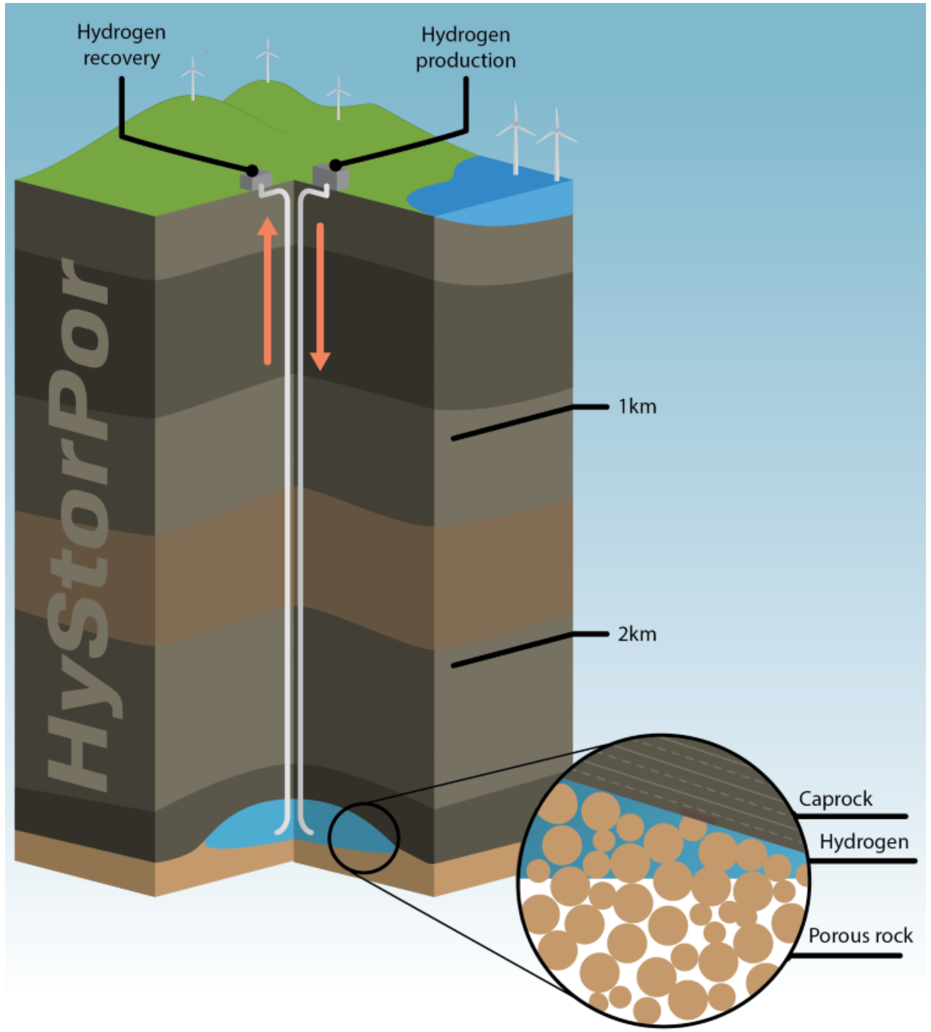
HyStorPor Hydrogen Storage in Porous Media

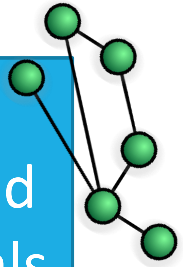


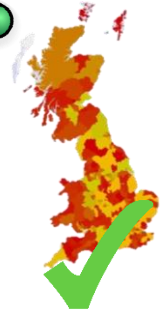
- To identify if **chemical and microbial reactions** between the rock, fluids, cushion gas and hydrogen could compromise storage
- To determine what **flow processes** will apply to hydrogen migration and trapping through the brine and gas filled reservoir and caprocks during injection and withdrawal
- Undertake **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/

Abundant Hydrogen Storage Offshore

100s of TWh of storage connected to UK gas terminals

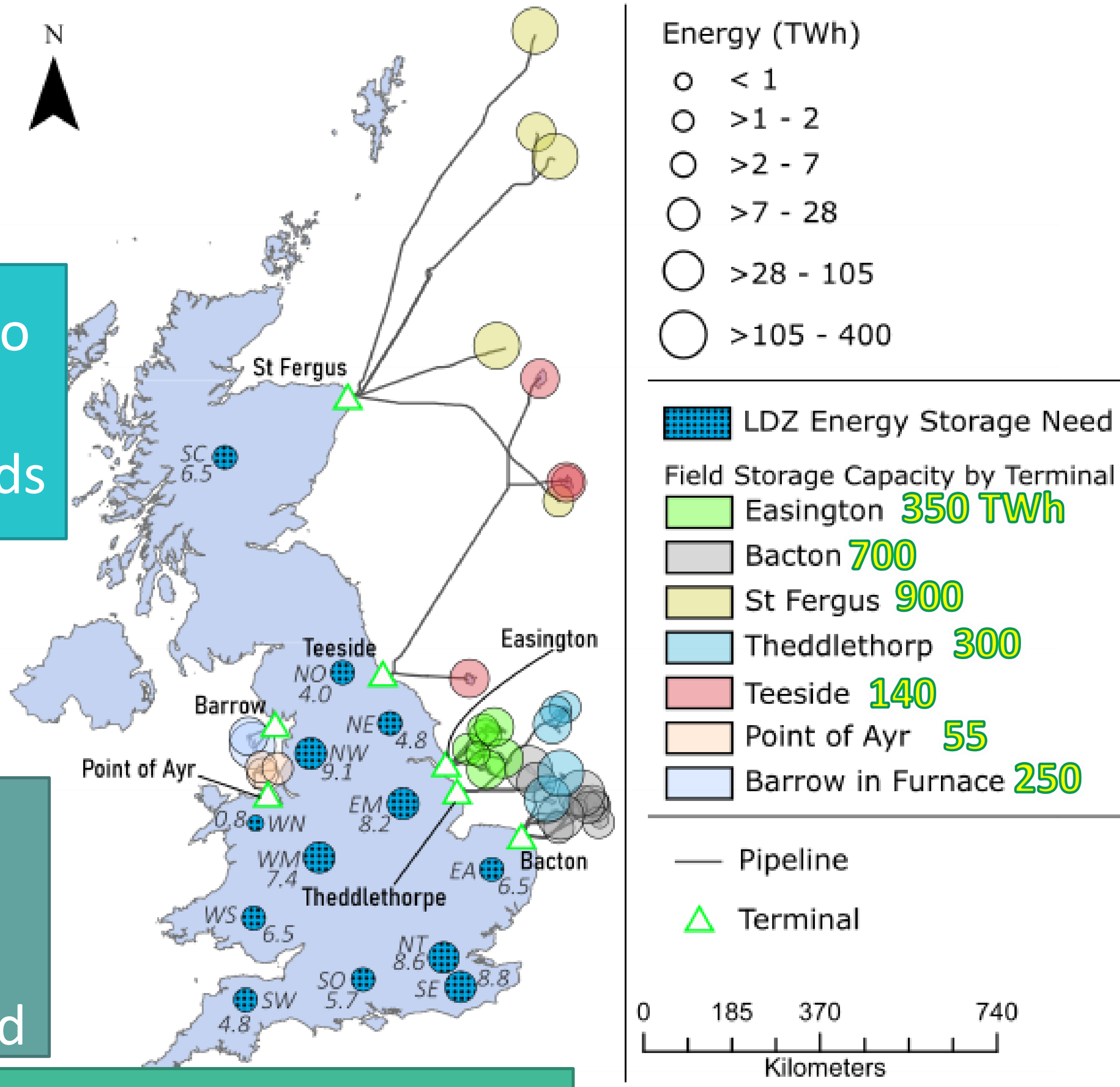




Enough capacity to store regional seasonal heat needs

Switching to hydrogen will reduce the storage capacity of existing salt caverns by about 2/3rd!

Some fields are large enough to store the UK's entire heat demand

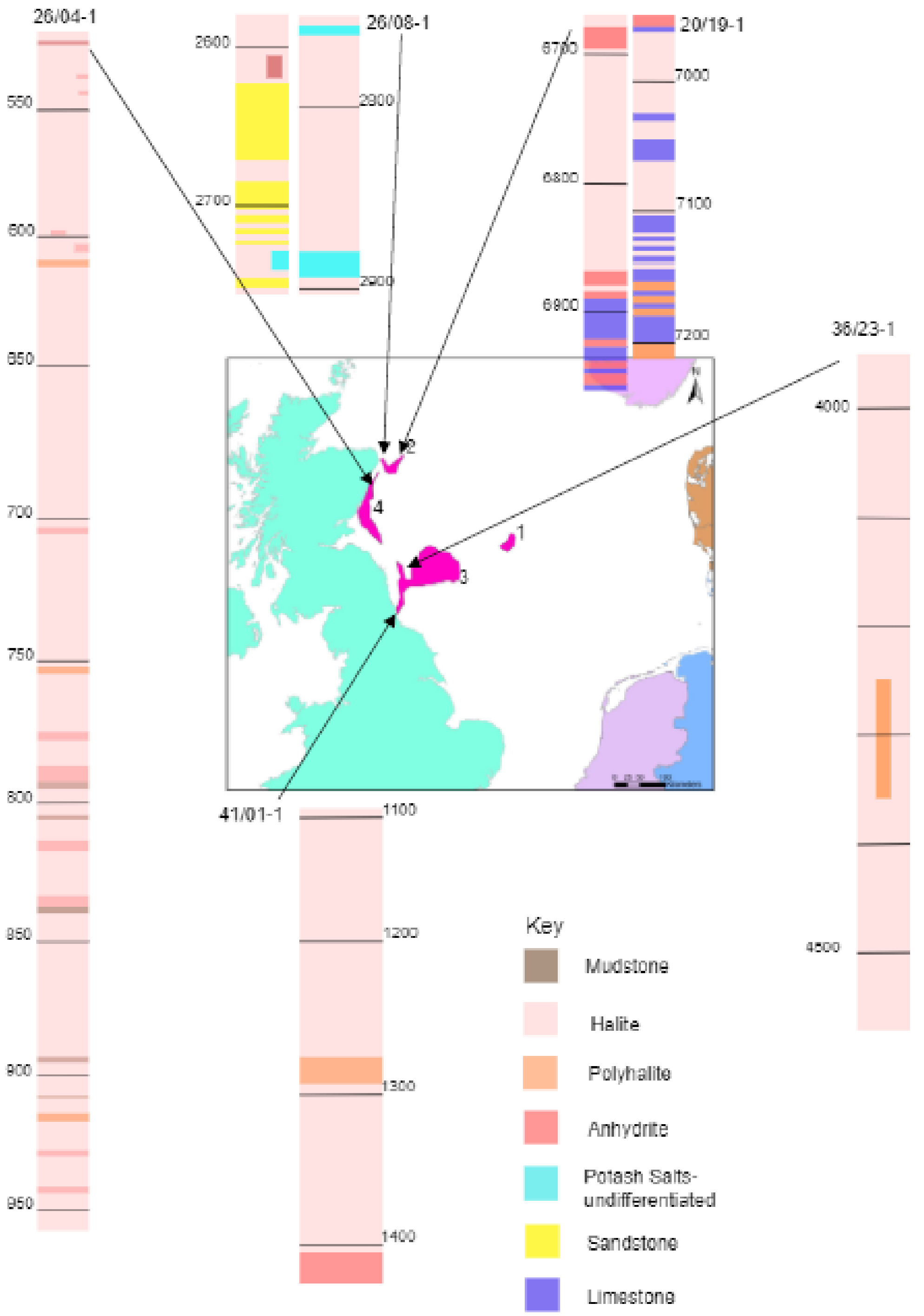


Contact: Julien Mouli-Castillo PhD. | Julien.moulicastillo@ed.ac.uk | 07456304430

Mouli-Castillo, Heinemann, Edlmann (2020)

UK offshore salt cavern storage potential

By Shannon Aitchison
for more information contact katriona.edlmann@ed.ac.uk



Salt integrity during hydrogen storage

- Investigate the physical and chemical effects of hydrogen on salt deposits
- Range of temperatures, pressures, formation fluid chemistries
- Investigate geochemistry changes
- Investigate mechanical changes
- Investigate diffusion and fluid flow

For more information please contact Katriona Edlmann katriona.edlmann@ed.ac.uk

Quantitative cost & emissions evaluation of electric and hydrogen road transport fuelling infrastructure for Scotland

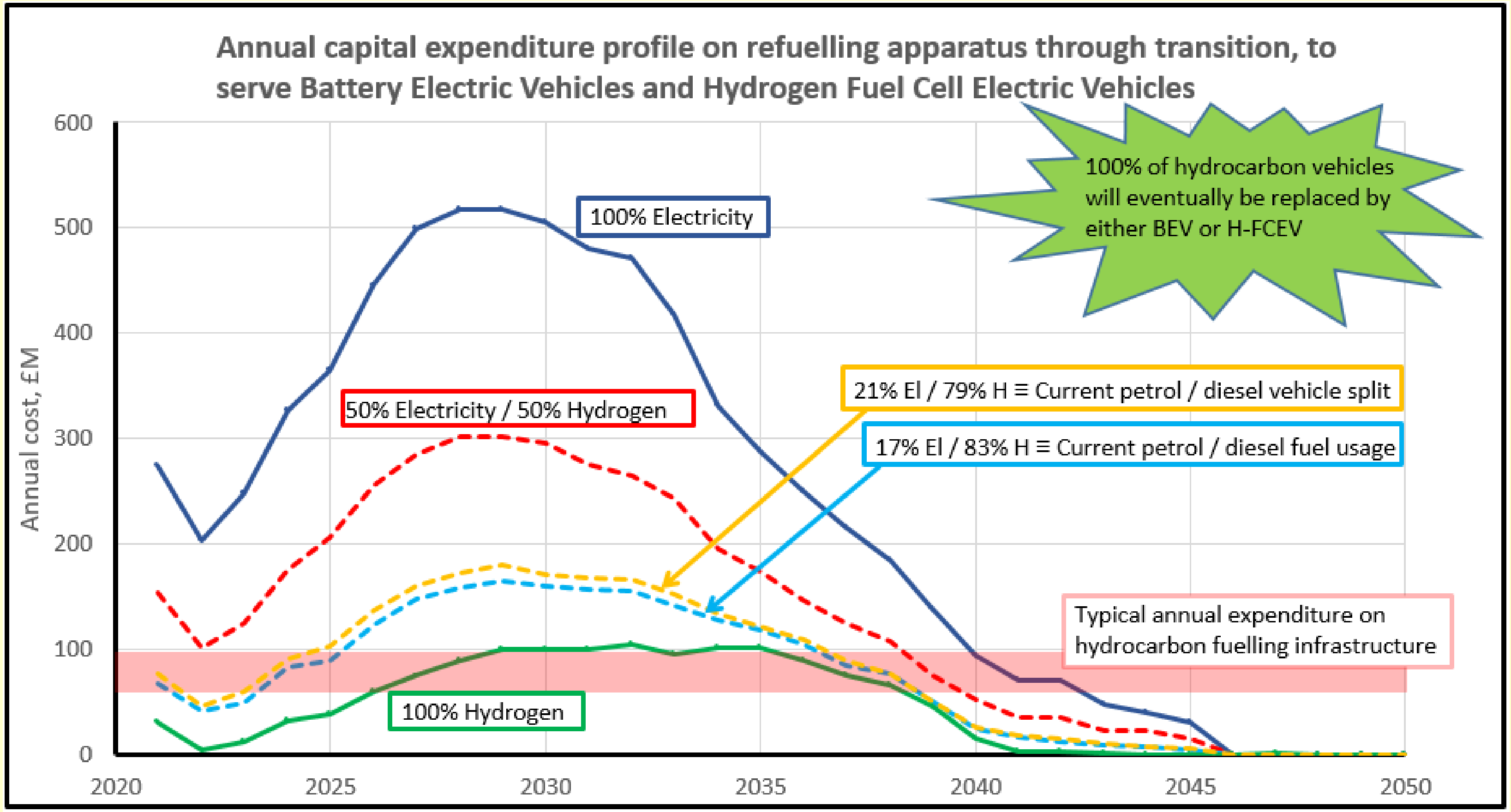
John M. Low
University of Edinburgh

Road transport is responsible for 26% of Scotland’s emissions

Road Transport Emissions:
Now: 10,000 kT CO_2 eq / year
Targets:
2030: 75% all-sectors reduction => 5,690kT for road transport.
2032: End hydrocarbon sales of cars & vans
2045: Net zero all-sectors => 1,207kT for road transport

