Microbial risks in hydrogen storage in porous media

Eike Marie Thaysen, PhD Biogeochemistry

eike.thaysen@idaea.csic.es
Microbial risk in UHS

- Energy generated from renewable sources
- H₂ production via electrolysis
- H₂ transport for geological storage
- H₂ injection
- H₂ recovery
- H₂ storage in sandstone reservoir
- H₂ loss
- Biofilm → clogging (injectivity, recovery)
- H₂S production
- Corrosion
Microbial processes using H₂

- Methanogenesis
  - \( \frac{3}{2} \text{HCO}_3^- + \text{H}_2 + \frac{3}{2} \text{H}^+ \rightarrow \frac{1}{2} \text{CH}_4 + \frac{3}{2} \text{H}_2\text{O} \)

- Denitrification
  - \( \frac{3}{2} \text{NO}_3^- + \text{H}_2 + \frac{3}{2} \text{H}^+ \rightarrow \frac{1}{2} \text{N}_2 + 1\frac{1}{2} \text{H}_2\text{O} \)

- Iron(III) reduction
  - \( 2\text{FeOOH} + \text{H}_2 + 4 \text{H}^+ \rightarrow 2\text{Fe}^{2+} + 4\text{H}_2\text{O} \)

- Cr, Mn, V, Tc, U, As, Co, Se reduction
  - \( \frac{1}{3} \text{CrO}_4^{2-} + \frac{1}{2} \text{H}_2 + 5/3 \text{H}^+ \rightarrow \frac{1}{3} \text{Cr}^{3+} + 4/3 \text{H}_2\text{O} \)

- Sulfur species reduction (SSR)
  - \( \text{H}_2 + \text{S} \rightarrow \text{H}_2\text{S} \)
  - \( \frac{1}{3} \text{SO}_4^{2-} + \frac{1}{2} \text{H}_2 + \frac{4}{3} \text{H}^+ \rightarrow \frac{1}{3} \text{HS}^- + \frac{2}{3} \text{H}_2\text{O} \)

- Halogenated compounds + H₂ → dehalogenated compounds + 2HCl

- Fumarate reduction
  - \( \text{H}_2 + \text{fumarate} \rightarrow \text{succinate} \)

- Dehalorespiration

- Aerobic H₂ oxidation
  - \( \text{H}_2 + \frac{1}{2} \text{O}_2 \rightarrow \text{H}_2\text{O} \)

- Homoacetogenesis
  - \( \frac{1}{3} \text{HCO}_3^- + \text{H}_2 + \frac{4}{3} \text{H}^+ \rightarrow \frac{1}{4} \text{CH}_3\text{COO}^- + \frac{1}{2} \text{H}_2\text{O} \)
Methodology

• Creation of a microbial risk register based on a novel collection of microbial growth constraints (incl. DIRB)

• Collection of temperature and salinity data for 75 DGF on the UK continental shelf

• GIS-mapping of suitability for hydrogen storage in terms of the risk of adverse microbial effects

• Overlaying of the microbial risk register with data on wind and solar operational capacities as well as offshore gas and condensate pipeline infrastructure to optimize geographical centers of green hydrogen production, transport infrastructure and underground storage
Amplification of collection of microbial strains

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 have reduced risk for adverse microbial effects.

Storing H₂ >55 °C and >1.7 mol L⁻¹ NaCl reduces the risk of H₂ loss.

Thaysen et al., 2023, Microbial risk assessment for underground hydrogen storage in porous rocks
Microbial risk site screening of UKCS gas fields

- **No risk**: fields with a temperature $>$122°C can be considered as sterile, as no $\text{H}_2$ 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 $\text{H}_2$ consuming bacteria can grow in this combination. 22 UKCS gas fields

- **High risk**: fields $<$55°C 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*
Alignment with centres for renewable energy production

**Largest capacities** for renewable electricity production from offshore windfarms can be found in the SNS and NNS.

Only the SNS holds ‘no risk’ or ‘low risk’ depleted gas fields that are connected up to windfarms.

*Thaysen et al., 2023, Microbial risk assessment for underground hydrogen storage in porous rocks*
Alignment with not-in-use pipelines

Southern North Sea holds many not-in-use pipelines which could be repurposed for H₂ transport to ‘no risk’ or ‘low risk’ depleted gas fields.

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

• 9 DGT are ’no risk’
• 35 DGF are ‘low risk’
• 22 fields are ‘medium risk’
• Alignment with wind farms and out-of-use pipelines suggests that No Risk or Low Risk DGF in the SNS are the most suitable candidates for H₂ storage

may be considered as potential H₂ storage sites after careful evaluation of the microbial community
Microbial risk assessment for underground hydrogen storage in porous rocks

Eike M. Thaysen a, b, Timothy Armitage a, Lubica Slabon a, Aliakbar Hassanpouryouzband a, Katriona Edlmann a, *

a School of Geoscience, Grant Institute, The King’s Buildings, The University of Edinburgh, James Hutton Road, Edinburgh EH9 3FE, United Kingdom
b Department of Geosciences, Institute of Environmental Assessment and Water Research (IDAE), Severo Ochoa Excellence Center of the Spanish Council for Scientific Research (CSIC), Jordi Girona 18-26, 08034 Barcelona, Spain

ARTICLE INFO

Keywords: Hydrogen, Geological storage, Adverse microbial effects, Risk analysis

ABSTRACT

Geological hydrogen storage, e.g. in depleted gas fields (DGF), can overcome imbalances between supply and demand in the renewable energy sector and facilitate the transition to a low carbon emissions society. A range of subsurface microorganisms utilise hydrogen, which may have important implications for hydrogen recovery, clogging and corrosion. We gathered temperature and salinity data for 75 DGF on the UK continental shelf and identified correlations with the following measured parameters: water depth, salinity, pH, T, and log_10 of the hydrogen production rate. A Mann-Whitney U test was applied to determine if the differences in microbial production rate were significant. The results show that hydrogen production rates are significantly different between the two groups with a p-value of 0.0001. The study highlights the need for further research to understand the microbial processes involved in hydrogen storage.