

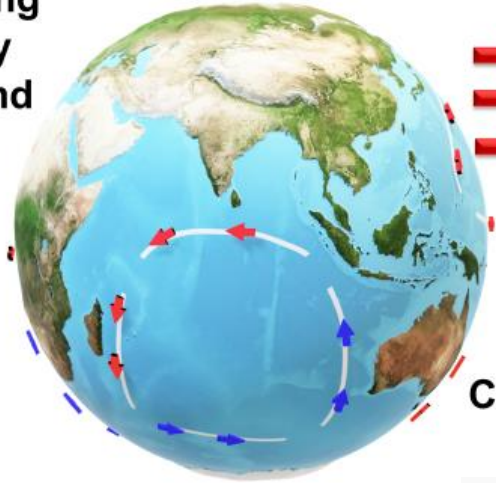
Hydrogen geological storage in saline aquifer

14 March 2021

Dr. Sina Gomari, s.Rezaei-gomari@tees.ac.uk

Hydrogen need

Growing
Energy
Demand



Climate Change



Why Hydrogen Storage

- Transportation : In the case of vehicular applications, it is necessary to store hydrogen in several links of the chain from production to use: in **the vehicles** themselves, in **hydrogen fuelling stations**, and in connection to **centralized locations** for hydrogen **production and distribution**.
- Hydrogen gas has a **very low density**: 1 kg of hydrogen gas occupies over 11 m³ at room temperature and atmospheric pressure. (**0.089 kg/m³**)
- Economically viable, its **storage density** must be increased.
- The goal of the stationary storage of hydrogen is generally either **to minimize the cost of delivered hydrogen** through the **balancing of supply and demand or to use it for backup purposes**.

H2 Storage challenges

- Conventional storage solutions include **liquefaction or compression**, however there are **energy efficiency** and **major safety concerns** associated with both these options
- A more promising alternative is **solid-state hydrogen materials** however the conventional alloys used, such as **LaNi₅**, have very **poor gravimetric hydrogen storage densities**
- Another challenge, is delivering high purity hydrogen. **Polymer Electrode Membrane (PEM)** fuel cells are **sensitive to gas impurities** and, for prolonged exposure, require a **very pure hydrogen** feed

Storage technique

Operational Challenge

Compressed hydrogen

High pressure +700 bar

Liquid hydrogen

Boil off , low temperature (-253 C)

Metal hydrides

Low capacity

Chemical hydrides

High temperature (140 c), reversibility

Porous materials (MOF)

Low temperature (-196)

High pressure (up to 150)

Storage Options

Specialist tanks or storage vessels

- Can store energy at KWh-MWh scale 1KW- 100 MW
- Suitable for meeting **hourly demands** within the grid
- Already used in the **chemicals industry** and at **hydrogen refuelling stations**

Salt caverns

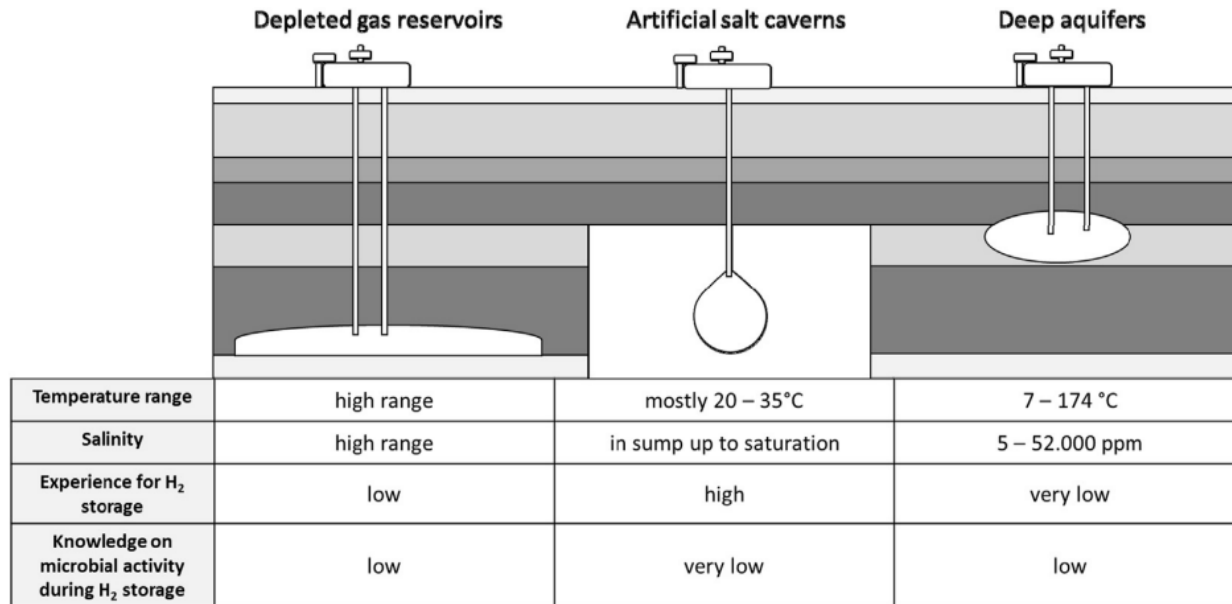
- Can store energy at MWh-GWh scale 10 MW – 20 GW
- Suitable for meeting **daily/weekly demands** within the grid
- Already used in the **chemicals industry** and for **natural gas storage**

