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 …

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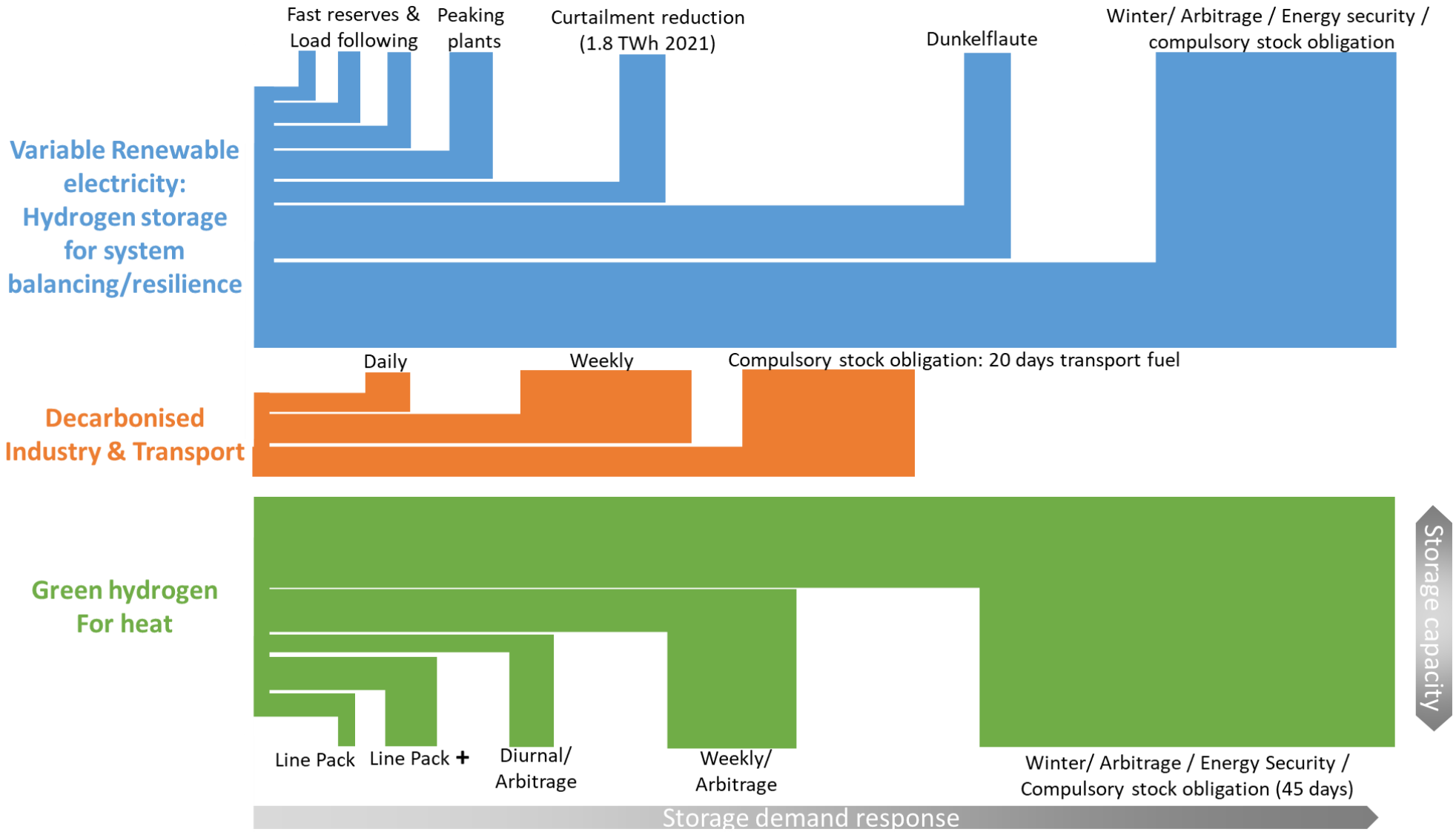
Why hydrogen energy storage

