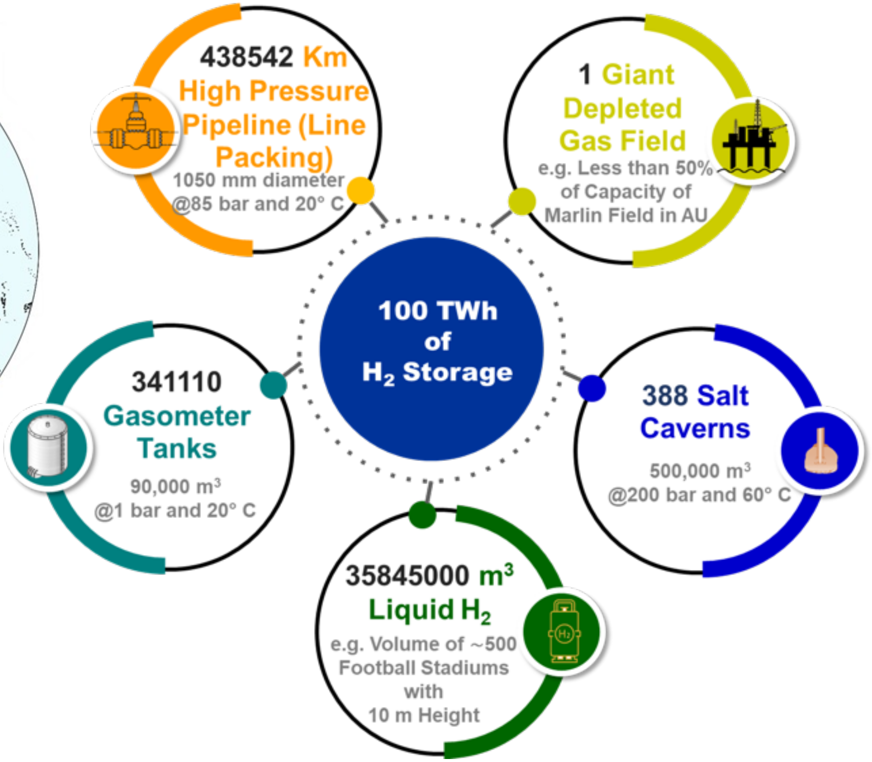


Hassanpouryouzband et al. "Thermodynamic and transport properties of hydrogen containing streams." Scientific Data 7.1 (2020): 1-14. doi.org/10.1038/s41597-020-0568-6
https://github.com/aliakbarhssnpr/H2ThermoBank
https://figshare.com/articles/dataset/Thermodynamic_and_Transport_Properties_of_Hydrogen_Containing_Streams_Data_sets/12063297

Storage Capacity Estimation Tool (H2CAPES)







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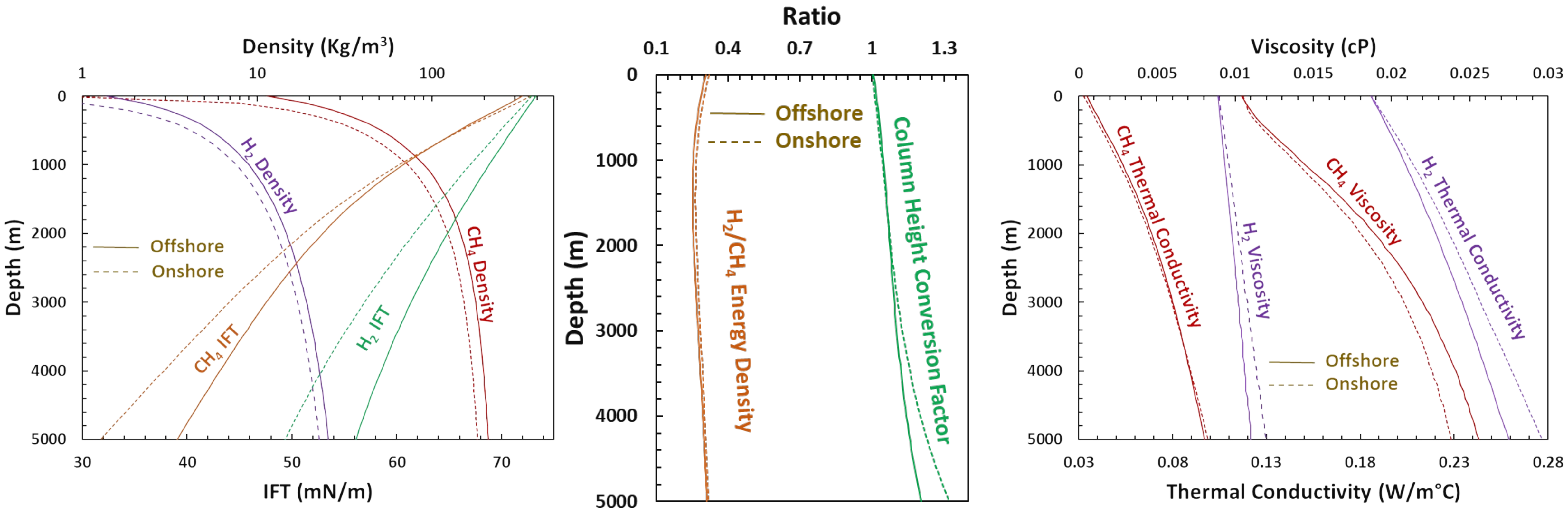
https://github.com/aliakbarhssnpr/H2CapEs

