Hydrogen Storage In Caverns 2024

"Filling the gaps: making scale hydrogen storage a reality".

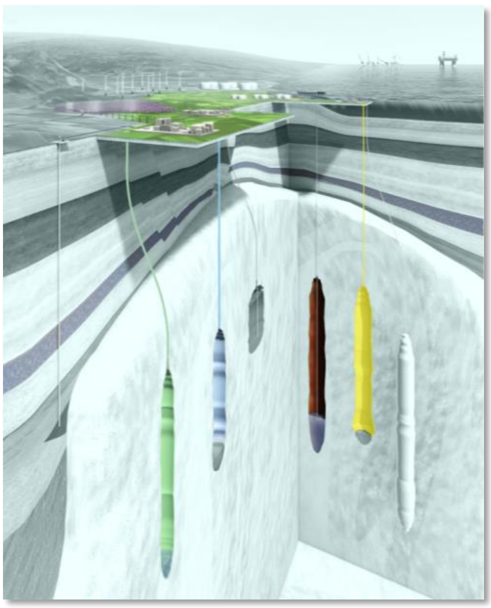
Report from the 2024 Energy Research Accelerator Event.

1. Executive Summary

- Consensus has grown that only hydrogen can "fill in the gaps" left by intermittent renewable energy production troughs in a cost-effective Net Zero UK power grid.
- Publications by The Royal Society, NG ESO, the Climate Change Committee and industry analysts in the last 12 months all confirm the same direction – that "tens of TWh" of geological hydrogen storage provides the lowest cost pathway to a Net Zero UK grid and economy.
- However, as the big picture becomes clearer, industry and academic work is revealing missing elements required for hydrogen storage to become a reality.
  - A project gap is emerging. Announced projects, even if all funded, do not appear to sufficient to support meet government hydrogen targets for 2030.
  - Technology Readiness Level (TRL) and supply chain gaps are emerging. The UK government Business Model support scheme requires TRL 7 for applicants and all their equipment. TRL for depleted gas field conversion was estimated at 3-4 by IEA in 2020; although salt cavity storage in general is 7-8, individual components need to be developed and tested further.
  - Policy framework gaps are emerging. From the consenting, permitting and planning systems, to the grid connection offer process and business model subsidy support schemes, there are gaps that need to be filled in order to create the investor confidence required for further development expenditure commitment.
- These gaps are a "now" issue. They need to be filled urgently, to make hydrogen storage at sufficient scale in time to meet government targets in 2030, 2035 and 2050.

2. Background: output and conclusions from previous events

- Great Britain's geology features both a large amount of salt layer suitable for cavern creation, and large quantities of suitable porous rock in depleted gas fields which can potentially store hydrogen in vast quantities. This is a source of national competitive advantage in a net zero world.
- Energy stored as hydrogen underground will be the most cost-effective long duration storage solution to a net zero power grid in Great Britain and should form the backbone of intermittency mitigation (beyond daily and weekly cycles and variations).
- Despite short term turbulence, the downward trajectory of renewable generation means that a combination of intermittent renewables and energy storage appears to be the lowest cost solution to a net zero power grid.
- Requirement for storage is driven more by sustained periods of low wind (such as the UK saw in July-September 2021) than the by winter/summer pattern of demand (that has historically driven gas storage provision).
- A diverse base of storage types and assets will prove economically optimal, and necessary for grid operability. Lower round trip efficiency will place hydrogen in the "slow cycle" storage role. Lower capital costs per GWh of output electrical energy means that hydrogen salt cavities will nonetheless provide most of the 40-140 TWh (LHV) requirement.
- Inventories of hydrogen of this quantum will also fulfil the role of providing energy resilience. The UK is required to hold oil stocks to meet obligations imposed by both the International Energy Agency (IEA); in a net zero future, only hydrogen stored underground can provide an equivalent buffer against unexpected eventualities – potentially including aggressive actions by external actors.



Salt Cavern Schematic: Graphic courtesy and copyright of DEEP.KBB GMBh

3. Acknowledgements

Hydrogen Storage in Caverns 2024 ("HSiC 2024") was run on 12th April as part of the larger UK Energy Storage 2024 (UKES 2024) three-day conference hosted by University of Nottingham.

