Geological Hydrogen Energy Storage for an Integrated Renewable Energy System

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

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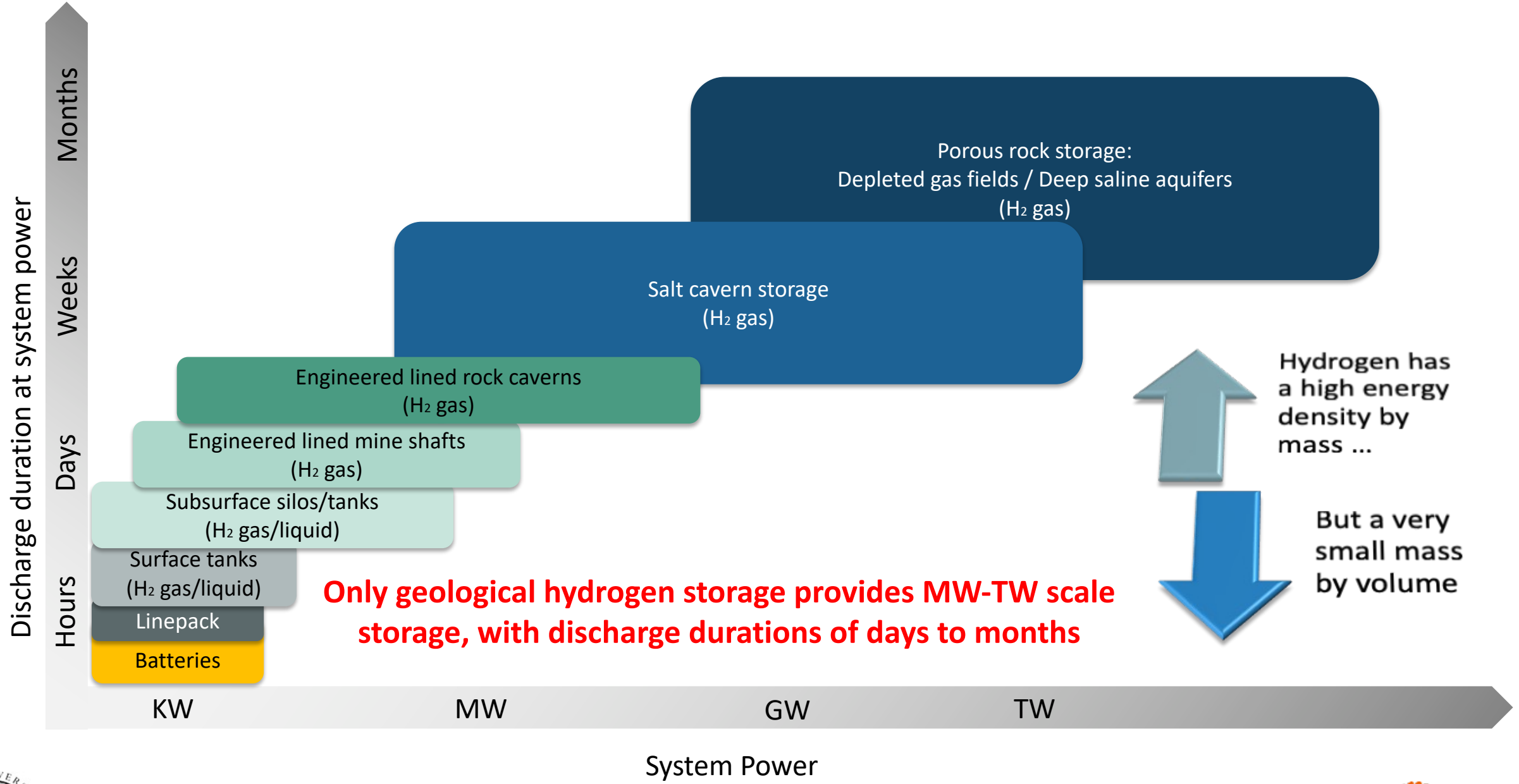

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Hydrogen energy storage within an integrated renewable energy system ….

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in the UK 58% of curtailment periods last longer than 3 hours, limiting the options for battery storage – There is a need for longer duration storage.

Supports increase renewable energy deployment, providing **inter-seasonal energy storage** to balance supply and demand

Provides electricity grid balancing = short term operating reserve (STOR), fast reserve, load following, peaking plants, reserve capacity

Reduces energy wastage from renewable energy curtailment

Creates new industries and new sources of demand in heavily constrained (often rural) regions

Optimises (cost effective) development of network infrastructure assets (electricity and hydrogen) lowering investment and operational cost of the whole energy system.

Balances price fluctuations (daily to inter-seasonal)

Supports **a dynamic export market**

Supports **energy system resilience and security**
+
Delivers stability of hydrogen supply

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UK Integrated Hydrogen Storage Database

Hydrogen Storage in Depleted Gas Fields (offshore and onshore) – Locations/Hydrogen Storage Capacities/Depth to Reservoir/Pressure/Temperature/Salinity/Microbial Hydrogen Consumption Risk/Wells per Field (leakage risk proxy)

Hydrogen Storage in Salt Caverns (onshore and offshore) – Geology/Locations/Wells with Halite/Prospectivity (i.e. proven appearance of salt at appropriate depth, thickness and purity)/Hydrogen Storage Capacity

Hydrogen Storage in Lined Rock Caverns/Underground Silos – Geology/Locations/Prospectivity (i.e. suitable rock types at appropriate depth, thickness and extent, with limited fractures and heterogeneity)/Hydrogen Storage Capacity

Oil and Gas Infrastructure – Wells/Field Type (gas/condensate/oil)/Field Status (producing/production ceased/under appraisal)/Well Status (abandoned/not in use/active)/Pipeline Status (abandoned/not in use/active)/ CO2 storage license blocks

Energy Infrastructure – Existing Gas Storage Sites/Electricity Grid/NTS Gas Grid/Ports/Solar and Wind Renewable Energy (location/capacity/curtailment/license agreements)

Wider Considerations – UK Population Density/UK Region Gas Use/UK Region Electricity Use/Conservation Areas (land/marine)/Bathymetry

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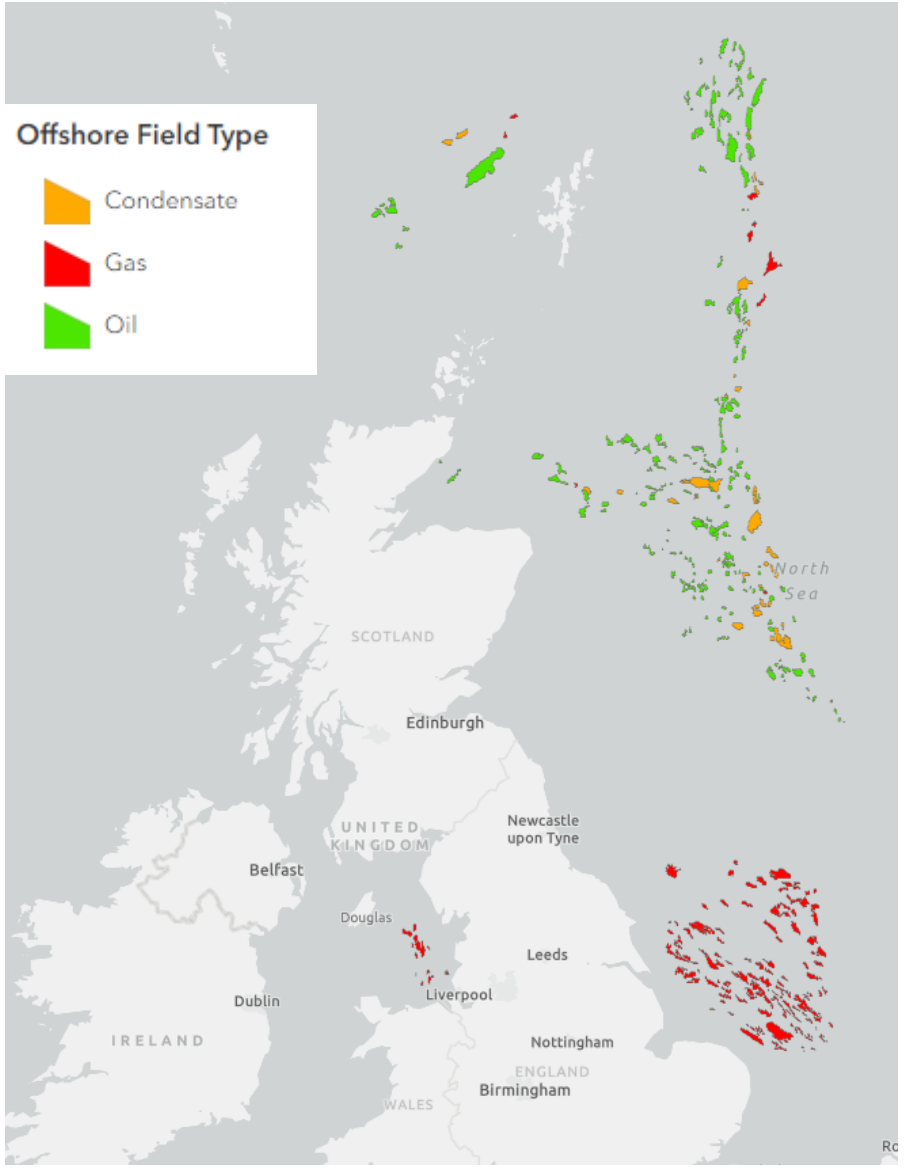
Hydrogen storage in Depleted gas fields

(unlikely to use depleted oil fields?)