H_2 vs Natural Gas: Physical Properties



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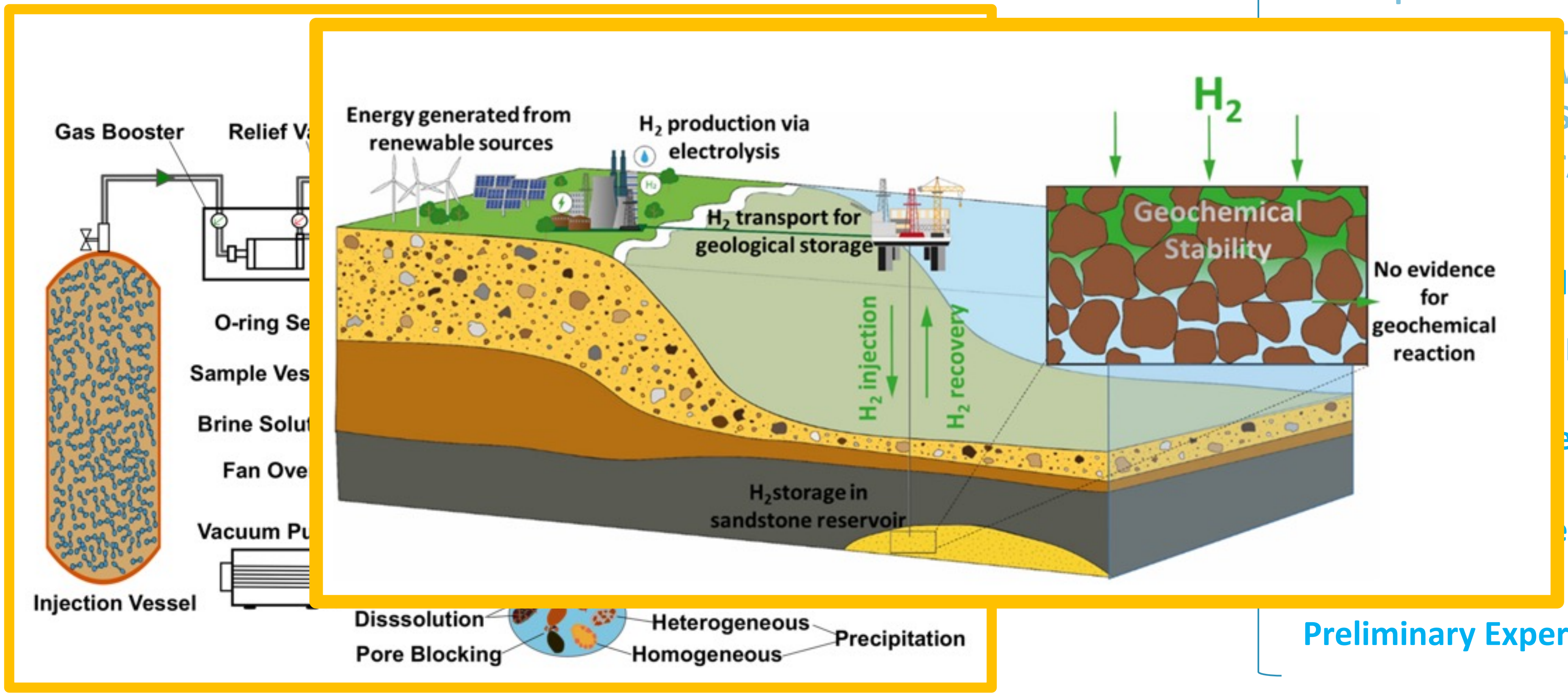
Geo-Chemistry Experiments



