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Longer Duration Energy Storage

Overview

- The UK’s energy system relies on the storage of fossil fuels to manage variations in supply and demand over varying timescales. As these are replaced to meet the net zero emissions target, new types of longer duration energy storage will be needed to provide secure energy supplies.

- There is a range of different energy storage technologies in development, which includes flow batteries, mechanical devices (such as pumped hydro, liquid air and compressed air), thermal storage and hydrogen.

- Longer duration storage can support a future energy system with high proportions of renewable energy by providing flexible energy supply and demand, and increasing the resilience of energy networks.

- Increasing amounts of energy storage will be needed, but to deploy the technologies at scale will likely require further innovation, demonstration, better business cases, investment and government support. Deployment will also depend on ongoing developments in energy markets and a better understanding and communication of the risks.

- The Government will implement a policy on longer duration energy storage by 2024.

Background

The UK's plans for a decarbonised, net zero energy system will involve a greater proportion of electricity from variable wind and solar generation, as well as an increase in total electricity demand as the heat and transport sectors are electrified.[1–3] To balance this future system, low-carbon, longer duration energy storage (LDES) technologies are being developed that can store surplus generation from renewables for use in periods of high energy demand or low output from renewables.[4]

There is no agreed definition for longer duration energy storage.[5,6] Existing definitions generally compare energy storage systems according to size and discharging duration.[5,7,8] The categories of short, medium and long duration storage are separated by overlapping boundaries, which are influenced by factors such as a technology's capabilities, energy system needs and market arrangements.

Short duration storage technologies are suited to discharging energy over a 0–4 hour output timeframe.[5] Batteries (mainly lithium-ion) have been deployed successfully in the UK to provide services for the electricity system over seconds, minutes and hours (usually one or two at most).[3,9–11]

Medium duration storage assets are designed to help balance daily discrepancies between electrical supply and demand (4–12 hours), and multi-day variation in wind generation (12–200 hours).[12–14] These technologies will be deployed at all scales of the UK energy system from large grid-scale to smaller local or domestic applications.

Long duration options (over 200 hours) could store energy over weeks, months, seasons and years. These help to balance inter-seasonal variation in heating or cooling demand (PN 642) and address system resilience challenges in the power sector, such as wind droughts or interconnector failure (electricity supply connections between grids).[15–18] Long duration storage will need to be deployed at the larger grid scale to address these challenges.

Storage technologies can also store thermal energy (see Thermal), and so indirectly support the electricity system by reducing the amount of electricity needed for heating and cooling applications during periods of peak demand.[19,20] The storage technologies discussed are considered 'low-carbon' as they do not use fossil fuels while operating. However, the building, operation and decommissioning of energy storage facilities can produce carbon emissions and other negative environmental impacts.[21,22]

This POSTnote focuses on sectors (such as power and heat) suited to new longer duration storage technologies rather than other sectors (such as transport) where short duration storage is used.

Technologies suited to longer durations

Energy capacity (total amount of energy stored) and power (rate of discharge) are the key characteristics of energy storage technologies. These can be coupled (fixed together) or decoupled inside a storage technology. Storage technologies that can more readily decouple power and energy capacity, allowing one to be scaled without changing the other, are potentially more suited to longer duration applications.

Flow batteries

Batteries work by converting electricity into chemical energy. In a rechargeable battery, the processes that convert electricity to chemical energy can be reversed when the device discharges. There is a range of new batteries with different chemistries and configurations being developed, such as flow batteries.[9,23–27] This new type of battery shows promise for a range of applications in the UK.

Flow batteries store chemical energy as a liquid (usually water based). The liquid is pumped out of the internal battery system into external storage tanks, which decouples the capacity from the power. This novel configuration enables the battery to store more chemical energy and discharge electricity for longer periods of time.

The UK Government is supporting flow battery innovation and commercialisation (see Government Strategy).[28,29] Different flow battery chemistries are emerging, with vanadium being the most advanced.[30,31]

Mechanical

Mechanical storage technologies convert electricity into mechanical energy, relating to an object's kinetic energy (motion), pressure or gravitational position. Energy can be stored by spinning a wheel (flywheel storage), compressing or liquefying a gas (such as compressed air or liquid air storage), or raising the height of something heavy (such as water, high density fluids and weights).[32–37] The stored mechanical energy is released by reversing these processes, such as slowing the wheel, allowing gas expansion, heating a liquid to a gas, or allowing the mass to drop. The released energy is used to drive turbines or generators, producing electricity. For example:

- Air can be compressed in salt caverns or liquefied through cooling in tanks.[38,39] For these systems, capturing and storing waste heat or cooling (thermo-mechanical) can improve their efficiency.[40,41]

- Pumped hydro is deployed at grid-scale in the UK, and compressed air at grid-scale overseas (PN 492).[42–44] Other types are at different stages of commercialisation, with large-scale liquid air the most advanced in the UK.[45–47]

Thermal

Thermal storage technologies store energy as heat in various materials such as water, concrete, rocks, molten salts, underground aquifers or metals, or use it to cool down a material in a process that can be later reversed to release the stored energy. Thermal energy is captured directly (from the sun, air, underground, or waste heat from buildings and machines) or produced using electricity.[48] It is discharged directly into heat networks or reconverted into electricity (PN 632).

Examples of technologies that discharge energy directly as heat (or cooling) include water tanks, underground aquifers and mine water systems (PB 46).[49–51] Phase change materials store heat via changes between a liquid and a solid state.[52,53]

Pumped thermal energy storage uses electricity to power a heat pump that moves heat from a cold to a hot store (PN 426).[54] In reverse, the system allows heat to flow back from higher to lower temperatures and turns a generator to make electricity.

The Government is supporting innovation in small-scale, local thermal storage technologies.[28,29] Storage of subsurface heat in underground aquifers has been deployed overseas and to a limited extent in the UK (PB 46).

Hydrogen

Low-carbon hydrogen can be stored in large quantities and converted back to electricity when needed on the grid (PN 645). Also, it could be used directly in industry, heating and transport applications.[20,55,56]

Hydrogen can be stored as a gas in underground salt caverns. Storage in underground aquifers and depleted gas fields is also being considered.[57–61]

Hydrogen can also be converted to other gaseous or liquid synthetic fuels (such as ammonia or methane), which may be easier and/or cheaper to store and transport (PN 665).[62,63]

System needs and storage

As the electricity system decarbonises there is a range of essential grid operation services that LDES could contribute that have traditionally been provided by fossil fuel generation.[64] The different services will require certain technical specifications that the various types of LDES may, or may not, be suited to.

Power system flexibility

The electricity system must balance electrical supply and demand minute by minute across the year. This has historically been achieved through the controlled variation in generation from fossil fuels, making use of the ability to store the fuels.

However, the proportion of electricity generated by wind and solar is expected to grow, with the UK Government setting a target to deliver 50 GW[*] of offshore wind generation by 2030 and 70 GW of solar generation by 2035 (current peak electricity demand is ~50 GW).[65,66] Due to the weather's variability, the output of wind and solar cannot be scheduled hours or days in advance. This means flexible types of generation (such as LDES), which can be scheduled to meet demand under low wind and dark conditions, will become increasingly important.

The future role of different storage options in providing system flexibility is currently unclear. Medium duration technologies that provide grid balancing services over hours and days earn revenues in arbitrage markets from buying energy when it is cheap, storing it, and selling it when the price is high. To maximise their income, they will cycle between charging and discharging frequently, suiting technologies with a higher efficiency as losses increase charging costs. Technologies suited to shorter durations of discharge tend to have higher efficiencies.[67–72]

Energy efficiency during charging and discharging is less important for longer duration technologies that cycle less frequently to provide energy balancing services over months, seasons and years.[73,74] The most important factor in this case is storing

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[*] A gigawatt (GW) is a unit of power equal to a billion watts.

a high capacity of energy securely, reducing energy losses while inactive, at the lowest possible financial cost. Geothermal and hydrogen storage technologies are suitable for this timeframe. Hydrogen and synthetic fuels derived from hydrogen are suitable for bridging multi-year shortfalls in variable energy generation caused by issues such as low annual wind speeds or the prolonged loss of large-scale equipment such as interconnectors or electricity generating plants.

Prolonged weather-related events

The UK's wind resource varies on different timescales, from days and weeks to months and years.[75] Low wind speed events can result in frequent periods of low output from the UK's wind farms.[76] Solar photovoltaic (PV) generation is unavailable overnight, and average output on shorter winter days can be very low. Periods of combined low wind and solar generation that last longer than a day coincide most frequently during periods of higher demand in winter, often caused by high pressure weather systems that last for hours or days, and sometimes longer.[77] A 'dunkelflaute'[†] is a term that is becoming commonly used to describe such events.[78–80]

Lengthy dunkelflaute periods of a few days to a week are rare but pose a greater risk to an energy system with a high proportion of renewable generation.[77] There is moderate correlation between dunkelflaute events in the UK and neighbouring countries. This suggests that generation shortfalls from shorter dunkelflaute events could be partly met by electrical interconnectors between GB and Europe.[77] Storage can also help to meet these shortfalls while contributing to security of supply (PN 676). It is likely that larger shortfalls will need to be met by large-scale hydrogen or hydrocarbon storage reserves.

