

Long-duration energy storage as part of a net zero grid

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British Geological Survey

The British Geological Survey (BGS) is a public sector organisation and the UK's premier centre for earth science information and expertise. BGS is a component body of the Natural Environment Research Council (NERC), which is part of UKRI (UK Research and Innovation). It has an annual budget of about £50 million, a little over half of which comes from the UK government's Science Budget, with the remainder coming from external commissioned research, and employs about 650 staff¹.

BGS is responsible for advising the UK government on all aspects of geosciences, as well as providing impartial geological advice to industry, academia and the public, with decades of corporate experience in the collection, collation, databasing, statistical evaluation, mapping and interpretation of geological and environmental data. We are the UK's principal provider of objective and authoritative geoscientific information and knowledge for wealth creation, sustainable use of natural resources, reducing risk and living with the impacts of environmental change.

Most relevant for this inquiry is our expertise and knowledge in the use of the subsurface for long-term energy storage, including thermal storage: heat, chemical storage- hydrogen and mechanical storage: Compressed Air Energy Storage (CAES).

1. How much medium- and long-duration energy storage will be needed to reach the Government's goal of a fully decarbonised power grid by 2035 and net zero by 2050, and by when will it need to be ready?

Under what scenarios would the grid draw heavily on long-duration storage? How well are these scenarios understood?

What is the range of estimates for likely electricity demand in 2035?

N/A

2. How sensitive is the amount of storage needed to assumptions about the future balance of supply and demand on the grid?

What role could nuclear power, fossil fuel generation with carbon capture and storage, or other energy technologies, play in reducing the need for energy storage on a net zero grid? What role could greater grid interconnectivity between Great Britain, Northern Ireland and other nations play in addressing the imbalance between supply and demand? What role could demand-side management of electricity play in reducing the dependence on storage?

What impact will future climate change have on demand – for example, how much will the seasonal differences in power demand change with warmer winters and greater use of air conditioning?

Increasing temperatures caused by climate change will increase the need for cooling of buildings. Ground-coupled passive and active cooling systems can be efficient solutions which could reduce demand on the grid by using the subsurface as a large inter-seasonal heat store.

3. Which technologies can scale up to play a major role in storage?

Which timescales for storage are different technologies most suited to? Is there a preferred technology for medium-duration and long-duration storage?

What are the technology readiness levels for these energy storage technologies?

Is it possible to produce enough domestic green hydrogen to fulfil long-term energy storage demand needs?

Is there a distinct role for technologies that store heat instead of electricity?

Several underground energy storage technologies can be scaled up. These include:

Thermal storage

The BGS considers that there are roles for heat and coolth (rather than electricity) storage. Principal of these is the potential for the support of low temperature 5th generation district heating networks coupled to centralized or distributed heat pumps, using either waste heat, solar collectors, and/or heat storage in underground geological formations.

Aquifer Thermal Energy Storage. The technology readiness level (TRL) is considered to be 9 as there are thousands of active schemes worldwide. Take-up is at different levels worldwide, with the Netherlands hosting the most systems; adoption in the UK lags behind with only 9 operating schemes in 2022 (although geology is not considered a barrier to uptake). Potential deployment is widespread across the UK, hosted in aquifers to a depth of ~300 m (limited by cost of drilling and pumping). Aquifer Thermal Energy Storage is likely more suited to longer duration energy storage – e.g., at the days-weeks to seasonal/annual scale. Where underground aquifers are not available the alternative is *Borehole Thermal Energy Storage* (BTES), Mine water storage or pit thermal storage, which can be deployed to store waste heat and repurposes it later for other users. This is well established in the Nordic countries. The EU *Heat Store* (<https://www.heatstore.eu/>) and *Push-IT* projects (<https://www.push-it-thermalstorage.eu/>) have/are demonstrating these underground thermal energy storage technologies and the UK Geoenery Observatories (<https://www.ukgeos.ac.uk/>) research facilities in the UK are studying the environmental impacts and thermal storage efficiency of such technology.

Molten salt energy storage (MSES). The TRL is considered is to be 9, and although commercial operations are few in number there are several pilot schemes in development. Molten salt energy storage requires connection to a heat source- typically a solar array- with thermal energy held in molten salt for up to a week and turned into electricity via a steam turbine. One limitation on upscaling this technology would be the availability of land to accommodate suitable amounts of solar panels.

Minewater thermal energy storage (MTES) has large potential in the UK (c. 16 TWh ΔT 5°C scenario, Gluyas et al., 2020). Ongoing research projects based in the UK include [STeAM](#) mine shaft storage and [Galleries to Calories](#) using the geobattery concept. Abandoned flooded coal mines are used in a 5th generation district heating and cooling network including

mine water geothermal energy and storage serving 250,000 m² of building floor area including offices, supermarkets, shops, education facilities, homes, industry and a swimming pool at Heerlen, Netherlands (IEA geothermal, 2023). A high temperature MTES demonstrator '[Heatstore](#)' has successfully been operated at Bochum, Germany.