Over 300 experiments

4 Different Sandstones

Temperatures: 50-80 ° C

-20 Mpa

weight% NaCl

Sizes

/Rock Ratios

les from Rough field

Reservoir Condition

e

es

Preliminary Experiments Pure Minerals

Hassanpouryouzband et al. "Geological hydrogen storage: Geochemical reactivity of hydrogen with sandstone reservoirs“ Under-review

Thank you!

ACS Energy Letters

http://pubs.acs.org/journal/aelccp

Offshore Geological Storage of Hydrogen: Is This Our Best Option to Achieve Net-Zero?

Cite This: ACS Energy Lett. 20[redacted]1, 6, 2181–2186

Read Online

Aliakbar Hassanpouryouzband*, Edris Joonaki, Katriona Edlmann*, and R. Stuart Haszeldine

www.nature.com/scientificdata

SCIENTIFIC DATA

OPEN

DATA DESCRIPTOR

Thermodynamic and transport properties of hydrogen containing streams

Aliakbar Hassanpouryouzband[1]✉, Edris Joonaki[2], Katriona Edlmann[1]✉, Niklas Heinemann[1] & Jinhai Yang[3]

Geological hydrogen storage: Geochemical reactivity of hydrogen with sandstone reservoirs

Aliakbar Hassanpouryouzband[1*#], Kate Adie[1], Trystan Cowen[1], Eike M Thaysen[1], Niklas Heinemann[1], Ian B. Butler[1], Mark Wilkinson[1], Katriona Edlmann[1*]

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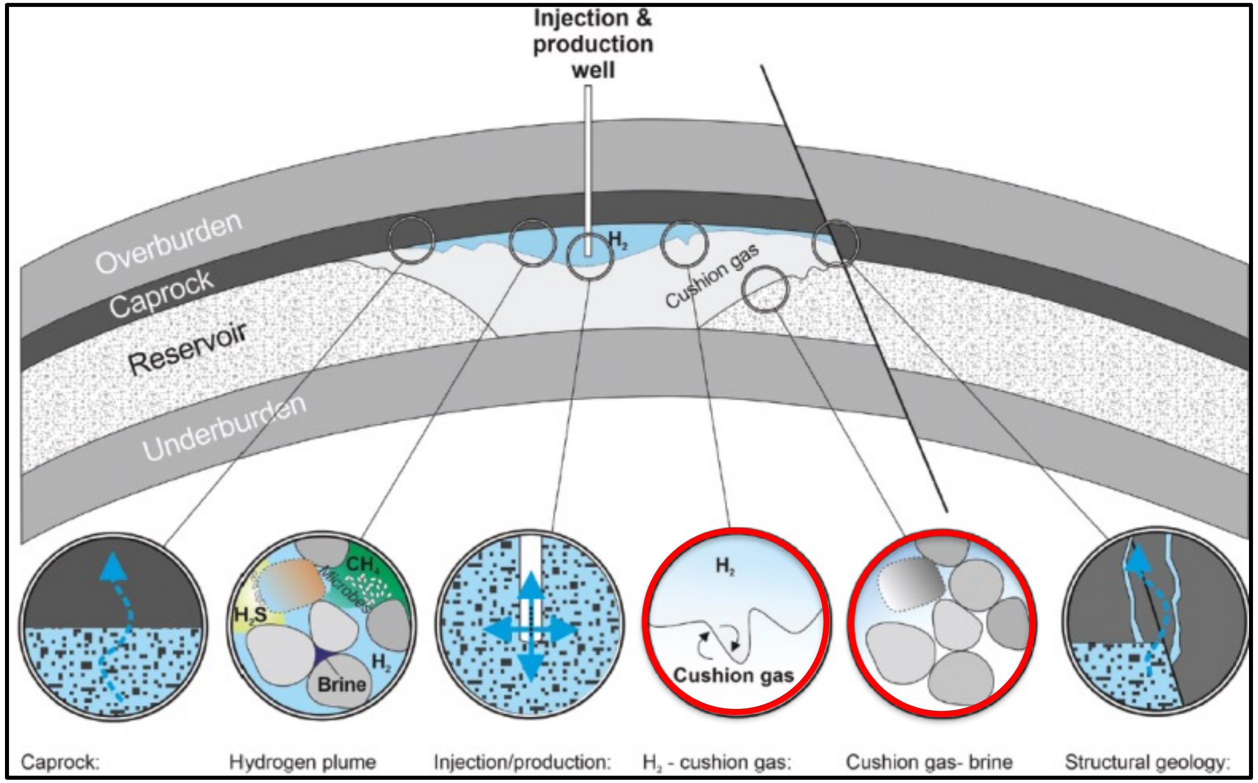
Understanding the role of cushion gas in subsurface hydrogen storage