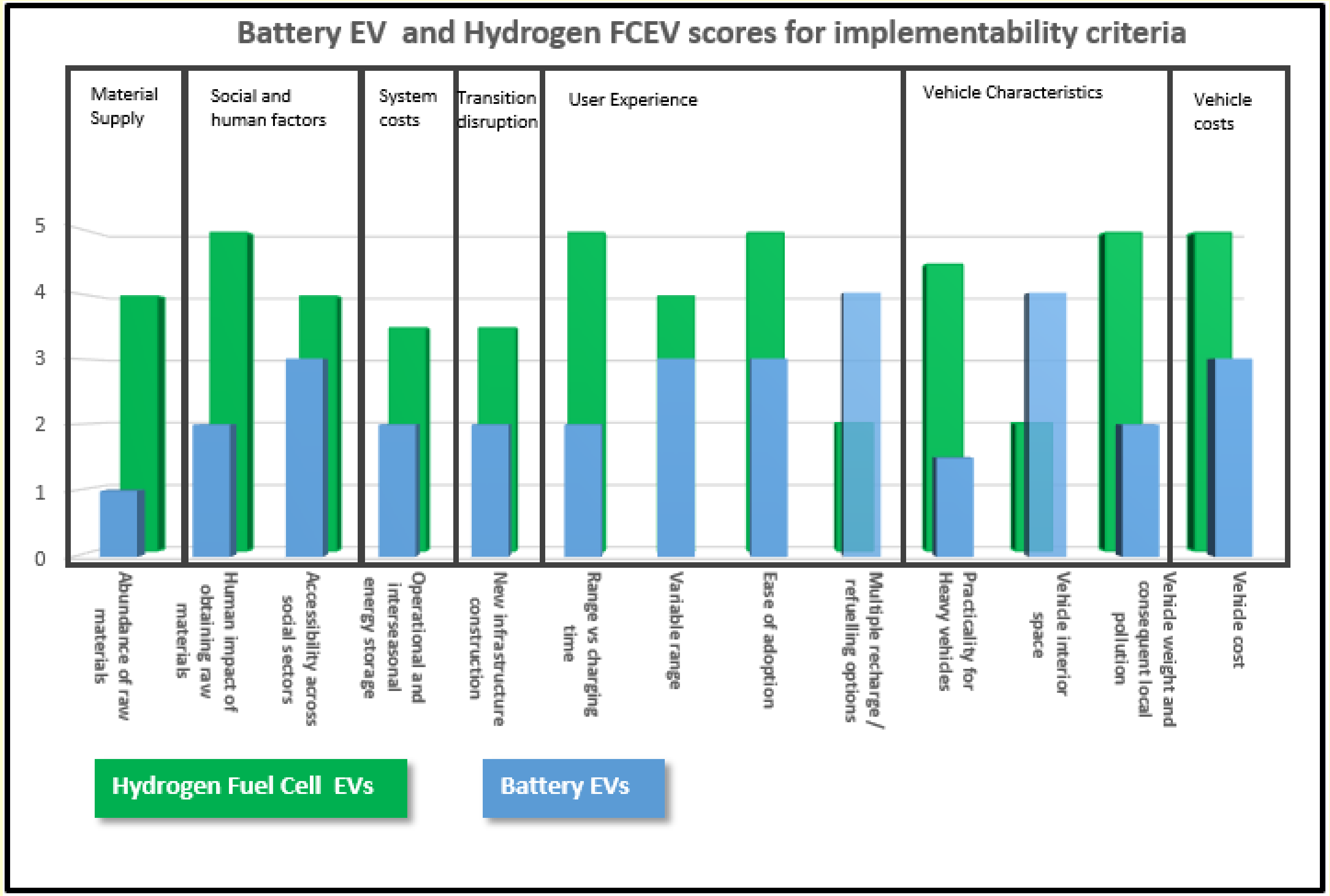
Expect enough renewable electricity to make enough green hydrogen and electricity for our needs

2030 emissions target met.
2045: effectively zero road transport emissions



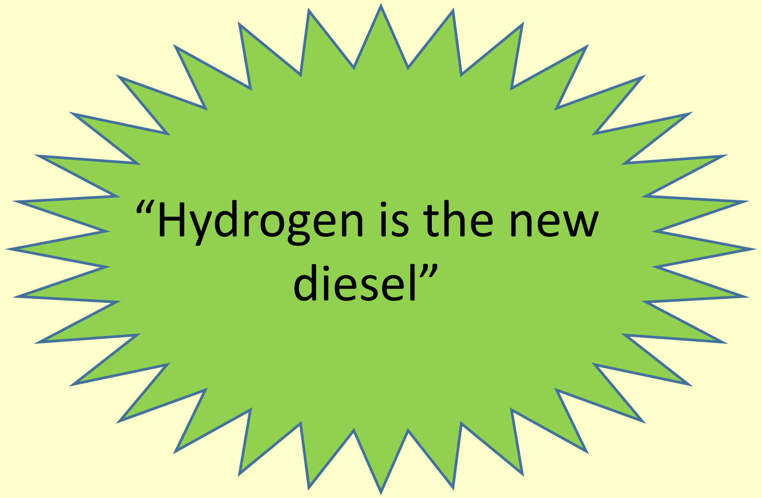
Usability comparison of battery electric and hydrogen fuel cell electric vehicles

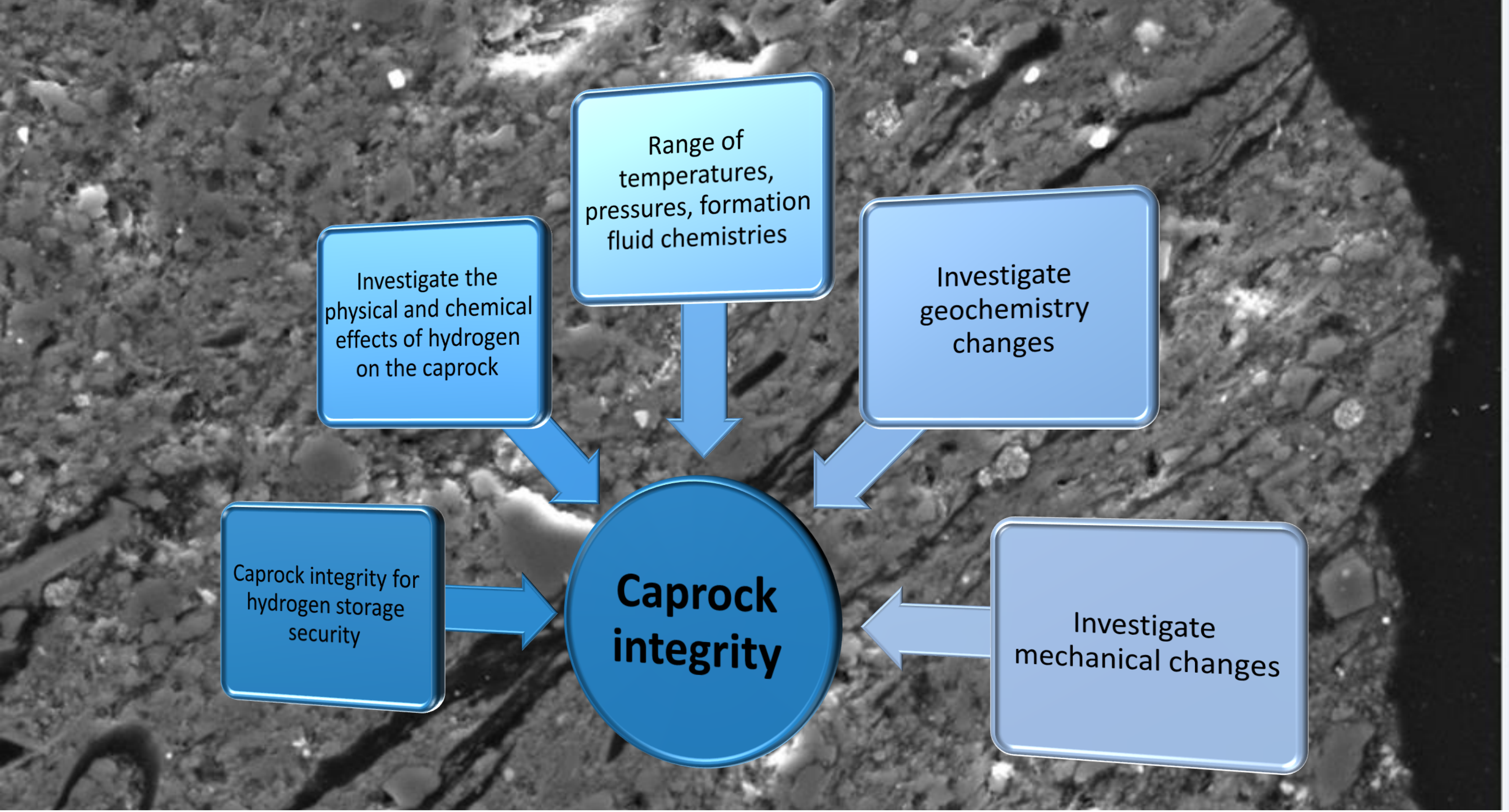
John M. Low
University of Edinburgh



General implications –

- Hydrogen is likely to be more beneficial for larger and longer range vehicles (comparable to diesel).
- Battery Electric likely to be of more benefit for urban or shorter range uses (comparable to petrol).

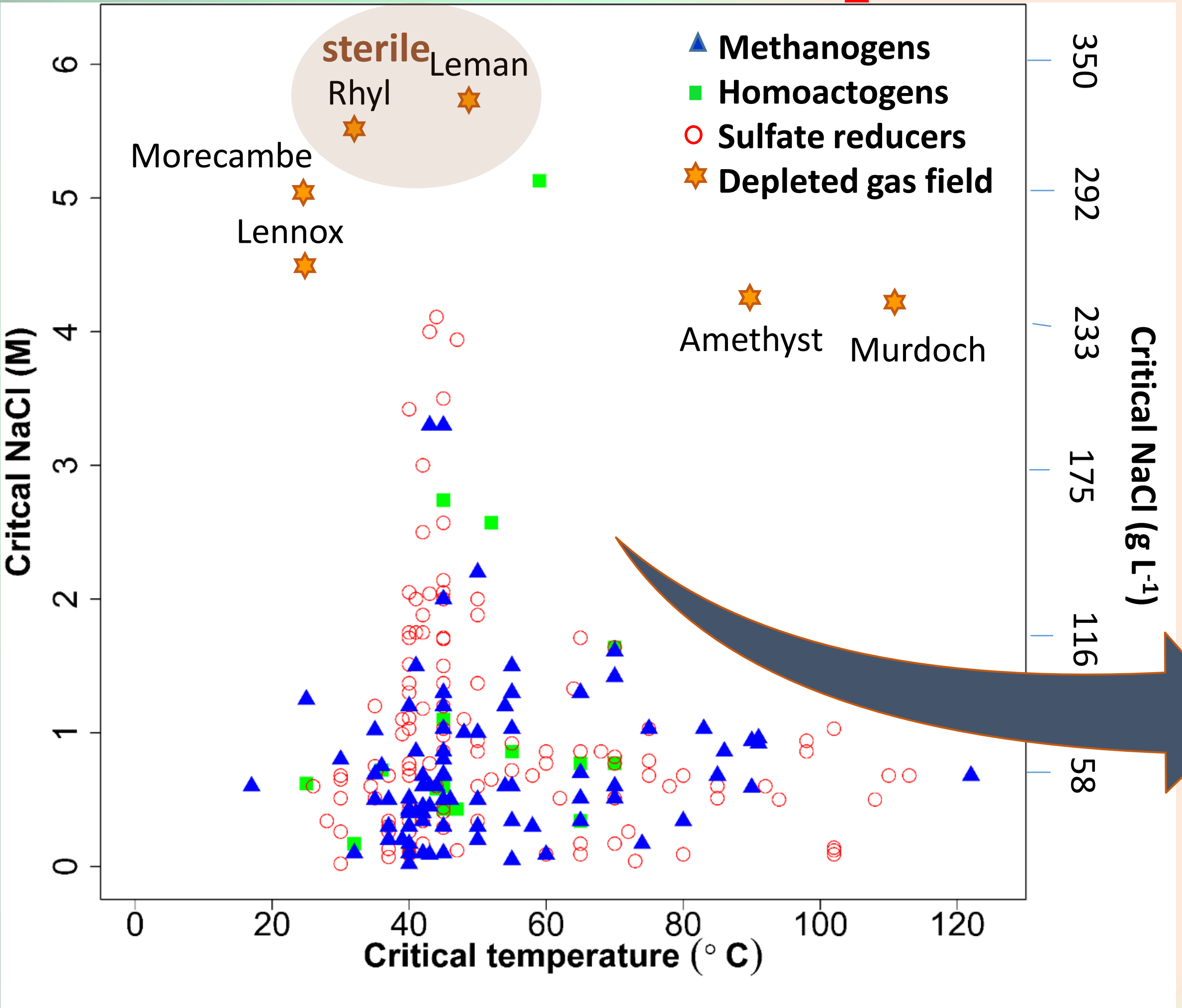


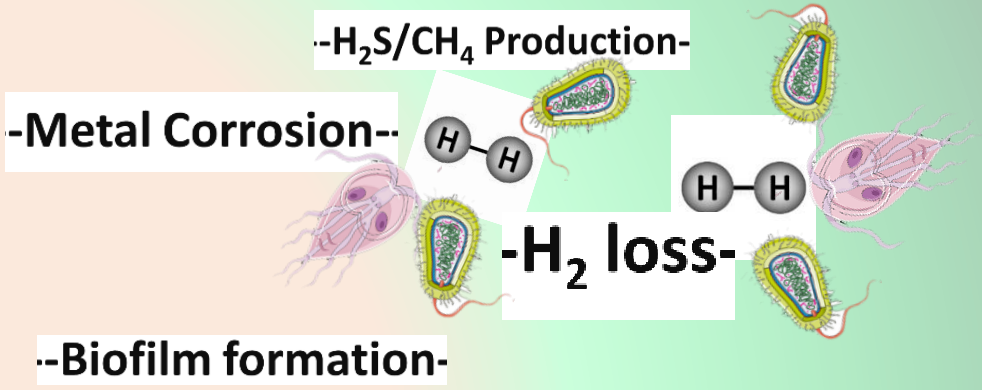


For more information please contact Katriona Edlmann katriona.edlmann@ed.ac.uk

Is microbial growth a concern for subsurface hydrogen storage?