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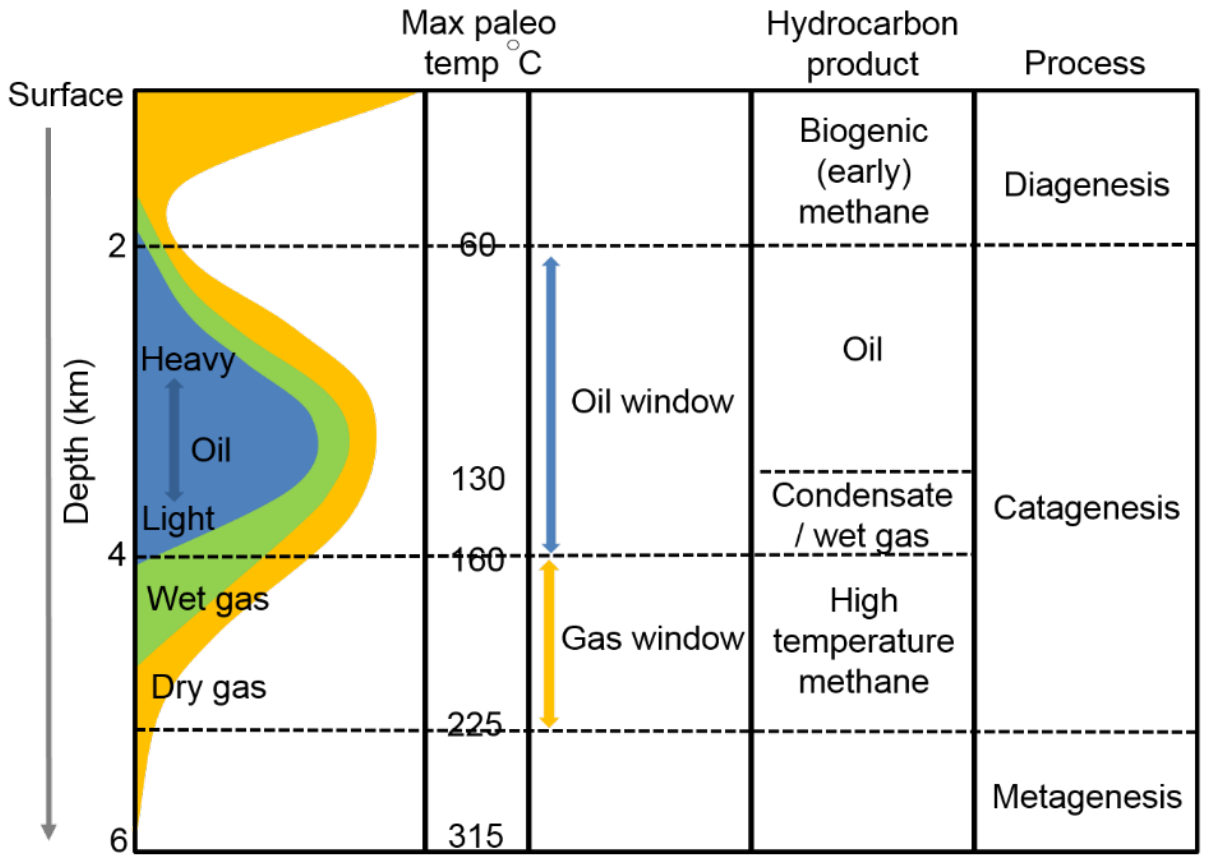
Why the UKCS North South divide in oil and gas?

Type of organic matter

	Type 1	Type II	Type III
Kerogen	Sapropellic	Planktonic	Humic
Kerogen source	Lacustrine algal matter	Marine plankton and organic matter	Terrestrial woody humic plant matter
Depositional conditions for maturation	Algal remains deposited under anoxic conditions in deeper lakes.	Marine planktonic and bacterial remains preserved under anoxic conditions at sea floor.	Terrestrial plant material decomposed by bacteria and fungi under oxic or sub oxic conditions.
H:C ratio	High H:C ~1.65	Intermediate H:C ~1.25	Low H:C ~<1
O:C ratio	Low O:C ~0.06	Intermediate O:C ~0.1	High O:C ~0.15
Organic composition	Rich in lipids	Rich in proteins.	Rich in lignin. Most coals and coal rich shales are Type III source rocks.
Likely hydrocarbon products	Generates oil under thermal maturation, high yields (up to 80%)	Generates oil and gas under thermal maturation, yields between 40 – 60%	Low oil yield - Generates gas under thermal maturation
Oil / gas prone	Oil prone	Oil and gas prone	Gas prone

Depth of burial



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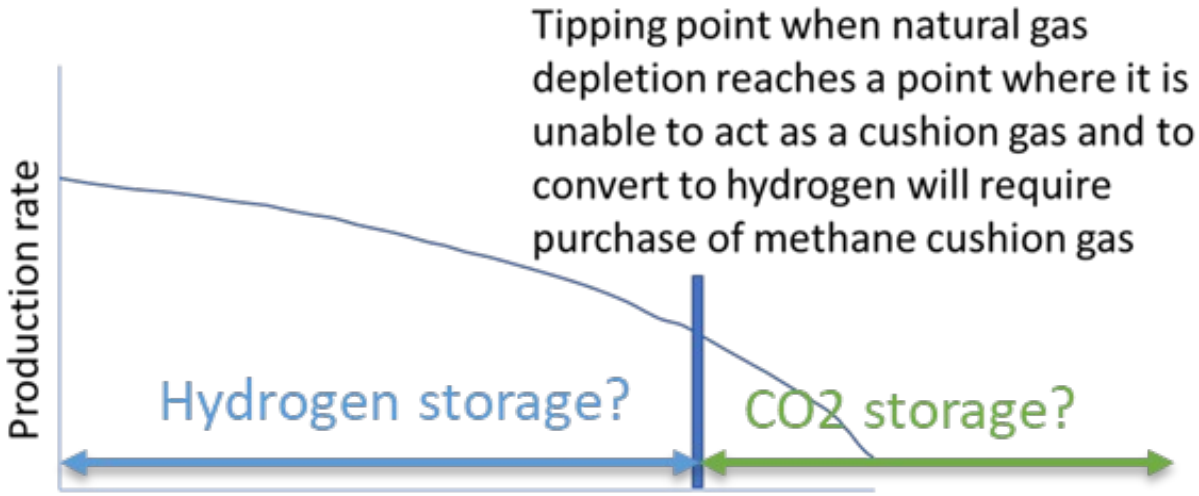
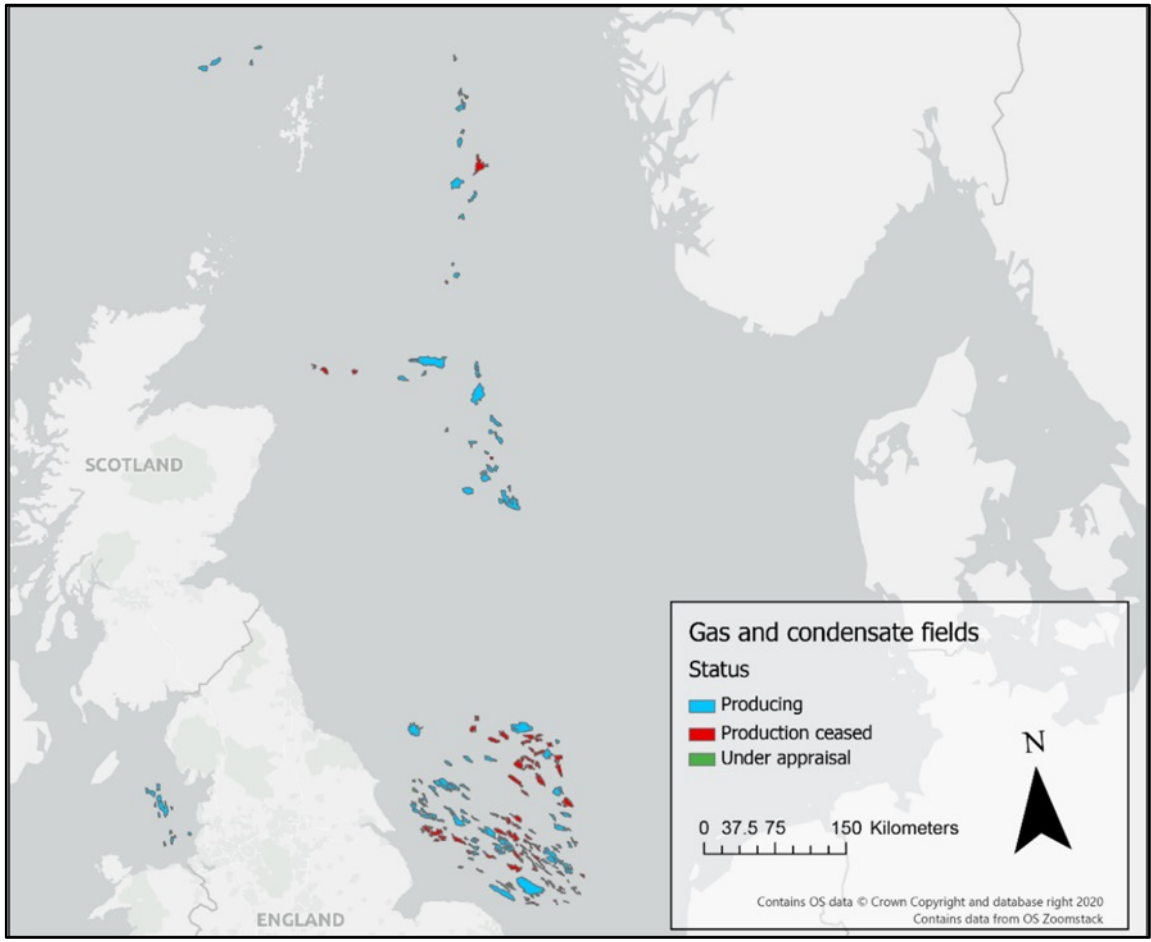
Field status screening for hydrogen storage