Geological porous media (Saline aquifers of depleted oil/gas reservoirs)

- Can store energy at TWh scale
- Suitable for meeting **monthly/seasonal demands** within the grid
- **Only used for natural gas storage**

**Storage
balances the
supply and
demand**

Underground Hydrogen Storage (UHS)



Nicole Dopffel et al. [Volume 46, Issue 12](#), 16 February 2021, Pages 8594-8606

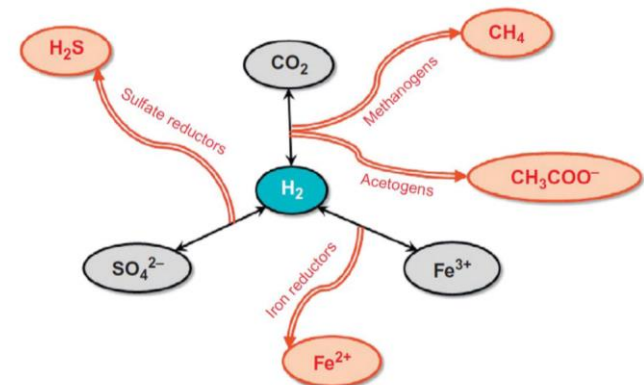
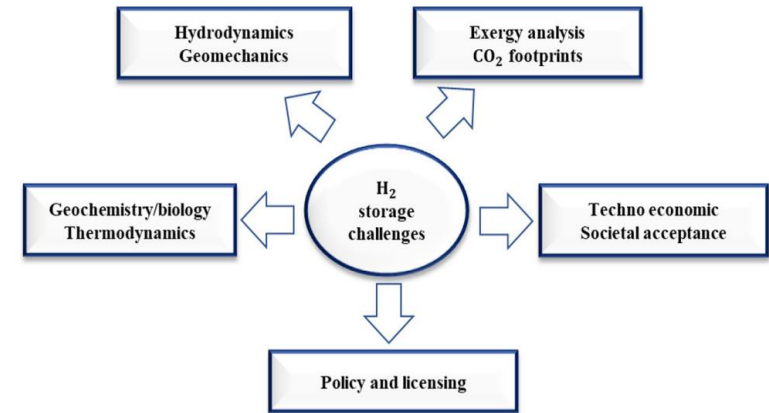
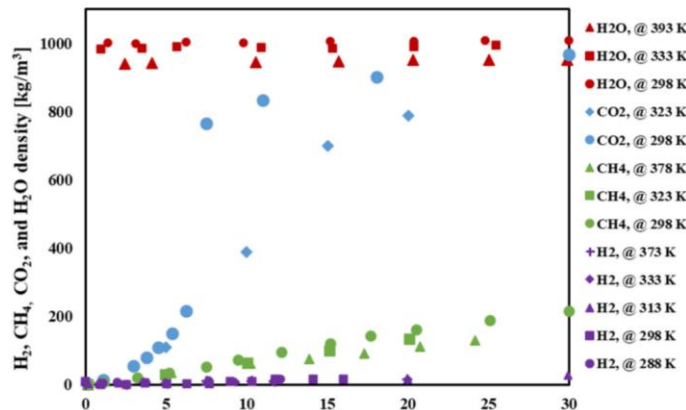
UHS –Challenges

Large Scale – Depleted Oil and Gas Wells

- existing infrastructure (wells, pipelines), easy to develop, operate, and low cost maintenance

