HyStorPor Project
Hydrogen Storage in Porous Rocks

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Energy sources in the EU

Production of primary energy, EU-28, 2017 (% of total based on tonnes of oil equivalent)

- 29.9% renewable energy
- 16.4% nuclear energy
- 13.6% other
- 8.8% natural gas
- 3.5% solid fossil fuels
- 27.8% crude oil

Progress had been made in reducing emissions from electricity by increased renewables

Only 57.7% of EU energy sources can be considered zero carbon

Hydrogen can replace natural gas, crude oil and solid fuels for heat and power generation and decarbonising transport to decarbonise the remaining 42.3% energy sources

Hydrogen can increase uptake of renewables by providing energy storage, balancing supply and demand

Data source: https://ec.europa.eu/eurostat
### Hydrogen production

#### Blue hydrogen
- Methane steam reformation.
- 96% hydrogen currently produced this way.
- 7kg CO\textsubscript{2} for 1kg hydrogen.
- Requires **Carbon Capture and Storage (CCS)** to be low-carbon blue hydrogen.

#### Green hydrogen
- Electrolysis and renewable electricity.
- Currently 70-80% energy efficiency.
- 1kg hydrogen (40kWh/kg) requires 50-55 kWh electricity.
- ~30% new renewable electricity for hydrogen = sufficient in green hydrogen by 2050.

Renewable to hydrogen data courtesy of Julien Mouli-Castillo, University of Edinburgh
Hydrogen storage options

2,000,000 km 12” diameter pipe @70bar and 25C

40,000 Olympic swimming pool sized tanks @100bar / 25C

230 salt caverns

~1 large offshore field (Rough)

HyStorPor Project Goals

To identify if chemical and microbial reactions between the rock, fluids and hydrogen could compromise storage (Work Package 1)

To determine what flow processes will apply to hydrogen migration and trapping through the brine and gas filled reservoir and caprocks during injection and withdrawal (Work Package 2)

Undertake reservoir simulations to estimate what volumes of hydrogen can be stored and recovered from storage sites of varying scales (Work Package 3)

To clarify what citizens and opinion shapers think about hydrogen storage (Work Package 4)
Work Package 1: Chemical (and biological) reactions in the reservoir and seal

- Review key microbial processes and impact on the reservoir
- Reaction of hydrogen with rock and brine under reservoir temp and pressure
- Geochemical modelling & Benchmarking standard geochemical software
Microbial Reactions involving hydrogen: Learnings from town gas / nuclear waste industry

Hydrogenotrophic methanogenesis (archaea that grow on H₂ and CO₂ = methane)

\[
\frac{1}{3} \text{HCO}_3^- + \text{H}_2 + \frac{4}{3} \text{H}^+ \rightarrow \frac{1}{3} \text{CH}_4 + \frac{4}{3} \text{H}_2\text{O}
\]

Iron(III) reduction by chemotrophic bacteria that oxidise dissolved ferrous iron

\[2\text{FeOOH} + \text{H}_2 + 4\text{H}^+ \rightarrow 2\text{Fe}^{2+} + 4\text{H}_2\text{O}\]

Sulphur / sulphate reduction by bacteria to form hydrogen sulphide

\[\text{H}_2 + \text{S} \rightarrow \text{H}_2\text{S}\]

Acetogenesis (anaerobic bacteria reduce CO₂ to acetate using H)

\[\frac{1}{3} \text{HCO}_3^- + \text{H}_2 + \frac{4}{3} \text{H}^+ \rightarrow \frac{1}{3} \text{CH}_3\text{COO}^- + 2\text{H}_2\text{O}\]

Aerobic hydrogen oxidation (Knallgas bacteria oxidise H with O₂)

\[\text{H}_2 + \frac{1}{3}\text{O}_2 \rightarrow \text{H}_2\text{O}\]

Dehalorespiration by bacteria using halogenated compounds

Halogenated compounds + H₂ → dehalogenated compounds + 2HCl

Fumarate Respiration by eukaryotic organisms

\[\text{H}_2 + \text{fumarate} \rightarrow \text{succinate}\]

Denitrification (reduction of nitrate) by hydrogen oxidising bacteria

\[\frac{1}{3} \text{NO}_3^- + \text{H}_2 + \frac{4}{3} \text{H}^+ \rightarrow \frac{1}{3} \text{N}_2 + 1\% \text{H}_2\text{O}\]
Results of biological reactions of hydrogen: Review of studies for model input