Site selection tool for H_2 storage





Aquifers with **salinities > 5.1 M and >122 °C may be considered sterile**

Storing H_2 >60 °C and >1.7 mol L^{-1} NaCl reduces the risk of H_2 loss

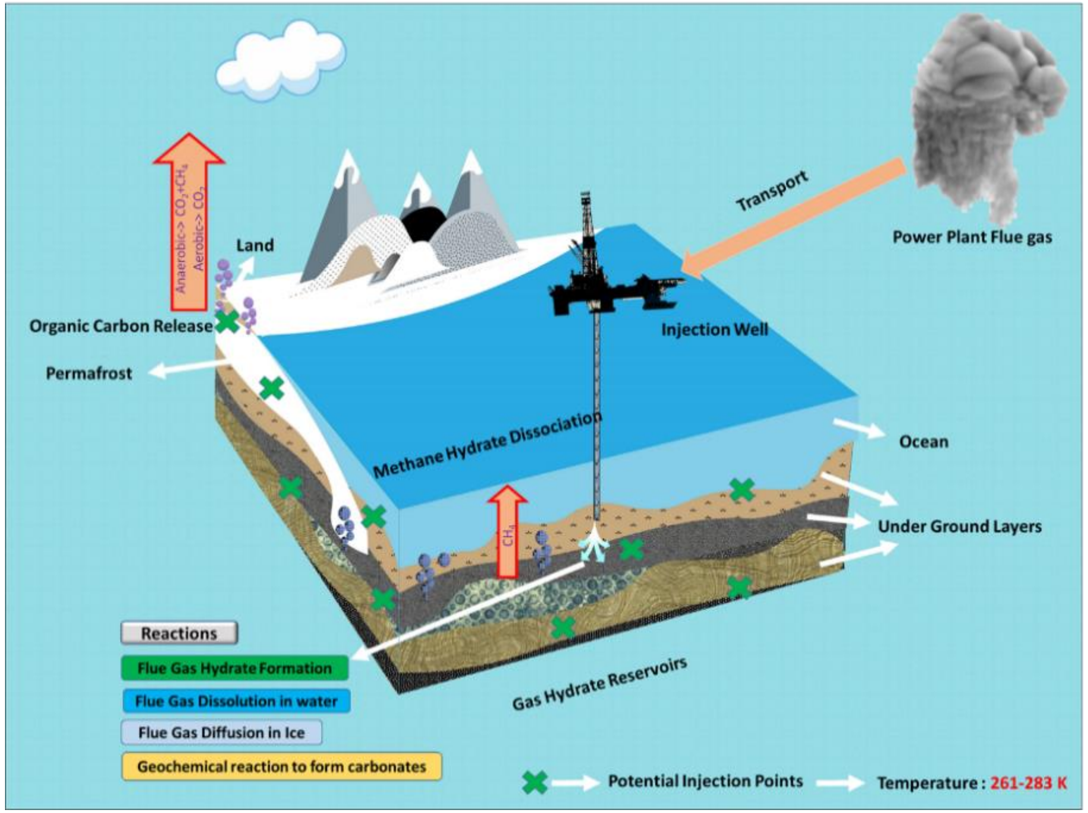
Testing our tool on 42 depleted gas fields showed that seven sites can be considered sterile

Interested? Please contact Eike Marie Thaysen *eike.thaysen@ed.ac.uk*

HyStorPor

HyStorPor

Geological CO_2 Capture and Storage with Flue Gas Hydrate Formation in Frozen and Unfrozen Sediments



Interested? Contact Ali at Hssnpr@ed.ac.uk

The increase in temperature in high-latitude regions of the Earth appears to be occurring **twice** as fast as the global average.

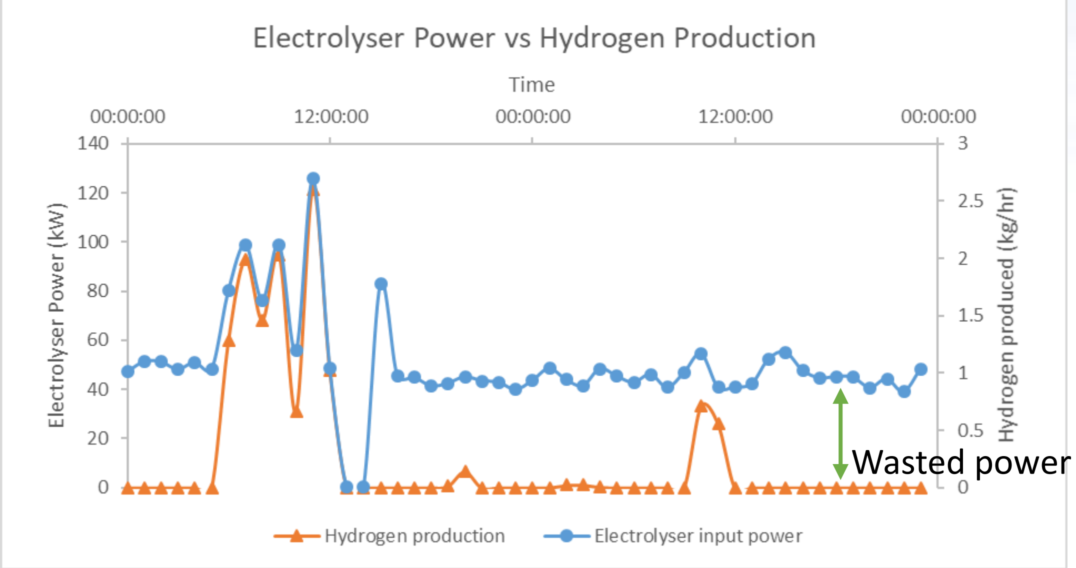
Hassanpouryouzband, A., Yang, J., Tohidi, B., Chuvilin, E.M., Istomin, V. and Bukhanov, B.A., 2019. Geological CO2 Capture and Storage with Flue Gas Hydrate Formation in Frozen and Unfrozen Sediments: Method Development, Real Time-Scale Kinetic Characteristics, Efficiency, and Clathrate Structural Transition. ACS Sustainable Chemistry & Engineering.

Maja Persson

Maja.Persson@ed.ac.uk

PhD project: "Local hydrogen production for energy storage and services"

- **Overview:** Project works with the data and learnings at Bright Green Hydrogen's Levenmouth Community Energy Project. A small-scale electrolytic hydrogen project that includes:
    - Wind energy
    - Solar energy
    - 250 kW PEM electrolyser
    - 100 kW fuel cell
    - Hydrogen energy storage
    - 2 hydrogen vehicle refuellers
    - 8 buildings
    - Hydrogen vehicle fleet



- Hot standby load of an electrolyser can be a major energy consumer for an electrolyser
- Important for control system to be carefully designed to:
    - Minimise time electrolyser is wasting energy being hot and ready but not producing hydrogen because of not enough renewable energy
    - Also make sure the electrolyser is ready when there is sufficient renewable energy

THE UNIVERSITY of EDINBURGH
School of Engineering | Institute for Energy Systems

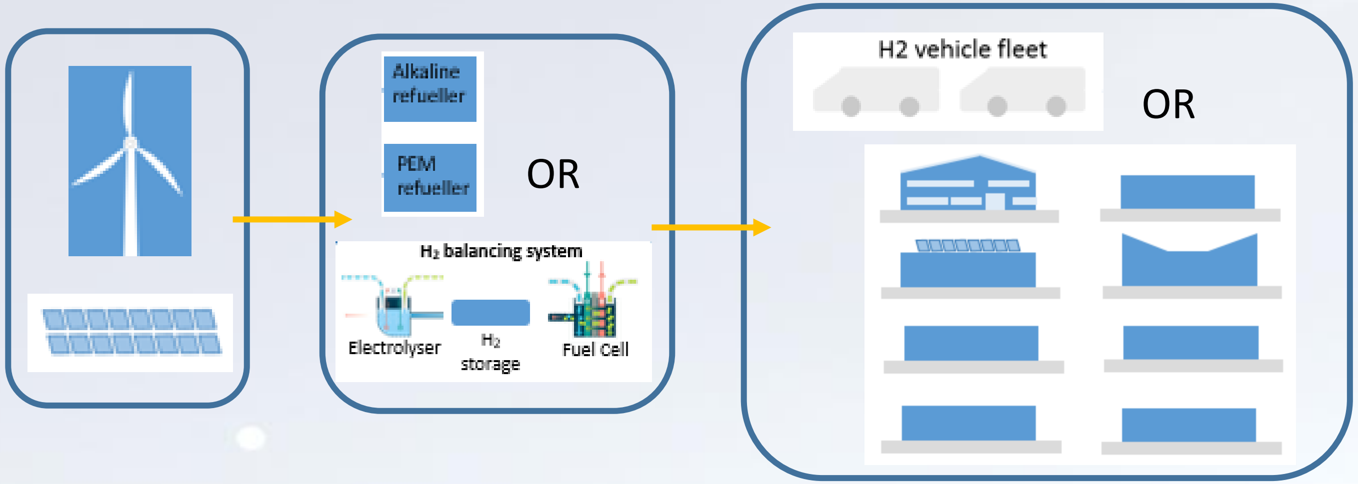
energy technology partnership

Bright Green Hydrogen

Maja Persson

Maja.Persson@ed.ac.uk

PhD project: “Local hydrogen production for energy storage and services”



- The computer model has explored different combinations of:
  - electrolyser capacity
  - renewable energy supply
  - vehicle demand
  - building demand
  - type of electrolysers
  - number of vehicle refuellers
  - number of end uses
  - hydrogen storage capacity
- Battery included to help electrolyser performance and economics

Every decision will impact the system’s Net Present Value, determining its feasibility

- A multi-purpose system means that the parts that are not prioritised for the renewable energy will struggle to operate well.
- Careful balancing of system will result in some improvement, but the user must decide what is the main purpose of the system.

Underground Hydrogen Storage: Abiotic Reservoir Reactions

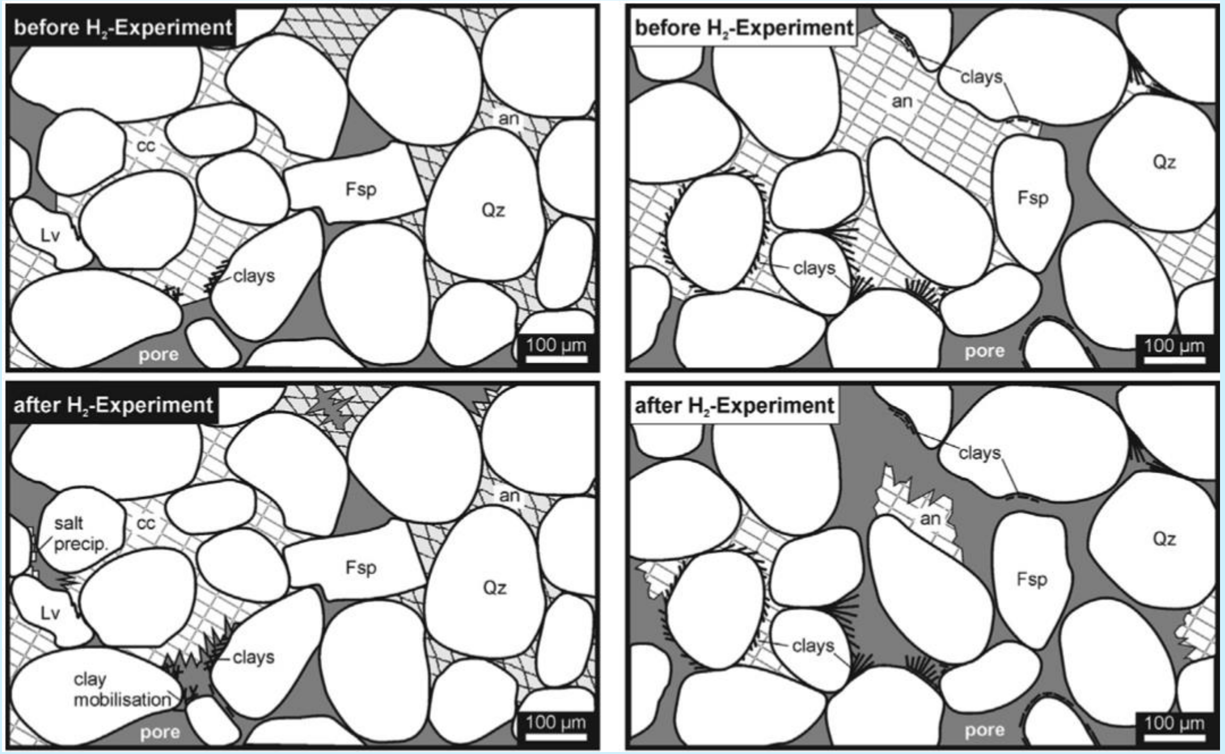
Kate Adie (MSc Geoenergy) | kate.adie@btinternet.com | 07805751014

1
wHy
Hydrogen
1.00794

THE PROBLEM: RESERVOIR REACTIONS

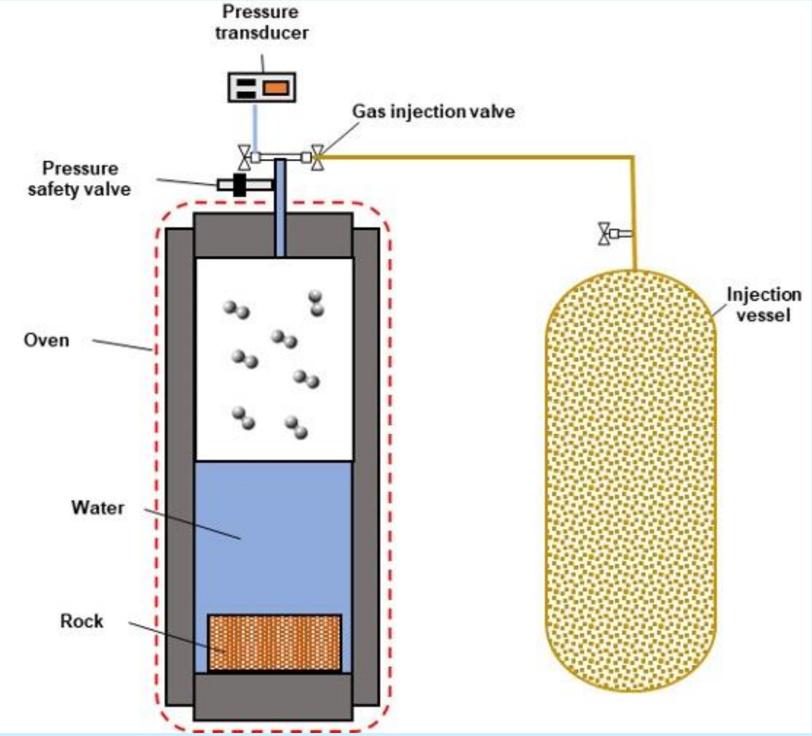
Geochemical reactions in porous hydrogen stores pose the threat of **alterations to the porous structure** of the reservoir and caprock and the **stored gas composition**.