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



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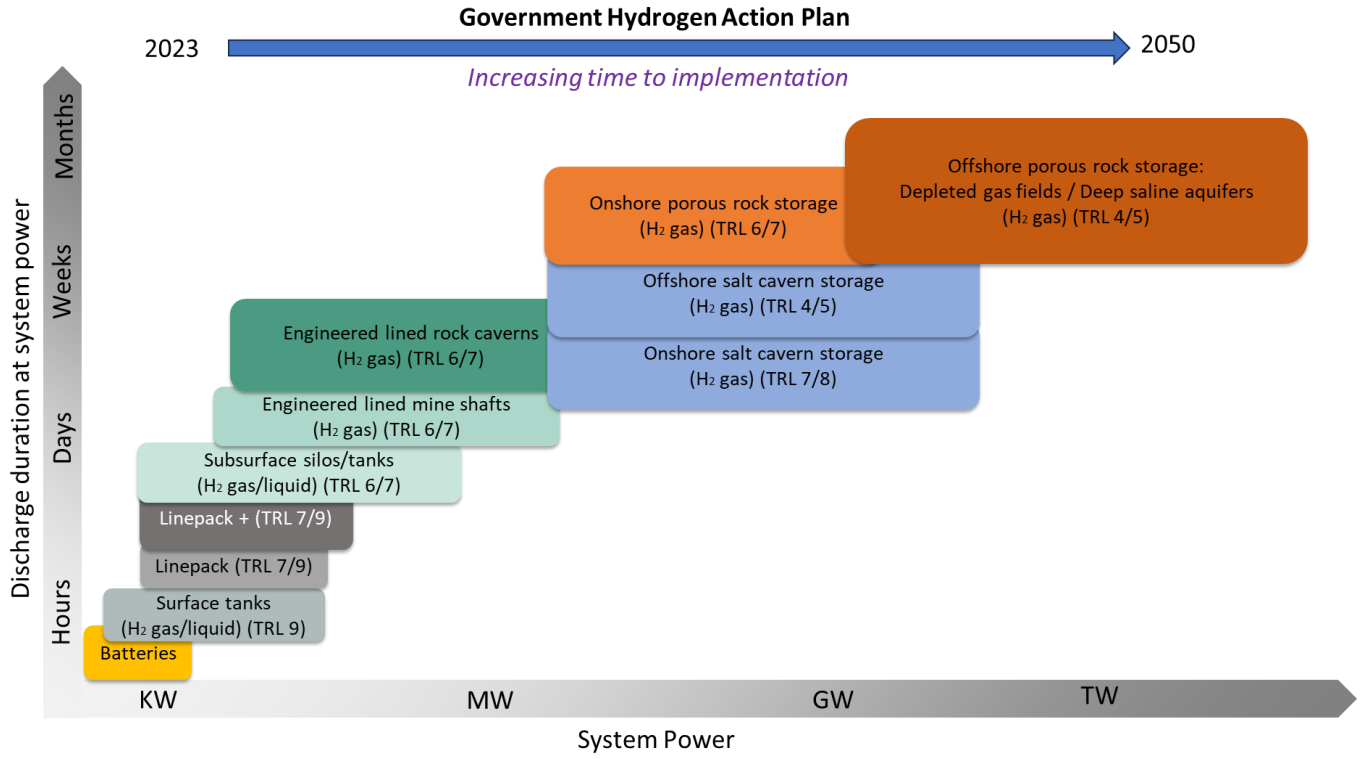
Anticipated hydrogen energy storage requirements

- 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

Hydrogen energy storage technologies



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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

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Decentralised local intermediate scale hydrogen storage in lined rock caverns and shafts

