



ED HOUGH, ENERGY STORAGE LEAD

UK Geological Resource Suitable for Hydrogen Storage

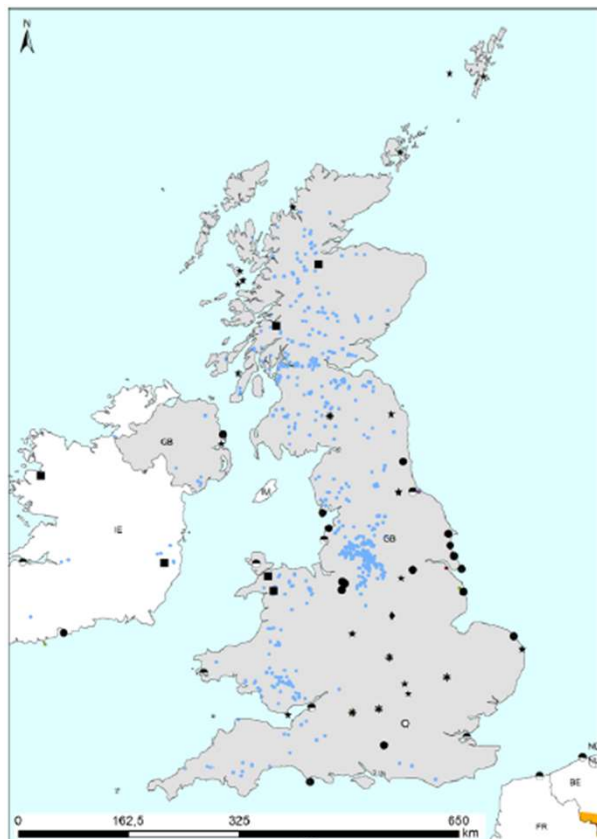
Hydrogen Storage in Caverns
Geological Society London/
Energy Research Accelerator/
Supergen Energy Storage Network
12 April 2021



British
Geological
Survey

Energy storage in the UK
Hydrogen storage in caverns
Hydrogen storage in porous rocks

Energy Storage in the UK- review



Storage of surplus energy crucial to provide peak load supply security and system flexibility*

Diverse geology = many technologies possible

- Physical storage:
 - Pumped hydro
(currently largest capacity by far)
 - Heat in abandoned mines, aquifers, excavated cavities
 - Compressed air energy storage
- Chemical storage:
 - Salt cavern
 - Hydrocarbon reservoirs and aquifers



ESTMAP

Energy Storage Mapping and Planning



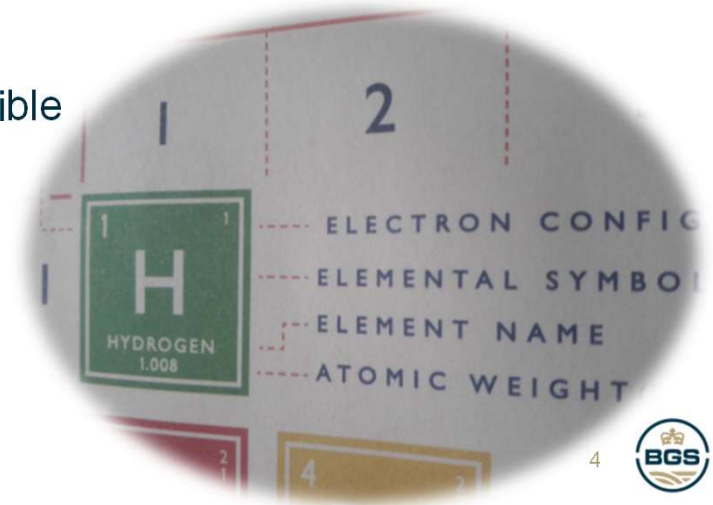
*EC, 2020. Energy Partnership



Hydrogen character

- An effective energy carrier- a high energy storage density when compared to water (pumped hydro) or air (Compressed Air Energy Storage)
- Allows grid balancing to accommodate renewable energy- above 50% and large increases in storage volume are required*
- But a low mass to volume ratio means that for the same volume, hydrogen represents $\frac{1}{4}$ - $\frac{1}{3}$ the energy of natural gas
- It is easily produced by a variety of technologies- flexible
- Easy to transport and store
- Can decarbonise transportation, heating and cooling

*Duigou et al., 2017. Intl Jnl Hydrogen Ener. 42



Hydrogen economy vs route to net zero

- Storage allows generation and consumption of energy to be decoupled
- TWh scale of hydrogen storage is required to support greater uptake of renewable energy*
- Hydrogen economy
 - Match production to use- minimises large scale storage need
 - Managing production or use
 - If production is constant and demand fluctuates then additional storage may be necessary
 - ‘Line packing’ may not be an option everywhere if steel infrastructure is used
- Greater proportion of renewable energy
 - Intermittency (fluctuations in supply via renewables)
 - Seasonal fluctuation in demand