Major \( \text{H}_2 \)-consuming processes in the subsurface where data are available:
- Methanogenesis
- Sulphate reduction
- Acetogenesis

\( \text{H}_2 \) consumption rates at excess \( \text{H}_2 \):
(2-180 \( \mu \text{M} \text{H}_2 \text{ d}^{-1} \text{ dm}^{-3} \text{ aquifer brine} \))

Microbial growth per mole \( \text{H}_2 \) consumed:
(0.2-1 g protein mole\(^{-1}\))

Volume increase in aquifer:
(0.02-0.4 mm\(^3\) bacterial biomass d\(^{-1}\) dm\(^{-3}\) aquifer brine)

Ranges for model:
Temperature: 20-100°C
Pressure: 1-50 MPa
Salinity: ~0-120 g L\(^{-1}\) NaCl

OpenGeoSys model

Protein content of cells:
(0.3-1*10\(^{-12}\) g protein cell\(^{-1}\))

Daily protein production:
(0.6-1*10\(^{-5}\) g protein day\(^{-1}\))

Daily cell increase:
(6-30*10\(^6\) cells day\(^{-1}\))

Cell volume:
(0.9-1.8 \( \mu \text{m}^3\))
Preliminary results of reactions of hydrogen with rock and brine

<table>
<thead>
<tr>
<th>The effect of sand to water ratio</th>
<th>• Higher sand to water ratio $\rightarrow$ more concentration of different component in water, and better repeatability.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repeatability</td>
<td>• Optimum sand to water ratio should be chosen to have repeatability of experiments. It depends on grain size / heterogeneity. If heterogeneous (higher grain size in our samples) need higher sand to water ratio</td>
</tr>
<tr>
<td>Boiled water</td>
<td>• No effect was observed</td>
</tr>
<tr>
<td>The effect of sand size</td>
<td>• Generally, smaller sand sizes demonstrate lower measured concentrations of various components. Until we get to the powder where the concentrations are significantly higher than even the larger sand sizes.</td>
</tr>
<tr>
<td>Effect of Salinity</td>
<td>• Higher salinities show increased concentrations of the different component in water except for Si.</td>
</tr>
<tr>
<td>The effect of sand sterilization</td>
<td>• No effect has been observed so far</td>
</tr>
<tr>
<td>The effect of Hydrogen</td>
<td>• Different effects have been observed for different sand types in the limited experiments so far - However, all experiments so far have shown significantly increased Ni and Fe concentrations for both sands.</td>
</tr>
</tbody>
</table>
Work Package 2: Flow behaviour of hydrogen

- Hydrogen flow properties
- First time imaging of hydrogen flow through porous rocks using X-ray CT.
- Characterising mass transport through porous rocks
- Recovery efficiency over multiple cycles of injection and withdrawal?
- Sealing of caprocks to hydrogen?
- Benchmarking for numerical modelling
Preliminary results of Hydrogen flow through different cushion gases

Point of pulse release

Hydrogen pulse through CO₂ cushion gas

Hydrogen pulse through Nitrogen cushion gas
Work Package 3: Numerical Simulation of Hydrogen Injection, Storage and Withdrawal

- Benchmarked simulations to experiments – calibrating numerical simulators to Hydrogen
- Understanding of the impact of different cushion gasses
- Assessment of optimal geological trapping structures
- Sensitivity of caprock integrity to injection and withdrawal conditions
- Storage development plans for two potential storage sites – small onshore / large offshore
Work Package 4: Public and Stakeholder Understandings

Clarify existing societal views towards energy-related subsurface storage in the UK, through baseline review of extant research;

Evaluate community and opinion-shaper visions of a low carbon society, and the role of hydrogen storage in porous media within these;

Elaborate pathways to the governance and deployment of hydrogen storage in porous media within UK society.
HyStorPor Project Set-up

**WP4: Public and Stakeholder Understandings**
Social Science and Public Interest

**WP2: Fluid Flow**

**WP3: Reservoir Simulation**

**WP1: Chemistry & Biology**

**Sites & Samples**

**WP5 Dissemination Pathways to Impact**
- Industry
- Government
- Researchers
- Papers
- Workshops
- Conferences
- Public
- NGO
- Policy