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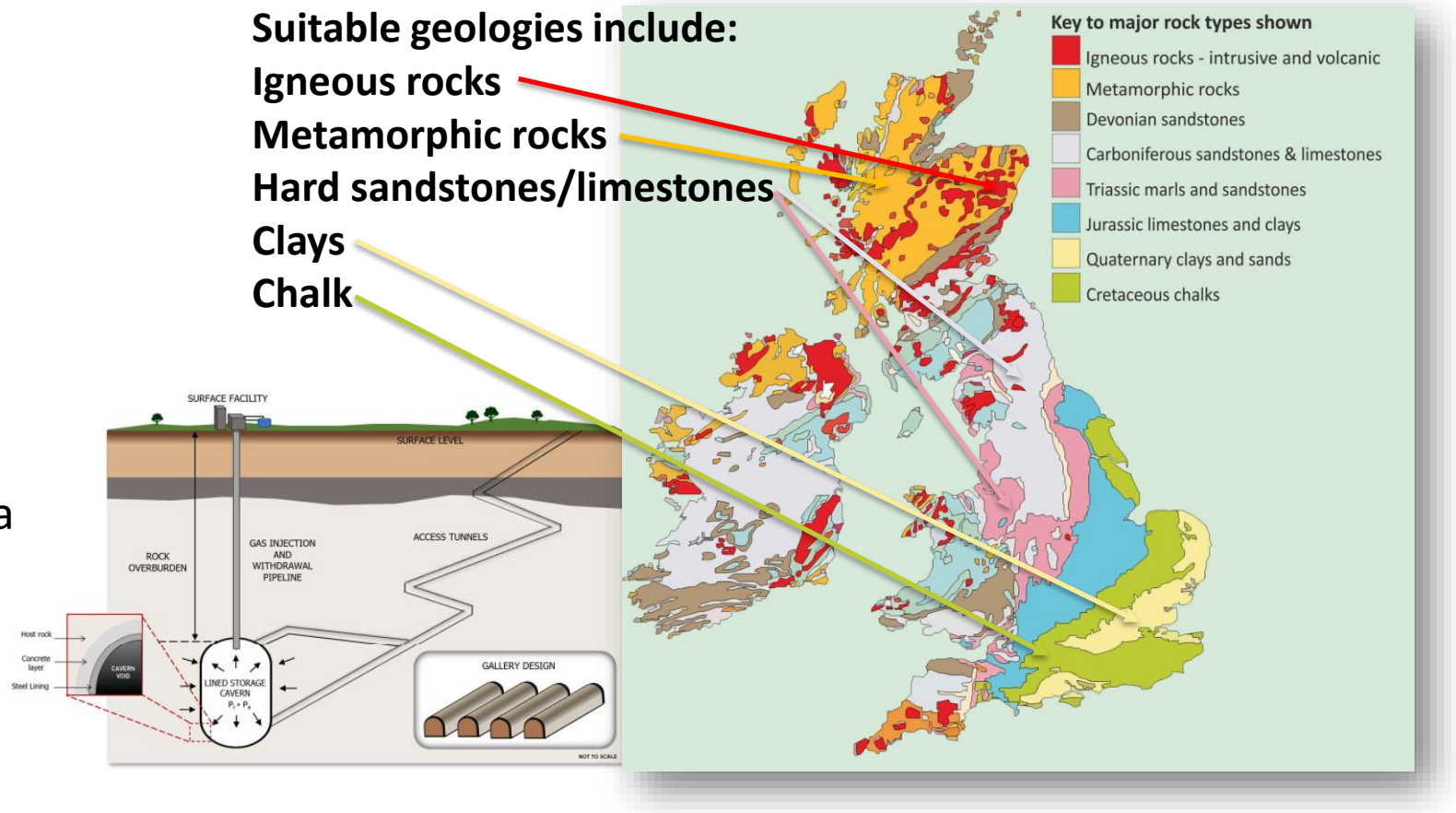
Lined rock caverns have the potential to:

- 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.