Recent works suggest that **pyrite, calcite** and **anhydrite** may be **susceptible to alteration** in the presence of hydrogen, and that hydrogen may be susceptible to transformation by microbial communities.

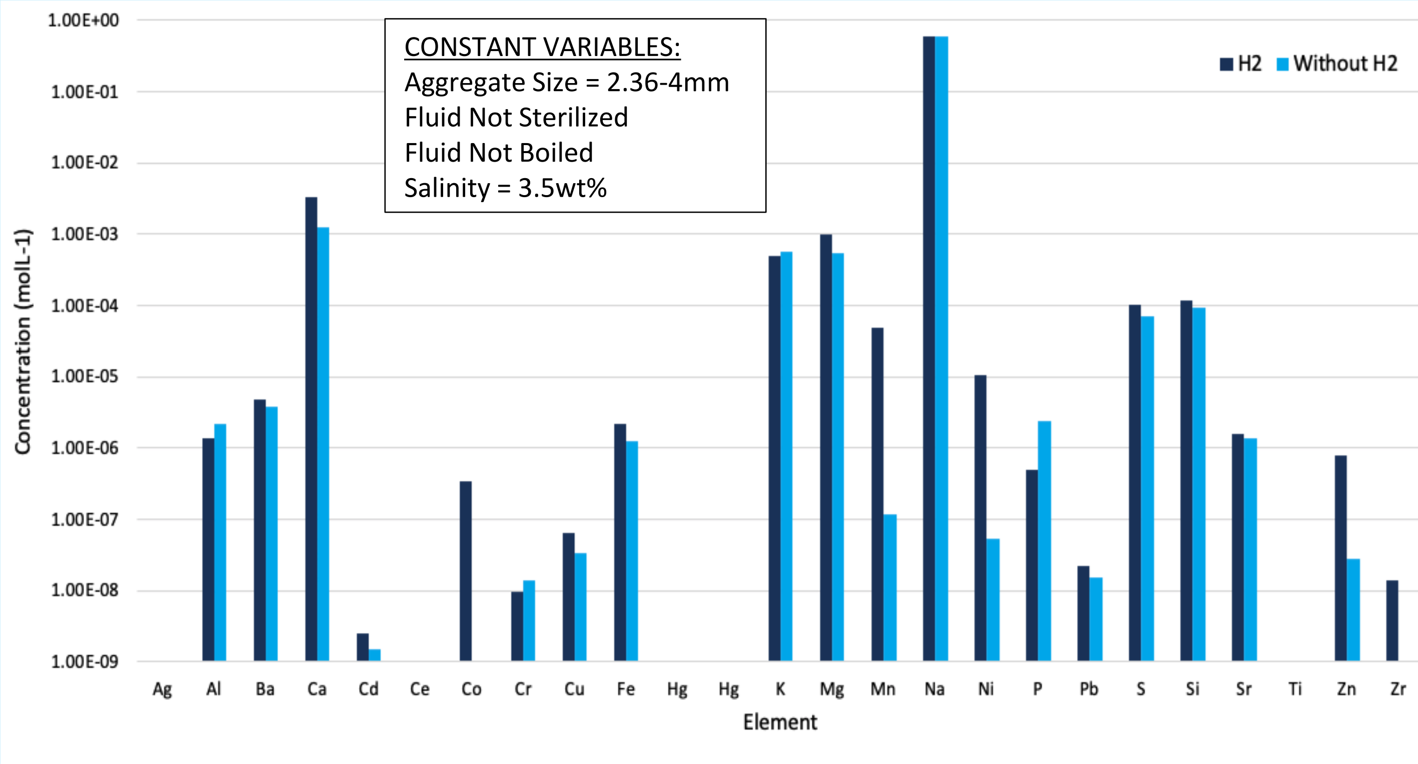


Schematic illustration of dissolution of calcite and anhydrite cements. *Source: Flesch et al., 2018*

EXPERIMENTAL RESULTS

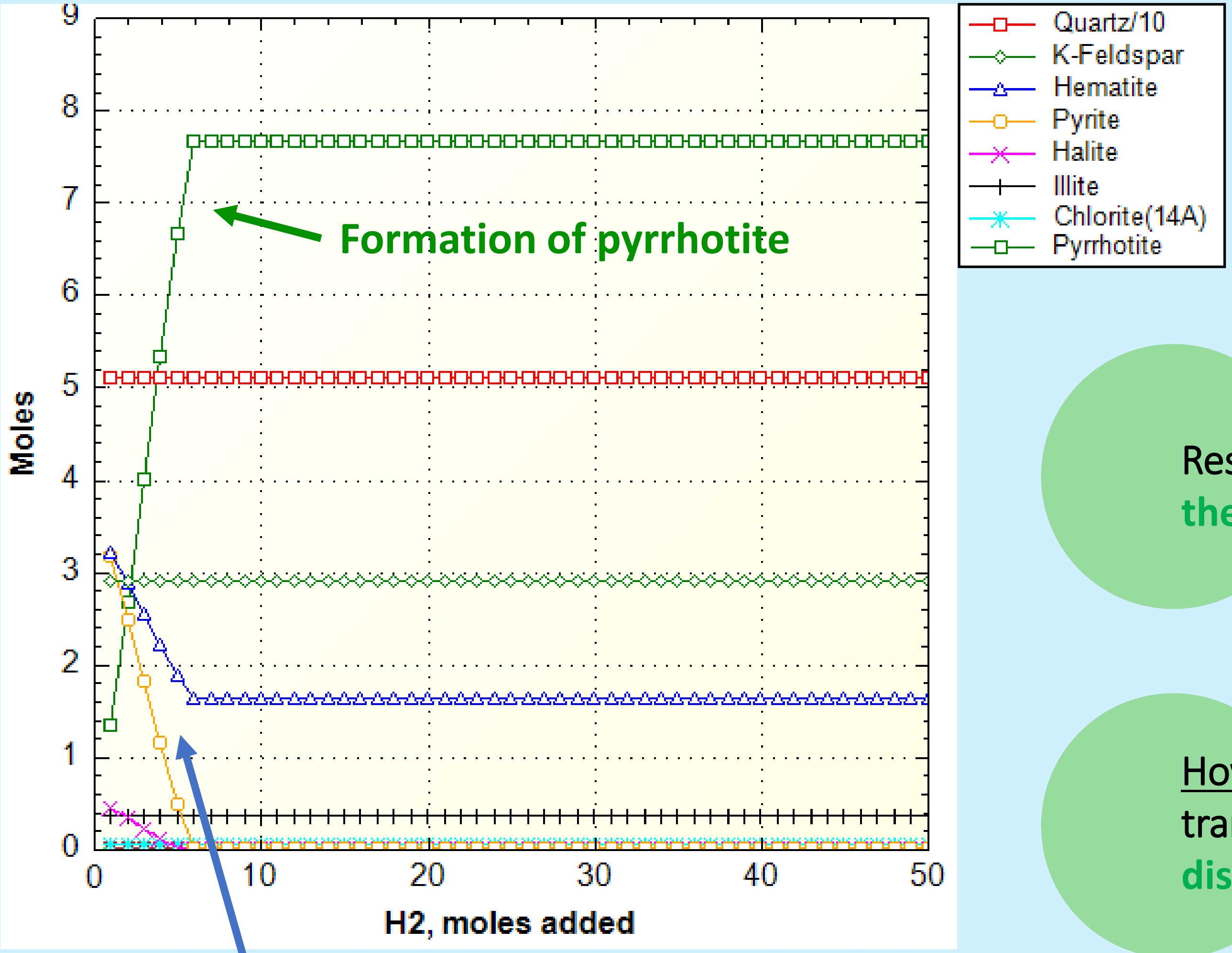


Static batch reaction experiments involving two (generic, aeolian Permian) quartz-dominated sandstone samples. ICP fluid analysis was investigated as a means of identifying hydrogen-water-rock reactions.



Results indicate negligible variations after exposure to hydrogen.

PHREEQC MODELLING RESULTS



Dissolution of Fe-bearing hematite and pyrite

PHREEQC was used to indicate the **thermodynamic stability** under **equilibrium conditions**, with increasing concentrations of hydrogen gas.

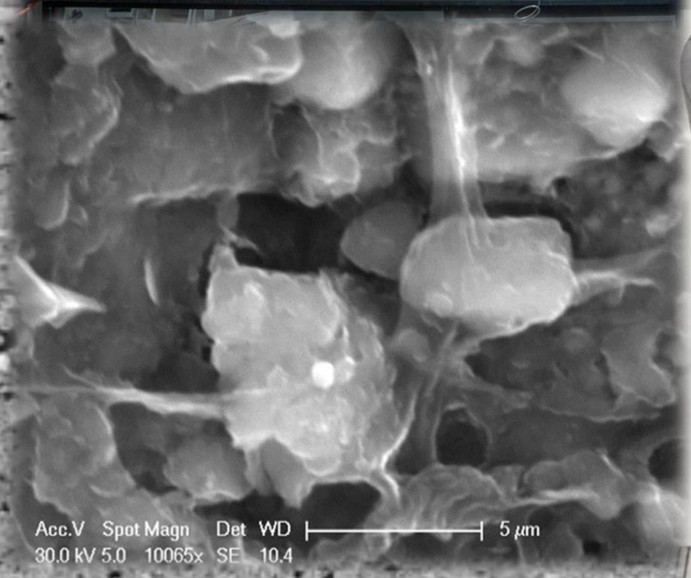
Results indicate that **pyrite, calcite, dolomite and anhydrite** are **thermodynamically unstable** in the presence of hydrogen.

However, literature suggests that **kinetics may inhibit** the transformation of calcite and sulfate bearing minerals, whilst the **dissolution of pyrite is likely**.

Kate Adie (MSc Geoenergy) | kate.adie@btinternet.com | 07805751014

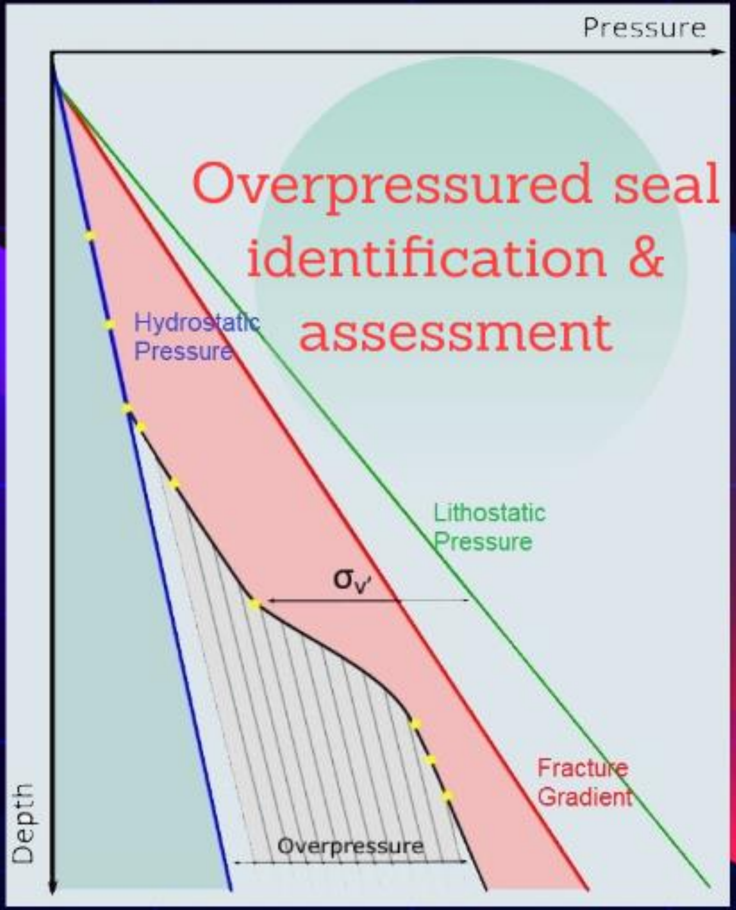
Cement integrity during hydrogen storage