- Gas field production status
  - 123 gas or condensate fields are currently producing
  - 96 have production ceased
- Degree of depletion
  - In-situ gas provides pressure drive = cushion gas
  - Depletion level tipping point / cushion gas support



- **Fields previously used/ identified for natural gas storage**: Rough, Deborah, Baird, Corvette and Forbes https://storymaps.arcgis.com/stories/2349ba3eb36d4473861b7701a08985e1



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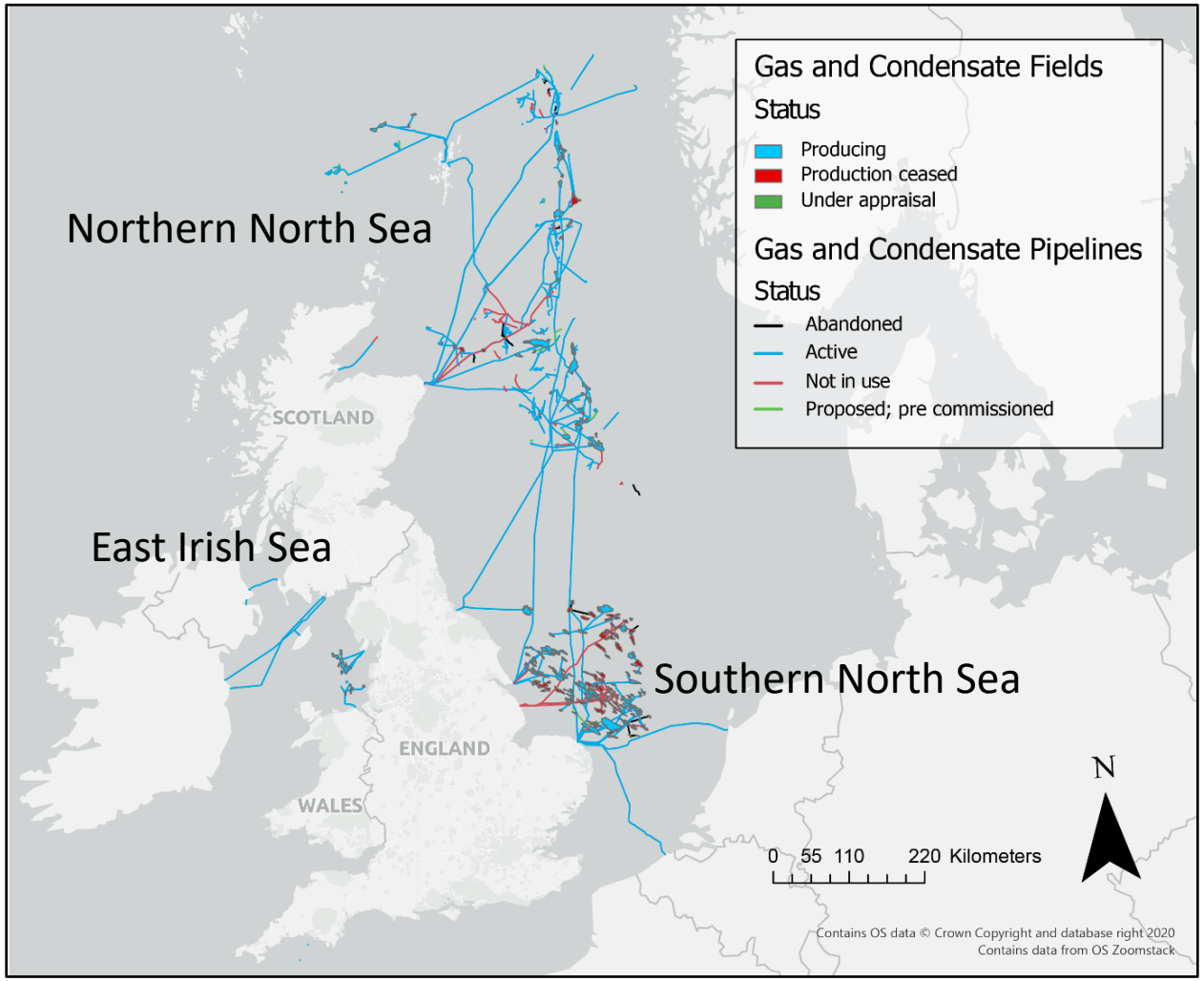
O&G Pipeline status screening for hydrogen

- Hydrogen production is likely to be onshore, with the renewable electricity cabled onshore for hydrogen production.
- Pipeline connections will be required between hydrogen production sites and hydrogen storage locations.
- Gas and condensate pipeline status
  - Southern North Sea: Theddlethorpe connects 90 gas fields that are no longer producing
  - Central North Sea: St. Fergus Gas Terminal connects six fields that are no longer producing
  - East Irish Sea: One gas pipeline is not-in-use connecting two gas fields that are no longer producing



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Microbial consumption of hydrogen risk site screening: UKCS gas and condensate fields

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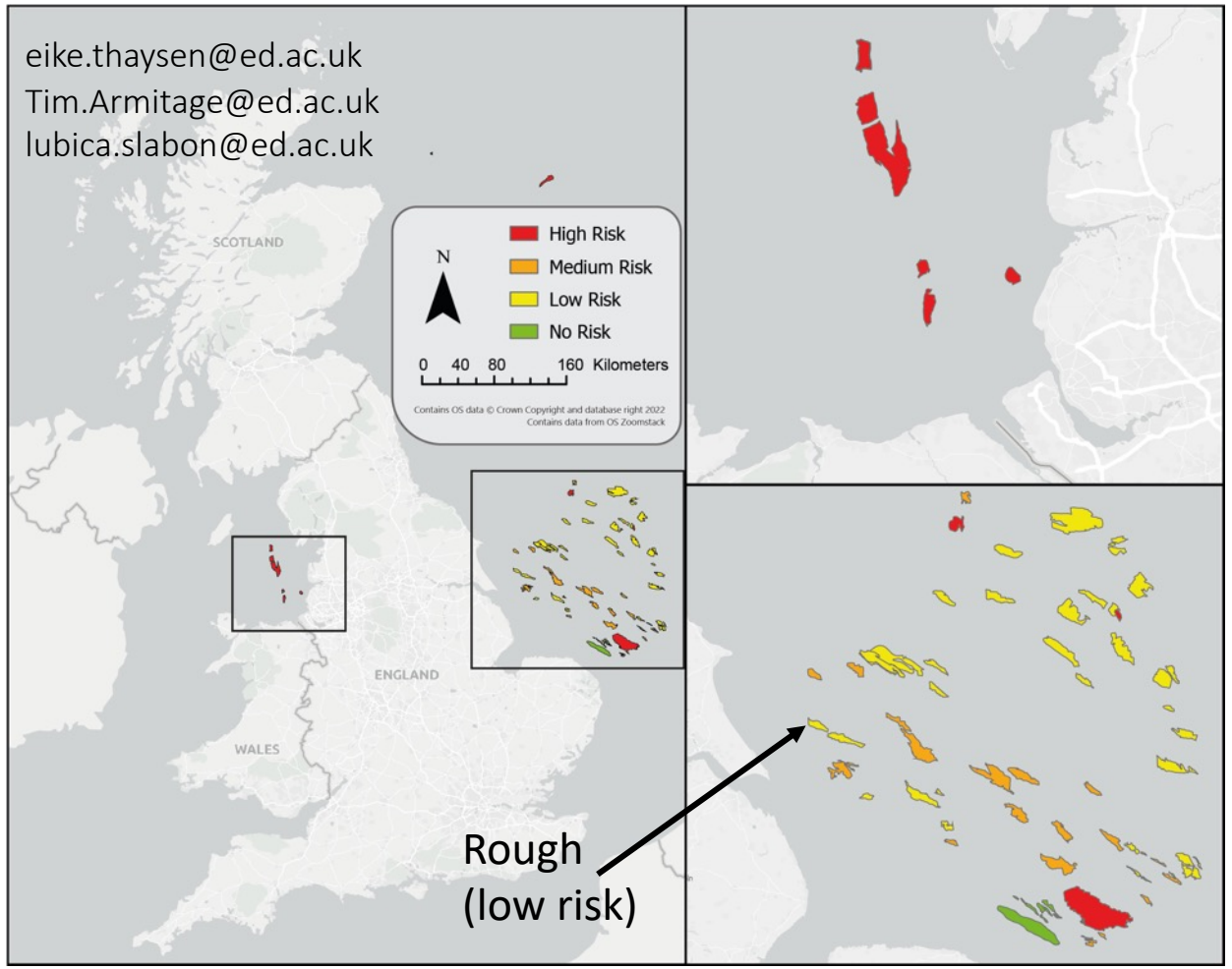
- **No risk**: fields with a temperature above 122°C can be considered as sterile, as no hydrogen consuming bacteria have been found above this temperature.
- **Low risk**: fields with a temperature equal to or above 90°C can be considered paleosterile.
- **Medium risk**: fields with a temperature above or equal to 55°C and salinities above 1.7M NaCl eqv.
- **High risk**: fields with a temperature below 55°C and salinity below 2 moles NaCl.
- Paper on this just published in Fuel: https://doi.org/10.1016/j.fuel.2023.128852