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Heinemann et al. 2021: https://doi.org/10.1039/D0EE03536J

Special thanks to the HyStorPor team, Computer Modelling Group and CGG for their ongoing support.

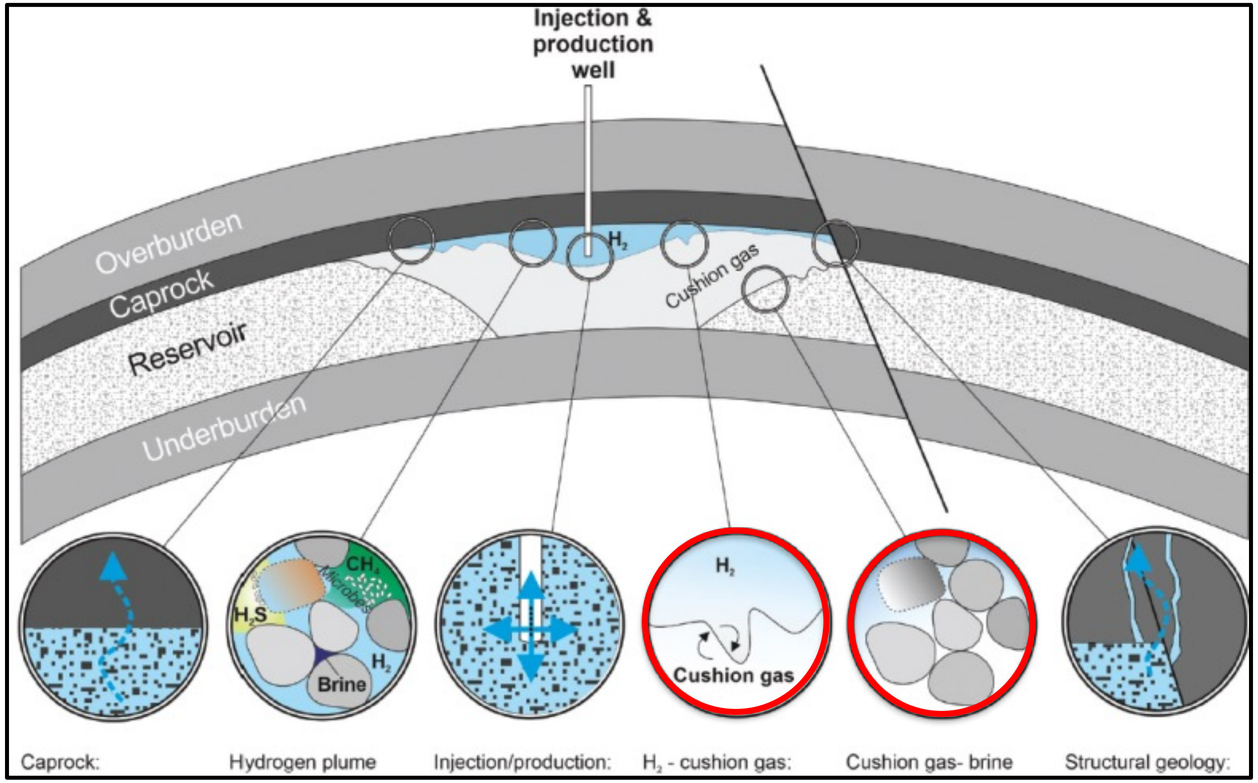
Cushion Gas (CG) in Porous Media and Cavern Storage

Porous media / salt cavern storage:

- **CG is standard practice in gas storage**
- **Operational pressure maintenance**
- **Protect the site / protect the well**
- **Alternative CG – CO_2 and N_2?**