Large Scale – Challenges

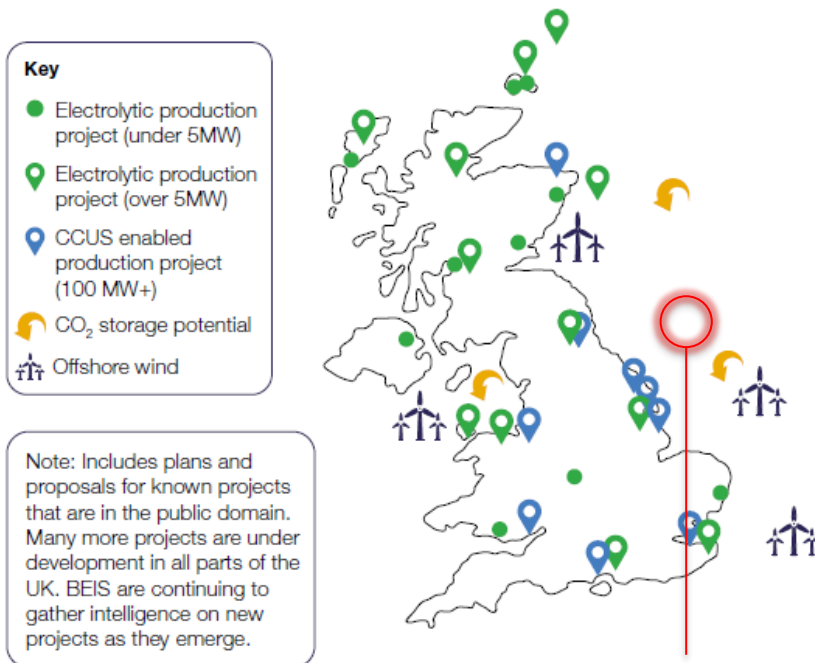
- Containment** : Salt mines have stable strata and good trap conditions
- Safety** : impermeable caprock along with a geologic structure to contain and trap gas
- Storability and Injectivity** : High poro-perm reservoirs
- Cushion Gas** : To maintain reservoir pressure and adequate withdrawal rate , 30-50% of the reservoir volume must contain cushion gas.
- Microbiology**: The main microbial H₂-utilizing terminal electron-accepting processes expected and identified to occur in UGS sites are **methanogenesis, sulphate reduction, and acetogenesis**)



Role of Hydrogen in meeting net zero

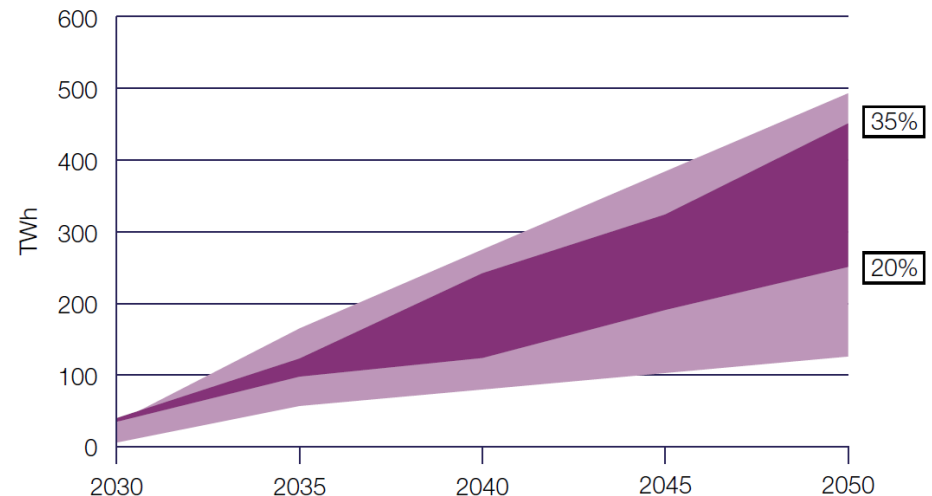
Analysis by BEIS for CB6 suggests 250-460TWh of hydrogen could be needed in 2050, making up 20-35 % of UK final energy consumption