*Abe et al., 2019. Intl Jnl
Hydrogen Ener. 44

Hydrogen storage in caverns

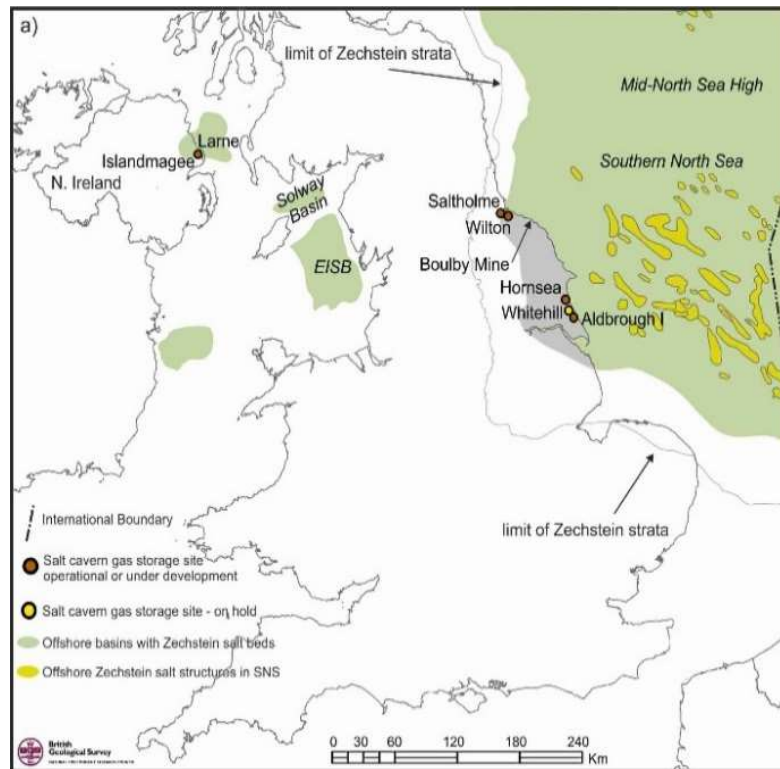
Why is halite a suitable rock for gas storage?

- Halite is a crystalline, sedimentary evaporite rock
- Visoplastic, self-healing and gas tight
- Soluble in water and under-saturated brine
- Inert
- Thick accumulations but limited distribution
- Present at depths suitable for storage of large volumes of gas
- Lower proportion of cushion gas and higher storage pressure than porous rocks
- Geology and potential host sites are variable and sites will need specific appraisal

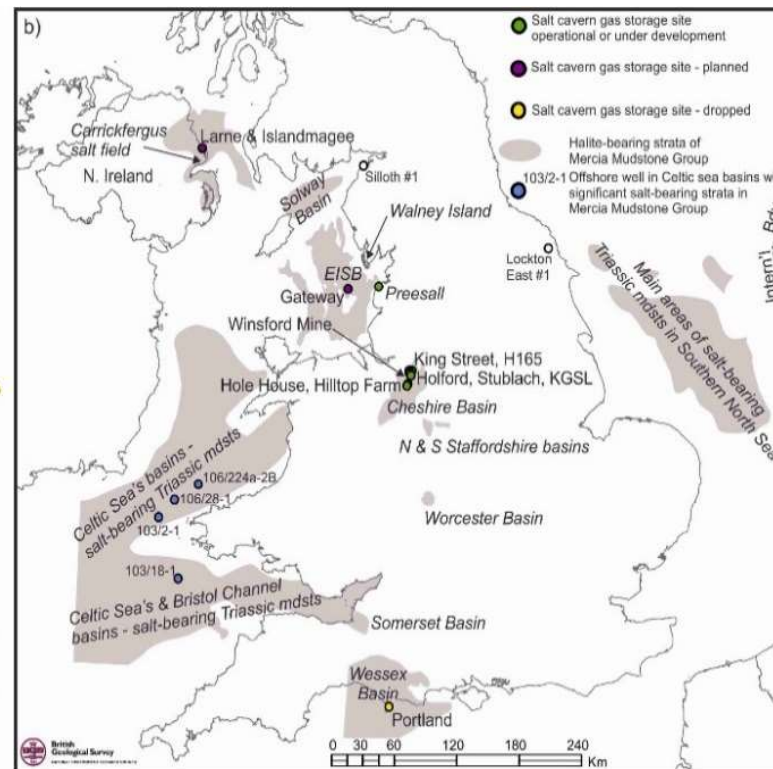


Rock core of halite (west Lancashire)