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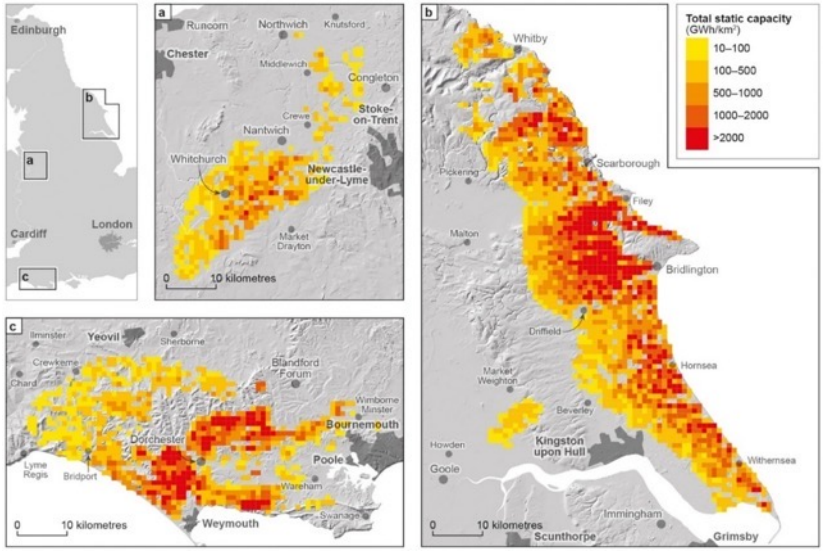
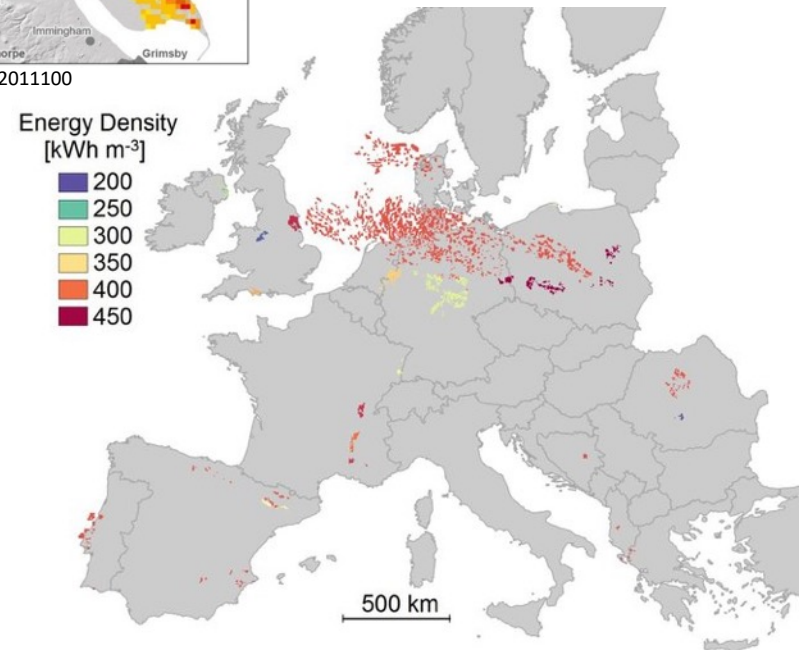
Hydrogen storage in salt caverns: UK onshore

- Williams and the team at BGS suggest an upper bound potential for hydrogen storage exceeding 64 million tonnes, providing 2,150 TWh of storage capacity, distributed in three discrete salt basins onshore in the UK.
- Caglayan estimates technical storage potential across Europe of 84.8 PWh hydrogen
  - Only 27% of which is onshore
- **However - salt is not equally distributed globally**.



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



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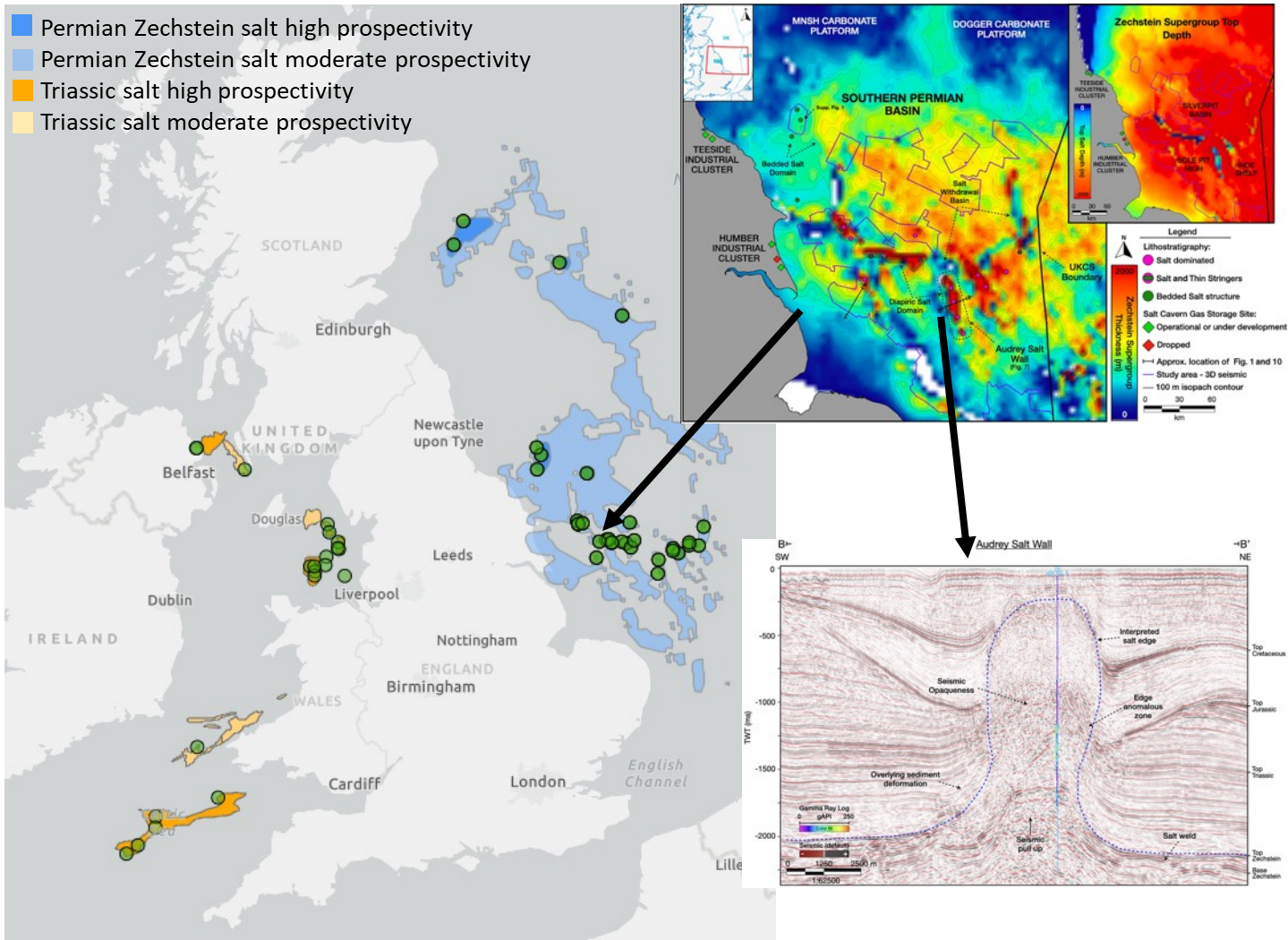
UK offshore salt for hydrogen storage

- Depending on public response to hydrogen storage in onshore salt caverns or availability of onshore salt, it may be necessary to explore offshore salt caverns.
- There are 5 projects that have looked at this in the UK
  - **Gateway project in the East Irish Sea** (https://www.stagenergy.com/gateway/)
  - **Larne Lough, Northern Ireland** (https://www.bbc.co.uk/news/uk-northern-ireland-64586453),
  - **dCarbonX & ESB at Poolbeg** (https://www.youtube.com/watch?v=qZ0IX8LY3dg),
  - **UKOG Portland Energy Hub concept** (https://www.offshore-energy.biz/ukog-to-work-on-hydrogen-ready-energy-storage-project-at-portland-port/)
  - **Tractabel** (https://tractebel-engie.com/en/news/2021/world-s-first-offshore-hydrogen-storage-concept-developed-by-tractebel-and-partners)