Chemical storage- hydrogen

Caglayan et al., (2020) estimate a storage capacity of 9,000 TWh hydrogen storage capacity in offshore and onshore UK salt caverns. TRL figures from IEA (2023).

- Static or low-cycle storage of hydrogen in caverns is considered TRL 9 and there are operational schemes in Teesside, UK (3 caverns), and USA.
- Fast-cycling storage of hydrogen in caverns is not yet deployed, and considered TRL level 5-6, with questions remaining regarding response of caverns to higher frequency/larger changes in ranges of pressure.

Williams et al., (2022) report 2151 TWh capacity for theoretical hydrogen storage if all available halite from 3 basins in the UK was developed for cavern storage:

Cheshire Basin: 129 TWh

East Yorkshire: 1,465 TWh

Wessex Basin: 557 TWh

- Storage of hydrogen in depleted gas fields- Considered TRL 3-4 for storage of pure hydrogen, and TRL 5 for storage of blended hydrogen.

Mouli-Castillo et al., (2021) report 2,661.9 TWh hydrogen storage working gas capacity in UK offshore gasfields, with Scafidi et al., (2020) indicating a working gas capacity of 6,900 TWh (P50 figure) for UK offshore gas fields.

- Storage of hydrogen in saline aquifers- Considered TRL 2-3 for storage of pure hydrogen, and TRL 9 for "town gas" blends (hydrogen with methane, CO₂, nitrogen etc)- this was first commercially operated during the 1960s.

Scafidi et al., (2020) indicate a working gas capacity of 2,200 TWh for UK offshore saline aquifers.

- Lined rock caver storage. Considered TRL 5 for pure hydrogen storage. An operational pilot for pure hydrogen has recently been established in Sweden (Hybrit project).

Mechanical storage- Compressed Air Energy Storage (CAES)

Compressed Air Energy Storage. The TRL level is considered to be 9 for schemes that do not store heat of compression (there are pilot and operational schemes, with the 290 MW Huntorf plant (Germany) having been operational since 1978 and the 110 MW McIntosh plant (Alabama, USA) commissioned in 1991). The TRL levels are lower (considered 5-6) for schemes that store and re-use heat of compression (e.g., it is technically, but not commercially feasible).

Hornsea (Atwick) gas storage facility could provide up to ~66,000 MWh when the cavern is fully charged (He et al., 2017) for a single storage cycle. Existing natural gas storage caverns in the UK could provide up to ~725 GWh of capacity (He et al., 2021). A model of 10 caverns in Cheshire could provide storage of 2.53 TWh and a power output of 40 TW (Dooner & Wang, 2019). Evans et al., (2021, 2022) report the following theoretical capacities for Isothermal Exergy CAES if all available halite (500 – 1500 m depth range, cavern heights 100 – 150 m) was developed for cavern storage:

Cheshire Basin: 87 MWh x 10⁶

East Yorkshire: 47 MWh x 10⁶

Wessex Basin: 557 MWh x 10⁶

East Irish Sea Basin: 426 MWh x 10⁶

4. What policy support is currently in place to support deployment of storage technologies? Is it sufficient to support deployment at scale?

How good is the economic case for long-duration energy storage? What policies and market structures need to be put in place to make the business case viable?

How will the grid need to change to support long-duration storage? Which stakeholders (e.g. energy companies, the Electricity System Operator, National Gas) should be planning for these changes?

What role does the Review of Electricity Market Arrangements need to play to support medium- and long-duration storage development?

Is the Government's current reliance on market actors and technology competitions likely to deliver the storage needs on time?

Overall, the efficiencies of low-carbon, long-duration energy storage are poorly understood. This is particularly the case for Compressed Air Energy Storage schemes. This is somewhat compounded by an uncertainty in how schemes would be operated in response to a demand scenario that is not clear.

Previous grant incentives for low carbon heat (RHI) did not include tariffs for cooling, which potentially deterred investors from considering ultra-high efficiency interseasonal heat and cooling system concepts such as ATES and BTES in HVAC designs for decarbonization of buildings, low enthalpy heat-using industries. There is no incentive in PSDS to encourage high efficiency underground heating and cooling storage systems (BTES and ATERS).

Relevant stakeholders with an interest in informing changes to changes required in the grid include operators, regulators and also relevant experts from academia.

5. How well developed is the UK industry across different storage technologies, such as hydrogen or redox flow batteries? How does the UK compare to global competitors in these industries?

Are there any storage technologies that have a significant export potential for the UK?