Proposed UK hydrogen production projects



Location of the case studied storage site

Hydrogen demand and proportion of final energy consumption



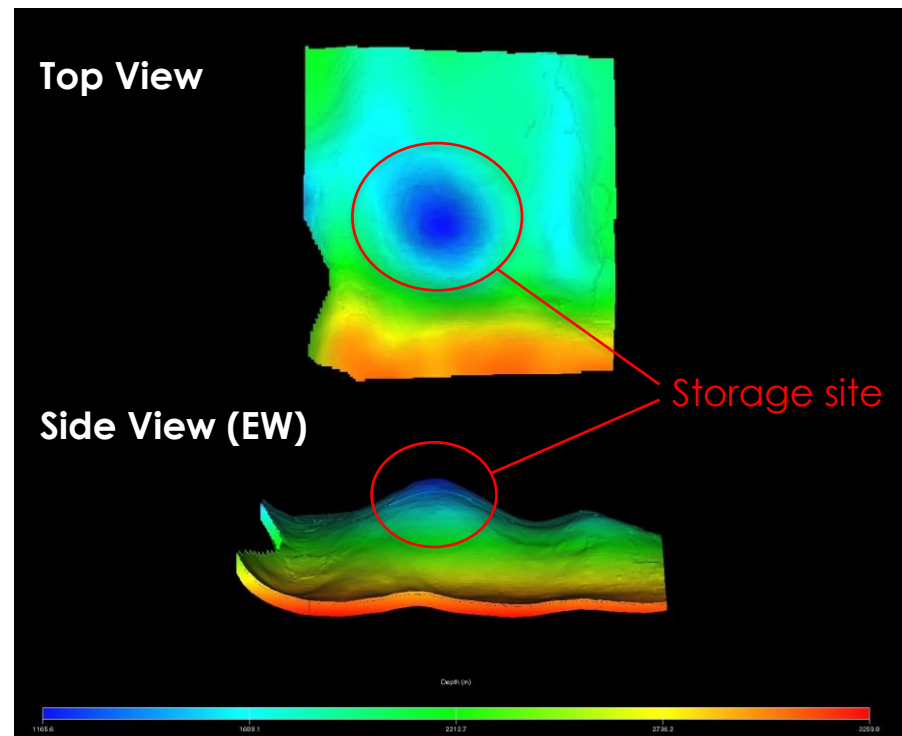
% = hydrogen as proportion of total energy consumption in 2050

Source: Modified after UK Hydrogen Strategy (2021)

Storage site: North Sea

- One of the dome shaped/ elongate anticline structural closures within the Lower Triassic Bunter Sandstone Formation
- Within the Southern North Sea (SNS) area, around 150 Km off the Yorkshire coast

Reservoir Parameter	Average Value
Dimensions (km)	25x25
Number of Cells	600,000
Average Porosity	0.23
Average Permeability (md)	210
Formation Top Depth (m) (DATUM)	1300
Formation Thickness (m)	50
Formation Net to Gross Ratio	0.95
Initial Pressure (bar) @ 1171m TVDSS	130
Temperature (°C)	45