The upper-bound theoretical capacity for hydrogen storage in UK OFFSHORE salt caverns in the Southern North Sea Audrey salt dome is **292 TWh**



https://www.lyellcollection.org/doi/abs/10.1144/SP528-2022-82

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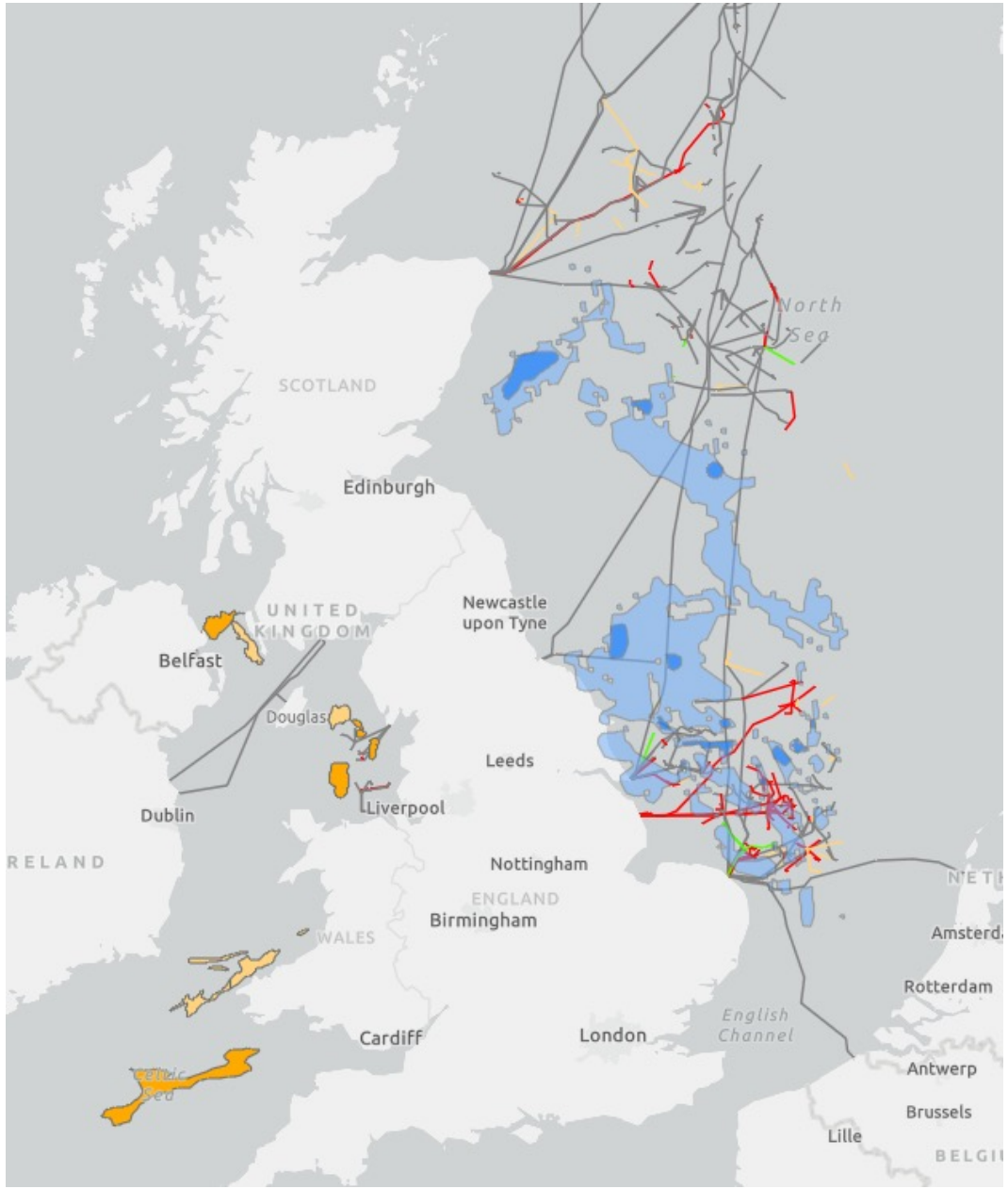
Permian Zechstein salt high prospectivity
Permian Zechstein salt moderate prospectivity
Triassic salt high prospectivity
Triassic salt moderate prospectivity

Gas and Condensate Pipeline Operational Status

Abandoned
Active
Not In Use
Pre-commissioned or Proposed



UK offshore salt: Pipeline connectivity

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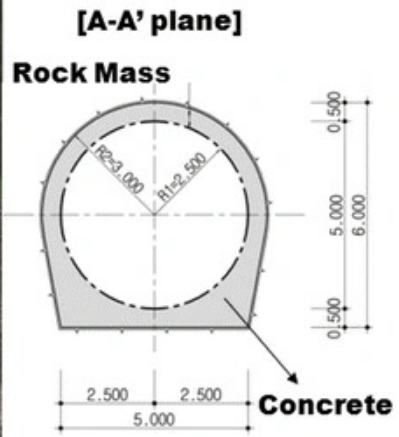
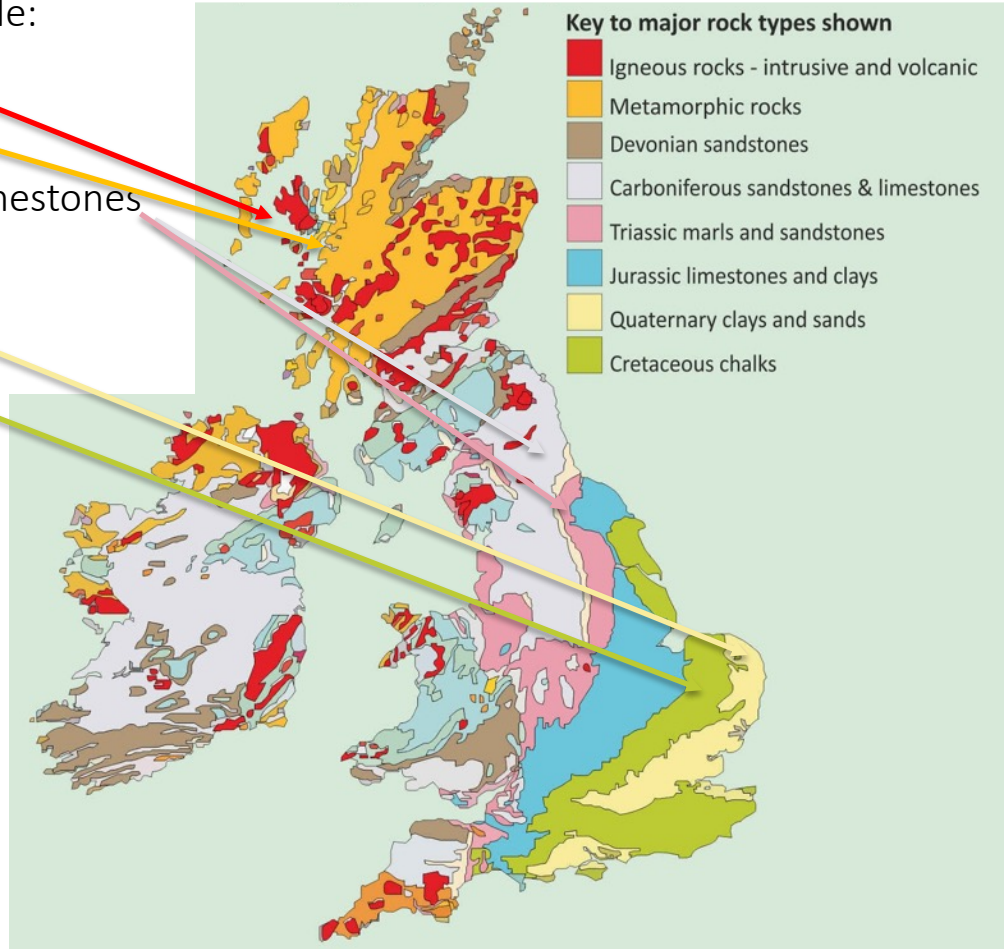
Supporting local hydrogen economy growth: Decentralised MW storage in lined rock caverns

- Caverns 50-100m high and km's long
- Pressurised up to 20 MPa
  - **100,000 m3 cavern = capacity of 6.75 GW**
- Additional requirements:
  - Minimal fracturing in area
  - 50-100m overburden



Suitable geologies include:

- ✓ Igneous rocks
- ✓ Metamorphic rocks
- ✓ Hard sandstones/limestones
- ✓ Clays
- ✓ Chalk



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Gas distribution networks

Offshore field type

- Condensate
- Gas
- Oil

Offshore pipeline fluid type

- Gas
- Condensate

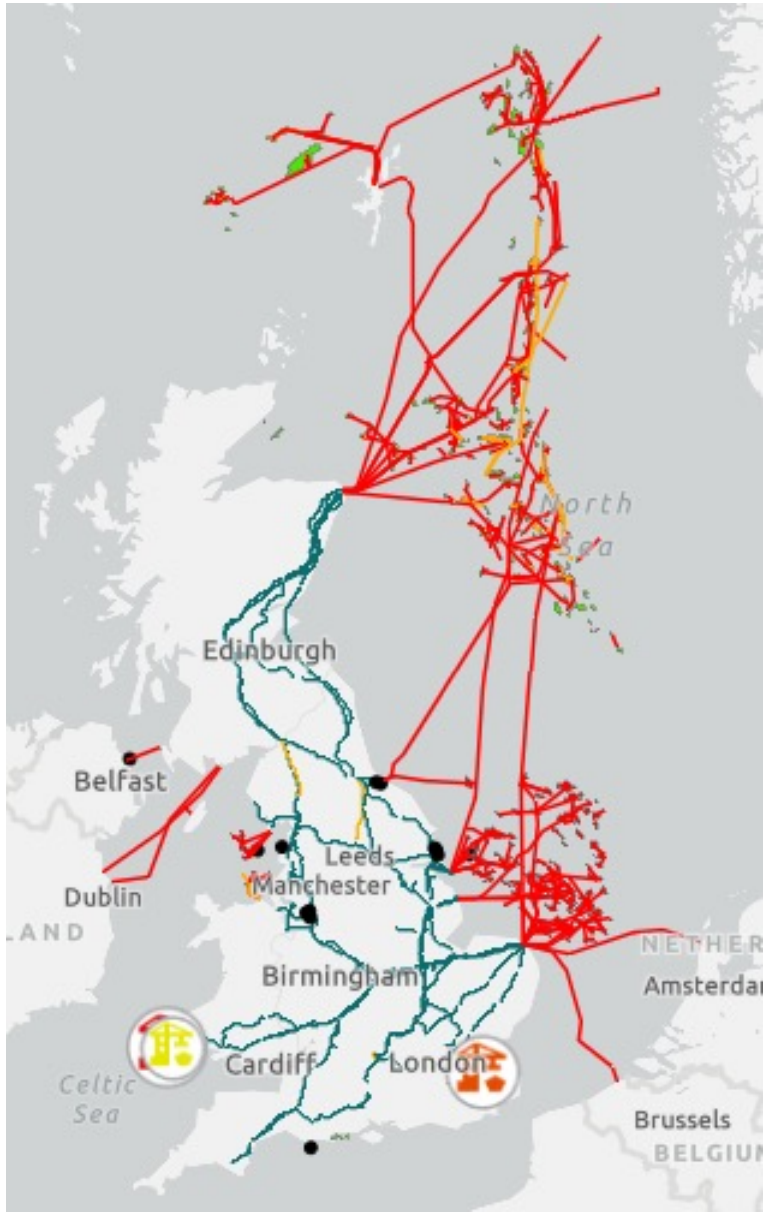
Gas Storage sites (consented/operational/ planning dropped

