Theoretical capacity for underground hydrogen storage in UK salt caverns

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UKCCSRC web series / CCS with hydrogen/ 20 May 2020
Introduction

• Hydrogen viewed as a credible option to displace natural gas in heating – particularly important in context of net-zero

• Majority of hydrogen in the near-term would be generated from natural gas by methane reformation rather than electrolysis

• A requirement for both permanent offshore CO₂ storage as well as inter-seasonal and inter-day H₂ storage

• Surface storage infrastructure and linepack are important components, however for larger storage volumes underground gas storage more efficient

• First national-scale assessment of hydrogen storage capacity of the UK
Underground H₂ storage

• Porous media such as depleted oil and gas reservoirs or saline aquifers, or engineered subsurface cavities

• Historical H₂ storage has mostly comprised storage of town gas, which contains 40–60% H₂ together with CO, CH₄ and volatile hydrocarbons, commonly used during the mid-20th Century

• Only a small number of underground pure H₂ storage sites: Teesside and three sites in the USA
  • Teesside salt field (25 GWh) in three small elliptical shaped caverns
  • Clemens Dome, Moss Bluff and Spindletop (~90 to 120 GWh) in Texas salt domes

• No current projects storing pure H₂ in porous reservoirs
Salt cavern storage

- Artificially generated cavities in underground rock salt (halite) formations created by the solution mining process
- Several natural gas storage caverns operating in Cheshire and Yorkshire (up to 14 TWh)
UK halite distribution

Cheshire Basin
- Lias Group
  - Penarth Group
    - Blue Anchor Formation
      - Branscombe Mudstone Fm.
  - Wilkesley Halite Member
- Northwich Halite Member

East Yorkshire
- Chalk Group
  - Lias Group
  - Penarth Group
    - Mercia Mudstone Group
- Sherwood Sandstone Group
  - Z4 & Z5
  - Boulby Halite Formation (Z3)
  - Fordon Evaporite Formation (Z2)

Wessex Basin
- Great Oolite Group
  - Inferior Oolite Group
  - Lias Group
    - Penarth Group
      - Mercia Mudstone Group
        - Sherwood Sandstone Group
          - Dorset Halite Member
Methodology

• *Determine the volume of H₂ that could theoretically be stored in new salt caverns in the selected halite formations*

• Modelling the placement of an idealised cavern configuration constrained by geological models representing the distribution, depth and thickness of bedded halite formations

• Buffers applied to rule-out locations underlying infrastructure, environmentally-sensitive areas, geographic and geological features

• Remaining cavern locations exported to a spreadsheet tool for modelling of cavern volumes and hydrogen storage capacity
Geological modelling and cavern placement

- Structural maps designating the top and thickness of the target salt formations generated from contour maps and borehole data
- Caverns placed in closed-packed hexagonal grid pattern
  - Uniform cavern width of 100 m (50 m radius)
  - Distance between caverns of 150 m (3 x radius)
- Exclusion zone of 150 m from buffer features
- Depth of top and base salt recorded for each remaining cavern location
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Cavern geometrical constraints

• Cavern depth, height, and minimum roof and floor salt thickness restrictions imposed based on industry practice
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Cavern and H₂ storage volumes

- Bulk cavern volumes calculated assuming simple cylindrical caverns, modified by the following corrections
  - Shape correction factor, Insoluble fraction, Inefficiency of mechanical sweeping, Bulking factor
- Pressure and temperature estimated for each cavern location
- Cavern operating pressure range estimated as function of pressure gradient (0.3 to 0.8 x pressure at casing shoe)
- Density of H₂ at operating pressures calculated from equation of state
- Working H₂ mass at max and min operating pressures
- Energy storage potential estimated from working H₂ mass using lower heating value
Modelling results

- Theoretical storage capacity of ~3000 TWh across the three regions
- Not practical capacity – detailed site investigation required, not matched to storage demand
Towards effective storage capacity (heat)

• Deliverability rates critical for efficient inter-day/seasonal storage
  • Very small or excessively large caverns may not be suitable
• Estimates refined by per-cavern energy storage ranges
• For maximum individual cavern storage capacities of 140 to 160 GWh the maximum available storage in the Cheshire basin exceeds 40 TWh
  • Leeds City Gate project required 8 x 122.1 GWh caverns to provide the inter-seasonal storage demands of the project
  • For caverns of that size, East Yorkshire alone could far exceed this requirement
Conclusions

• The first national-scale theoretical H₂ storage capacity estimate in new salt caverns
• Significant theoretical H₂ storage capacity of ~3000 TWh
• Includes individual caverns ranging in size from 6 to 441 GWh
• If cavern size restricted to 140 to 160 GWh range, storage capacity reduces to <200 TWh
• The modelled storage capacity estimates significantly exceed the requirements of current gas industry projects
• Storage capacity would not be a constraint to H₂ network development if cavern construction is determined solely by demand
• Development of any new underground gas storage development will require detailed site-specific geotechnical evaluations and will be subject to extensive environmental impact assessments and planning application processes
• Offshore regions may provide significant additional hydrogen storage potential
Acknowledgement

ACT ELEGANCY, Project No 271498, has received funding from DETEC (CH), FZJ/PtJ (DE), RVO (NL), Gassnova (NO), BEIS (UK), Gassco AS and Statoil Petroleum AS, and is cofunded by the European Commission under the Horizon 2020 programme, ACT Grant Agreement No 691712.