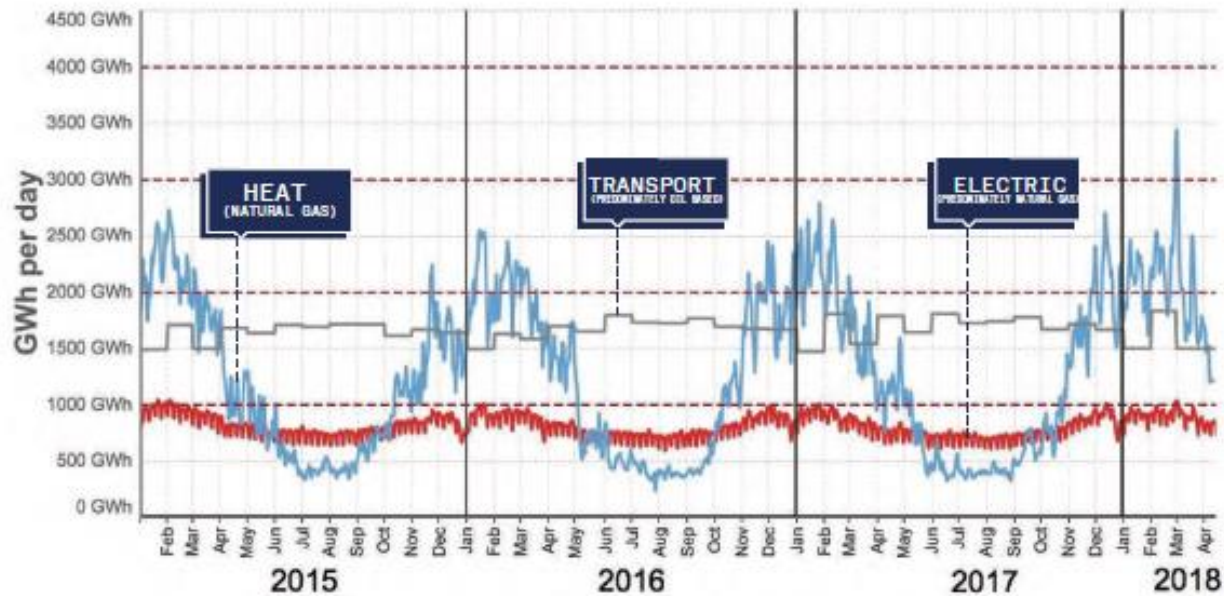


Source: Strategic UK CCS Storage Appraisal Project Report

Demand Scenario: Decarbonisation of domestic heat by replacing Natural Gas

- Domestic heat accounts for almost a quarter of annual final energy consumption in the UK
- Heating is the greatest seasonal fluctuations
- Heating accounts for 1/5 of total emission
- 80% of building heating from gas network

Seasonal variations in different energy sectors

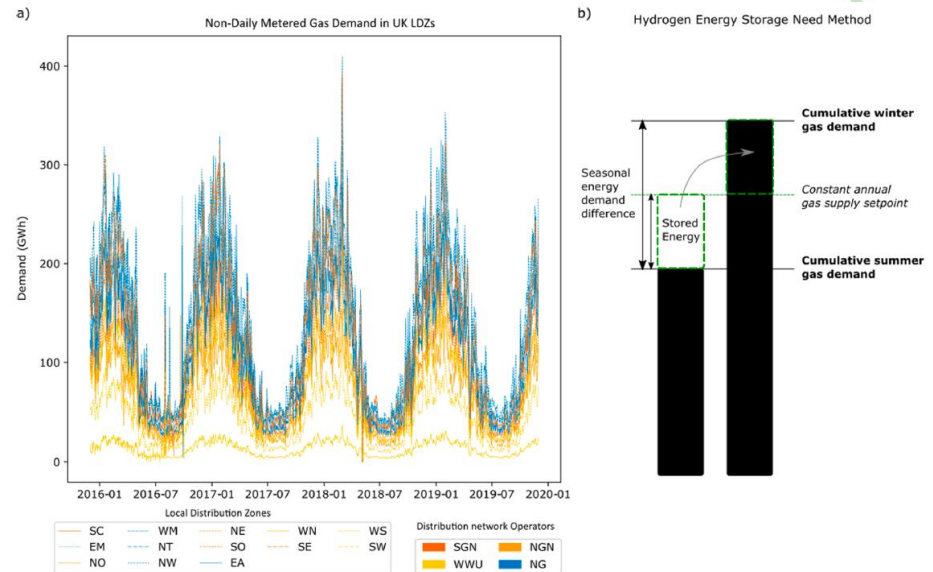


Source: H21 North O England Report

Storage scenario based on heating demand

Assumptions :

- The hydrogen production facility is operating at a constant load throughout the year,
- Surplus hydrogen can be injected during summer when NG demand for domestic heating is lowest,
- Hydrogen is withdrawn over cold days of winter when NG demand for domestic heating is significantly higher
- The total hydrogen energy demand of the UK based on this approach would be around 77.9 TWh,
- 4.8 TWh would be needed in the North East area
- Considering the H_2 lower calorific value, around 1.6 billion sm^3 of H_2 is required to meet 100% domestic heat demand of the North East UK



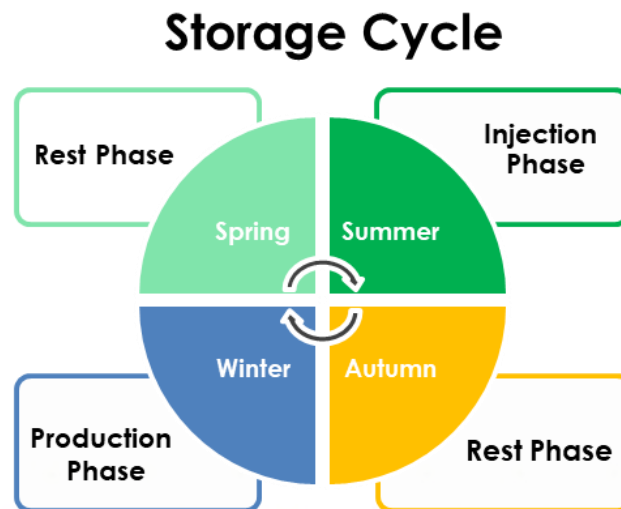
Source: J. Mouli-Castillo et al. (2021)

Research questions

- How much of the domestic heat energy demand of the North East UK can be responded by the selected storage site?
- What are the impacts of well number/placement on overall performance of storage (i.e., Working gas capacity, well injectivity/productivity, purity of produced gas)?
- How will the storage performance change after multiple injection/withdrawal cycles?