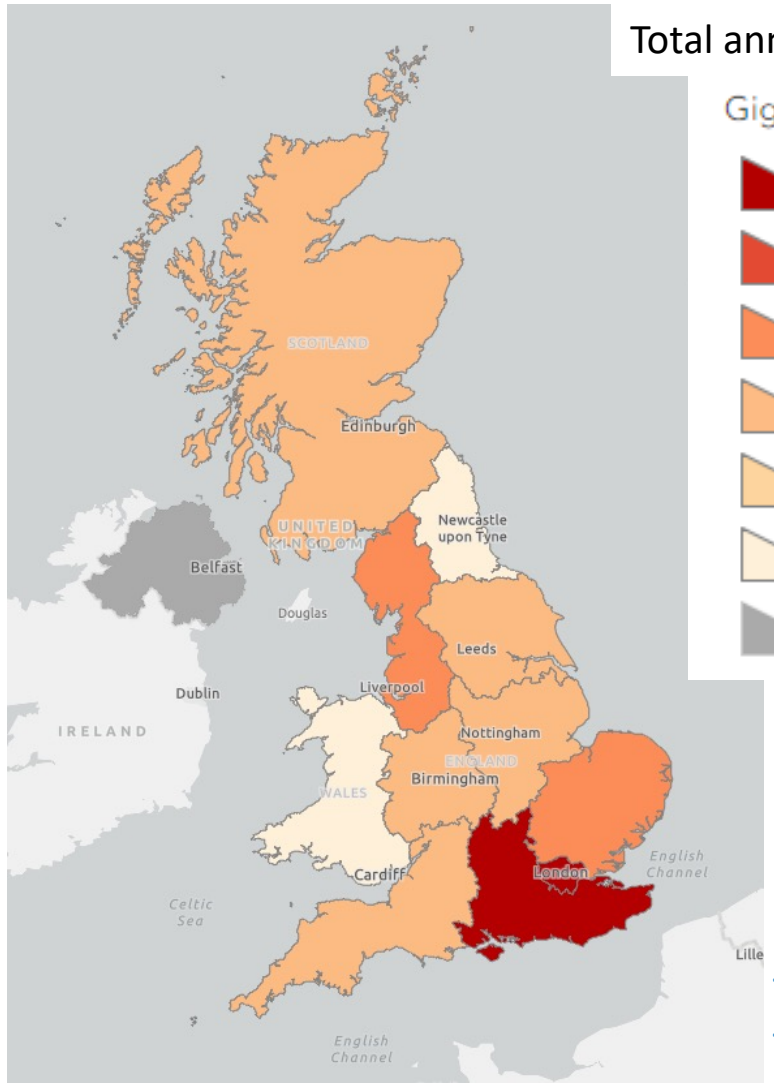
Liquefied natural gas ports

- 29,713.04 GWh
- 64,441.9 GWh
- 100,291.62 GWh

Onshore Gas Pipeline Status

- Not Abandoned
- Abandoned





= Well set up to integrate UHS in depleted gas fields and keep the status quo

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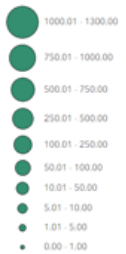
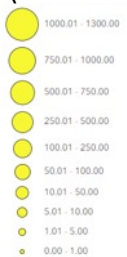
Renewable energy systems

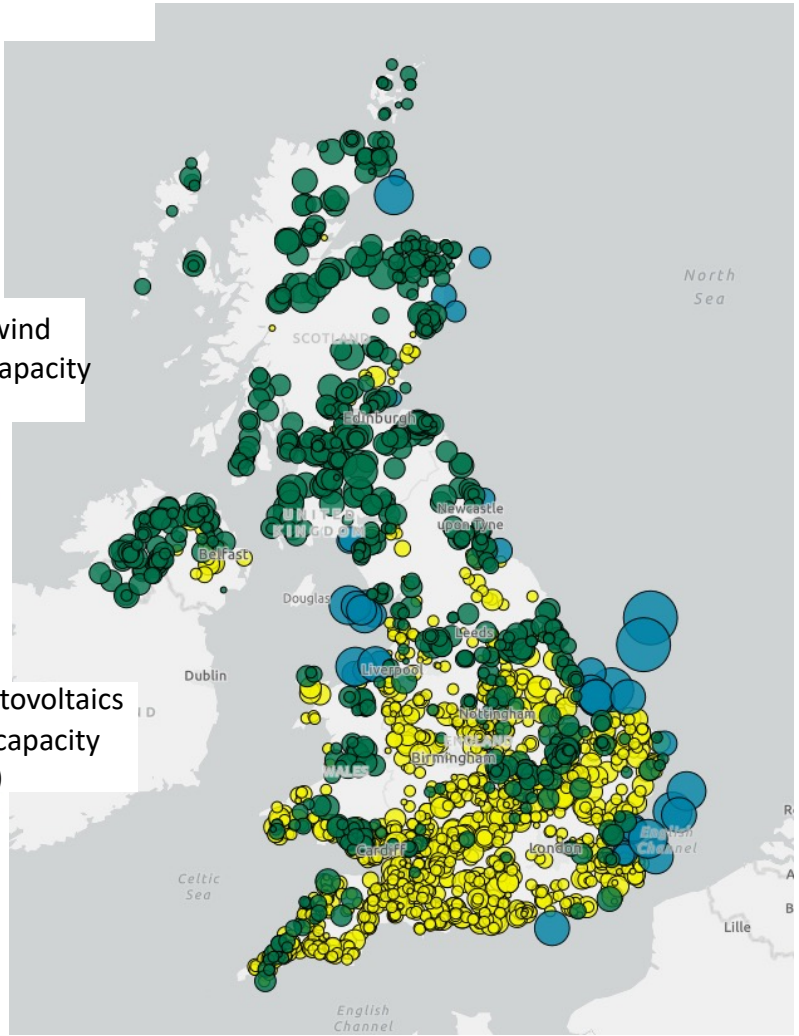
Onshore wind
Installed capacity
(MWelec)



Offshore wind
Installed capacity
(MWelec)

Solar Photovoltaics
Installed capacity
(MWelec)



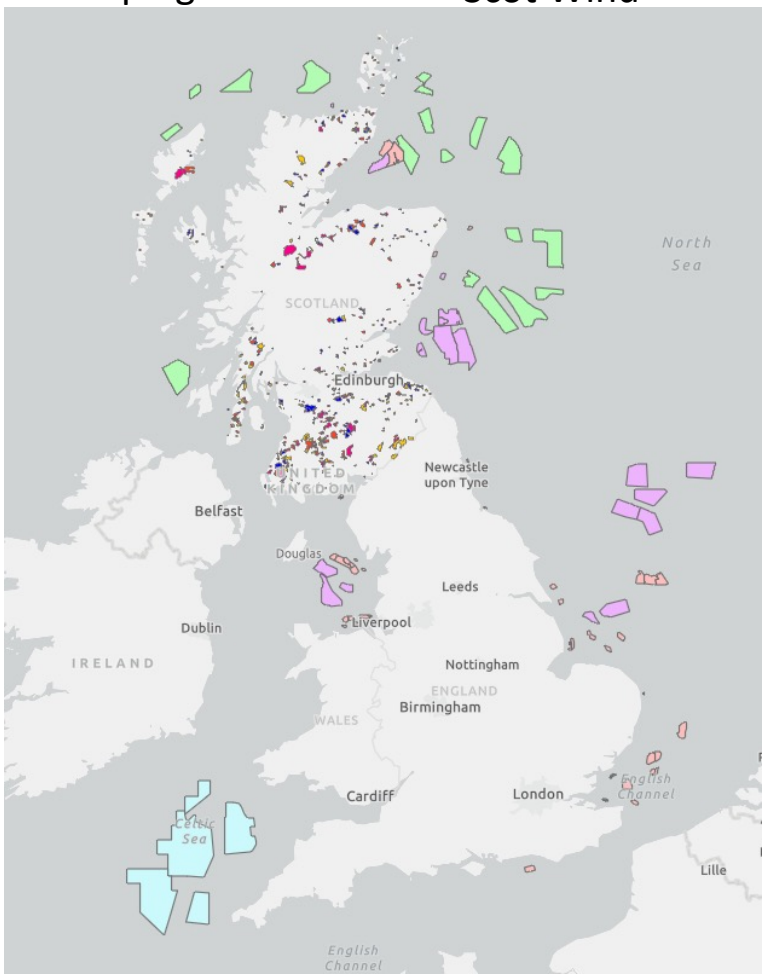


Onshore Wind Site Agreements (Scotland)

- Application
- Approved
- Installed
- Scoping

Offshore Wind (UK)