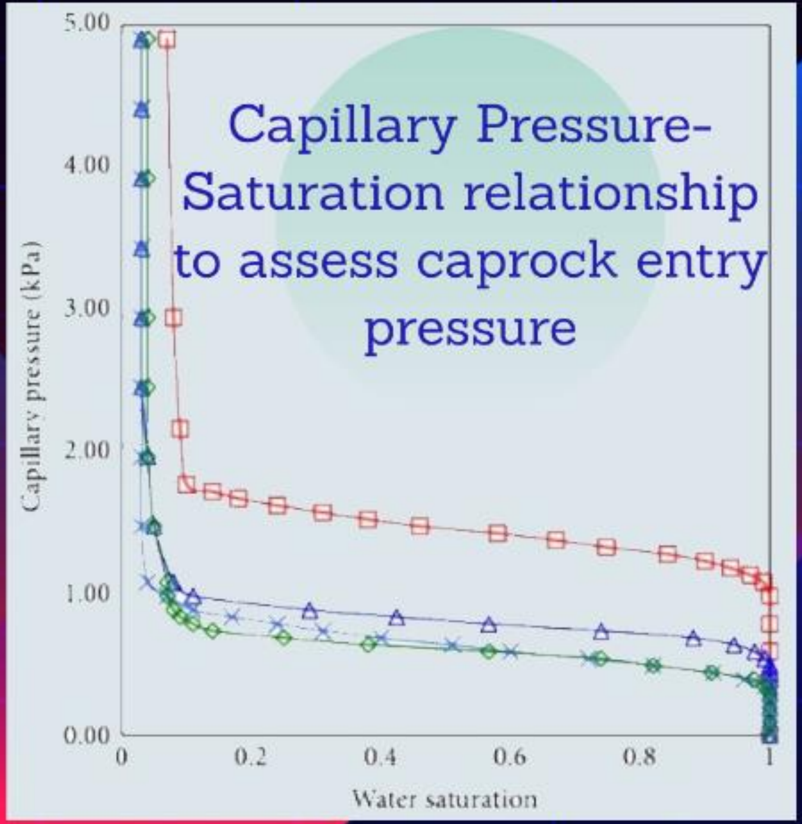
- Cements for well sealing during hydrogen injection and production
- Cements for sealing engineered cavern storage
- Investigate the physical and chemical effects of hydrogen on well cements
- Range of temperatures, pressures, formation fluid chemistries
- Investigate geochemistry changes
- Investigate mechanical changes

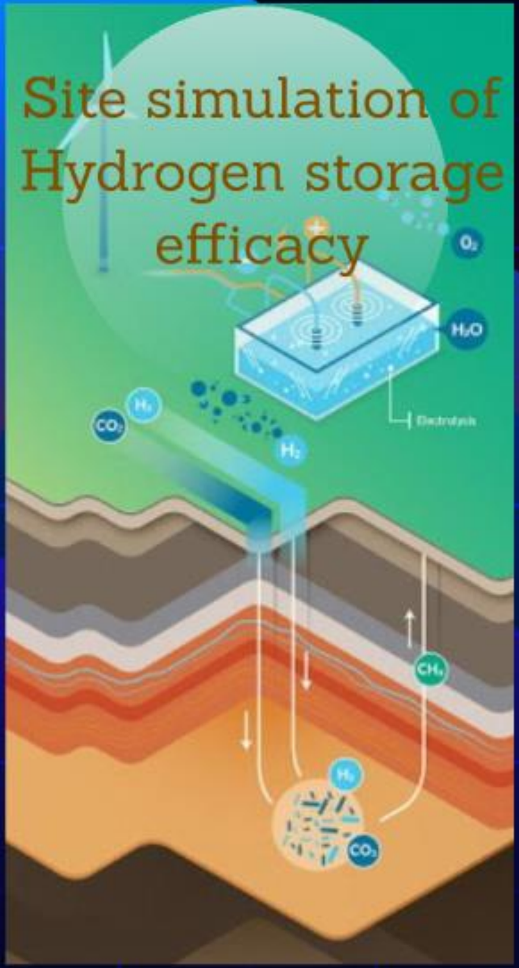


For more information please contact Katriona Edlmann katriona.edlmann@ed.ac.uk

Does overpressure increase Hydrogen underground sealing storage security?







Lubica Slabon

Hydrogen storage simulation study

Cousland gas field, UK

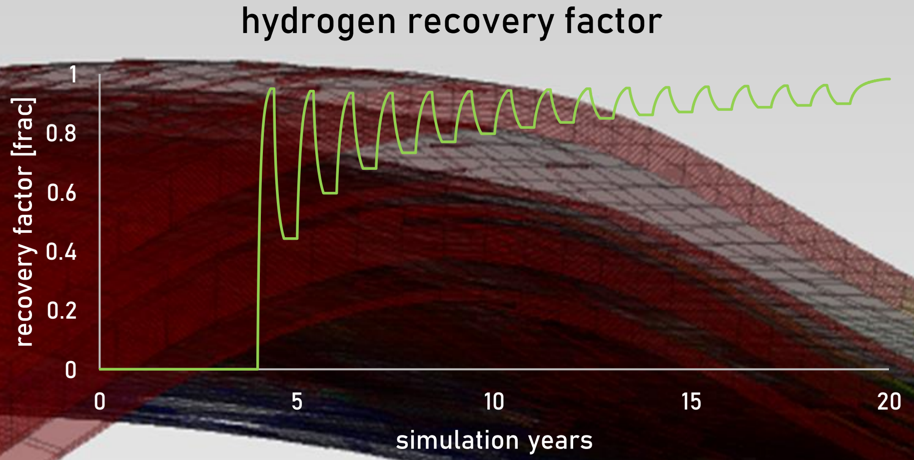
Jonathan Scafidi – University of Edinburgh School of Geosciences

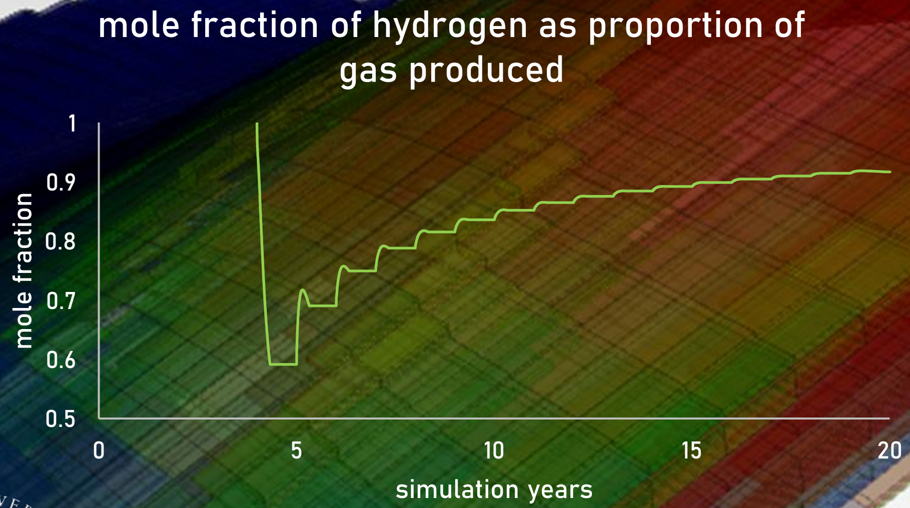
jonathan.scafidi@ed.ac.uk

Small (0.9 BCF), onshore depleted gas field

20 year seasonal storage scenario

350,000 kg injected per year





Remaining natural gas acts as cushion gas

Hydrogen recovery factor >95%

Mixing ratio (moles) decreases with time

THE UNIVERSITY *of* EDINBURGH
School of GeoSciences

@jonafushi

HYDRENOR

E^3 DTP
Edinburgh, Earth and Environment Doctoral Training Partnership

NERC
SCIENCE OF THE ENVIRONMENT

Why Producing Hydrogen Offshore?

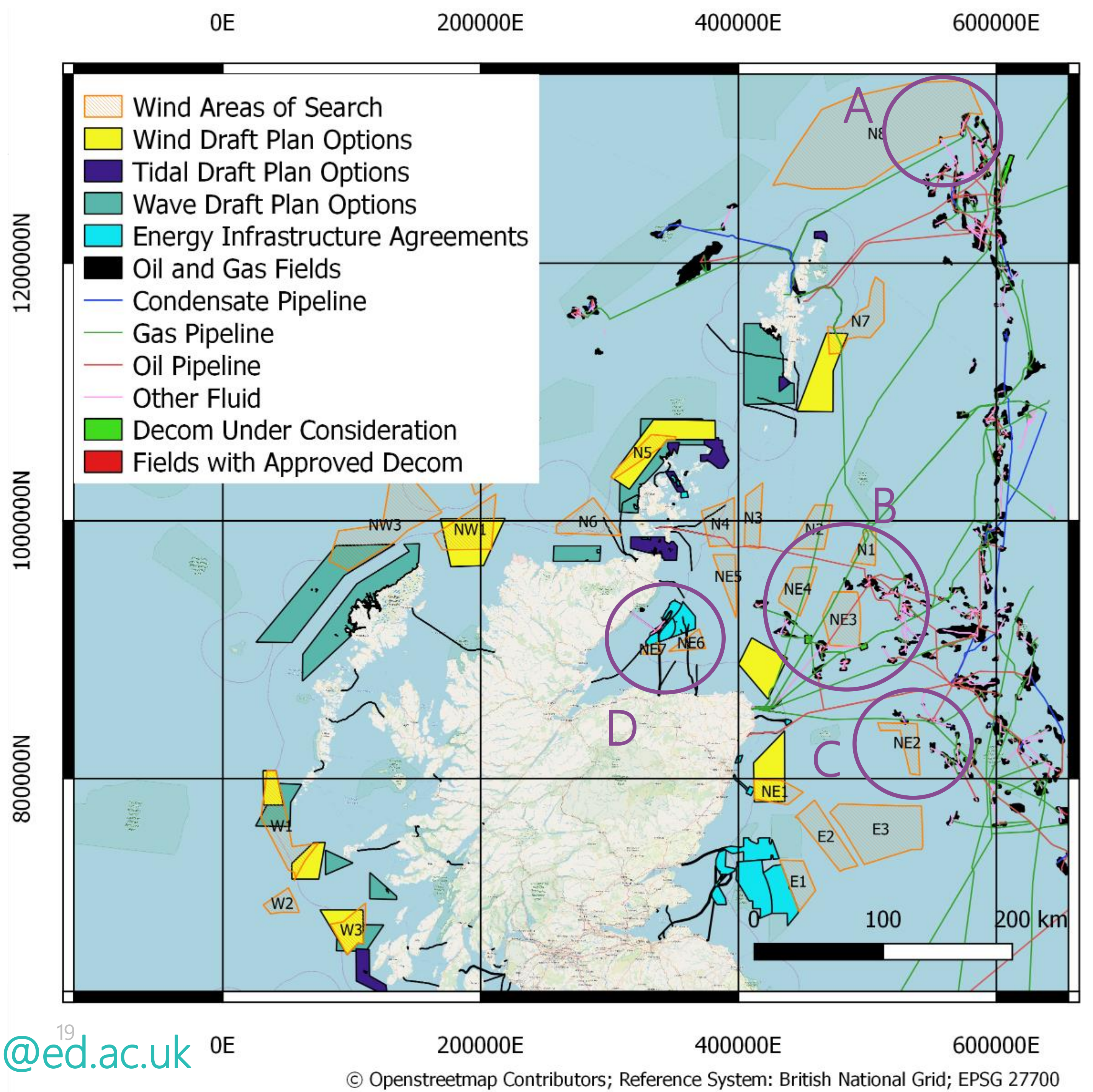
- Cost reduction for export cable
- Allows access to a better wind resource
- Deferring part of estimated £55.7bn decommissioning cost for UKCS
- Higher Public Acceptance

University of Strathclyde
UNIVERSITY OF EXETER
Diana.jelenova@ed.ac.uk
THE UNIVERSITY OF EDINBURGH
Idcore Industrial Doctoral Centre for Offshore Renewable Energy

Offshore Hydrogen Production in Scotland

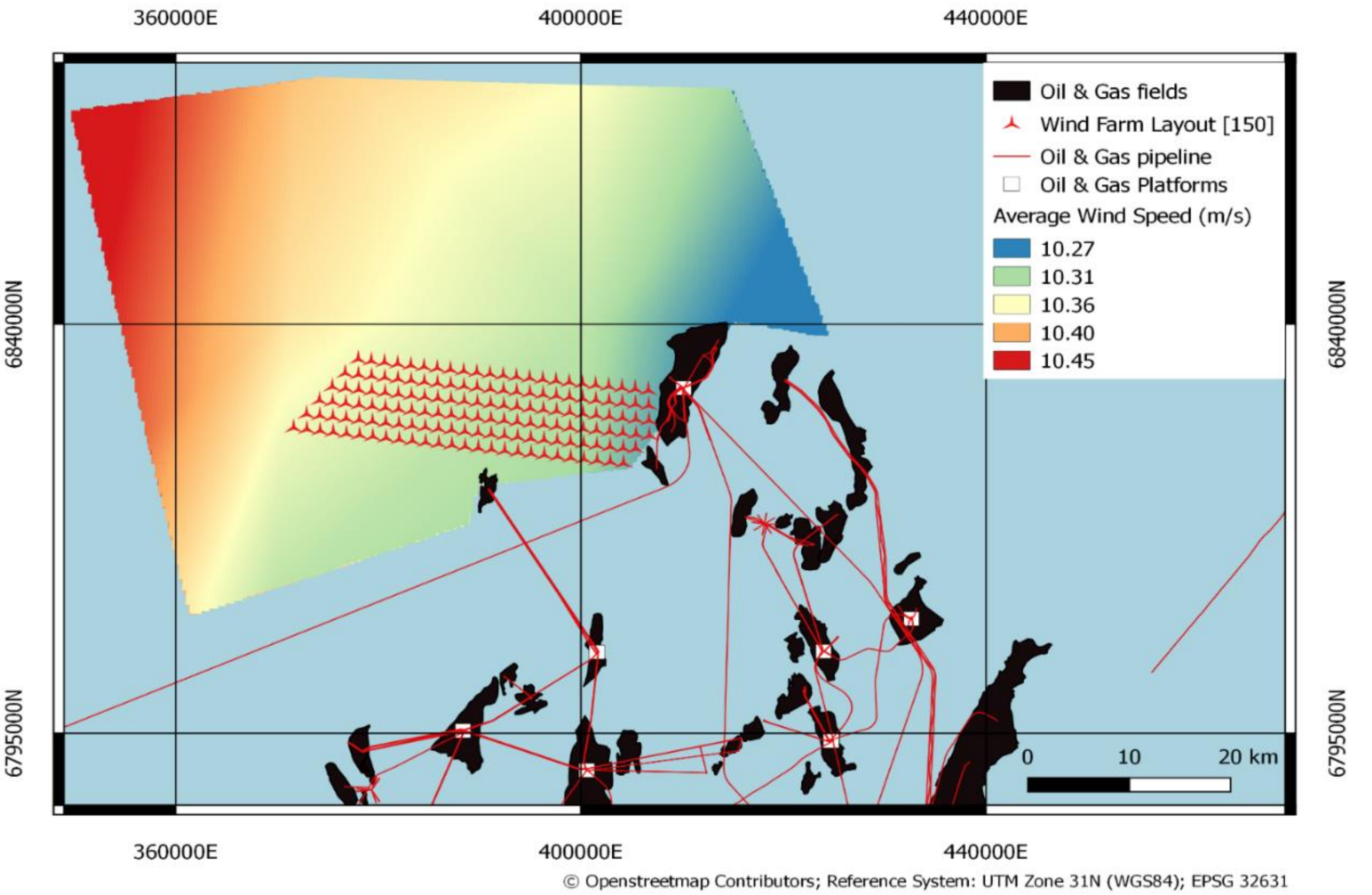
Four areas have been identified for offshore green hydrogen production as shown on the map.