Porous media storage:

- **Optimisation of porous media storage**



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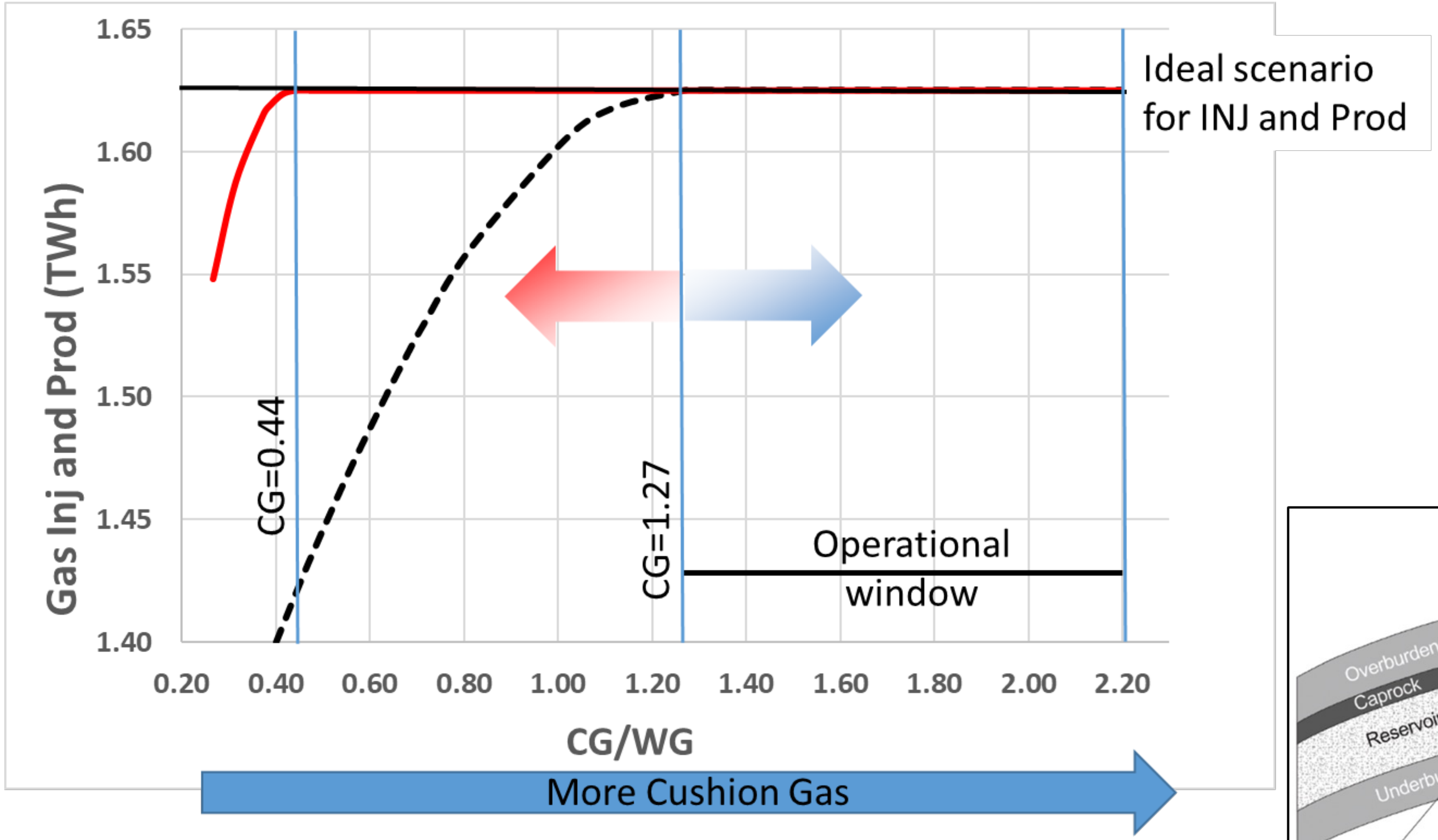
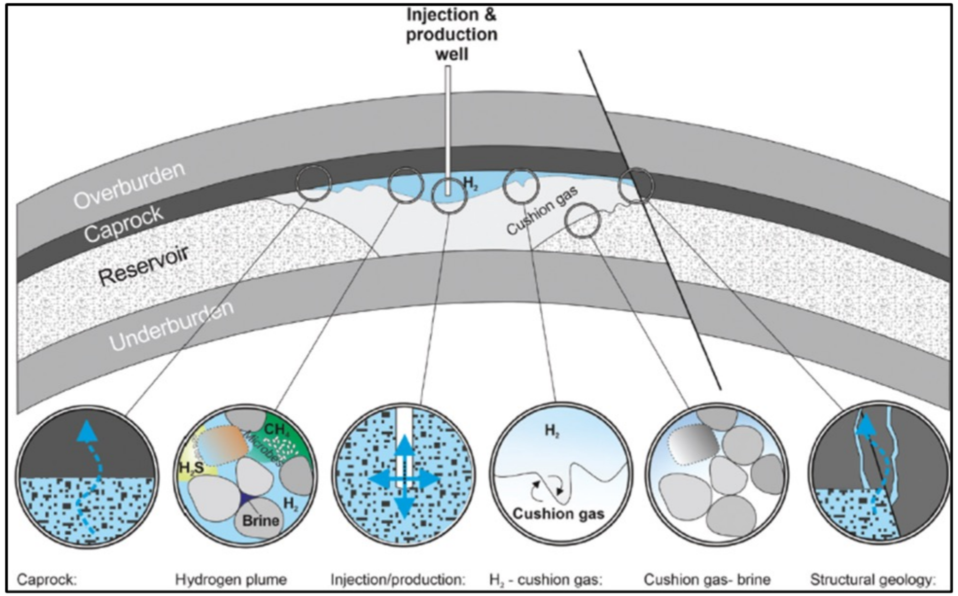