Halite and gas storage locations in the UK



Permian



Triassic

Evans & Holloway, 2009.
Geol Soc Spec Pub 313



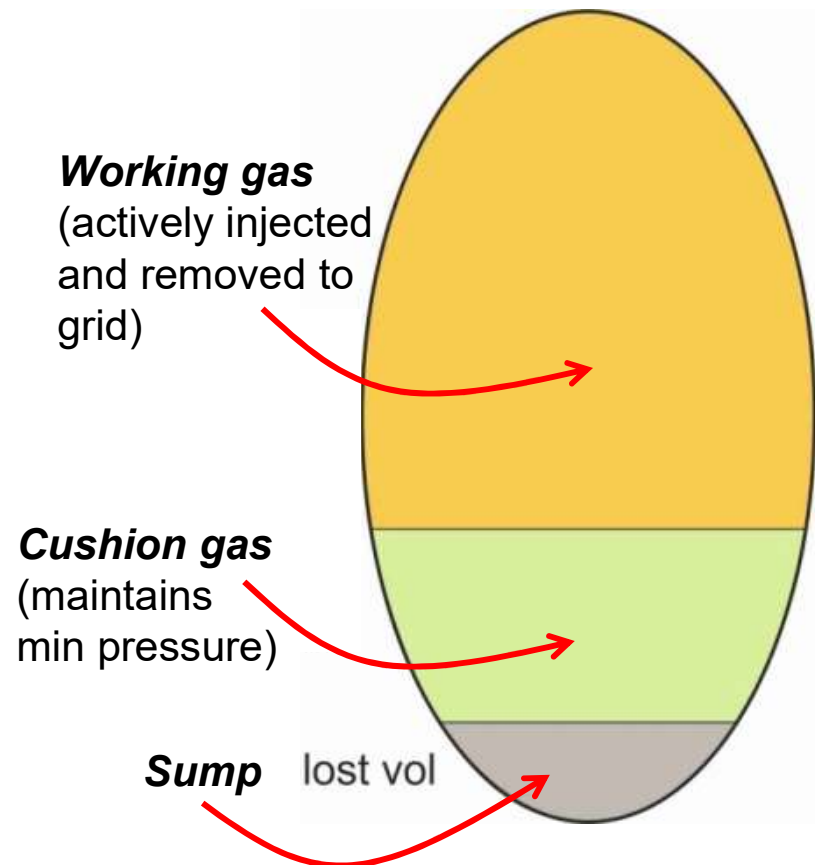
Cavern storage- principles

- We can learn from brine cavern management and underground storage of natural gas
- To maintain cavern stability-
 - Min storage pressure- supports cavern walls ~30% overburden
 - Max storage pressure- prevents fracturing of halite ~75-80% overburden
 - Pressure gradient: Depth dependant

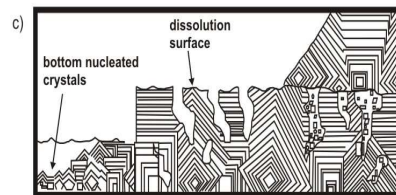
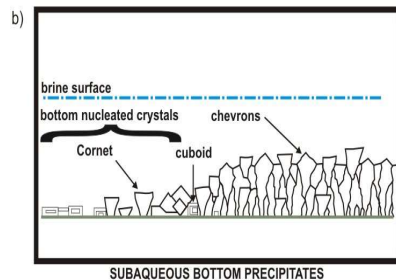
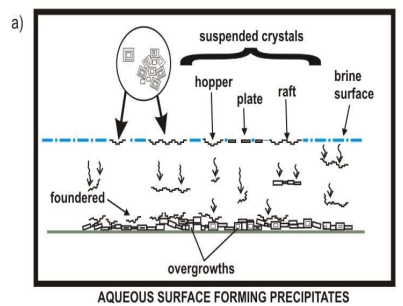
IMAGES

Integrated, **M**arket-fit and **A**ffordable
Grid-scale **E**nergy **S**torage: IMAGES

- These help determine the total cavern volume in terms of:



Halite- deposition and lithology



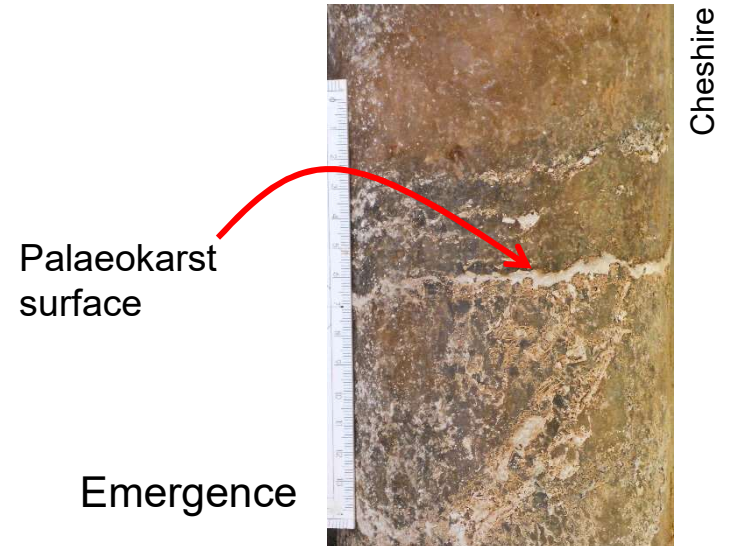
(based upon Arthurton, 1973; Gornitz & Schreiber, 1981; Handford, 1991)