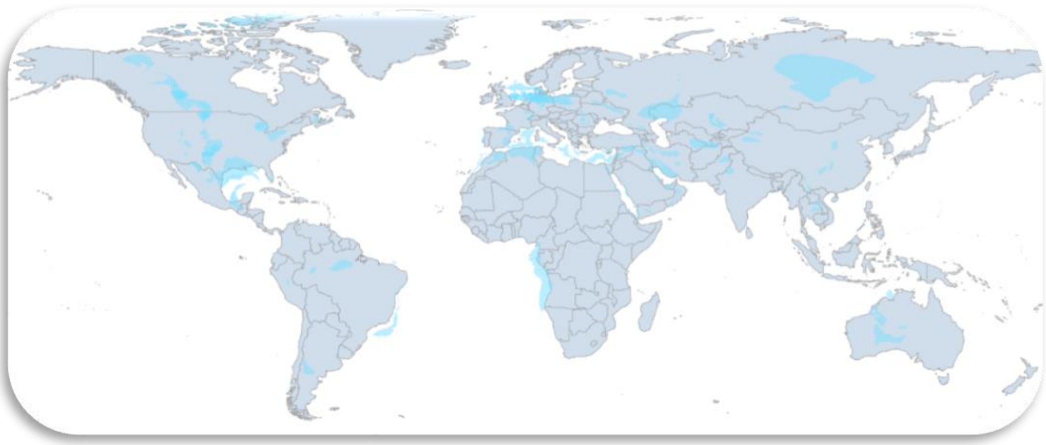
It is the fourth such event, following the successful events in 2020, 2022 and 2023.

[Insert links to HSIC events + UKES]

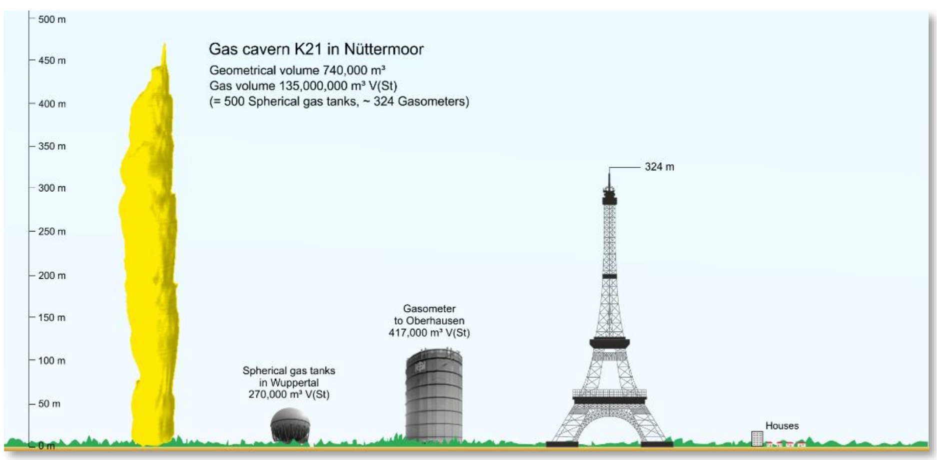
This report summarises the presentations made, and the panels observations, with the intention of providing policy makers and potential participants with a succinct reference source to the event.

We are grateful to all our sponsors and speakers for making the event happen.

Global Salt Layer Resource - Graphic courtesy and copyright of DEEP.KBB GMBh



Typical Salt Cavern for Scale - Graphic courtesy and copyright of DEEP.KBB GMBh



Summary of Presentations

There were ten presentations made including the keynote address:

i. Keeping the lights on: Underground hydrogen storage in the UK – Tim Armitage – Geoscientist - British Geological Survey
   - Hydrogen is the Swiss army knife of low carbon energy – with potential applications in heavy industry, shipping, aviation, and particularly despatchable low carbon power.
   - Hydrogen demand for the power sector is likely to be far more variable than the steady demand from industry and other sectors.
   - Allocation Round 1 of the UK's Hydrogen Storage Business Model support programme is imminent in Q3 2024
     - TRL 7 Requirement in the business model is potentially a subjective and variable hurdle.
     - Porous Rock storage in depleted fields potentially as low as 5; Salt Caverns as high as 10 or as low as 6.
   - For salt cavity creation the suitable salt layer in the UK is found primarily on the East Coast of England from Humberside to Teesside; and in North West England. There are large swathes of suitable geology under the North Sea and Celtic Sea.
   - All rock is not the same, and poor research, planning and investigation leads to poor results in cavity creation.
   - The theoretical capacity for storage in depleted gas fields is huge: >6000 TWh from fields with public data alone.
   - Dozens or hundreds of salt caverns are potentially needed for the 40-100 GWh
   - Measurement monitoring and verification of storage integrity is required.
   - Decommissioning burden should be considered at the creation stage.
   - High dozens of hundreds of TWhs of hydrogen storage will be required.
   - An the investment requirement of the order of £100bn will be needed, and does require government support intervention.
   - As headlined in the House of Lords Report it is time to "Get on with it".

ii. Geological storage of Hydrogen for Net Zero - Katriona Edlmann - Chancellor's Fellow in Energy - University of Edinburgh:
   - Hydrogen is necessary to meet UK Net Zero targets.
   - Only storage of hydrogen gas in suitable geological formations can deliver the required TWh capacity of energy storage with delivery over weeks to months that will be necessary for a renewable-heavy grid.
   - UK National Grid "Future Energy Scenarios" (FES) anticipate that 56 TWh of hydrogen energy storage is required by 2050 for their system transformation scenario.
   - Geological storage of hydrogen is recognised as the cheapest option for large scale energy storage.

- Various methods of underground storage are proven technically with historic schemes and demonstrator projects.
- The main methods for consideration Dedicated Pipeline Storage, Silos, Lined Rock Shafts, Salt Caverns – Onshore and Offshore, and Porous Rock Storage. Cost, land usage, and lead time to delivery vary between these methods.
- Gaps exist in integration

iii. <u>"Assessing the Regional Demand for Geological Hydrogen Storage: Building a Strategic Case for Investment in the East Coast Cluster - Adam Kemshell, Graduate Energy Engineer, Arup</u>

- A study was undertaken for Industrial Decarbonisation Research and Innovation Centre (IDRIC), with academic partner University of Edinburgh and British Geological Survey.
- The study was focussed on establishing the case for change to ensure UK has the storage required to support its hydrogen ambitions, that are intrinsically linked to its ability to reach legally-binding net zero targets.
- WP1 studied the need for hydrogen storage in the East Coast region, and concluded that 3.8-8.2 TWh of storage was required in 2035. Given the 10 year + lead time for salt cavern facilities, this is a "now" issue.
- WP2 studied available capacity, particularly for salt caverns, which was estimated at 22-48 TWh in the region – significantly lower than theoretical capacity which had previously been estimated at 100 – 1000s TWh by other studies.
- WP3 studied the case for change, and found significant market barriers:
  - Nascent nature of hydrogen economy - uncertainty around how and when storage will be needed and the optimum mix of storage technologies.
  - Ability to deploy salt cavern storage at pace – large salt caverns can take up to 10 years to build and follow a complex development process.
  - Lack of a detailed and coherent regulatory framework for hydrogen storage – significant levels of up-front investment are required, far ahead of demand.
- The study concluded that minimum-regret interventions were:
  - Strategic planning - to define the mix of storage technologies required and the optimum pace of development, establishing a consistent approach.
  - Undertake proactive public engagement and social baselining - to involve the community and assess attitudes, concerns and preferences.
  - Implement a structured R&D programme – for existing technology optimisation and to support the development of alternatives.