- Areas A,B and C are in deep water and will require floating wind technology
- Majority of identified O&G infrastructure to cease production by 2026 and unable to leave substructure in situ as structures are lighter than 10,000 tonnes



Diana.jelenova@ed.ac.uk

Offshore Hydrogen Production



Resource assessment has been carried out on Area A to determine how much hydrogen could be produced offshore to decarbonise different sectors across the UK.

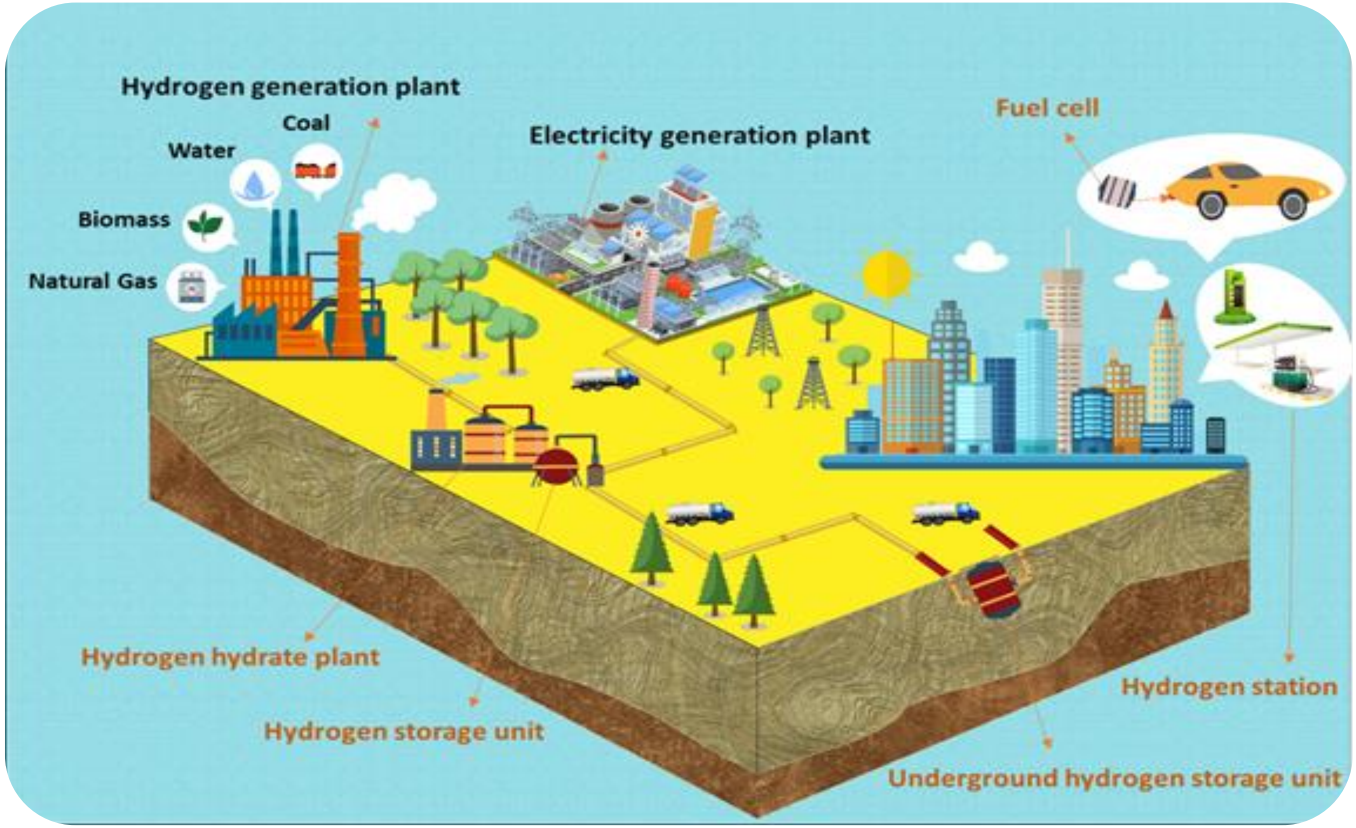
Hydrogen Production Estimations	
Annual energy production	5576 GWh/year
Equivalent hydrogen production	289 tons/day
Equivalent hydrogen bus supply	28,900 buses covering 100 km/ day

University of Strathclyde · University of Exeter

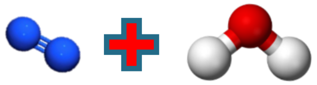
Diana.jelenova@ed.ac.uk

The University of Edinburgh · Idcore Industrial Doctoral Centre for Offshore Renewable Energy

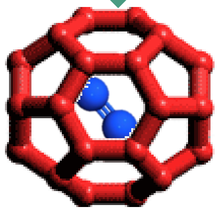
Hydrogen Storage in Molecular Clathrates

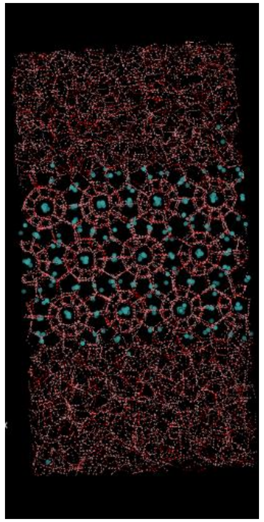


H_2 + H_2O + Additives



HydraSlush





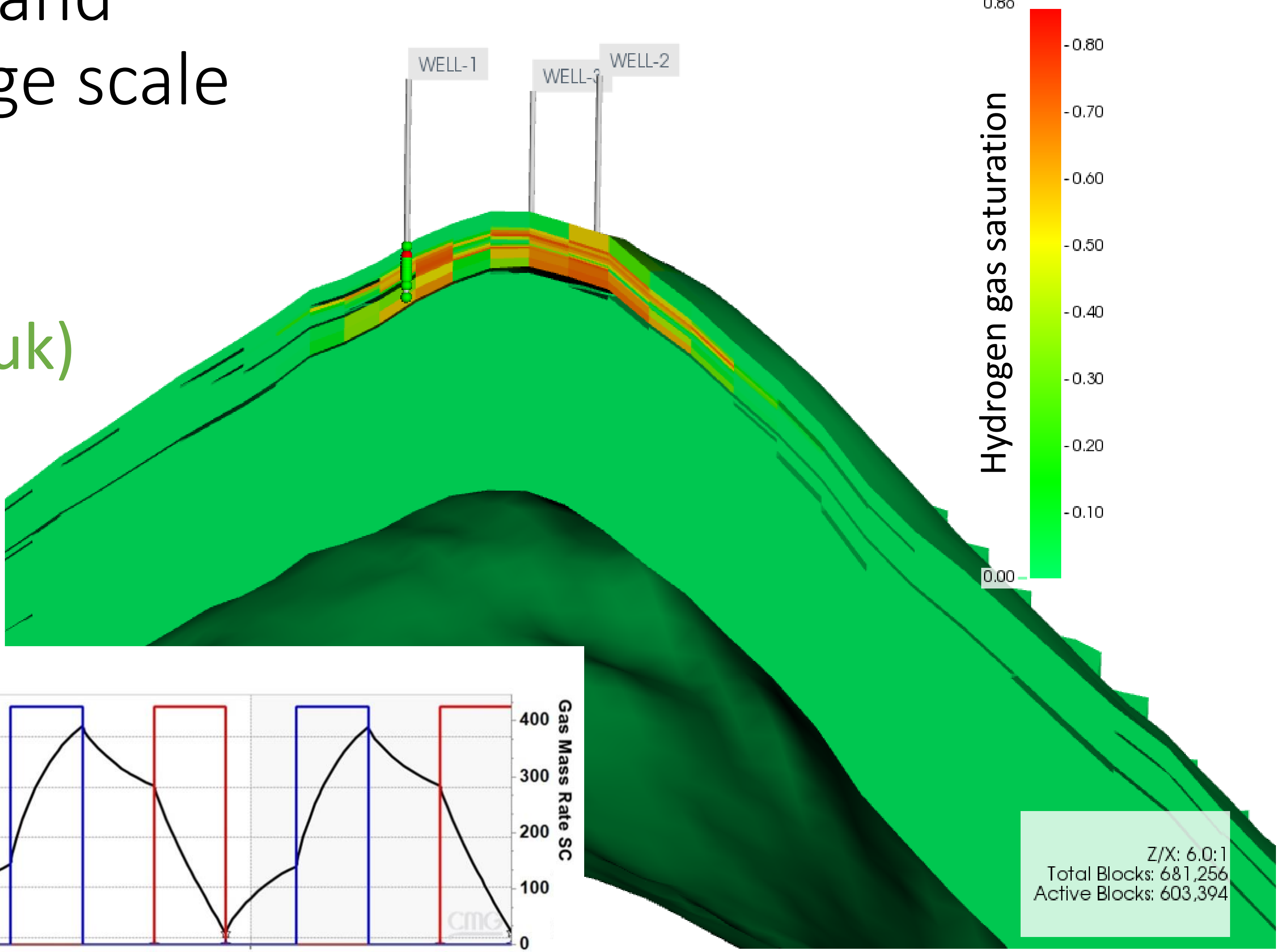
- **Ultra-Fast**
  - Day scale to Nano-second scale
- **High Capacity**
  - No Volumetric Constrains
- **Cost-Competitive**
  - Ambient Pressure/Temperature
- **Stable**
  - Controlled phase change
- **Safe**
  - No Possibility of Explosion

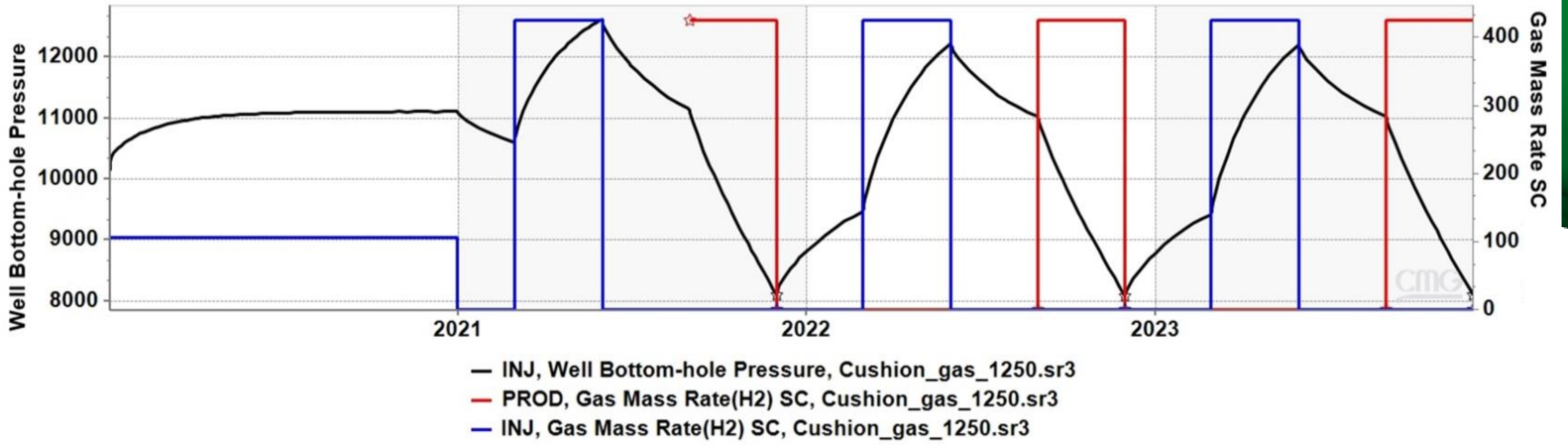
Interested? Contact Ali at Hssnpr@ed.ac.uk

H_2 injection, storage and reproduction in a large scale saline aquifer

Niklas Heinemann
(N.Heinemann@ed.ac.uk)

HyStorPor

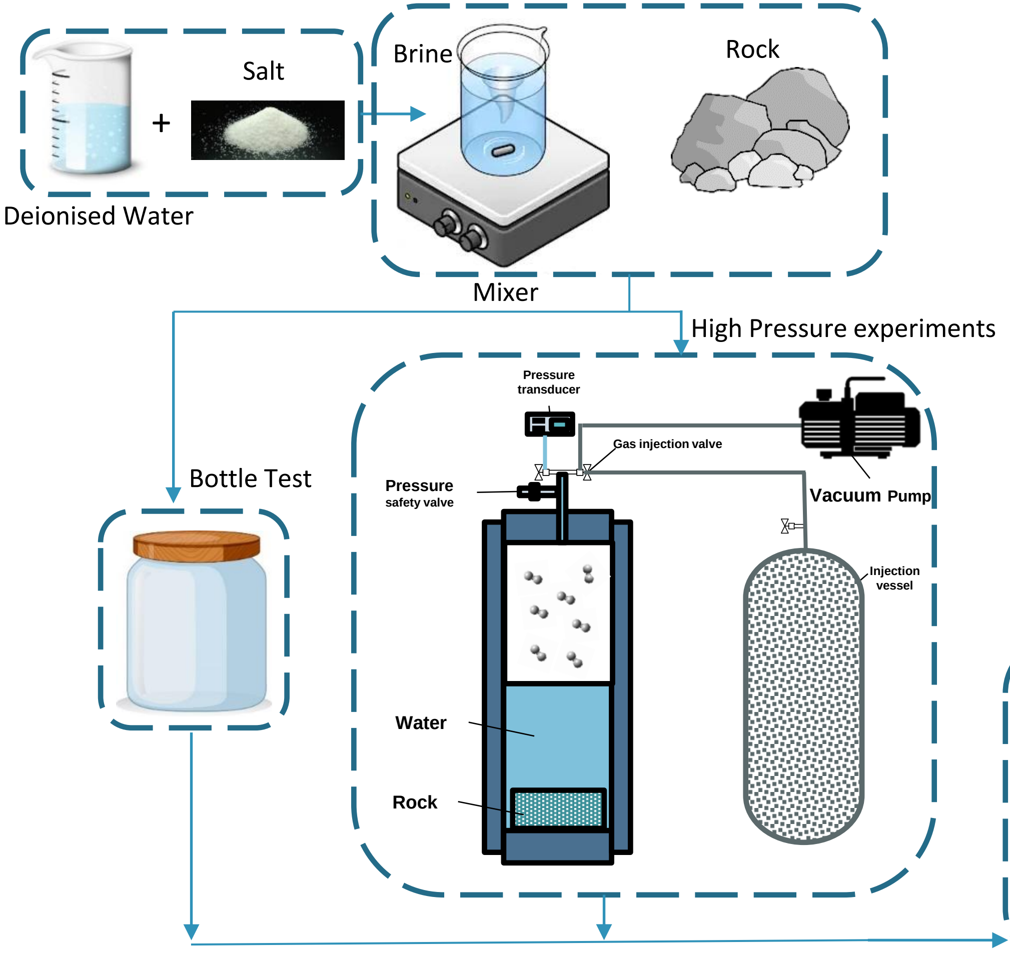


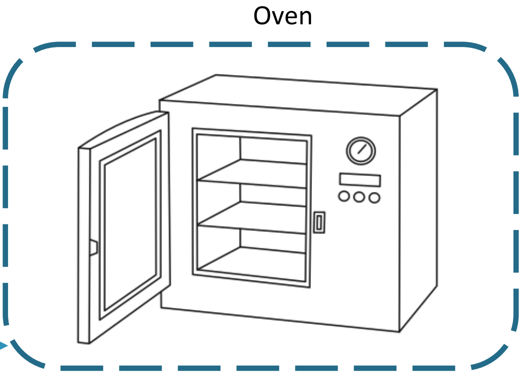


(ETI study/PBD)

