Energy Storage

An Energy Data Centre Introductory Guide

Keelan Colechin (Cultivate Innovation Ltd)

Mike Colechin (Cultivate Innovation Ltd)

January/2025

Introduction to UKERC

The UK Energy Research Centre (UKERC) carries out world-class, interdisciplinary research into sustainable future energy systems.

It is a focal point of UK energy research and a gateway between the UK and the international energy research communities.

Our whole systems research informs UK policy development and research strategy.

UKERC is funded by UK Research and Innovation.

Document Purpose

This document is an introductory guide to the topic of 'Energy Storage'. It highlights the main concepts, policies and technologies which influence this topic area in the UK, and is written for those with limited prior knowledge of energy storage. This document will not cover all relevant issues in this area but will serve as a starting point for those looking to research further.

The 'research and innovation' section is based largely on projects which can be found in the UK Energy Research Centre - Energy Data Centre's (UKERC EDC) projects database. This section is not exhaustive and focuses on publicly, rather than privately, funded research; as such, it will not cover all research in this area.

When referring to the role of UK Governments, the document focuses on policies rather than regulations or specific funding packages. Policies help to give a broad sense of Governments' direction without getting into the technical details which may: a) distract from the key messaging of the document and b) be subject to frequent change.

This document avoids using technical language or acronyms where possible and is written in plain English. As the use of some technical language is unavoidable in such documents, this guide lays out definitions and explanations as these terms arise.

The contents of this guide have been reviewed by domain specialists to ensure they are a useful and accurate introduction to the topic.

Suggestions about factors which should be included in future editions are welcome and should be sent to EDCManager@stfc.ac.uk

1. Overview

The UK's historic fossil fuel-based energy system could easily adjust to changing demand by ramping production up or down. This system provided electricity, heat and transportation fuels in a largely dependable and predictable way. Its reliability was underpinned by straightforward energy storage: coal piles (for electricity), pipes and chambers full of gas (for heat), and oil/petrochemical tanks (as transport fuels). But as the climate impacts of fossil fuel use have become clear, the energy system has begun shifting towards low-carbon alternatives—posing new challenges for how we store energy.

Unlike fossil fuels, renewable energy sources like wind and solar are variable and less controllable. Solar generation fluctuates with daylight, while wind output depends on weather. These sources don't always align with energy demand, which itself varies daily and seasonally (although demand for energy currently follows relatively consistent patterns). As a result, the system requires new forms of flexibility to avoid a host of technical, economic and social problems (Royal Society, 2023). Part of this flexibility will need to come from energy storage.

According to the Climate Change Committee (CCC, 2023), storage is now a priority for investment. The National Energy Systems Operator (NESO) reports that, as of 2023, the UK stored about 10 TWh of energy in short-to-medium-term solutions like batteries and pumped hydro (NESO, 2024). These are expected to scale up, but they don't address all challenges—particularly inter-seasonal storage.

Inter-seasonal storage is arguably the most difficult problem. No current technology matches the high energy density and long-duration capacity of fossil fuels. This becomes even more pressing as electricity generation becomes increasingly reliant on renewables with large seasonal variations. Without effective solutions, the system may face higher costs, wasted energy (curtailment), and risks to energy security.

A wide range of emerging technologies—including hydrogen and thermal storage—are being explored, as described in the 'Solution Types' section. NESO's Future Energy Scenarios (see previous reference) show these will need to complement existing systems to meet net-zero goals by 2050.

Finally, energy storage isn't limited to central infrastructure. It can be decentralised and behavioural. A smart washing machine delaying its cycle, a wood burning stove reducing reliance on the grid, or an electric vehicle discharging to the grid are all forms of demand-side flexibility. These shifts can both relieve and complicate the energy storage challenge as the system evolves.

2. Government direction

There are different tiers to government in the UK, from central government, through the devolved administrations, to local government. Each has certain powers within their jurisdictions to incentivise or mandate energy storage solutions. However, currently most policies and projects surrounding energy storage in the UK are headed up by UK Government. While different regional governments and local authorities refer to energy storage in local area energy plans (LAEPs), regional energy security plans, and net zero strategies, most concrete policies and funding come from the UK Government.

2.1 The UK Government

The UK Government has recognised a need for greater investment, capacity and diversity in our energy storage. In their Net Zero Strategy (BEIS, 2021) they particularly focus on the need to develop long-term storage alongside improving Carbon Capture Utilisation and Storage technologies. Such technologies would allow the energy system to still make use of the storage and flexibility benefits of fossil fuels in dispatchable energy plants without as many harmful emissions.