- Targeted interventions – to de-risk the development lead time for storage projects, such as to the consenting, permitting and planning process.

iv. "An overview of gas cavern construction and its energy requirements, Aura Alvarado de la Barrera, DEEP.KBB
   - Deep KBB are a specialist international engineering consultancy focused on subsurface technology and storage facilities. They have significant involvement in hydrogen storage studies, projects and research.
   - Ms. Alvarado de la Barrera described in detail the technical process of creating a salt cavern storage facility from geological exploration to first fill.
   - Deep KBB have studied the amount of energy consumed in the creation of a salt cavern.
     - Factors causing variation between schemes include lithology (hardness), depth and dimensions of the cavern, and compressor efficiency
     - Leaching is responsible for approximately 94% of the energy consumed by the creation process, with the remainder due to drilling (5%) and materials (1%).
     - A typical salt cavern, which could store c. 0.7TWh of methane or 0.2TWh of hydrogen, is likely to consume 18-28 GWh of energy for leaching. i.e. 10%-15% of the energy content of its first fill (for H2) or 2.5%-4% (for natural gas).
     - The leaching process does not need to be run "24 x 7"; and so leaching load could potentially be modulated as a demand-side flexibility tool for the grid.

v. "Transforming Rough for large-scale hydrogen storage, Chris McClane, Centrica
   - The Rough gas field has fulfilled a range of functions already in its lifetime including gas production (1975-84 and 2017-2022), strategic storage (1985-2001), merchant storage (2002-2017) and (2022-24).
   - Rough could be converted to also be able to store hydrogen by c. £2bn investment in a brand new offshore asset and modification of existing onshore infrastructure.
   - If converted Rough could store up to 16TWh of hydrogen (equivalent to c. 80 normal size salt caverns), with a design life of 45 years.
   - The project faces "First of a Kind" (FOAK) challenges and needs a suitable business support and regulatory framework to reduce financial risk.
   - H2 storage in depleted gas fields was estimated by IEA in 2020 at Technology Readiness Level (TRL) 3-4. Current Business Model support from the UK government requires TRL 7.

- Bridging the TRL gap involves mitigation of subsurface and facilities risks via lab and industrial-scale testing, and desk-top modelling and engineering studies. Work is ongoing.
- Initial status is positive in all categories for Rough as a specific asset: Geomechanics & Storage Integrity, Geochemical, Microbiological and Storage Performance.
- Centrica Energy Storage (CES+) are now developing a pilot scheme to demonstrate Rough H2 storage compatibility at industrial-scale.
- Piloting would deliver outputs that could underpin development of other porous rock H2 storage projects in the UK and globally.

vi. <u>“Pathfinder project: Engineering electricity storage using hydrogen, Klim MacKenzie, SSE</u>

- The Aldbrough Hydrogen Pathfinder is a first of a kind project in the Humber.
- The project encompasses a 35MW PEM electrolyser, a repurposed existing salt cavern which will initially hold 20GWh of hydrogen, and a 50MW open cycle turbine. Overall round trip efficiency is estimated at c. 24%.
- Project seeking support in the UK Government’s Net Zero Hydrogen Fund.
- Project aims to provide an evidence base for wider deployment.
- FEED (Front End Engineering Design) has been undertaken with Siemens Energy, Black & Veatch and Atkins.
- Challenges are presented by supply agreements, permits, planning, government requirements for Business Model support:
  - Grid connections in the Humber: 2035+
  - Planning application reviews
  - Regulator reviews
  - TRL 7 requirement for Business Model support
  - Long lead times for FOAK equipment
  - Fixed price approach for Business Model support
  - Public perception of hydrogen safety and industrialisation

vii. <u>“H2 long-duration energy storage: How much capacity will there be across Europe by 2030, and will this be enough? Brendan Murphy, LCP Delta</u>

- 32 projects with combined capacity of 8TWh are planned across Europe for 2030. 25 of the proposed projects are salt caverns.
- The proposed projects are developed by existing gas storage providers, with 84% of the capacity proposed by the top 8 companies.
- Detailed modelling reveals that whilst 2030 UK space (TWh) requirements could be met by existing proposed schemes, the peak daily withdrawal and injection capacity would not be met. Hence the UK needs more proposals to fill the gap to meet 2030 ambitions for hydrogen usage. Models suggest that space equivalent to 6% of annual usage is required.

- At the European level 8TWh of storage represents 1% of the EU+UK ambition for annual hydrogen production and consumption (810TWh/yr), and so would fall short of the space requirement.