Simplified geology of the British Isles



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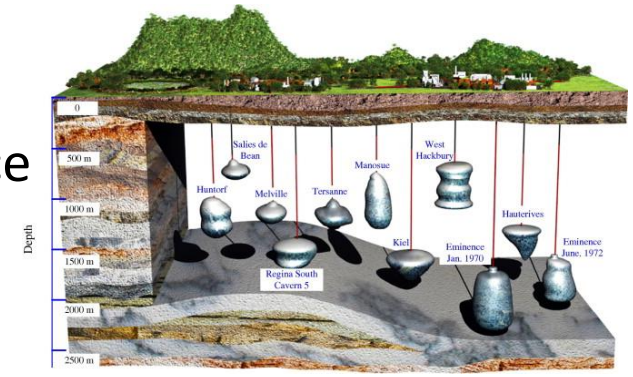
UK onshore salt for hydrogen storage

Hydrogen storage in salt caverns:

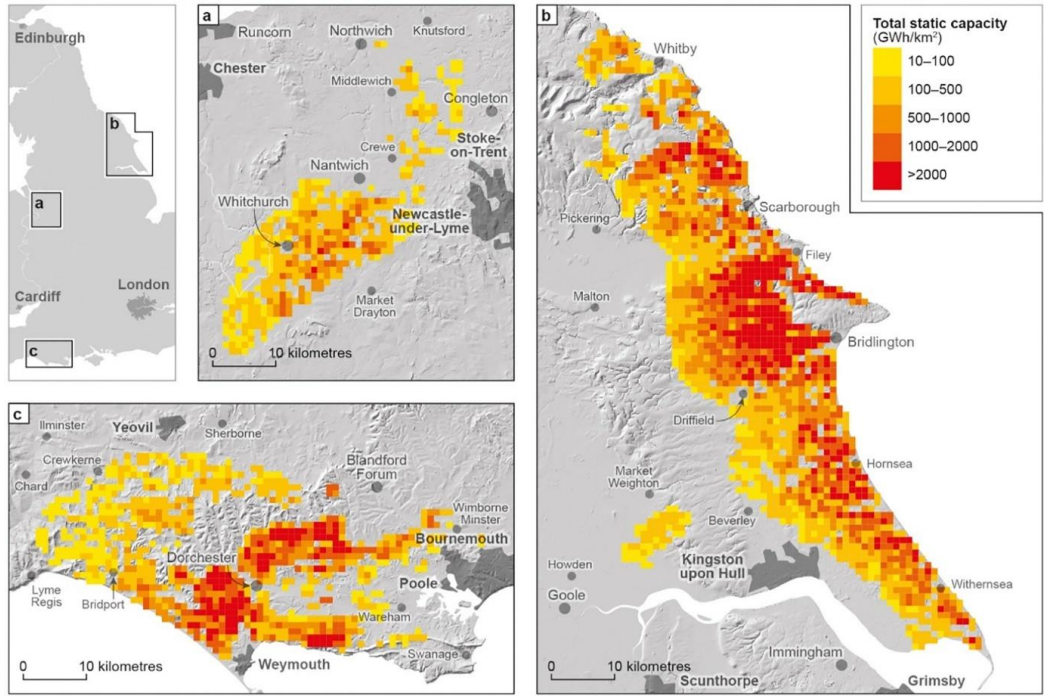
- Extensive commercial experience but not at high cycling rates.
- Geographically constrained



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

Ongoing research to:

- Salt interlayers and their long-term impact on sealing integrity and geochemistry
- Risk of H_2S generation from high sulphate salts (e.g., anhydrite/gypsum)
- Risk of microbial consumption/contamination
- Well integrity/leakage risk