To support a focus on long-term storage development, the Government launched a long-term storage competition, focused on proving solutions at scale. More recently a Cap and Floor scheme for long term energy storage (2024) has been announced to make long term storage more economically viable. Storage in all forms has been a key part of the Government's brief to NESO, highlighting their view of its importance to the UK's energy system (DESNZ, 2024).

Some of these policies will be subject to change following the recent 2024 General Election in the UK.

2.2 Devolved governments

Scottish Government in its Scottish Energy Strategy (2017) calls on the UK Government for additional support to develop energy storage in the UK. They also prioritise the deployment of pumped-hydro storage citing their specific regional potential for deploying this infrastructure.

Welsh Government appears to be championing hydrogen for a range of decarbonisation solutions (2025) including energy storage and flexibility. They also place an emphasis on localised energy planning and ownership in their Net Zero Strategic Plan (2022) to contribute to greater energy system flexibility.

The Northern Ireland Executive (2021) centres its efforts on continued electrification and expansion of renewable energy sources to meet the consequent demand. They acknowledge the need for energy storage that will accompany this, notably supporting the development of large battery storage projects.

2.3 Local authorities

Similarly, several local authorities highlight the importance of energy storage in their local area energy plans, but do not outline extensive energy storage projects. They too refer largely to national level efforts, policies and projects.

3. Solution Types

Different energy storage solutions have different optimal storage and discharge durations. While there are several ways of segmenting these durations, here we will use: short term, medium term, and long-term categories. ‘Short-term’ would range from seconds to hours for the purpose of balancing the energy system, ‘medium-term’ ranges from one day to several weeks for matching supply to changing patterns of demand. ‘Long-term’ or ‘inter-seasonal’ storage is intended to create strategic stockpiles of dispatchable energy in periods of renewable energy ‘drought’. Flywheels and supercapacitors are useful examples of very short duration energy storage, whereas hydrogen would only ever be cost effective as longer-term storage. The boundaries between these different durations are undefined, and many solutions can span several duration use-cases, so the categorisations used here should be viewed as indicative rather than definitive. The graph below gives greater detail on the discharge durations and capacities for different examples of energy storage solutions.

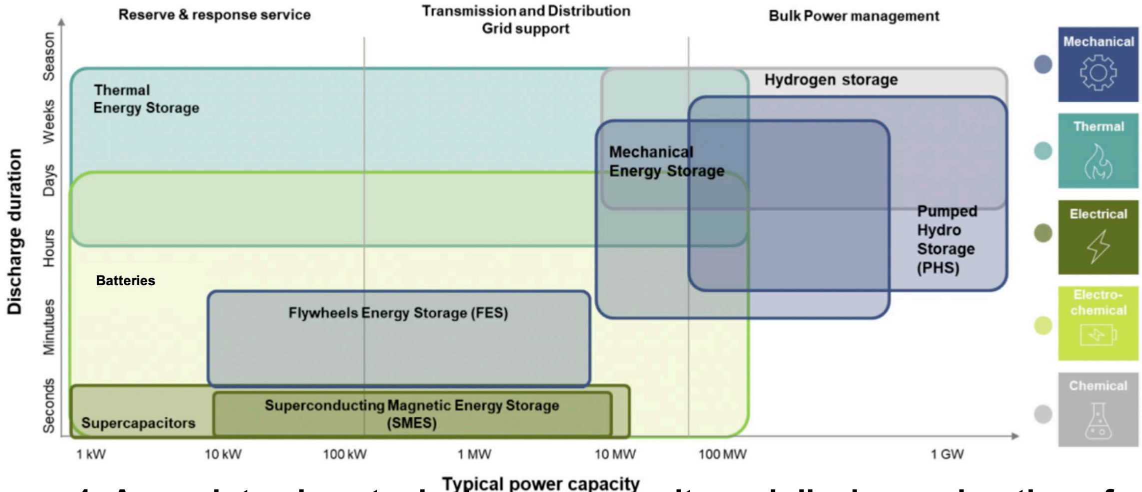

Figure 1. A graph to show typical power capacity and discharge duration of storage solutions (European Commission, 2023)

3.1 Short term

- **Supercapacitors** - capacitors are a very well established and understood technology, 'supercapacitors' store electricity directly as potential charge and can load and unload extremely quickly. They do, however, lose substantial amounts of energy over time, and release their energy in short bursts rather than maintaining a sustained supply. This means they can work well as a complimentary technology to battery storage when managing energy produced from variable renewable sources. They can also work well in technologies like electric vehicles which require fast charging and discharging rates.