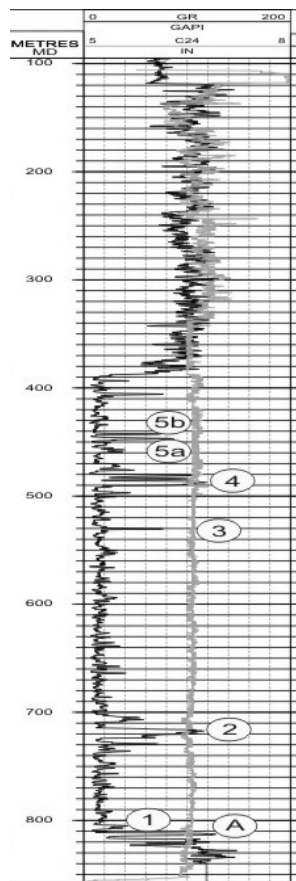
Deeper water indicators



Shallow water indicators



Strong cyclicity in bedded halite



Hough et al, SMRI 2011

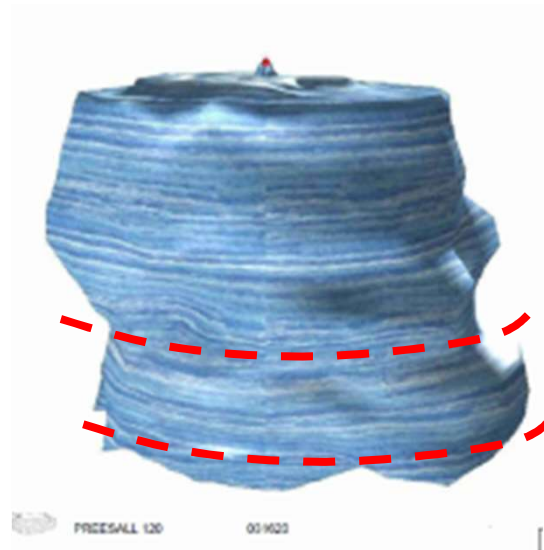


West Lancashire

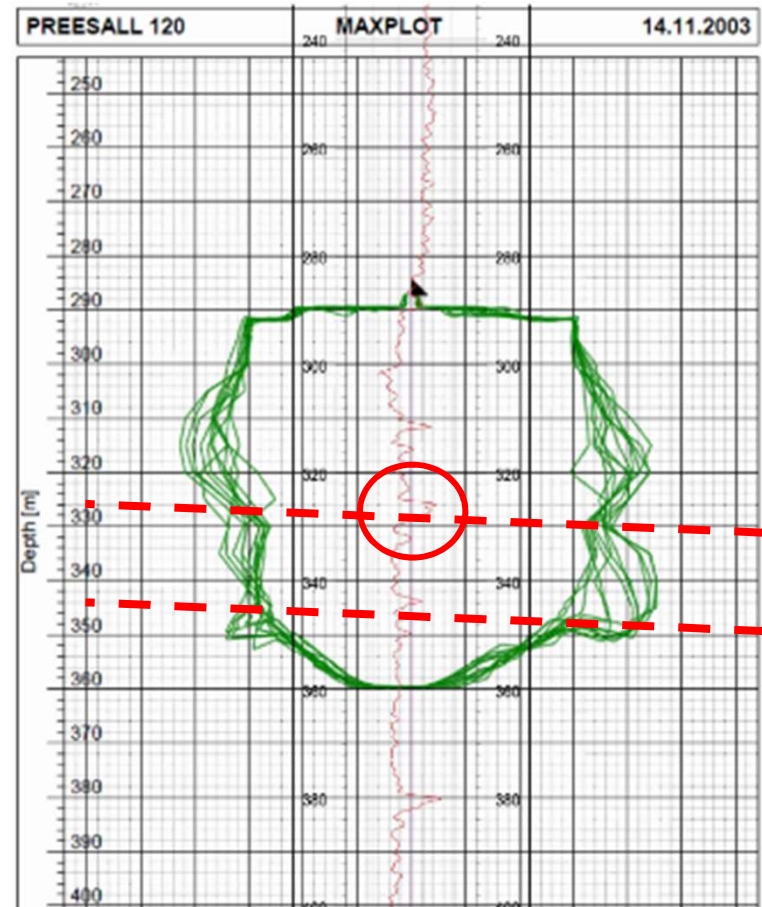
Upward 'cleaning' cycles:
Mudstone
Mudstone-halite: 'Haslegebirge'
Chickenwire halite
Clean halite



Geology influences cavern morphology



- Note: brine cavern



Courtesy HEG/Evans

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Pro's and Con's of resource estimates



- Informative
 - Based only on technical factors
 - Storage volume distribution and properties
 - Cap rock distribution
 - Pore volumes where fluids can be retained
 - Storage efficiency factors
 - Good first pass to see where capacity lies



- Misleading?
 - Does not take geological risk into account
 - Does not take economics into account
 - Produces some large and misleading numbers
 - Need to make the limitations of the estimate clear