- Celtic Sea Floating
- Consented
- Operational
- Scot Wind



England banned the construction of windfarms onshore in 2015

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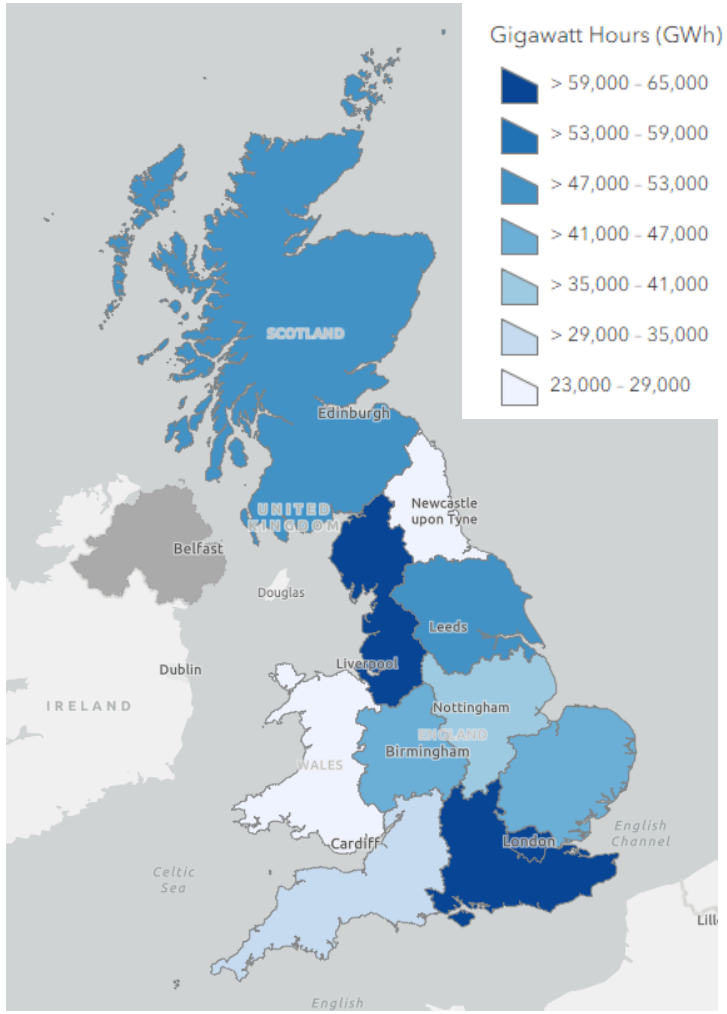
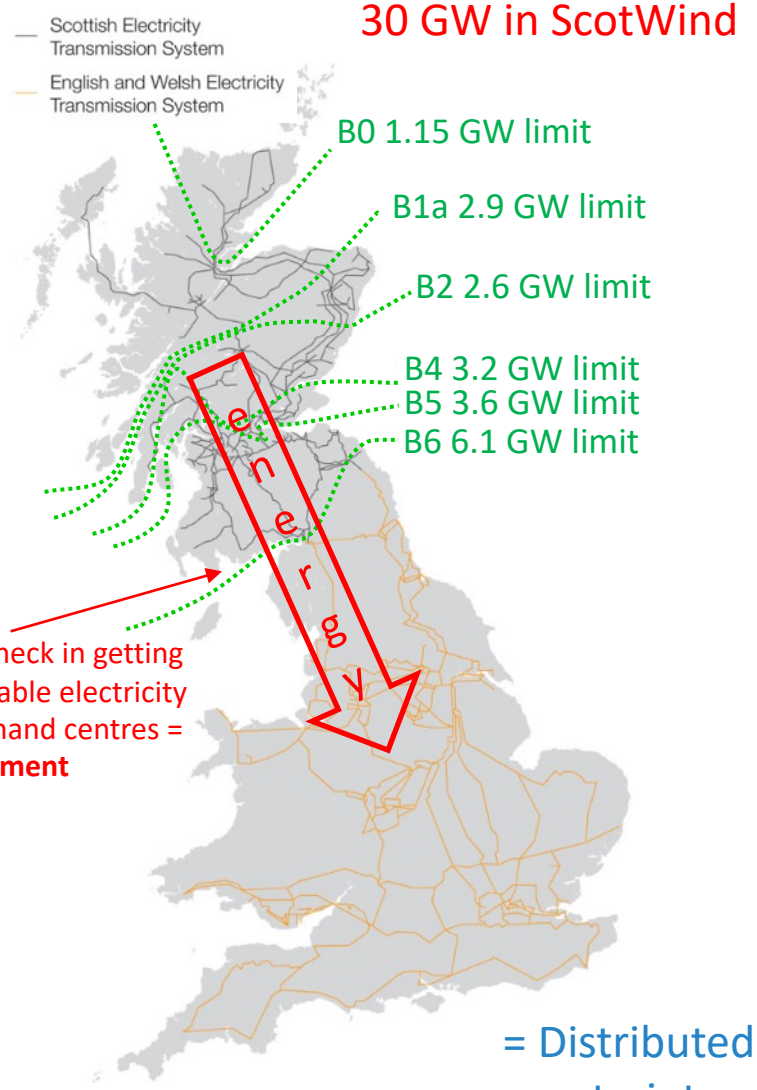
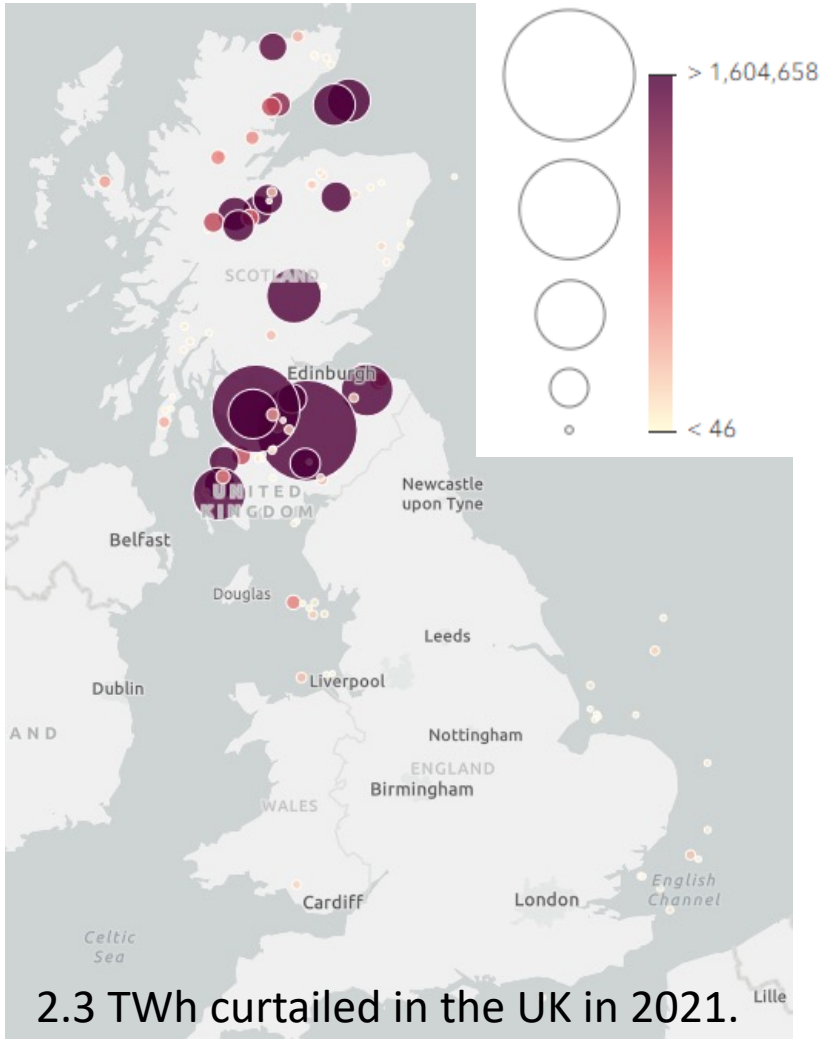
Electricity distribution networks

Total Annual Electricity demand





Total curtailed energy 2010 -2022 (MWh)



2.3 TWh curtailed in the UK in 2021.

= Distributed generation of renewable energy and grid constraints will require distributed UHS at a range of scales.