https://www.sciencedirect.com/science/article/pii/S2352152X22011100#f0005

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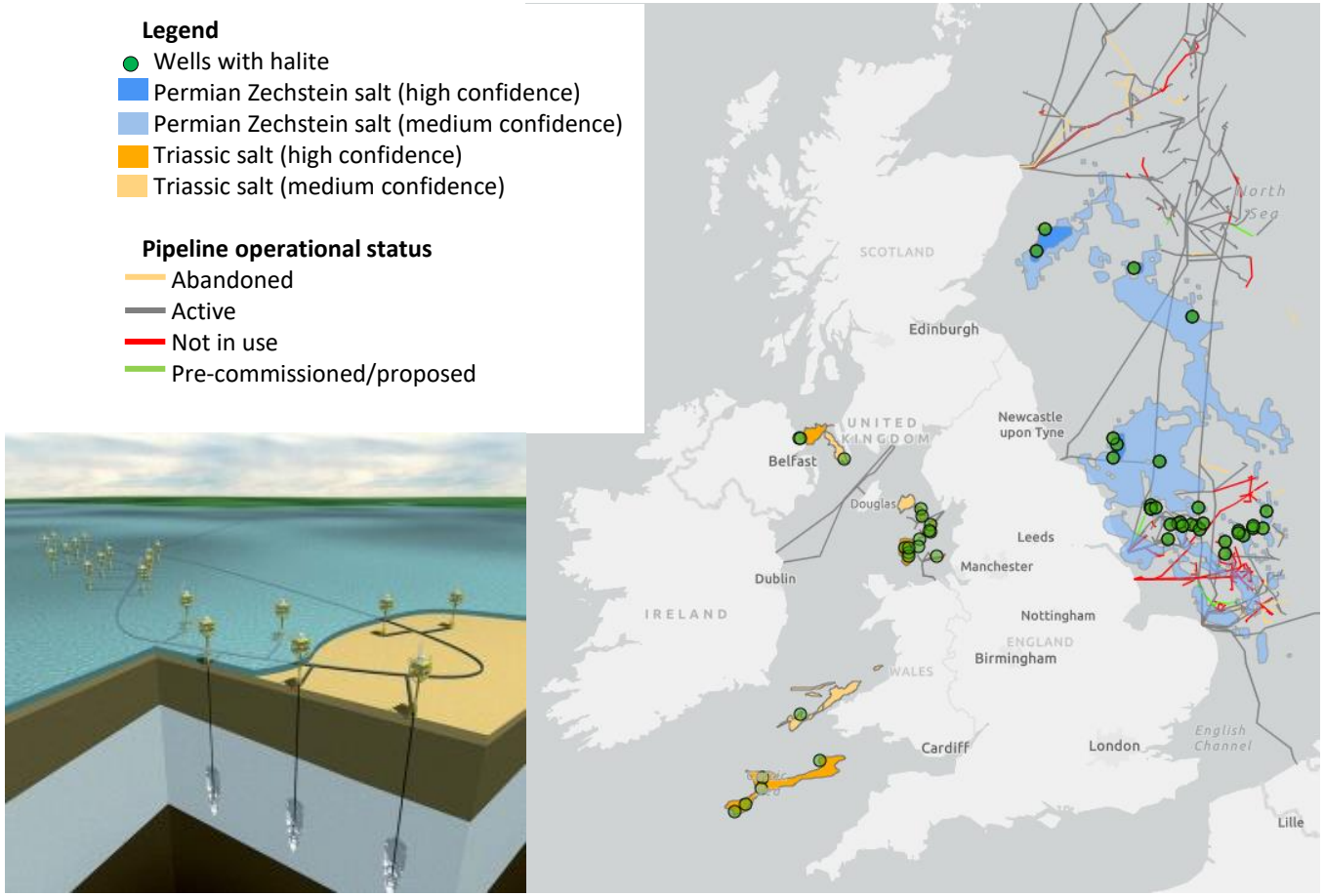
UK offshore salt for hydrogen storage

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

The theoretical capacity for hydrogen storage in UK OFFSHORE salt caverns in the Southern North Sea is 292 TWh