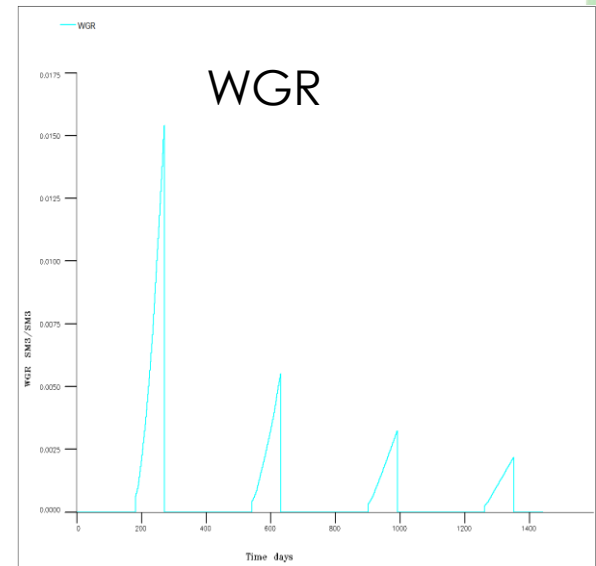
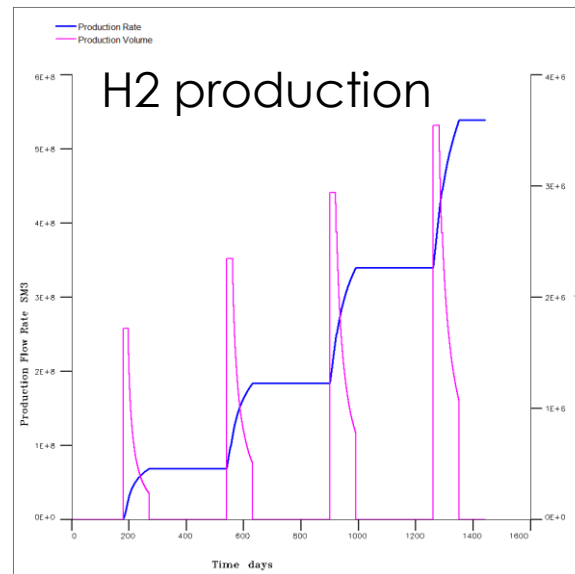
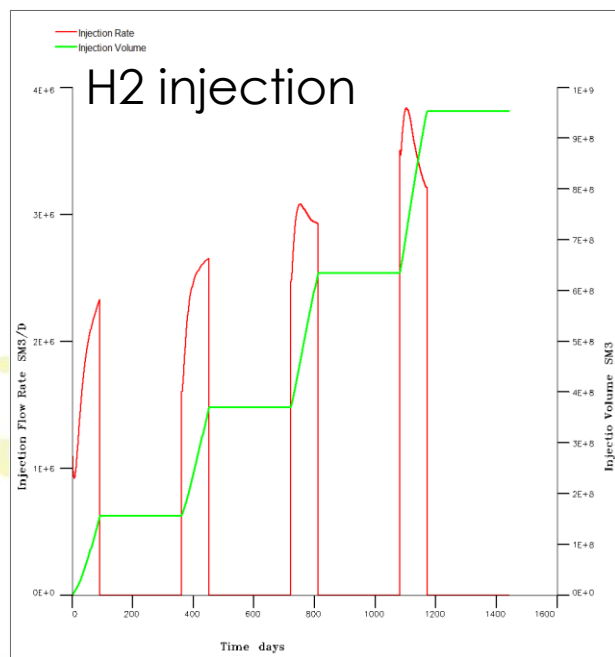
Simulation Assumptions

- The storage site is supplying the H₂ demand in the North East UK
- Each cycle represents one year , comprising 4 phases as illustrated
- Injection and withdrawal flowrates are constrained by BHP
- Geochemical and microbial activities in the reservoir are not considered