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Offshore wind energy integration with storage

A. Transport of electrons from renewable energy

B. Conversion to molecules (onshore/offshore?)

C. Transport/Storage of molecules (centralised/decentralised?)

Permian Zechstein salt high prospectivity
Permian Zechstein salt moderate prospectivity
Triassic salt high prospectivity
Triassic salt moderate prospectivity

Gas and Condensate Pipeline Operational Status

- Abandoned
- Active
- Not In Use
- Pre-commissioned or Proposed

Offshore Wind Site Agreements (UK)

- Celtic Sea Floating
- Consented
- Operational
- Scot Wind

Offshore Field Type

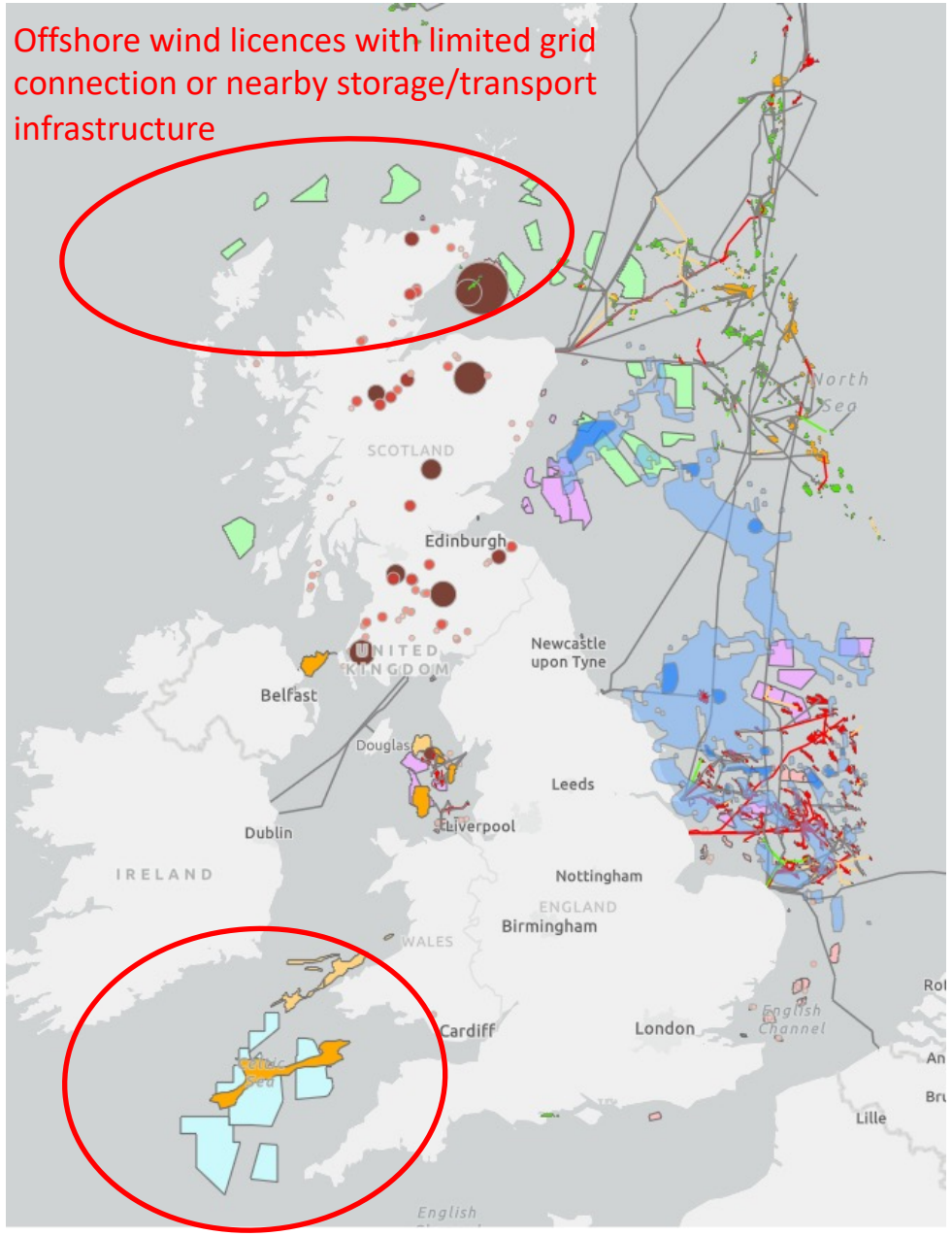
- Condensate
- Gas
- Oil

Energy Curtailed 2021 (MWh)

Megawatt Hours Curtailed in 2021 (MWh)

> 310,673

< 2



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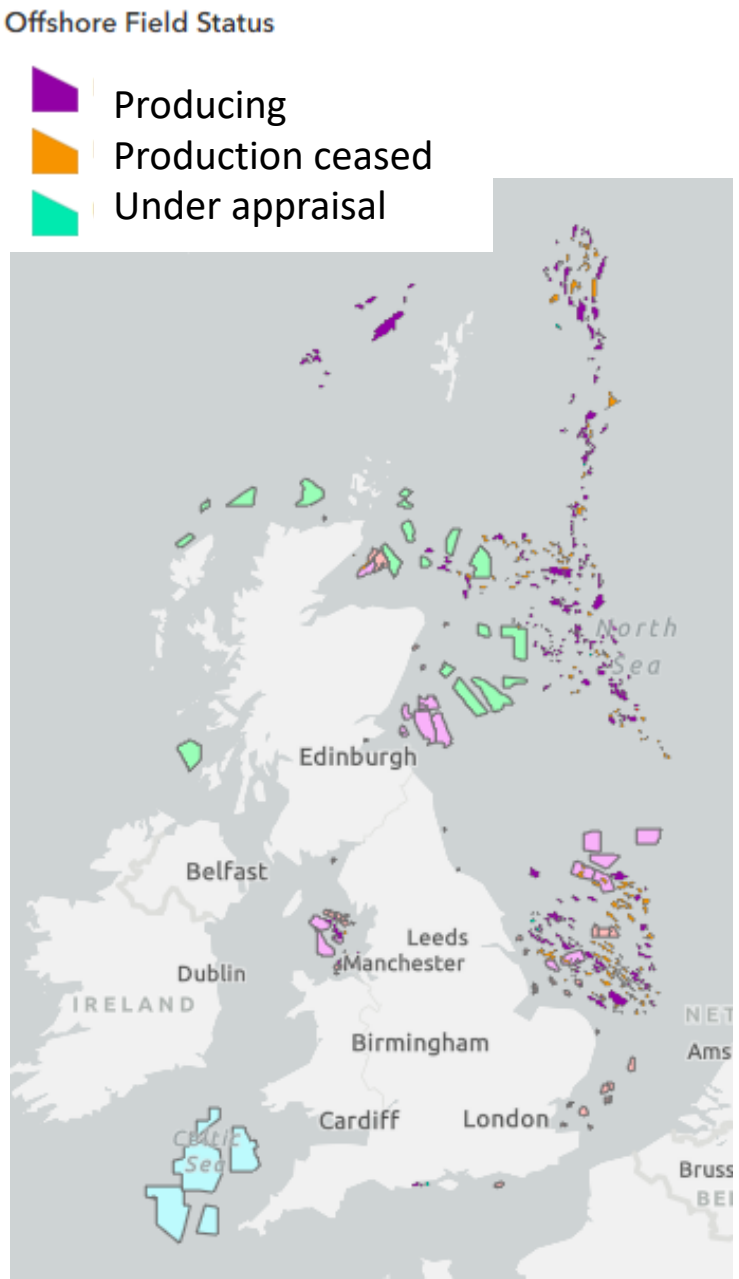
Add in Carbon storage licences = storage infrastructure demands getting crowded



Celtic Sea Floating
Consented
Operational
Scot Wind

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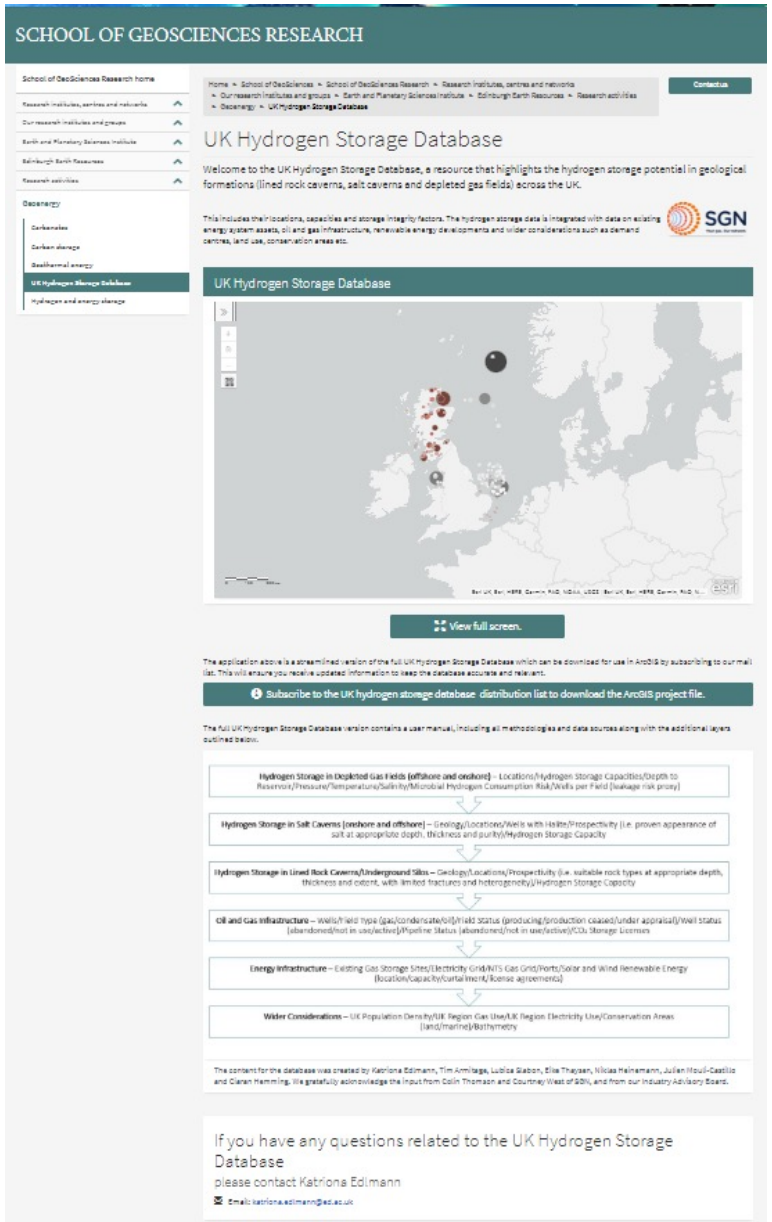
Hydrogen storage database

- 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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