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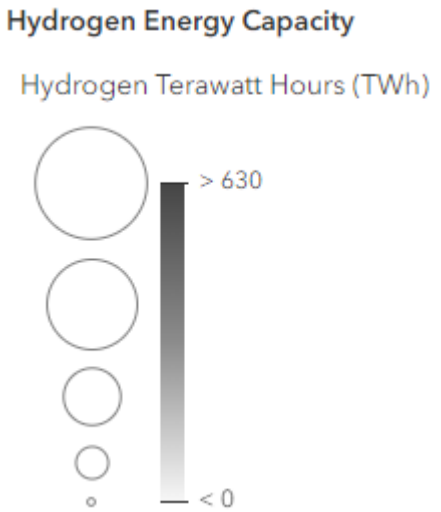
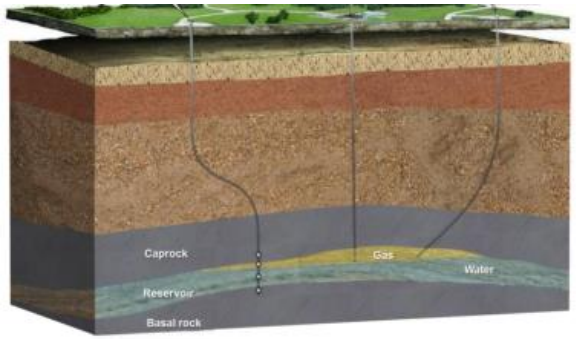
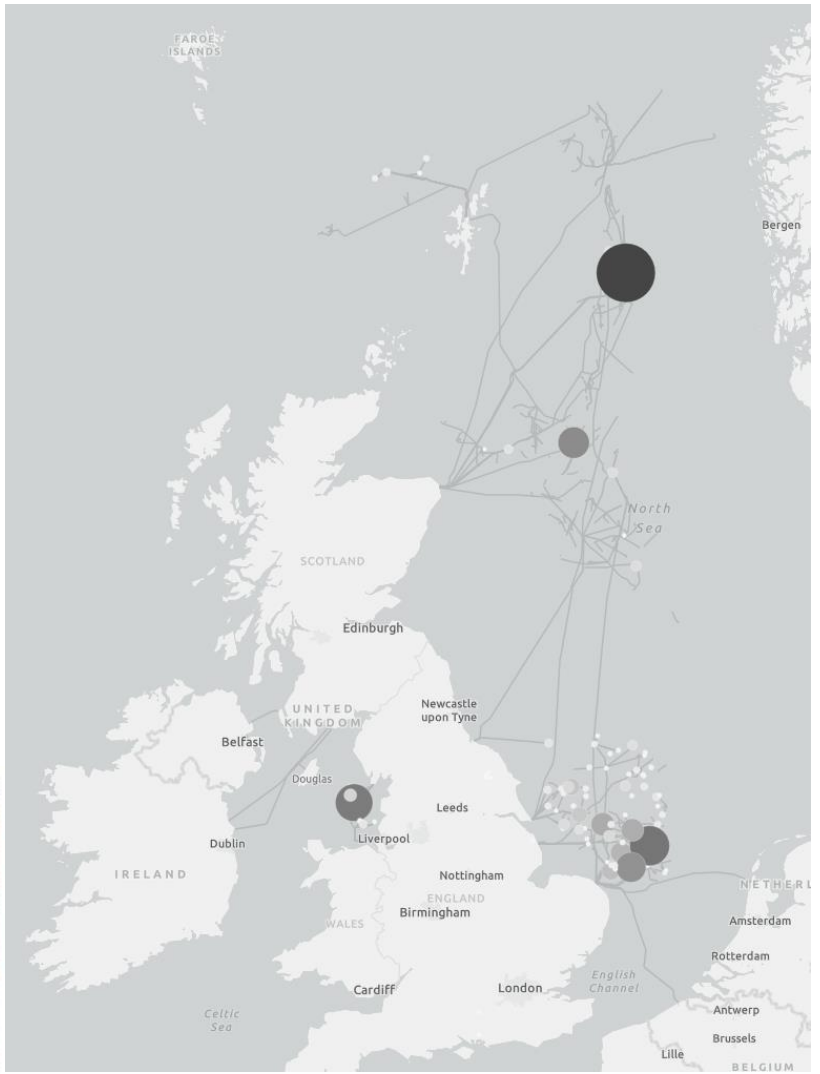
Porous Rock Storage: Depleted gas fields

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.