Parameters

- Holford #165- Cheshire basin
 - Operational
 - Triassic, bedded halite
 - 1 cavern, 70 m x 70 m x 70 m
 - Cavern depth (top, base):
350, 420 m bgl
 - Cavern volume 175,000 m³
 - Pressure range:
Max = ~8.5MPa/1233psi/85bar;
Min = ~7MPa/1015psi/70bar

Status	Age, sites	Volume (mcm)
Operational	Triassic: 5 sites	16+
	Permian: 2 sites	4.41
Sum	7 sites	20.41+
Planned	Triassic: 5 sites,	40.27
	Permian: 2 sites	5.86
Sum	7 sites	46.13
Total	14 sites	66.54

Evans & Holloway, 2009.
Geol Soc Spec Pub 313



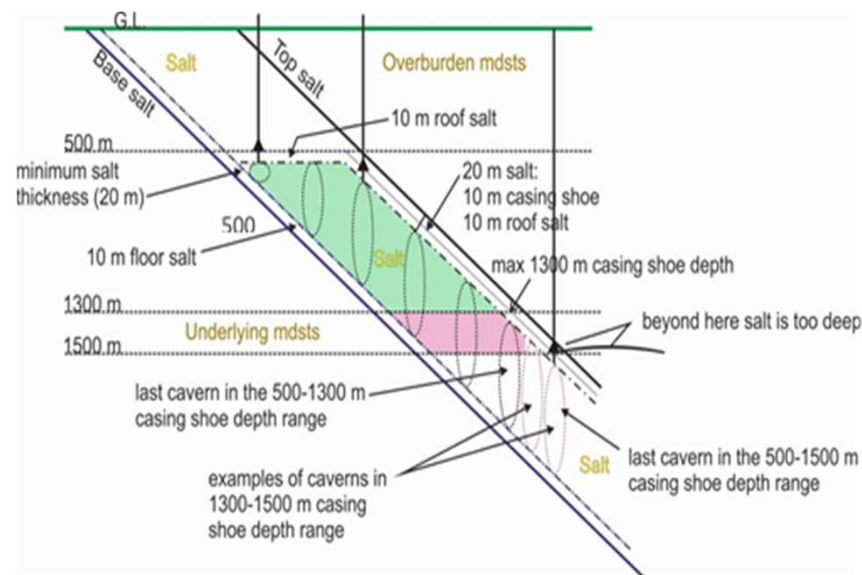
Geological constraints

- **Halite**

- Thickness of halite >20 m
- Casing shoe 250 m – 1500 m
- 10 m roof salt, plus casing shoe 10 m below roof
- Floor salt >10 m

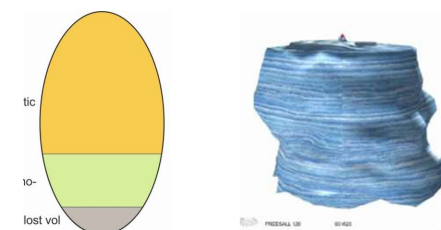
- **Cavern**

- Radius 50 m
- Pillars $3R = 150$ m
- Regular hexagonal close packed grid



- **Sources of error**

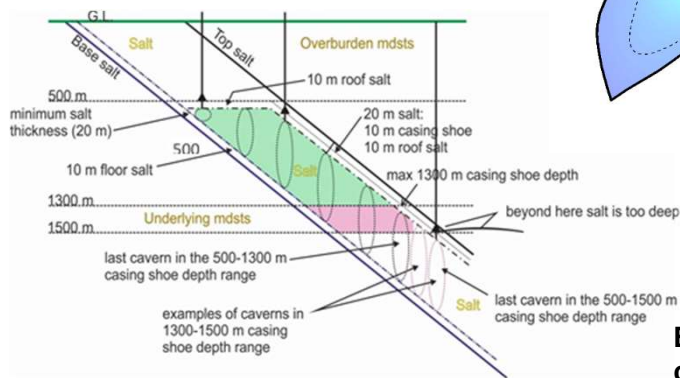
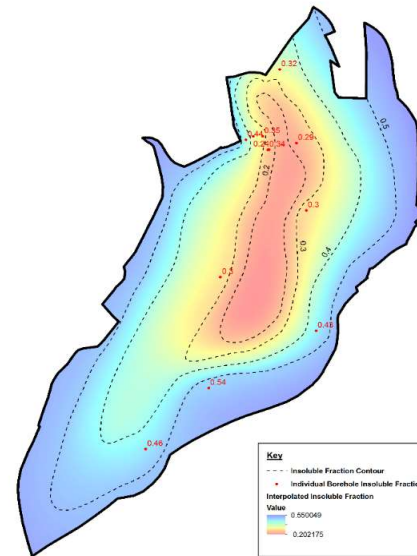
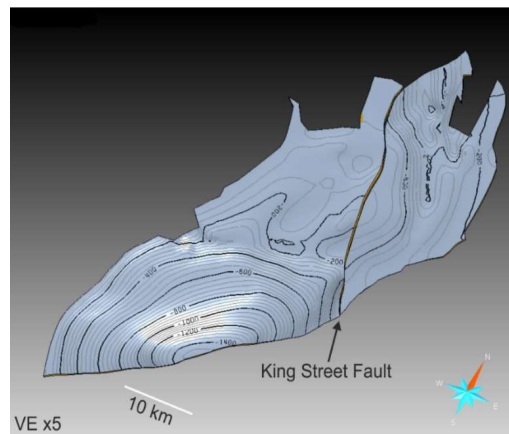
- Maximum volumes rarely utilised
- Raw caverns assumes cylindrical (shape factor 0.7 applied)
- Insolubles modelled across basins (20% volume reduction)
- Remove unfeasible caverns (existing infrastructure and facilities, geology- faults, wet rockhead) (74% volume reduction)