HyStorPor

Schematic of the high-pressure cell setup





We designed and developed high-pressure batch reaction vessels

No significant geochemical reaction with hydrogen has been observed so far (@ pressures up to 1MPa)

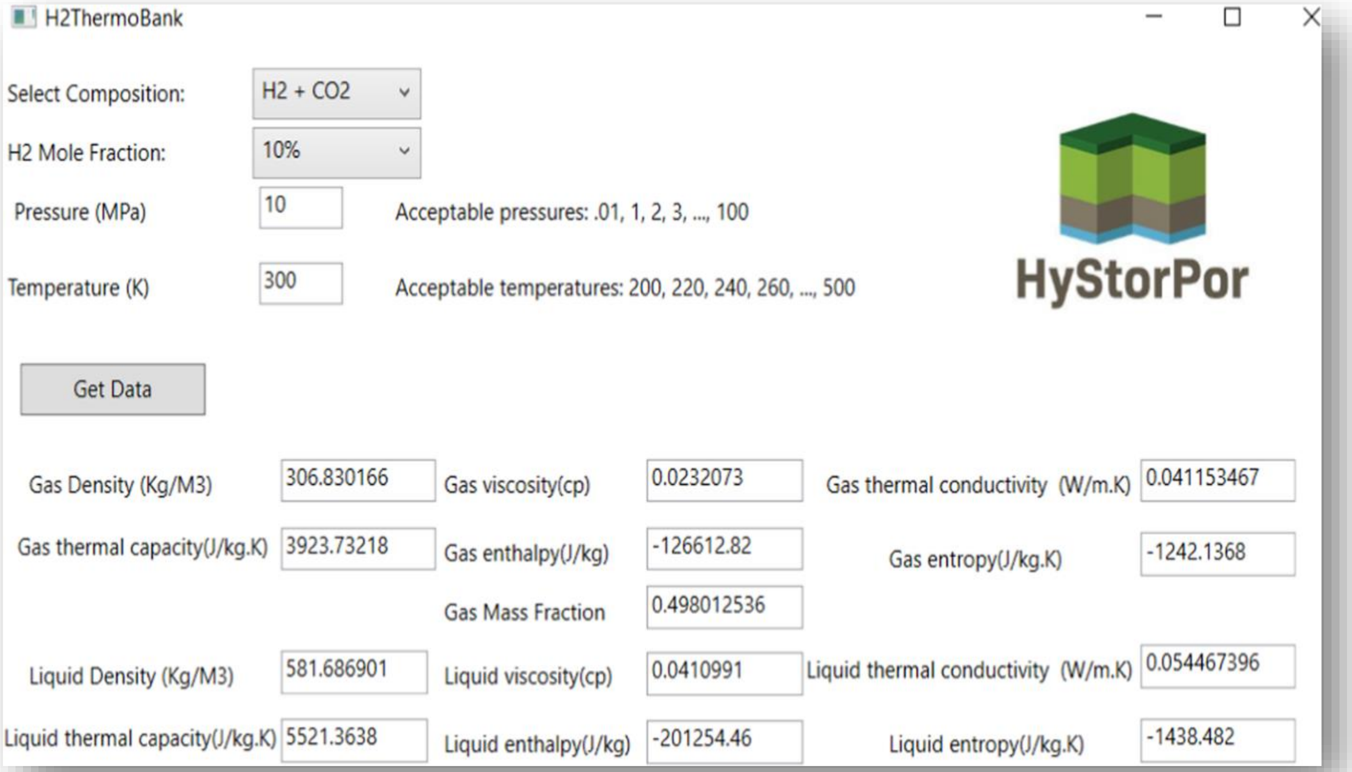
We have run over 100 experiments so far.

Interested? Contact Ali at Hssnpr@ed.ac.uk

H_2Thermobank: Thermodynamic 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 %.
- Pressures from 0.01 – 100 Mpa.

  Temperatures from 200-500 K (-73C to 227C).



https://www.nature.com/articles/s41597-020-0568-6

https://github.com/aliakbarhssnpr/H2ThermoBank

Interested? Contact Ali at Hssnpr@ed.ac.uk

Expert elicitation for the risk assessment of the potential for hydrogen to leak from geological stores.

- A risk assessment of three geological scenarios was carried out using ISO 31000
- This involved a construction of a features, events and processes database and explanations of their contribution towards leakage
- 7 categories of potential hydrogen leakage pathways from 3 types of geological store were thus included in the FEP Database
- The goal was to identify high impact / high uncertainty risks based on these factors
- 12 cohort members from University of Edinburgh were invited to assess the risks and a review was conducted
- Monitoring and mitigation strategies from other technologies were then applied to the highest impact and uncertainty risks and adapted for hydrogen storage

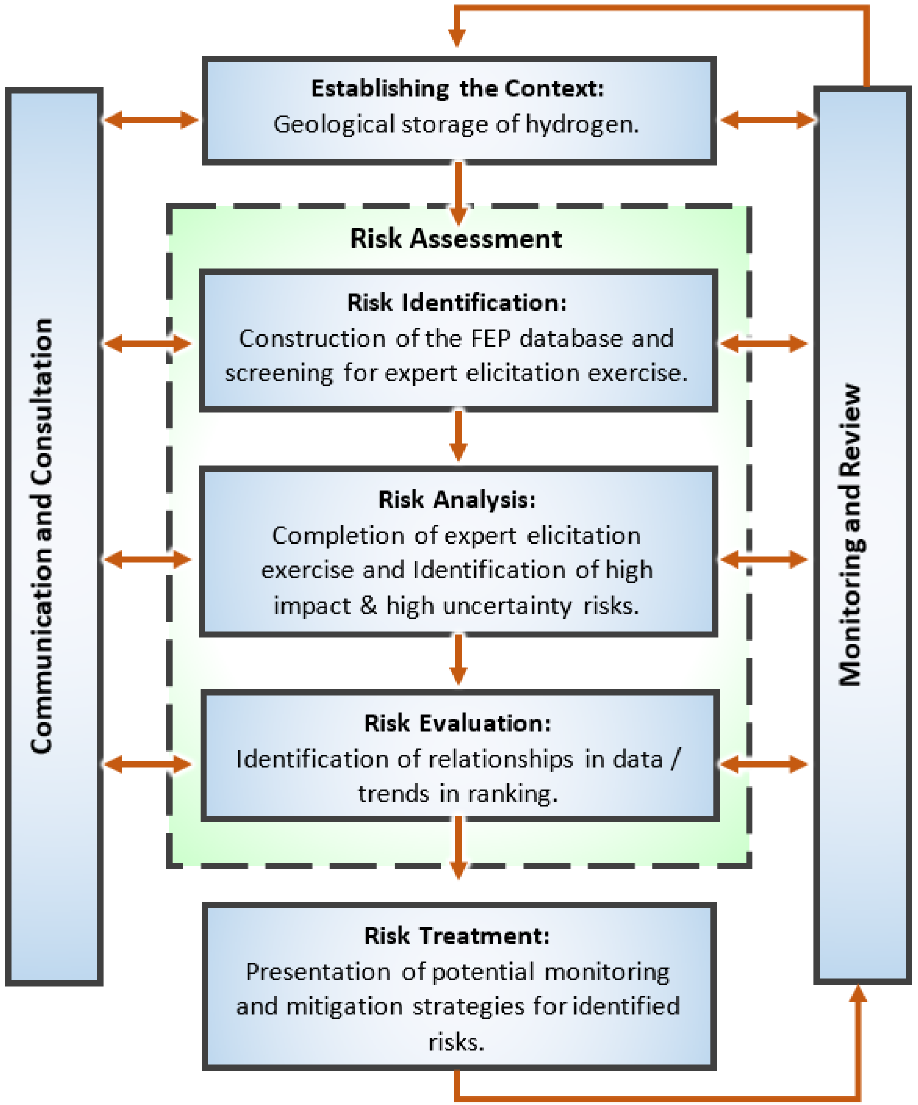


Figure 1.0 Risk Assessment process from ISO 31000 adapted to reflect project tasks.

Contact: Gabriellafuentes@hotmail.co.uk

Hydrogen leakage elicitation results: Impact and Uncertainty / Risk Ranking

- There were 4 high impact & high uncertainty risks that could contribute to hydrogen leakage
- Salt Caverns had the lowest impact ranking but greatest uncertainty range of the 3 geological scenarios
- Depleted Gas Reservoirs / Porous Aquifers carried higher ranking impact risks but lower uncertainty range.
- Chemical risks were consistently ranked lowly in impact & uncertainty by experts across 3 scenarios.
- Wellbore and drilling environment and stress / faulting risks were consistently ranked high in impact and uncertainty across 3 scenarios.

Table 1.0 The presence of the highest ranked risks across the three geological categories.

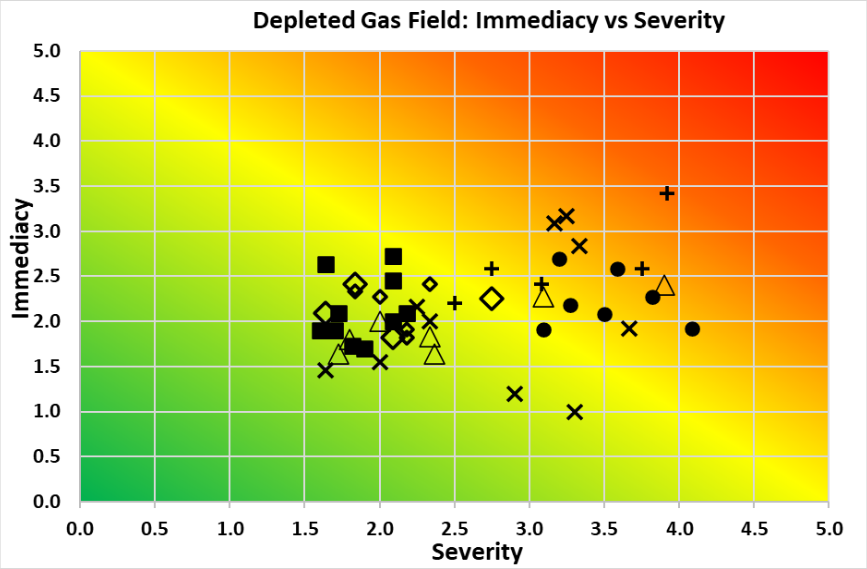
		Depleted Gas Reservoir		Porous Aquifers		Salt Caverns	
	Highest Ranking Risks	High Impact	High Uncertainty	High Impact	High Uncertainty	High Impact	High Uncertainty
1	Equipment Malfunction	X	X	X	X	X	X
2	Human Error/ Miscalculations	X	X	X	X	X	X
3	Multiple Well Drilling	X	X	X	X	X	X
4	Well Sealing	X	X	X	X	X	X
5	Fracture Density / Geometry	X	X	X	X	X	
6	Well Blowout	X	X	X	X	X	
7	Induced Fracturing (Matrix)	X	X	X	X		X
8	Faults / Undetected Features (Over / Underburden)	X	X	X		X	X
9	Caprock Thickness	X	X	X	X		
10	Pressure Changes of Gas	X		X	X	X	

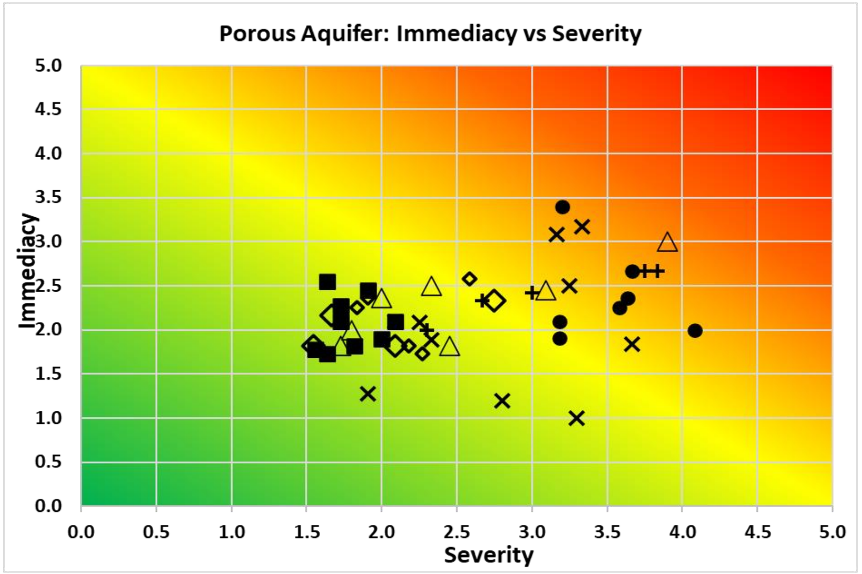
Table 2.0 Colour coordination of the categories included within the elicitation exercise and FEP database.

Chemistry	Gas Properties	Stress / Faulting	Geological Architecture	Wellbore and Drilling Environment	Events	Processes

Contact: Gabriellafuentes@hotmail.co.uk

Hydrogen leakage elicitation discussion: Impact & Uncertainty.