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Underground Hydrogen Storage projects currently in planning

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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 NyNEt NW Keuper	Salt cavern	1.38	2025
4 HySecure	Salt cavern	0.04	TBD
5 Cerville	Salt cavern	TBD	2028
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	0.0002	2023
23 H2Storage Stasfurt	Lined rock cavern	0.21	2030
24 Bad Luuchstadt	Salt cavern	TBD	2026
25 Underground Sun	Depleted gas field	0.004/0.52	2023/2030
26 HYBRIT	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

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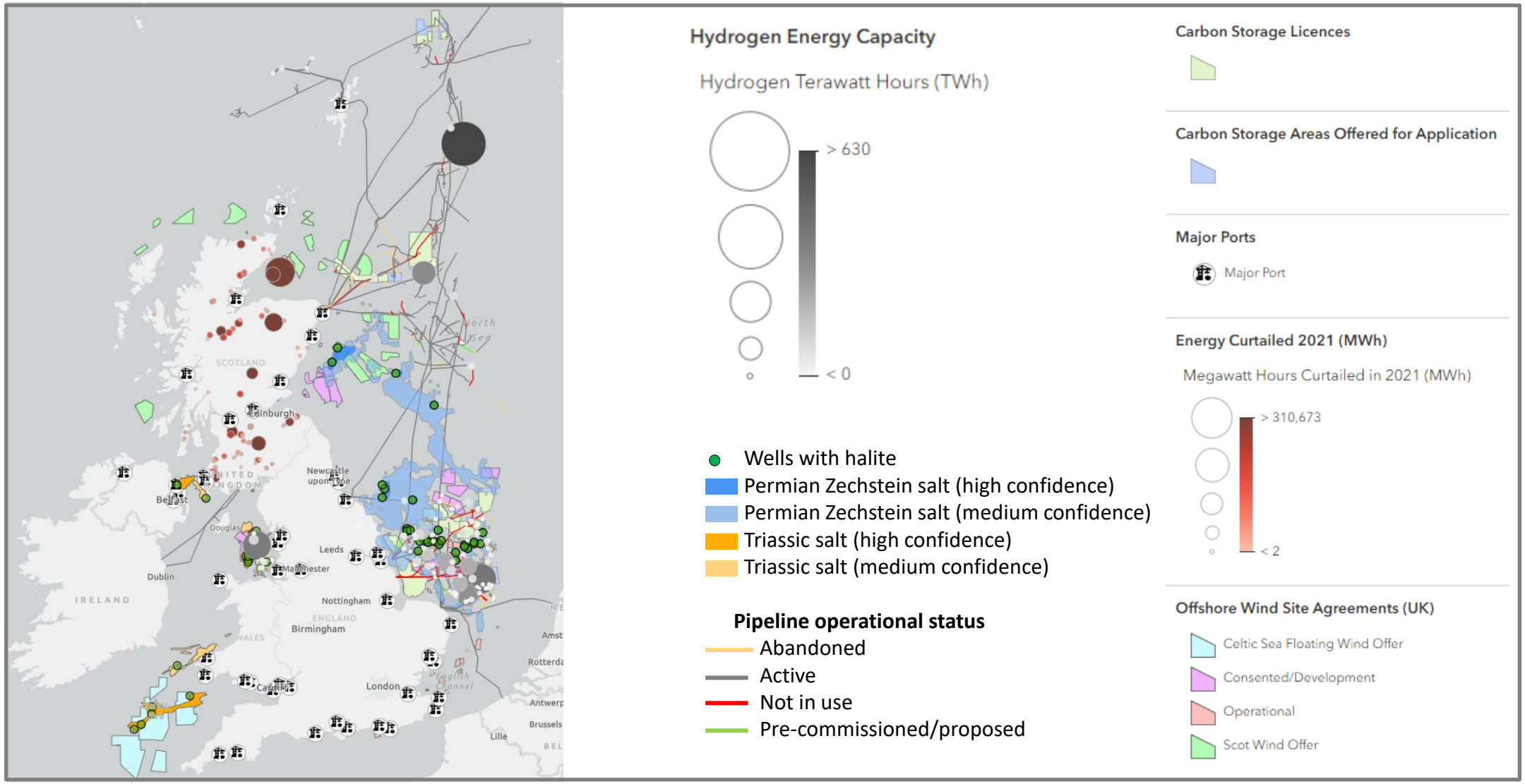
Storage: Energy System Integration