Constraints on the power grid

Grid constraints occur when the power generated on parts of the system exceeds the physical capacity of the local grid to export the power.[81,82] The system operator manages this by paying generators to reduce their supply to the system.[83] Constraints have been increasing over recent years, mainly due to the increase in wind generation outpacing the development of the necessary grid capacity. Wind generation equivalent to 2% of electricity total demand was curtailed on the GB grid across 2020 and 2021, mostly (88%) from Scottish wind plants.[84] The yearly cost of transmission constraints has grown from £170 million in 2010 to £1.3 billion in 2022 and this is likely to increase proportionally as wind generation (mainly offshore) grows in the future.[3]

Co-locating medium and long duration storage facilities with renewable generators would provide a source of local demand for any surplus electricity, reducing the need for curtailment. The stored electricity could then supply the grid when the network is less congested or supply other local sources of demand.[85,86] Most types of storage would be suitable for this, although in the case of hydrogen or compressed air it would also depend on whether there are also suitable underground conditions to enable geological storage sites in the location. Nuclear power might also be suitable for the co-location of hydrogen production and storage. For example, hydrogen

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[†] Dunkelflaute is a German word that translates as a dark calm lull.

produced from waste heat is being considered for the planned Sizewell C nuclear plant in Suffolk (PN 687).

Scale of storage requirements

Fossil fuels (particularly natural gas) are currently used in the UK as a store for most types of energy over all timescales. Low-carbon electricity storage plays a relatively minor role on the GB electricity grid at present: in 2021 there was 28 GWh[‡], just 0.01% of total electricity demand.[87] Government, National Grid and academics agree that future levels of low-carbon electricity storage will need to increase significantly to reduce reliance on storing and using natural gas to produce electricity.[3,5,88–90] An estimate suggests the following ranges of LDES capacity might be required to replace the use of natural gas for power system balancing:

- Medium duration storage: 3-4 TWh[§] capacity for inter-day applications.[91,92]
- Long duration storage: 10s of TWh capacity for seasonal applications and ~100 TWh for multi-year applications.[91,92]

Substantial electrification of the heat sector would also transfer much of the heat demand, currently met largely by natural gas, onto the electricity system. This may create the need for even more electricity storage capacity.

Scaling-up

Commercialisation

Energy storage companies are building a business case by securing revenue streams from a range of applications (such as providing flexibility or addressing power system constraints) in a so-called 'revenue stack'.[93–95]

Current flexibility services (balancing electricity supply and demand), procured by the national transmission system operator National Grid ESO, predominately reward storage facilities that can provide short duration, rapid discharge.[96] For example, fast-acting energy storage technologies (such as lithium-ion batteries) can earn money by providing a 'frequency response' service, which helps to balance the electricity system on a second-by-second basis.

These current market arrangements limit the potential revenue companies can secure from providing flexibility services over longer durations at the larger grid scale. While storage assets are eligible to participate in the Capacity Market (a policy mechanism that pays for dependable reserves of electricity capacity), it does not currently reward

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[‡] A gigawatt-hour (GWh) is a unit of energy equal to a billion watt-hours. A GWh is equivalent to a steady output of 1 GW running for an hour.

[§] A terawatt-hour (TWh) is a unit of energy equivalent to 1,000 GWh. Electricity demand in 2021 was 334 TWh.

the low-carbon LDES needed to meet demand during significant shortfalls, such as dunkelflautes.[97–99]

The future components of this revenue stack are currently unclear as the Government is reviewing electricity market arrangements for the GB power system.[100,101]

The business case for storage over seasons and years is especially challenging. For these LDES assets cycling frequency will be much lower, and there is the potential that the asset may not be used for extended periods, such as in a warmer winter. This could require the Government to pay for 'warehousing' storage as a reserve (see Government Strategy).

Stakeholders suggest that a policy mechanism is needed to provide support for a suitable business model that values both resilience and energy security and de-risks investment (see Box 1).

Investment

Significant levels of investment in power system storage assets may be needed, with some estimates suggesting this could be as much as £172 billion by 2035.[102] For example, while various models predict a future increase in hydrogen demand, actually scaling-up supply and sources of demand for hydrogen represents a key investment challenge (PN 645).