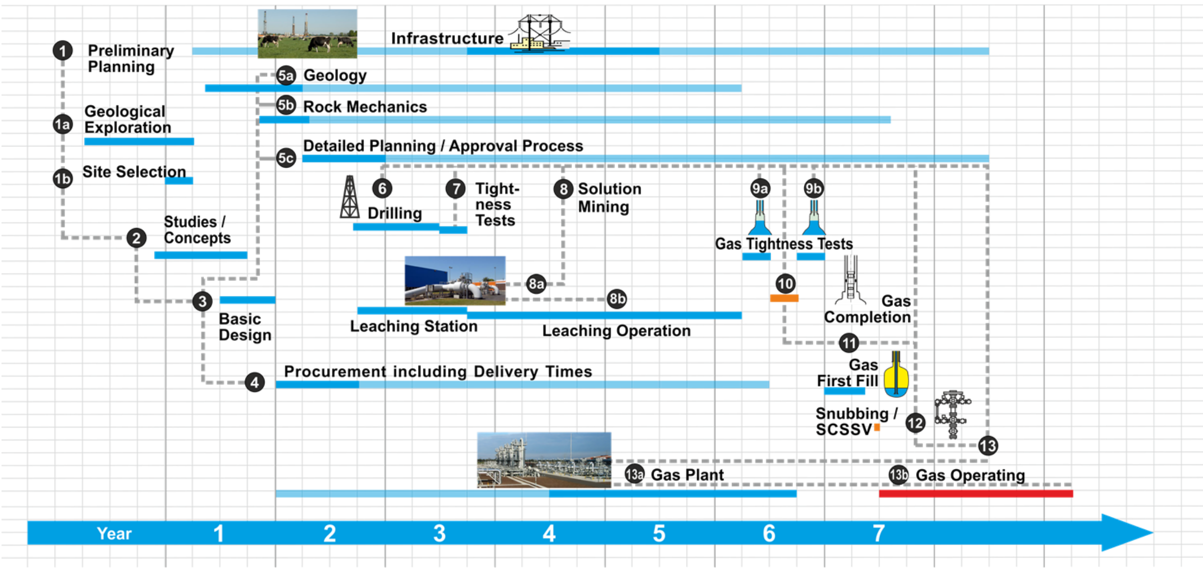
viii. <u>“Projects EMStor: Exploring potential for geological hydrogen storage in the East Midlands, Dr. Faye McAnulla, Net Zero Strategy</u>

- EMSTOR is a recently initiated feasibility study to examine the potential for hydrogen storage in East Midlands.
- The project encompasses 70 demand sites with a prospective hydrogen demand of 10TWh/yr and three prospective producers of hydrogen with GW scale potential.
- The context is that hydrogen storage is required to secure the future location of the interested demand sites; without hydrogen availability including storage, the area risks migration or loss of local industry.
- The East Midlands is remote from current proposed storage projects. All possibilities are being considered, including storage outside the region with transport infrastructure.

4. Links To Further Reading and Resources.

- Net Zero Power and Hydrogen: Capacity Requirements for Flexibility (AFRY report for the Climate Change Commission)
  - https://www.theccc.org.uk/wp-content/uploads/2023/03/Net-Zero-Power-and-Hydrogen-Capacity-Requirements-for-Flexibility-AFRY.pdf
  - https://www.theccc.org.uk/wp-content/uploads/2023/03/Net-Zero-Power-and-Hydrogen-Capacity-Requirements-for-Flexibility-Additional-Sensitivities-AFRY.pdf

- Large-scale electricity storage briefing (Royal Society Report by Professor Sir Chris Llewellyn Smith FRS, University of Oxford)
  - https://royalsociety.org/-/media/policy/projects/large-scale-electricity-storage/large-scale-electricity-storage-policy-briefing.pdf
  - https://royalsociety.org/-/media/policy/projects/large-scale-electricity-storage/large-scale-electricity-storage-report.pdf
- House of Lords Report: Science and Technology Committee Long-duration energy storage: get on with it.
  - House of Lords - Long-duration energy storage: get on with it - Science and Technology Committee (parliament.uk)



Project Timeline of New Cavern Creation - Graphic courtesy and copyright of DEEP.KBB GMBh

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