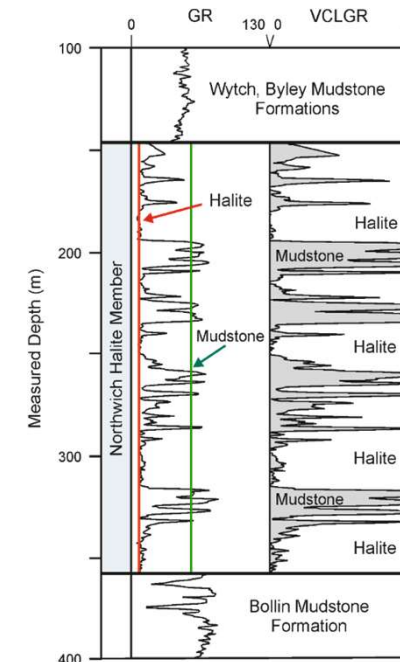
Parkes et al., 2018.
Jnl Energy Sci.



Geological model: Northwich Halite (Cheshire)



Estimate maximum cavern volume

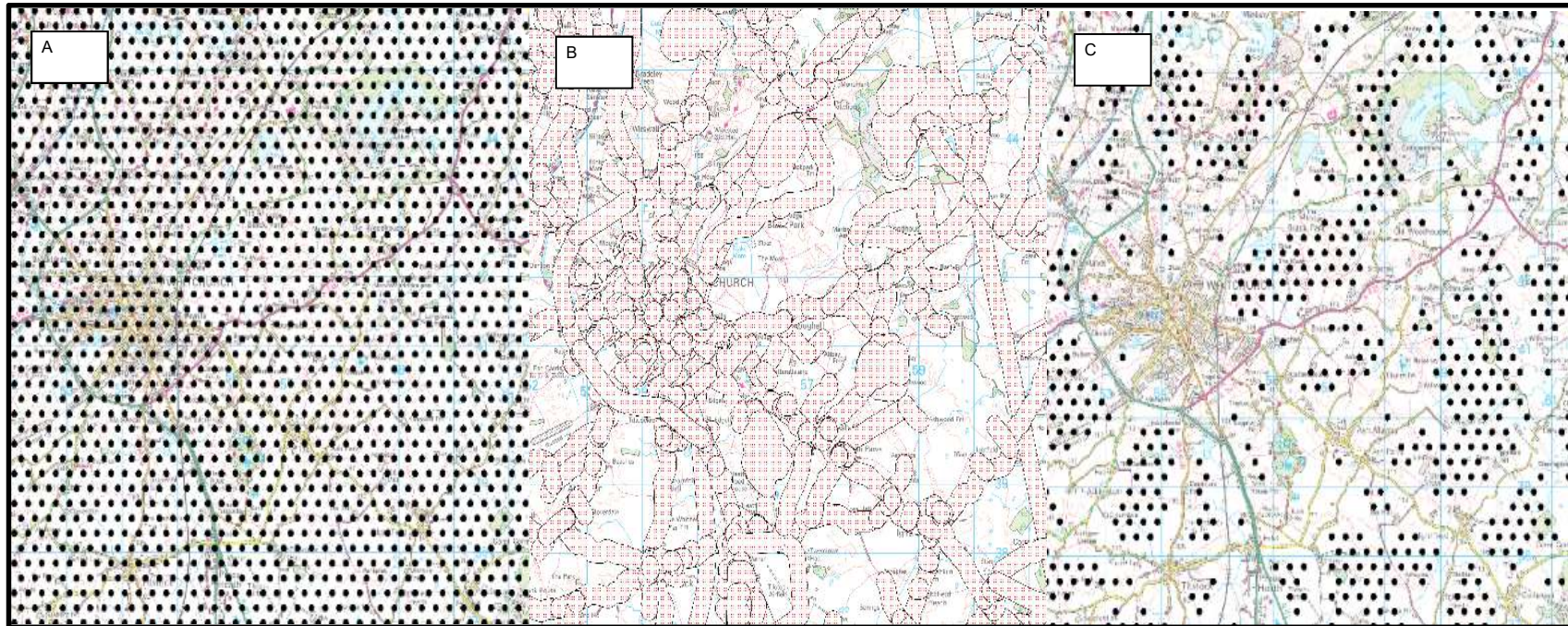


Insolubles

Parkes et al., 2018.
Jnl Energy Sci.