- **Superconducting magnetic energy storage** works by cooling a superconducting material and then generating a current in that material. As superconductors at low enough temperatures have almost zero resistivity, it means that they maintain their generated current for a very long time. This means they can be used as a form of energy storage. However, due to the high costs of components and refrigeration challenges, they are generally only used for short term storage and grid balancing applications.

- **Flywheels** work by storing energy in a spinning mass that rotates more quickly as energy is supplied to it. Again, they lose a lot of energy over time but can be charged and discharged quickly and frequently without causing damage to the hardware of the unit. This also makes them useful for power grid frequency modulation, providing inertia and very short-term storage. In fact, the large, heavy turbines in many fossil fuel generation plant act as flywheels, and currently provide inertia and frequency modulation services to the system. Similarly, synchronous condensers are used at various sites throughout the UK and work in broadly the same way, providing inertia that helps to regulate the transmission frequencies of the grid.

- **Batteries**, particularly lithium-ion batteries, are being deployed at ever larger scales both in the grid and in technologies such as electric vehicles. They are relatively energy dense (although more than an order of magnitude less than fossil fuels) and store/release energy quite flexibly and rapidly, making them ideal for vehicles and some grid storage uses. Typically, they would be used within a day to manage the mismatch in peak load and peak supply but can also be used for some grid frequency modulation.

- **Demand side storage** means shifting periods of energy use to when there is sufficient supply in the energy system. This can be achieved through smart energy systems, or by introducing economic incentives for consumers to move their own demand time. Such practices may become more necessary as more of our energy consumption becomes electrified, e.g. with heat pumps and electric vehicles. For more details, refer to the Energy Demand Reduction Landscape Document.

3.2 Medium term

- **Pumped hydro** works by moving water from a lower reservoir to a higher one, using the gravitational potential of the water as storage. It is quite efficient and is a well understood and commercially viable technology. However, it requires a very large upfront capital investment due to the extensive infrastructure needed, typically two dams with very large turbines. It is also geographically restricted to locations with appropriate topologies and watersheds to allow for such infrastructure.

- **Thermal storage** works by storing heat in a medium (water, oil, rocks, etc.) and then either drawing on that heat directly or converting it into electricity. Water tanks in homes are a form of thermal storage, and so it's a developed concept that is well understood. However, there are many more nascent technologies looking at storing heat in rocks, blocks of graphite, aquifers, and phase change materials, all of which are becoming more commercially viable. Some of these technologies also have the potential to provide inter-seasonal energy storage, which could be impactful given the predictable seasonal variability in heat demand.

- **Compressed air energy storage** works by using energy to pressurise air and store it in a chamber before releasing it through a generating turbine. This technology has been receiving increasing attention and there are various versions of this solution type, some using large metal cylinders and others using underground caverns. As such, some technologies can be quite geographically dependent. Similar to compressed air storage, liquid air energy storage cools air to its liquid form, stores it, and then uses it much like compressed air storage to generate electricity again.

- **Flow batteries** are a specific type of battery technology which operate using liquid electrolytes stored in tanks. This makes them larger and less energy dense than their lithium-ion or solid-state counterparts, but it also means they can use much less rare/expensive materials. Some also have the capacity to be 'hibernated' and used as much longer-term storage, this means they potentially could serve many energy storage needs. Many of these nascent technologies have yet to become economically viable, however.

3.3 Long-term and seasonal

- **Hydrogen** and hydrogen derived products such as ammonia can be useful long-term stores of energy as, when stored correctly, they do not degrade and could be easily scalable forms of storage. Hydrogen could be produced using excess renewable energy through electrolysis and could then be stored in salt caverns. Some have concerns over the economic viability and overall efficiency of this solution, and it has yet to be proven at scale, but many see it as a key piece of our future energy storage.

- **Biomass generation** currently makes up around 11% of the UK's annual energy production where biomass plant run as part of 'base load' power production. Biomass is much like fossil fuels, however, in that it can be stored in stockpiles and used quite flexibly. Stacks of wood for use in wood burning stoves is a simple but illustrative example of this, and similar concepts apply for most forms of biomass. Biomass has the additional advantage of being carbon negative when combined with carbon capture and storage (BECCS plant), but only when the fuel is sustainably sourced. However, many argue that scarce biomass feedstocks would be more useful in manufacturing and chemical applications than as energy storage.

- **Fossil fuels** can also be combined with carbon capture and storage to reduce their greenhouse gas impact. Theoretically, this could mean you keep all the storage and flexibility benefits of fossil fuels without the same environmental impact. However, this technology struggles with economic viability, and many express concerns about issues of greenwashing.