Investment in hydrogen and other technologies could support economic growth in areas such as leasing intellectual property, exporting components and supplying hydrogen on future global markets (such as for generating electricity, producing fuels, and industrial applications).[103,104] This could stimulate new jobs throughout the UK. Other countries will also invest in developing LDES facilities. This could cause competition for investment, skilled labour and materials and affect the potential costs of storage projects.

Grid-scale projects (such as hydrogen storage) require substantial amounts of capital investment (for preparing a geological site and purchasing machinery).[105–107] Currently, hydrogen storage needs to be co-located with hydrogen production (an electrolyser) and the capability to re-convert to power (hydrogen turbines). This further increases the potential capital costs of first-of-a-kind storage projects.

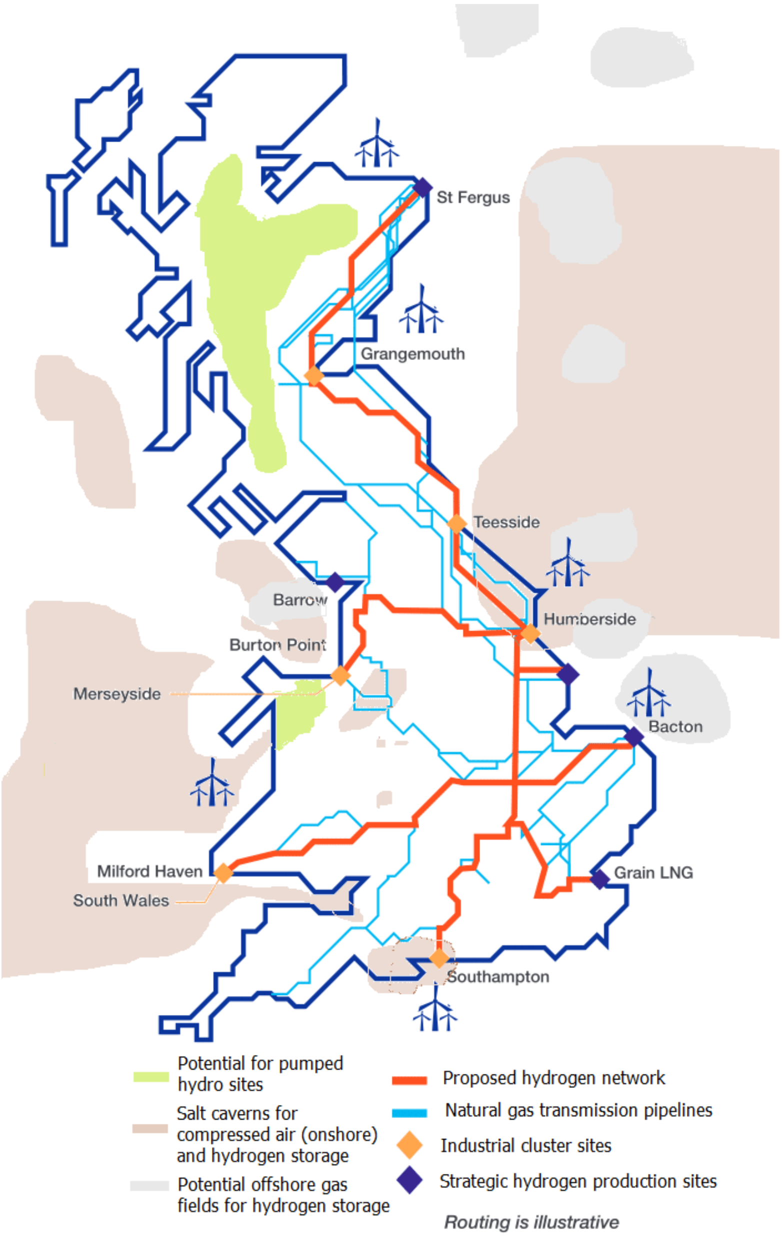
Overall, LDES assets are expensive to build and will have a long lifespan, making potential projects particularly sensitive to uncertainties relating to construction costs and the ability to generate revenues over their lifetime.

Location

The 2020 reform of the Planning Act 2008 has streamlined the planning process in England and Wales for certain grid-scale electricity storage projects (excluding pumped hydro).[108–110] Storage projects are now subject to local planning procedures rather than the Nationally Significant Infrastructure Projects procedure (CDP 0102).