Buffering potential caverns



CavernCapacity = mworkingGas * Lower Heating Value of gas

Compressibility influenced by T and P

Parkes et al., 2018.
Jnl Energy Sci.



For Hydrogen storage, rank potential caverns by GWh based on capacity



For each location, volume and pressure ranges inform working gas volume and energy storage potential

Blue – 180 GWh
Orange – 16500 GWh

Confidence given by comparing to existing cavern volumes

Parkes et al., 2018.
Jnl Energy Sci.



Storage volumes- subject to local site characterisation

East Yorkshire (Fordon Evaporite) 1875 TWh

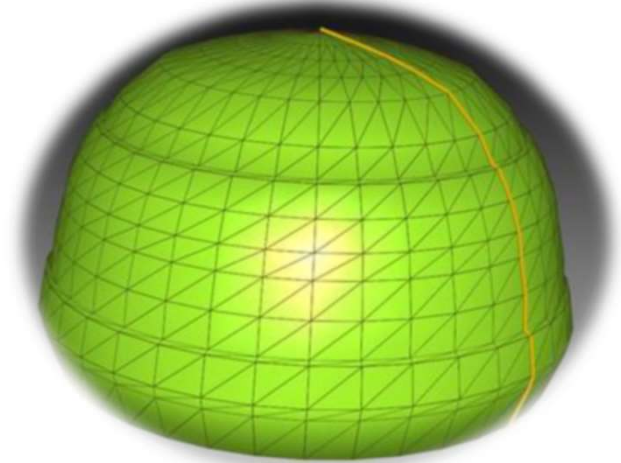
Cheshire 284 TWh

Dorset 812 TWh

With 1184 caverns above the 140-160 GWh range that could provide 178TWh hydrogen storage capacity

Other districts (west Lancashire/
offshore: East Irish Sea/ North Sea) yet to be evaluated

A recent Europe-wide assessment (Caglayan, 2020)
estimated 9,000 TWh offshore and onshore in the UK



Williams, J et al., 2020. Elegancy deliverable report D5.4.1e
Caglayan et al., 2020. Intl Jnl Hydrogen Ener 45

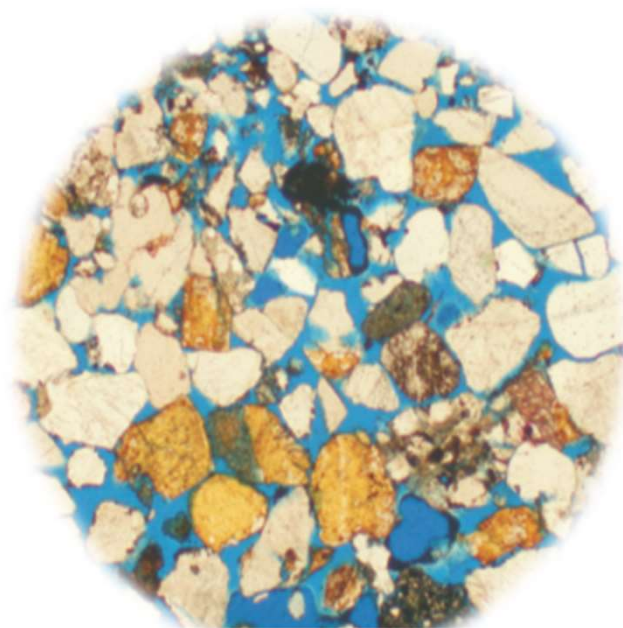




Hydrogen storage in porous rocks

Why are porous rocks suitable for hydrogen storage?

- Widespread occurrence of sedimentary basins
- Hydrocarbons reservoirs and saline aquifers
- Long history of hydrocarbons extraction
- Depleted reservoirs- proven storage units
- Saline aquifers- would require sealing overburden
- Lower injection/withdrawal rates than caverns
- Higher cushion gas ratio (~50%) than caverns*
- Larger storage volumes than caverns
- Natural gas storage sites operational at Humbly Grove and Hatfield Moors



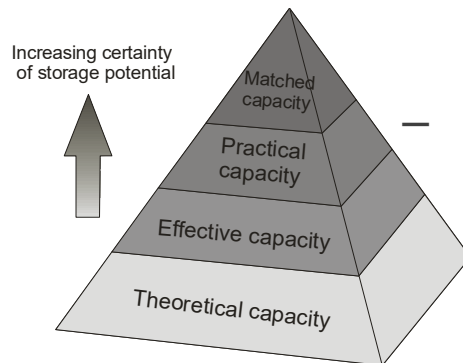
UK Triassic sandstone:
pore space dyed blue