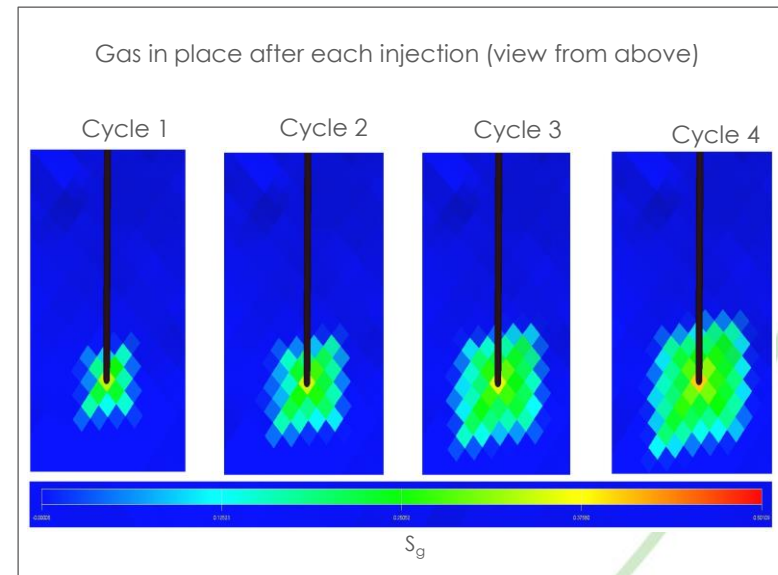
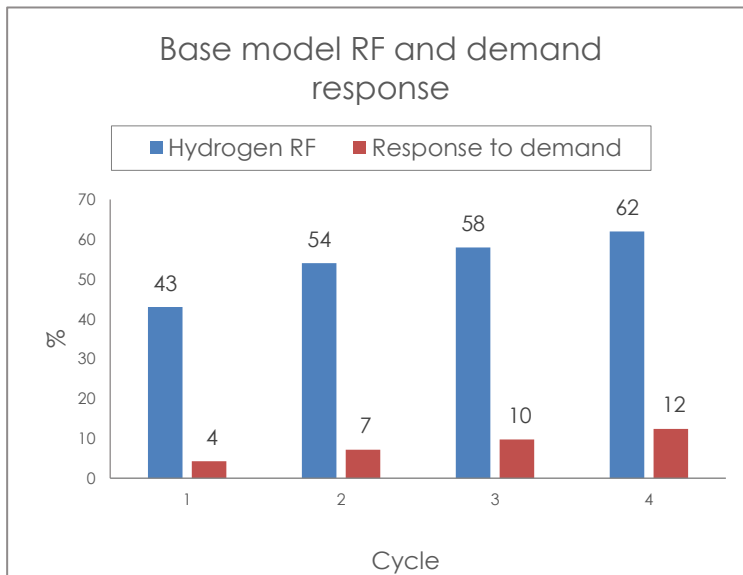
Single injection/withdrawal well placed at the crest of the reservoir

- Well injectivity and productivity is increased after each cycle
- The volume of working gas is increased after each cycle
- Water/Gas Ratio (WGR) during production is decreased after each cycle



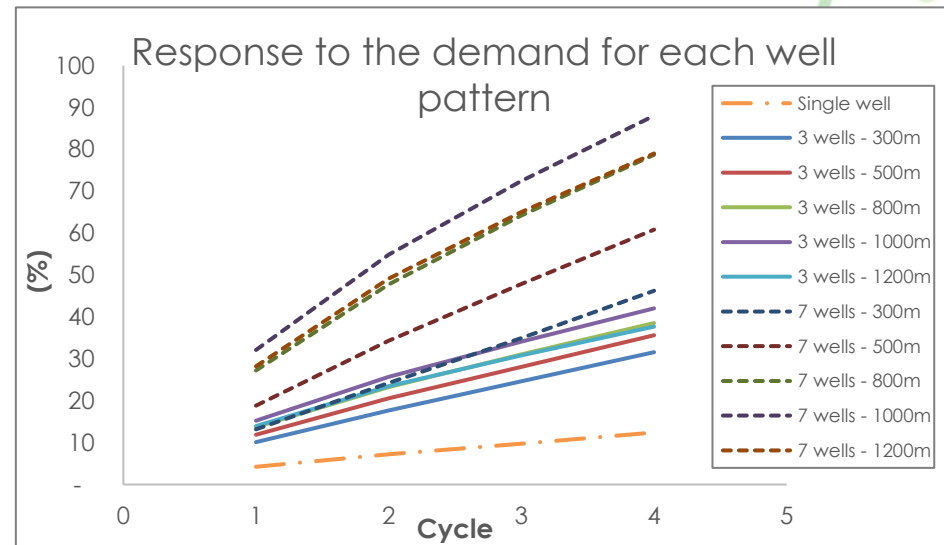
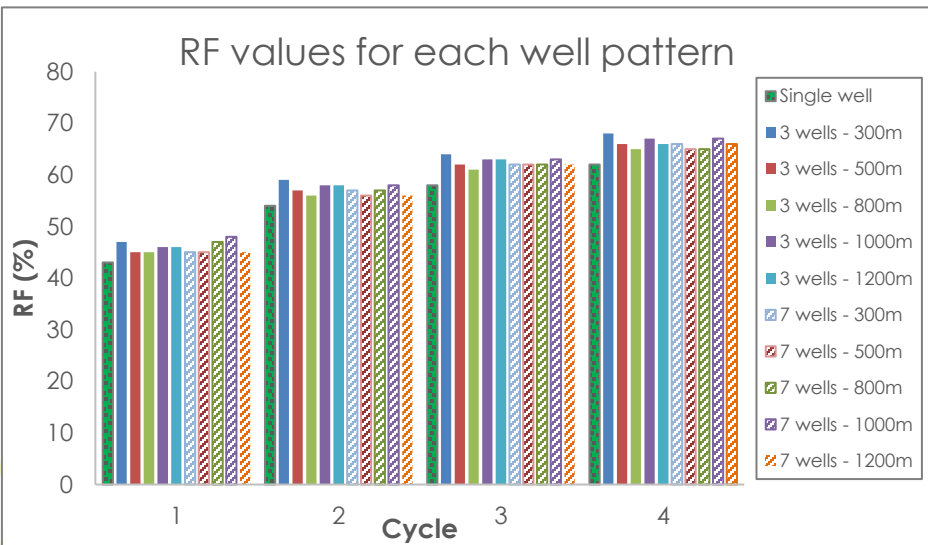
Single well RF and Demand Response