Key

- ◇ Gas Properties
- △ Geological Architecture
- ✕ Events
- ■ Chemical Properties
- ● Stress / Fracturing
- ＋ Wellbore and Drilling Environment
- ◇ Processes

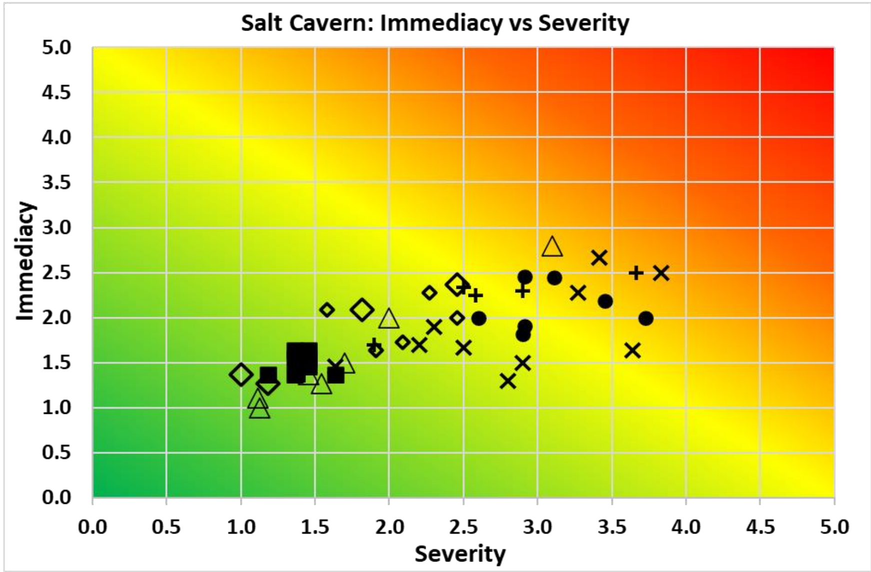


Figure 3.0 , 5.0, 6.0: Matrix plots for Immediacy vs Severity for DGRs, PAs and SCs.

- Increase in severity values the highest immediacy value, 5, corresponds to leakage during injection (high immediacy)
- Expert opinion concludes that hydrogen leakage is most likely to occur during injection and early stages of storage operation
- The dispersion of risk categories across the 3 geological scenarios suggests that experts recognize that some risks take time to develop (e.g. chemical reactions)

Contact: Gabriellafuentes@hotmail.co.uk

Expert elicitation for the risk assessment of the potential for hydrogen to leak from geological stores

- Hydrogen is a challenging substance to contain in comparison to natural gas and CO^2 and so it security in the subsurface must be ensured to aid in the energy transition help achieve reaching net 0 by 2050
- It is import to carry out early risk assessment to secure environmental and economic safety in developing technologies
- Results of the study are consistent with other projects using this risk assessment method including CCS, hydraulic fracturing, nuclear waste disposal
- Results depict Salt Caverns as carrying the greatest uncertainty yet lowest impact risks
- Experts believe that high impact / high uncertainty risks are most likely to be unplanned events or faults in wellbore / drilling environment causing hydrogen leakage
- Risks consistently ranked as low impact / low uncertainty risks were considered for de- risking as due to low immediacy vs severity and confidence in cohort knowledge.
- Methods for monitoring and preventing leakage of hydrogen from geological store have been drawn on from other technologies and their suitability for hydrogen storage was considered

Contact: Gabriellafuentes@hotmail.co.uk

Modelling Hydrogen Storge in the subsurface using CO2 as a cushion gas.

Harri Williams Geoenergy MSc - harri.14@hotmail.co.uk

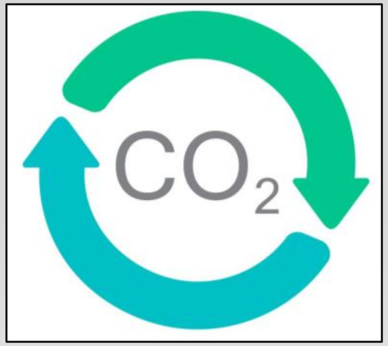
Approximately 40-70% of cushion gas is residually trapped and offers no economic return.

High cost of hydrogen production accounts for great initial costs for a storage site

High mobility ratios between a H_2 cushion gas and reservoir water will also produce unfavorable mixing effects e.g viscous fingering and gravity override

CO_2 - alternative cushion gas

- Cheap
- Accessible
- Potential increase in storage volumes within the reservoir
- Abundant
- Offers potential to sequester CO_2 from industry



The Problem of gas mixing:

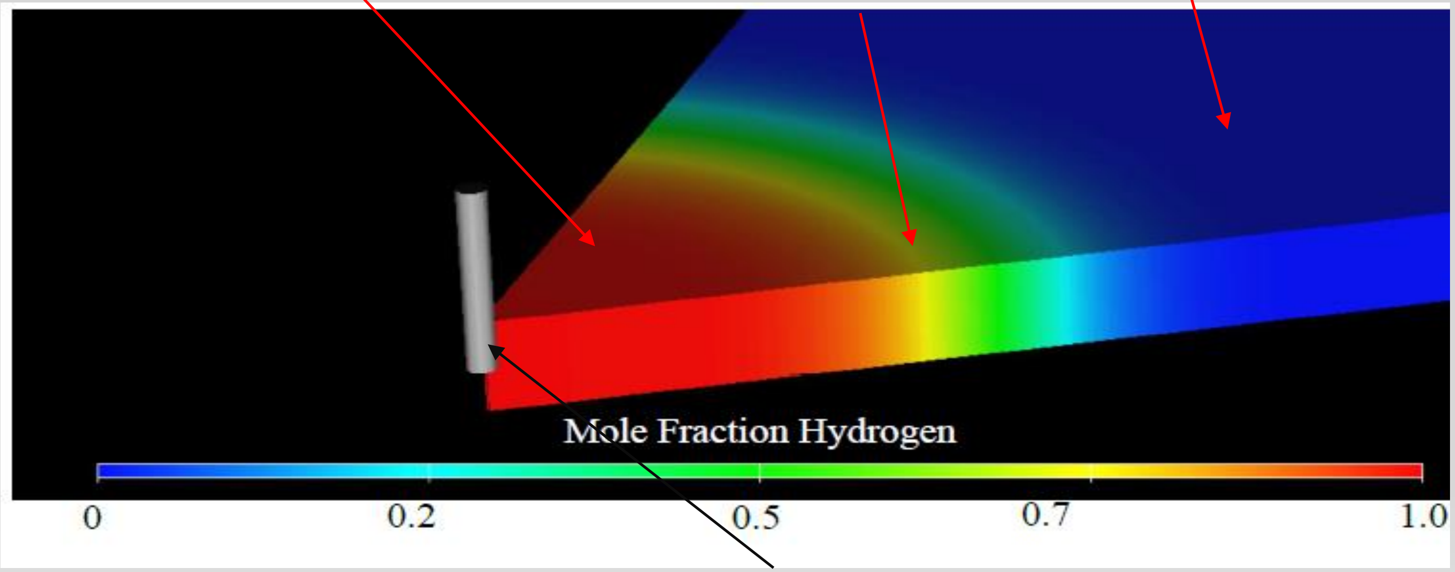
Harri Williams Geoenergy MSc - harri.14@hotmail.co.uk

When H_2 is injected into the reservoir it will mix with the CO_2 cushion gas.

Increased mixing leads to an increase in cost of separation after production.

Measuring the rate of mixing and discovering operational methods to reduce the level of mixing is therefore important.

A 1D radial model was produced on Eclipse300 to model the gas mixing effects under seasonal storage scenarios:



What is the level of gas mixing?

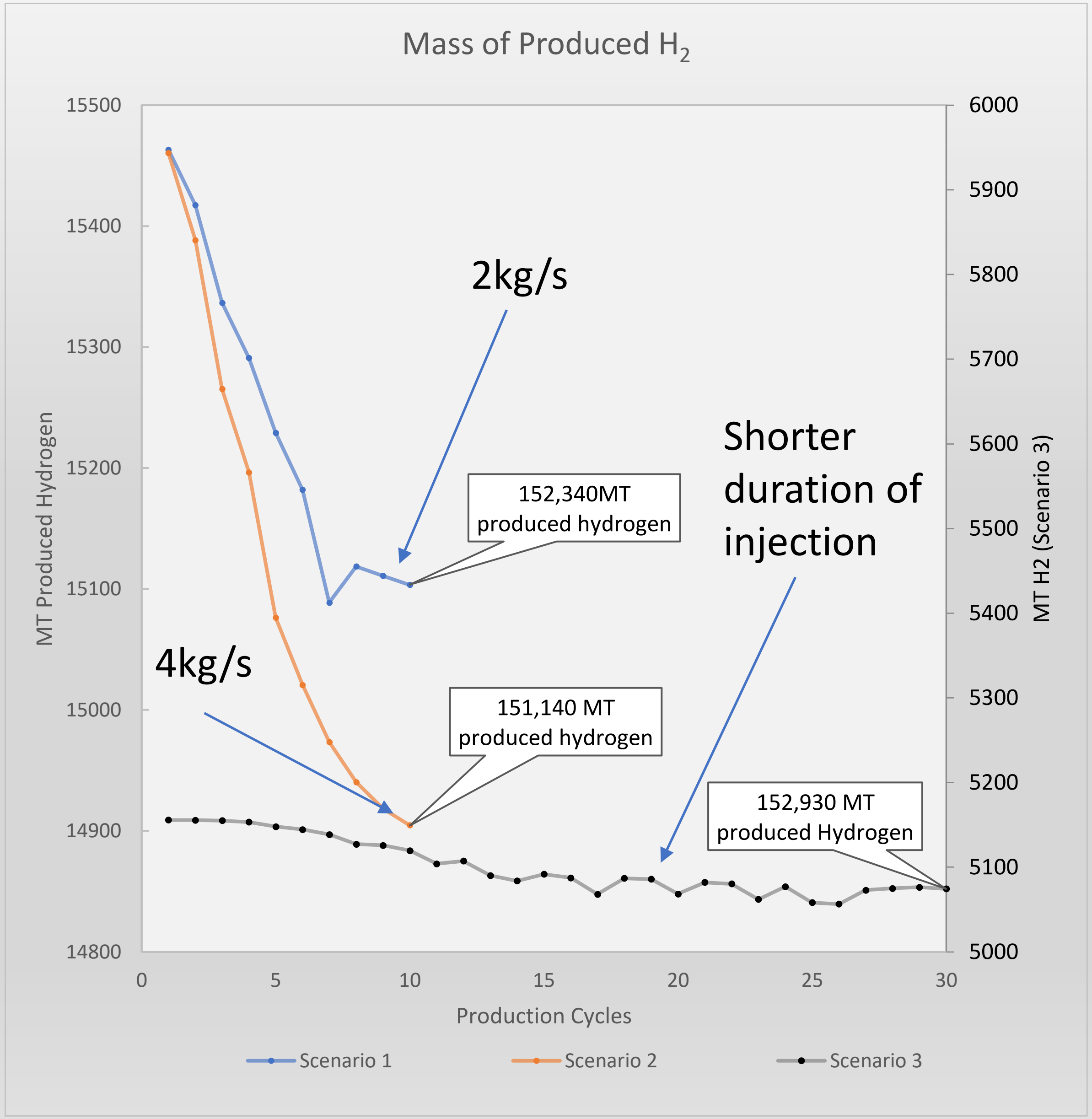
Harri Williams Geoenergy MSc - harri.14@hotmail.co.uk

At 4kg/s injection & production - 97.7% of hydrogen is able to be produced from the reservoir (Scenario 2).

Gas mixing can be reduced by changing the reservoir operational parameters:

At 2kg/s - Around 98.5% H2 is produced (Scenario 1).

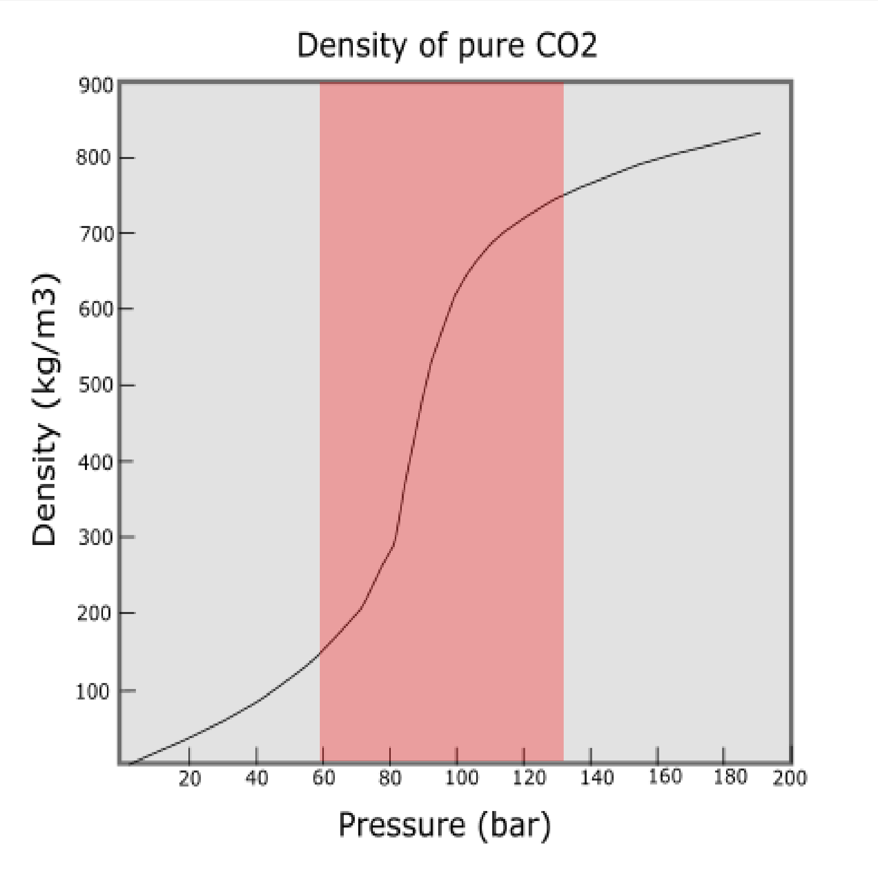
Shortening the duration of injection - mixing is reduced further and 98.9% H2 is produced (Scenario 3).



Harri Williams Geoenergy MSc - harri.14@hotmail.co.uk

CO_2 Compressibility:

A pressure of greater than 73.8 bar and a temperature greater than 31°C will lead to a supercritical state of CO_2.



The compressible nature of CO_2 can be used to increase storage volumes within the reservoir and ensure reservoir pressures are kept to a minimum.

When pressure changes from 60 to 130 bar the density of CO_2 increases by a factor of 5.

Email: Harri.14@hotamil.co.uk Tell No: 07555515698