Storage modelling in open saline aquifers (modified from Heinemann et al. 2021)

Will Inj/Prod change with CG requirement? "YES"



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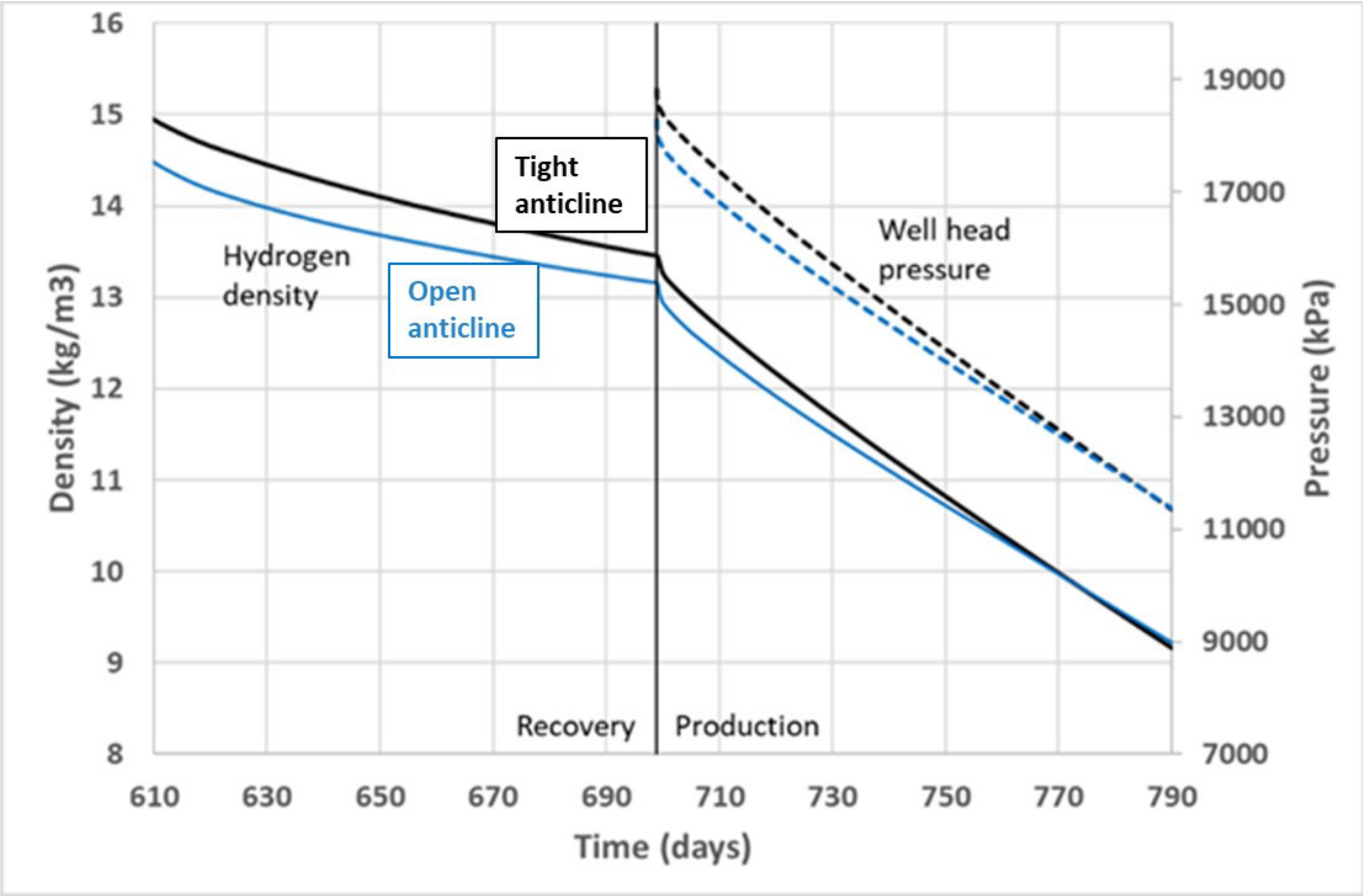
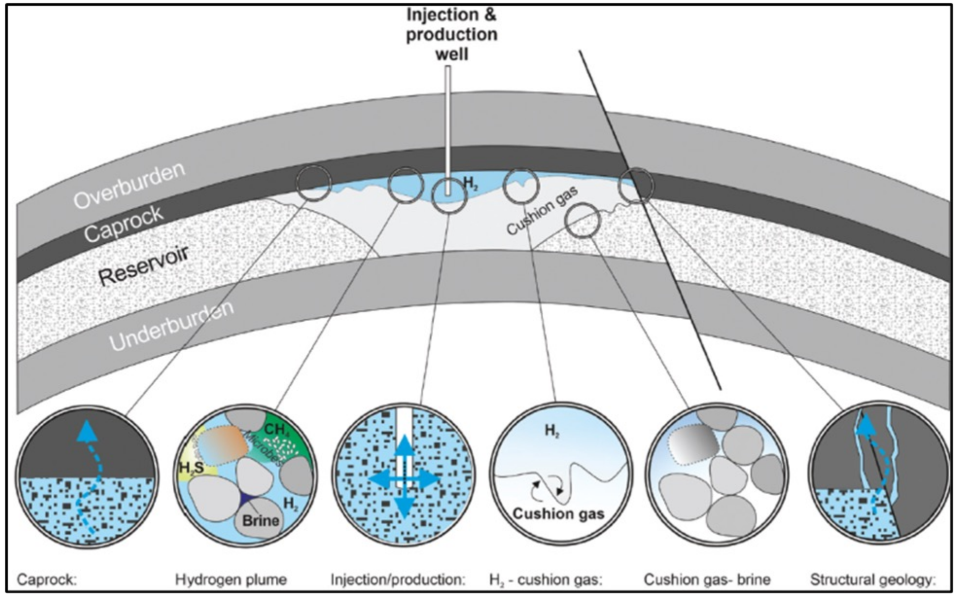


Storage modelling in open saline aquifers (Heinemann et al. 2021)

Will Geology change the CG requirement? "YES"



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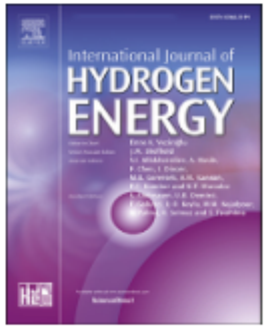

Hydrogen storage in saline aquifers: The role of cushion gas for injection and production

Check for updates

N. Heinemann [a,*], *J. Scafidi* [a], *G. Pickup* [b], *E.M. Thaysen* [a], *A. Hassanpouryouzband* [a], *M. Wilkinson* [a], *A.K. Satterley* [c], *M.G. Booth* [c], *K. Edlmann* [a], *R.S. Haszeldine* [a]

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Thank you!

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- Dr Aliakbar Hassanpouryouzband - hssnpr@ed.ac.uk
- Dr Niklas Heinemann - N.Heinemann@ed.ac.uk

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