Exploring Essential Large-Scale Energy Storage Solutions

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With support from the entire subsurface hydrogen team at Edinburgh Geosciences including Niklas Heinemann, Ali Hassanpouryouzband, Eike Thaysen, Tim Armitage, Andrew Cavanagh, John Low, Lubica Slabon, Mark Wilkinson, Ian Butler, Stuart Haszeldine, David Stevenson, Hannah Bryant ...
Why hydrogen energy storage

Energy transition to achieve Net Zero:
2023: 80% fossil fuels/20% renewable electricity energy mix
2050: ~70% renewable electricity/~30% hydrogen energy mix
Anticipated hydrogen energy storage requirements

- No UK future energy scenario reaches Net Zero without hydrogen (... and hydrogen energy storage).
- The UK National Grid Future Energy Scenarios anticipate that 56 TWh/year of hydrogen energy storage is required by 2050 for their system transformation scenario.
- Gas Infrastructure Europe estimate an EU hydrogen energy storage requirement of 70 TWh/year hydrogen by 2030 and 450 TWh/year hydrogen by 2050.
- The US DOE National Clean Hydrogen Strategy and Roadmap, indicates their current goal of a 100% clean electricity grid will require 132-264 TWh/year hydrogen energy storage.
Worldwide Underground hydrogen storage experience = Commercially and technically feasible

### Aquifer storage of hydrogen (town gas)
- Ketzin, Germany (62% hydrogen town gas – now closed)
- Beynes, France (50% hydrogen town gas from 1956-1972)
- Lobodice, Czech Republic (50% hydrogen town gas from 1965, now used for natural gas storage)

### Salt cavern storage of hydrogen
- Teeside, UK (active since 1959 storing 95% hydrogen)
- Kiel, Germany (62% hydrogen, now operating with natural gas)
- Spindletop, US (95% hydrogen storage)
- Clemens Dome, US (95% hydrogen storage)
- Moss Bluff, US (95% hydrogen storage)

### Hydrogen storage for biomethane production
- Hychico, Argentina (10% hydrogen storage in a depleted gas reservoir)
- Underground Sun Storage, Austria (10% hydrogen storage in a depleted gas reservoir from 2015)

### Hydrogen storage in lined rock caverns
- HYBRIT, Sweden for 100% decarbonised steel production
Lined rock caverns have the potential to:

➢ Deliver decentralised storage to support the initial growth of the hydrogen economy and industrial decarbonisation

➢ Provide future fast response and daily electricity grid balancing/resilience

➢ Single cavern of ~40,000 m³ at 20 MPa pressure will hold around 15-20 GWh (500-800 tonnes) hydrogen.

Suitable geologies include:

- Igneous rocks
- Metamorphic rocks
- Hard sandstones/limestones
- Clays
- Chalk
UK onshore salt for hydrogen storage

Hydrogen storage in salt caverns:
➢ Extensive commercial experience but not at high cycling rates.
➢ Geographically constrained

Ongoing research to:
➢ Salt interlayers and their long-term impact on sealing integrity and geochemistry
➢ Risk of H₂S generation from high sulphate salts (e.g., anhydrite/gypsum)
➢ Risk of microbial consumption/contamination
➢ Well integrity/leakage risk

The upper-bound theoretical capacity for hydrogen storage in UK ONSHORE salt caverns is 2150 TWh


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UK offshore salt for hydrogen storage

Hydrogen storage in offshore salt caverns:

➢ Offshore may be necessary depending on public perception.
➢ Higher costs than onshore.
➢ https://doi.org/10.1144/SP528-2022-82
Porous Rock Storage: Depleted gas fields

Hydrogen storage in depleted gas fields:

➢ Very large storage capacities
➢ Proven ability to store gas
➢ Utilise existing infrastructure and skills.
➢ Research so far has not identified any insurmountable issues when repurposing to hydrogen.
### Underground Hydrogen Storage Projects Currently in Planning

**Site Name** | **Storage Type** | **Planned Storage Capacity (TWh)** | **Planned Commission Date**
--- | --- | --- | ---
1 Teeside | Salt cavern | 0.027 | Existing
2 Aldborough | Salt cavern | 0.32 | 2028
3 NyNef NW Keuper | Salt cavern | 1.38 | 2025
4 HySecure | Salt cavern | 0.04 | TBD
5 Cervelle | Salt cavern | TBD | 2027
6 HyPSTER | Salt cavern | 0.002 | 2023
7 GeoH2 | Salt cavern | 0.24 | 2028
8 GeoGaz H2 | Lined rock cavern | 0.04 | 2028
9 HyGeo & HySow | Salt cavern | 0.002 & 0.5 | 2024 & 2030
10 H2 Storage North-2 | Salt cavern | 0.24 | 2029
11 H2 Storage North-1 | Salt cavern | 0.335 | 2029
12 Carrico | Salt cavern | 0.2 | 2025
13 Green Hydrogen Hub | Salt cavern | 0.25 | 2025
14 HyStock | Salt cavern | 0.24 | 2028
15 WestKuste 100 | Salt cavern | 0.003 | 2023
16 SaltHy | Salt cavern | 0.205 | 2030
17 Astora H2 Jengum | Salt cavern | 0.5 | 2030
18 Krummhorn | Salt cavern | 0.0006 | 2024
19 H2Cast Etzel | Salt cavern | 2.3 | 2024
20 Get H2 | Salt cavern | 0.13 | 2029
21 H2 Storage Xanten | Salt cavern | 0.14 | 2030
22 HyCavmobil | Lined rock cavern | 0.002 | 2023
23 H2Storage Staufurt | Lined rock cavern | 0.21 | 2030
24 Bad Luchstadt | Salt cavern | TBD | 2026
25 Underground Sun | Depleted gas field | 0.004/0.52 | 2023/2030
26 HYBRITE | Lined rock cavern | 0.004 | 2022
27 UGS Damaslawek | Salt cavern | TBD | 2030
28 UGS Velke Kausany | Depleted gas field | 0.01 | 2025
29 Aquamarine | Depleted gas field | 0.01 | 2023

**Legend**

- Depleted gas fields
- Lined rock caverns
- Salt caverns
Storage: Energy System Integration

- Wells with halite
- Permian Zechstein salt (high confidence)
- Permian Zechstein salt (medium confidence)
- Triassic salt (high confidence)
- Triassic salt (medium confidence)

Pipeline operational status:
- Abandoned
- Active
- Not in use
- Pre-commissioned/proposed
Hydrogen storage database

• GIS based map of geological storage locations and capacities integrated into the existing energy infrastructure

• Landing page@ www.edin.ac/uk-hydrogen-storage-database

• The database comprises:
  – Streamlined public facing online version
  – Full database shapefiles available for download on the website
Thank you
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