For which technologies does the UK have significant existing research or industrial capacity? Is the Government doing enough to support the industry to grow and drive exports and economic growth?

Hydrogen storage technology in the UK is advanced for static/low-cycle cavern storage, with the UK hosting one of the few operational geological stores of hydrogen in the world. However, as the technologies are upscaled and applied to a range of demands, there is a likelihood that faster cycling/higher pressure storage will be required at larger scales. This will require rapid developments in the understanding of how different operational scenarios will behave in terms of technical and also economic performance. The UK stands as a leader in cavern storage of natural gas and this experience can be directly applied to hydrogen storage. The UK appears to be more advanced in large-scale geological energy storage than some countries (e.g., China). However, the UK lags behind other EU member states (e.g., France, Germany) in cavern design and construction. Much of the UK's expertise in reservoir management for oil and gas can be applied to hydrogen storage in porous rocks (depleted gas fields and saline aquifers).

Whilst there are some aquifer thermal storage schemes operating in the UK, it is not a technology that is widely deployed.

The UK hosts research and innovation facilities for both Aquifer Thermal Energy Storage and mine water geothermal as part of the UK Geoenergy Observatories, giving the UK a potential research niche in these technologies.

All these technologies represent significant export potential in terms of developing technologies worldwide. Of particular note, hydrogen production and storage in the North Sea may be a model that could be exported globally. The development of risk reduction approaches and innovation of more cost-effective technologies at research sites (e.g., UK Geoenergy Observatories www.ukgeos.ac.uk- Glasgow for mine water geothermal and Cheshire for Aquifer Thermal Energy Storage) is a particular niche that could be further exploited if dedicated funding was available.

The UK funds active research into Aquifer Thermal Energy Storage (e.g., NERC Smart-Res project NE/X005097/1; EPSRC Aquifer Thermal Energy Storage- Heating and Cooling project EP/V041878/1), Compressed Air Energy Storage (e.g., EPSRC Integrated, Market-fit and Affordable Grid-scale Energy Storage EP/K002228/1, Sustainable, Affordable and Viable Compressed Air Energy Storage EP/W027569/1), mine water geothermal (e.g. EPSRC EP/V042564/1 Geothermal Energy from Mines and Solar-Geothermal heat) and hydrogen storage in porous rocks (e.g., through the EPSRC Industrial Decarbonisation Research and Innovation Centre EP/V027050/1). This research gives the UK a competitive advantage in understanding the potential capacities, environmental impact, locations and operational constraints of energy storage technologies. Expertise developed during these projects (e.g., storage capacity estimates) can be viewed as an exportable capability.

6. Beyond the cost of deploying long-duration energy storage, what major barriers exist to its successful scale up (e.g. the availability of a skilled workforce, the ability to construct the necessary infrastructure on time, or safety concerns around new technologies)?

Are there sufficient training schemes in place to ensure the UK has the workforce to deliver the energy storage the grid will need?

How long is it likely to take to develop the necessary infrastructure?

Public perception and understanding of geological energy storage schemes is generally not well developed, and could represent a significant barrier to the uptake of schemes if the communication and messaging of such schemes is handled poorly (e.g., Cadent Gas-Whitby Hydrogen Village trial).

The UK likely have relevant skills from the hydrocarbons industry, and these need to be applied to new and emerging sectors.

Local geology (including the absence of key geological formations such as halite, the presence of geological faults, or previous use/planned use via licensing of areas suitable for energy storage schemes) can represent a barrier to deployment of schemes in some areas.

Effective planning of storage needs to be implemented to ensure optimum use of the subsurface in supporting Long Duration Energy Storage schemes. For example, the roll out of hydrogen storage schemes needs to be placed in the context that hydrogen represents approximately 1/3 of the power of the same volume of natural gas.

7. What steps should the Government take now to ensure this storage can come online later in the current decade?

Can the UK learn from other countries that have successful policies for supporting large-scale energy storage, or from pilot projects elsewhere?

A clear understanding of anticipated hydrogen demand (in terms of location and amount) would enable assessments of potential storage sites to be effectively targeted.

There is a requirement for a consistent dataset to be built up describing the operational efficiency of different types of energy storage schemes implemented in the UK.

Valuable experience relating to the large-scale deployment, licensing and regulation can be gained from the Netherlands.

Research programmes such as IDRIC (www.idric.org) in terms of developing industry-academic partnerships should be continued. Pilot schemes for heat storage underground are providing learning (EU Heat Store and Push-IT projects) and case studies in IEA Heat Pumping Technologies TCP (e.g. Heat Pumps in Positive Energy Districts - Annex 61).

A recent White Paper for deep geothermal (Abesser et al. 2023) contains recommendations that are also relevant for borehole, aquifer and mine water thermal energy storage from UK stakeholder consultation, as well as consideration of policies from other European countries.

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