However, multi-year delays in securing grid connections are limiting deployment of new projects in the UK.[111,112] The National Grid Gas Transmission plan to construct a hydrogen transmission network (see Figure 1), connecting industrial clusters with hydrogen power and storage, that will allow for more strategic siting of hydrogen storage facilities.[113]

Figure 1 Energy Storage Locations and Planned Hydrogen Network in GB



Source: National Grid Gas Transmission – key, pumped hydro, salt caverns and gas fields overlaid.[113–116]

Certain storage technologies (such as batteries, liquid air and thermal) are more modular and can be scaled for deployment in various settings. Other options, such as pumped hydro, hydrogen and compressed air need to be located in particular geographic areas that have suitable conditions (such as onshore salt caverns, depleted offshore gas fields and mountains - see Figure 1) and are more cost-effective at the larger grid scale.[114,115,117]

Hydrogen storage is being considered in underground aquifers or offshore in disused gas fields near wind farms. High-density pumped storage (which uses liquids that are denser than water) may provide new smaller-scale opportunities, opening up a greater range of geographical locations (such as on hillsides or underground).[36] Geothermal energy storage can be located throughout the UK and often corresponds with areas of heat demand (PB 46).[118,119] Technically, these natural resources are sufficient in size to deliver the 10–100 TWh of energy storage needed in the UK.[114,115,117–120]

Operational risks

The safety and environmental impact of storage technologies is a key issue that is still to be fully understood. Some storage technologies pose potential risks, for example through the leakage of gases, liquids and harmful materials.[121–124] Risks may be reduced in some cases, such as flow batteries with chemistries that are water-based and do not pose the same risk of combustion as lithium-ion batteries.[23,125–127]

The bulk storage of substances beneath the Earth's surface poses some notable risks. The repeated compression and extraction of gas can compromise borehole infrastructure associated with containment in salt caverns, posing the risk of leaks and surface subsidence, which in the case of hydrogen could contribute indirectly to global warming.[61,128–130]

Hydrogen storage in the subsurface might cause hazardous unintended reactions, producing methane and corrosive hydrogen sulphide gas.[131,132] Preparing some types of geothermal storage sites may involve practices that pose a risk of induced seismic activity (PB 46).

Natural seismic activity has the potential to compromise the integrity of underground storage structures for hydrogen and compressed air by fracturing the sealing rocks, although salt caverns have been operated successfully for industrial purposes in Teesside, England since the 1970s.[133–135]

These technologies are not well known to the public, with positive and negative perceptions of their safety starting to emerge.[136–138]

Government strategy

The UK Hydrogen Strategy and British Energy Security Strategy outline the Government's support for deploying more medium duration storage, hydrogen power storage and heat networks.[65,103]

Stakeholders have suggested that this begins to give clarity about the future role of longer duration storage in the UK. However, they also suggest that setting clear targets and support mechanisms could assist the adequate and timely deployment of storage technologies.[4,99]

Previous Government schemes have incentivised research and demonstration in longer duration options (such as the Storage at Scale competition) and the deployment of storage co-located with renewable plants (such as the Feed-in Tariff) (CBP 6200).[139–142]

Recently, it has made £68 million in capital funding available to actual and prototype demonstrations of storage technologies in the Longer Duration Energy Storage Demonstration competition.[143] Some of the successful projects that will enter Phase 2 ‘build and commission’ have recently been announced.[144] This competition is helping to prove the business case for new LDES technologies to investors.

The Government has outlined several potential policy mechanisms to de-risk investment in new storage options (see Box 1).[4,100] Storage developers generally expressed a preference for the cap and floor mechanism.[4,99] Stakeholders suggest that separate support for first-of-a-kind, large-scale projects (such as subsurface storage of hydrogen) may also be needed.[4,99,145] Without an appropriate incentive, industry stakeholders also noted concerns that there may be insufficient reserve storage capacity deployed on the energy system, undermining energy security.[4]

Box 1: Policy Mechanisms: De-risking Investment

- Contracts for Difference (CfD) – a long-term Government contract protecting against volatile wholesale prices by paying developers a guaranteed price for energy generated (currently supports the renewable generation sector).[146,147]
- Regulated Asset Base (RAB) – developers recover costs by raising funds for construction from consumer electricity bills for new projects before the asset is in use (recently agreed to support new nuclear projects and previously used to finance utilities infrastructure).[148,149]
- Cap and Floor – maximum and minimum prices for energy are set for an agreed period to provide security to investors (currently supports interconnector projects) (PN 569).[150]
- Strategic Reserve – Government purchases ‘warehousing’ services from storage operators, providing additional capacity with specific conditions for discharging electricity (like a prolonged dunkelflaute).[4,151]

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