*Landing et al., 2014. 21
HyUnder project update



Learn from Carbon Capture & Storage assessments

- National and local assessments- of natural gas storage (e.g., Rough field) and CCS
 - Static models:
 - Static capacity **estimates** need to be followed up by detailed assessments
 - The estimate does not take into account other factors such as pressure increases, time factors, injectivity, multiple injections into one storage unit, displacement of pore fluid etc.....
 - Dynamic models...
 - Can potentially provide a **better estimate** of capacity. However more data is required, too time consuming and costly to do for a whole country, so can only be carried out on a site by site basis.....
- CSLF (Carbon Sequestration Leadership Forum)

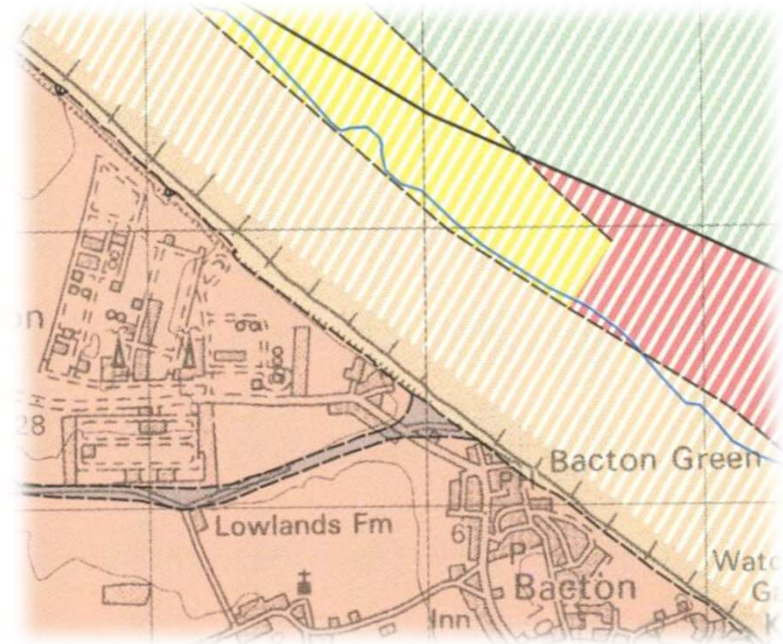


Hydrogen storage capacity, UK Continental shelf

- Estimate based on CO₂ storage data
- Study considered:
 - data on gas fields (depth, quality, type)
 - Efficiency of saline aquifers to estimate useable pore space
 - Hydrogen capacity
- Working gas capacity of UK offshore gas fields = 6,900 TWh (P50); less confidence of ~2,200 TWh for saline aquifers
- Low T high P capacity sites favoured- could link to offshore wind (with production by steam methane reformation most likely to replace natural gas)

Offshore hydrogen storage potential in gasfields

- Hydrogen storage capacity est. 2661TWh
- Gasfields- plenty of reservoir data; proven traps
- Few sites needed to balance seasonal demand variation- no conflict in use (e.g., with CCS, CAES, CH₄)
- Ample capacity in offshore via existing gas terminals
- Employ offshore wind energy
- Suggested use of natural gas as a component of cushion gas?

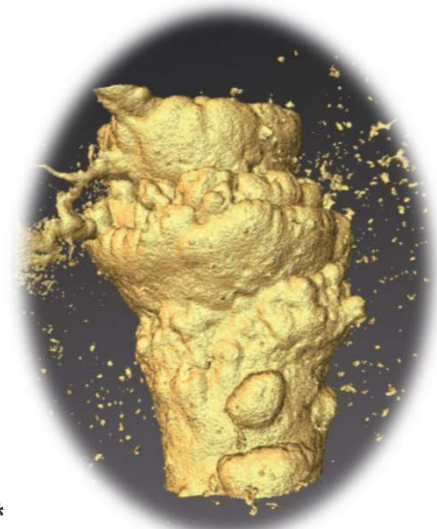


Mouli-Castillo et al., 2021. Applied Energy 283. ²⁴



Research questions

- Specific to cavern storage
 - Influence of geology on cavern morphology
 - Influence of stress “ “
 - Operating parameters- impact on insoluble layers and borehole completions
- Specific to pore storage
 - Impact of existing boreholes and faults on storage integrity*
 - Hydrogen interaction/impact on gas quality**
 - Microbial
 - Geochemical
 - Caprock integrity
 - Methane as a cushion gas
- Consider closure of storage sites
- Measurement, Monitoring and Verification (MMV)



Laser scan of
void generated
in halite***

*Heinmann et al., 2021. *Ener & Environ Sci.*

**Ozarslan, 2012. *Intl Jnl Hydrogen Ener* 37

***Field, L P et al., 2017. *Quart Jnl Eng Geol Hyd* 52

Summary

- The UK already employs many energy storage technologies, supported by the natural subsurface asset
- Cavern/ pore storage- initial estimates are that we have enough potential capacity to support a hydrogen economy / uptake of additional renewables
 - Onshore
 - Offshore
- Spatial distribution of storage locations is not evenly distributed across the UK
- Research questions





ED HOUGH, ENERGY STORAGE LEAD:

EH@BGS.AC.UK

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