4. Research and Innovation

Research and innovation on energy storage spans numerous disciplines. Some illustrative examples are highlighted below, broken down by the same duration categories as above.

4.1 Short term

4.1.1 Demand side solutions

- Demand flexibility service evaluation, exploring how smart meter data can be turned into action for consumers.

- Flexible heating and cooling, looking at the effects of intermittent supply.

- Some modelling of aggregate demand side flexibility (eg combining heat and transport).

- Digital twins of industrial plant for industry.

Note: there is a more detailed view of wider demand related research in the Energy Demand Reduction Landscape Document.

4.1.2 Chemical Batteries

- Exploring ways of more efficiently producing lithium-ion batteries, including recycling.

- Looking at batteries using materials other than lithium-ion, solid-state in particular. Similarly, some research is investigating different materials for electrodes.
- Vehicle to grid storage for cost effective localised storage.
- Ways of reducing weight and building fire suppression into the designs are also being explored.

4.1.3 Supercapacitors and flywheels

- New supercapacitor designs and materials.

- Some research looking at the potential to combine flywheels with lithium-ion batteries to extend the lifespan of the batteries.

4.2 Medium Term

4.2.1 Thermal Storage

- Research on phase change materials to enhance their thermal performance, stability, and applicability.

- Exploring the technical, societal, and economic barriers to the roll out of aquifer thermal energy storage. This includes mine-water energy storage.

- How aquifer thermal storage can be used to save waste heat, and connect to district heating networks.

4.2.2 Compressed and liquid air storage

- Both largely concerned with how we can reduce heat wasted in the process of air compression and cooling.

4.3 Long Term

4.3.1 Flow batteries

- New materials and designs for improved efficiency and density, etc.

4.3.2 Hydrogen

- Wide range of research into improving the efficiency, flexibility and cost effectiveness of electrolysis plant to accommodate a potentially inconsistent supply of energy.

- Research into storage, and the use of depleted gas wells and salt caverns.

- Research into distribution networks as well as the economically viable use cases (with some research questioning its economic viability altogether).
- Investigations into the safety implications of hydrogen, including embrittlement leak protection.
- Studies examining hydrogen's greenhouse gas warming potential.

4.3.3 Biomass

- Some research centres are using AI to understand how bioenergy might be used in energy systems, including its capacity for energy storage.

4.3.4 Fossil fuels with CCUS

- The development of better performing carbon capture solutions, surfaces and materials.

- Some work on the storage part of CO2, testing the viability of different sites.

- Much of the discourse is still focussed on technical issues. Research suggests that as CCUS matures there will need to be more dialogue at a systems, social and economic level.

4.4 Economic Research and whole systems

While there is research into the economic implications of specific technologies, the economics of energy storage more broadly are also being investigated. As more energy storage is deployed, this will have an economic impact not only on storage itself, but on energy production too. Some research seeks to model these relationships and predict these impacts. Other studies are examining the impacts of economic signals on different solutions, especially the impacts of changing energy prices.

Similarly, while much research seeks to optimize the performance of specific solutions, whole systems research seeks to understand how a blend of different solutions could be optimised. The consensus amongst researchers is that no matter which solutions are championed, a blended, whole systems approach will be essential.

5. References

- Climate Change Committee. (2023). *Delivering a reliable decarbonised power system.* Retrieved from https://www.theccc.org.uk/wp-content/uploads/2023/03/Delivering-a-reliable-decarbonised-power-system.pdf
- National Grid Electricity System Operator (NESO). (2024). *Future Energy Scenarios: ESO Pathways to Net Zero.*
- The Royal Society. (2023). *Large-scale electricity storage.* Retrieved from https://royalsociety.org/-/media/policy/projects/large-scale-electricity-storage/large-scale-electricity-storage-report.pdf
- Department for Energy Security and Net Zero. (2021). *Net Zero Strategy: Build Back Greener.*
- Department for Energy Security and Net Zero. (2024). *Strategic Spatial Energy Plan: Commission to the National Energy System Operator.*
- Department for Energy Security and Net Zero. (2024). *New scheme to attract investment in renewable energy storage.* Retrieved from https://www.gov.uk/government/news/new-scheme-to-attract-investment-in-renewable-energy-storage
- Scottish Government. (2017). *Scottish Energy Strategy: The Future of Energy in Scotland*.
- Welsh Government. (2025). *Hydrogen policy*.
- Northern Ireland Executive, Department for the Economy. (2021). *Energy Strategy – The Path to Net Zero Energy.*
- European Commission. (2023). *Energy Storage – Underpinning a decarbonised and secure EU energy system.*