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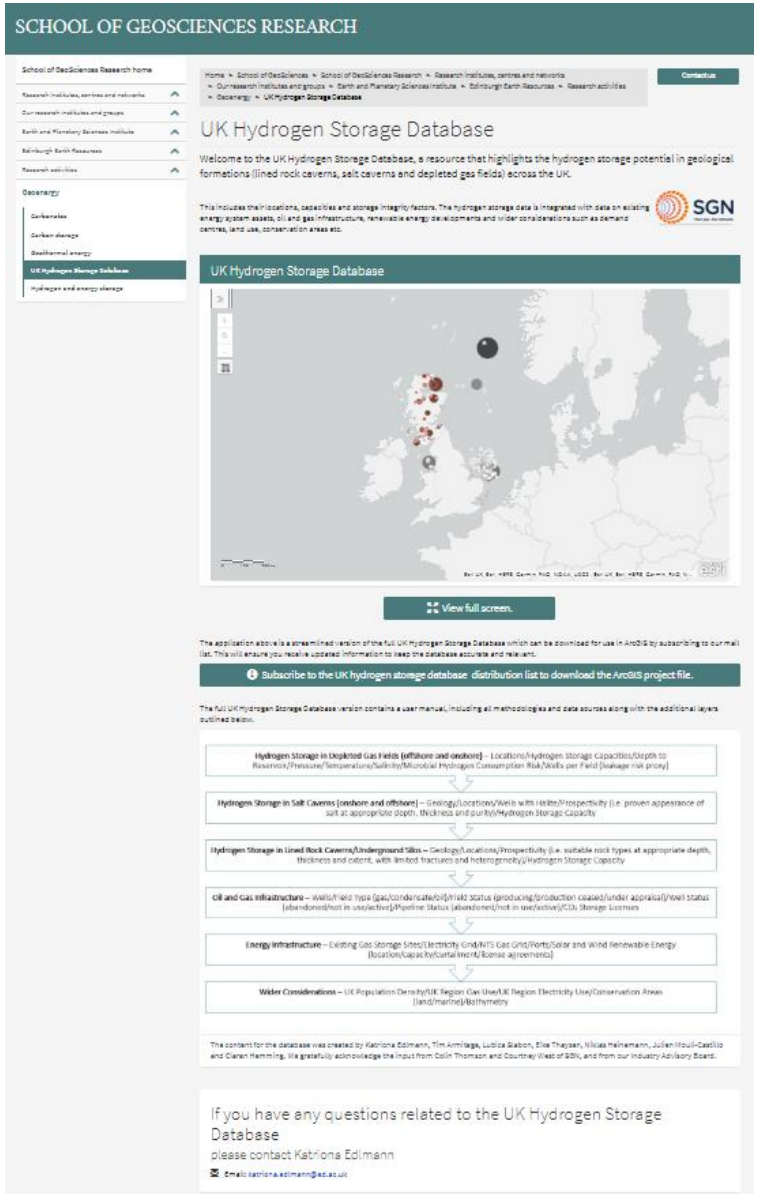
Hydrogen storage database

- 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



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Thank you

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Funding acknowledgements:

- EPSRC HyStorPor "Hydrogen Storage in Porous Rocks. Grant Agreement EP/S027815/1.
- EU H2020 and Clean hydrogen partnership HyUsPRe "Hydrogen storage in underground reservoirs" project. Grant Agreement 101006632.
- EU Marie Curie Post Doctoral Network: SHINE "Safe underground Hydrogen storage IN porous subsurface rEservoirs" Grant Agreement 101073271 and UKRI EPSRC Grant EP/X026957/1
- Scottish Government Emerging Energy technology Fund "StorageUpscale" project
- Net Zero Technology Centre and CGG "Geological controls on efficient hydrogen storage operations: Investigating depleted gas field reservoirs for future low carbon energy storage" project.
- NERC "Hydrogen Emissions: Constraining The Earth System Response" project. NERC Grant Agreement NE/X010236/1
- Net Zero Technology Centre and SGN funded "Hydrogen Storage in Porous Rock, Demonstrator Feasibility Study, Balgonie Fife".
- SGN funded "Balgonie hydrogen storage" project
- SGN funded "Hydrogen Storage Database" project

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