- Hydrogen Recovery Factor (RF) is increased after each cycle, leading to a higher response to the demand



Well pattern design: Well distance and well Number

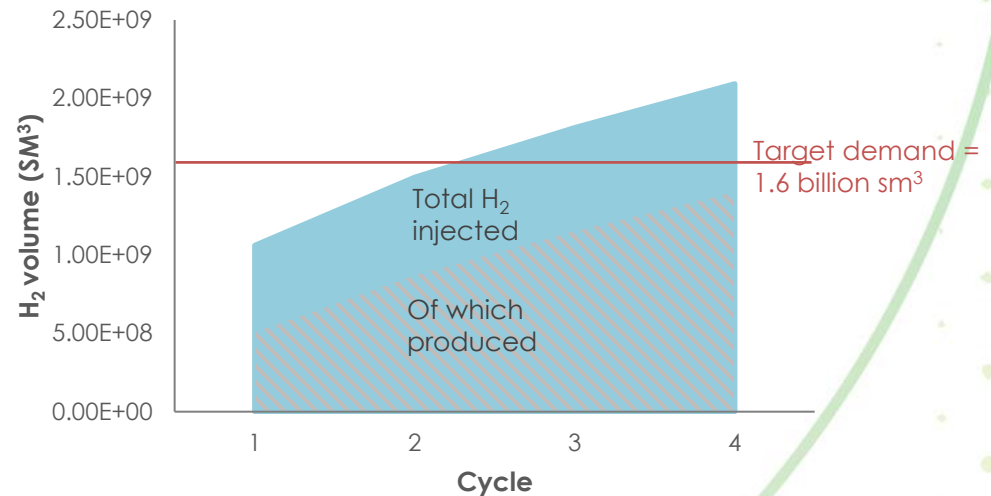
- Reservoir H_2 capacity and deliverability are increased significantly with number of wells, leading to a higher response to the demand
- Well distance has also a critical role in reservoir H_2 capacity and well injectivity/productivity
- However, the impact of well pattern design on RF is insignificant



Optimal well design to respond to the demand

- The highest reservoir H₂ capacity and demand response was achieved by the 7 well pattern with distance of 1000m between each well

Cycle	Injection volume (billion sm ³)	Production volume (billion sm ³)	RF (%)	Response to demand (%)
1	1.06	0.513	48	32
2	1.50	0.879	58	55
3	1.81	1.16	63	72
4	2.09	1.41	67	88



Ongoing plan

- Aquifer is used as case study due to less complex computational analysis
- Use of cushion gas type (N₂ , CO₂ and CH₄) and its impact on H₂ delivery
- H₂/rock/fluid interaction (Geochemical and Microbial activities)
- Developing screening criteria for site selection

Future is Colourful with Hydrogen



Teesside
University

Dr. Sina Gomari, s.Rezaei-gomari@tees.ac.uk

tees.ac.uk

With Special thanks to Saeed Harati , PGR