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Batteries in Stationary Energy Storage Applications

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Battery energy storage is becoming increasingly important to the functioning of a stable electricity grid. As of 2023, the UK had installed 4.7 GW / 5.8 GWh of battery energy storage systems,[1] with significant additional capacity in the pipeline. Lithium-ion batteries are the technology of choice for short duration energy storage. However, they are not as cost-effective for long duration storage, providing an opportunity for other battery technologies, such as redox-flow or sodium-ion, to be deployed alongside clean technologies such as hydrogen storage.

Introduction

Since 2019, the UK Government has committed to a legally binding net zero target of 100% reduction in greenhouse gas emissions by 2050. The UK power sector is aiming to reach zero carbon electricity by 2030 (subject to security of supply).[2] To achieve this, a large amount of renewable energy generation (i.e., wind and solar) will need to be deployed to replace fossil-fuel-based generation. The UK Government has set targets of having 140 GW of renewables in operation by 2030.[3] Although the likelihood of reaching these deployment targets has been put into question,[4] the government remains committed to the roll out of renewable energy and achieving zero carbon electricity by 2030, as shown by the success of the recent AR6 auction,[5] and the launch of Great British Energy, a publicly-owned investment body dedicated to developing clean power projects.[6]

The transition to net zero will require changes across the whole UK economy with particular challenges in the power sector. Balancing electricity supply and demand will be challenging due to the intermittent nature of renewable energy, while the electrification of heat and transport will substantially increase total electricity demand and peak demand. To support this transition, a large amount of flexibility on the electricity grid will be required. The UK has previously relied on fossil fuels to provide flexible power generation, but this option is planned to be phased out under net-zero. Given the phase-out of fossil fuels, three main solutions can provide the necessary flexibility:

- Increased electricity network interconnection;
- Demand side response;
- Energy storage.[7]

Interconnectors allow the UK to trade excess electricity with neighbouring countries, while demand side response includes measures to align electricity demand with supply by incentivising consumers to use electricity during certain periods. While both these solutions will be required in the transition to a net-zero electricity grid, they are unable to provide the required flexibility alone.[7] Energy storage can help bridge that gap and will become a crucial part of the future energy system. There are five main categories of energy storage technologies: chemical, mechanical, thermal, electrical, and electrochemical.

[1] ESO - Future Energy Scenarios 2024.
[2] Department for Energy Security and Net Zero - Energy Secretary Ed Miliband sets out his priorities for the department.
[3] Labour - Make Britain A Clean Energy Superpower (March 2024).
[4] The Guardian - Solar and wind 'will miss 2030 clean energy target without £48bn funding' (July 2024).
[5] Current News - Awarded capacity triples, offshore wind returns: CfD AR6 results in detail (September 2024).
[6] Department for Energy Security and Net Zero - Great British Energy founding statement (July 2024).
[7] Oliver Schmidt, Iain Staffell – Monetizing Energy Storage (August 2023).

This Insight will focus on the role that energy storage, particularly electrochemical energy storage, or batteries, can play in delivering flexibility for a decarbonised electricity system. First, the role of energy storage in a net-zero energy system will be outlined. Next, the market for energy storage globally and in the UK will be presented, with a particular focus on batteries. Key characteristics of different battery technologies are then reported, providing insight into which battery technologies are best suited to which applications. Finally, the energy storage policy landscape will be discussed.

A glossary of terms is provided as an appendix at the end of this Insight.

UK Grid Flexibility and the Role of Energy Storage

Transition to net zero and renewable energy

Historically, the UK has relied on thermal power plants burning fossil fuels to generate electricity. Certain types of thermal power plants, such as gas-fired power plants, operate with a high degree of flexibility to meet changes in electricity demand. These plants use large turbines to generate electricity, delivering inherent stability to the grid by providing inertia (i.e., the ability to resist changes in frequency). In addition, existing thermal power plants are distributed across the country, often near areas of demand or close to historical supplies of coal.

In a net-zero energy system, renewable energy resources such as wind and solar will be critical for clean electricity generation (Figure 1). However, renewable energy generation is variable and cannot always be dispatched to meet electricity demand, while renewable energy resources do not provide inherent stability to the grid. In addition, the location of wind and solar generation is selected based on the availability of renewable resources, typically located far from demand centres, with significant components being offshore. This can lead to constraints on the transmission network.

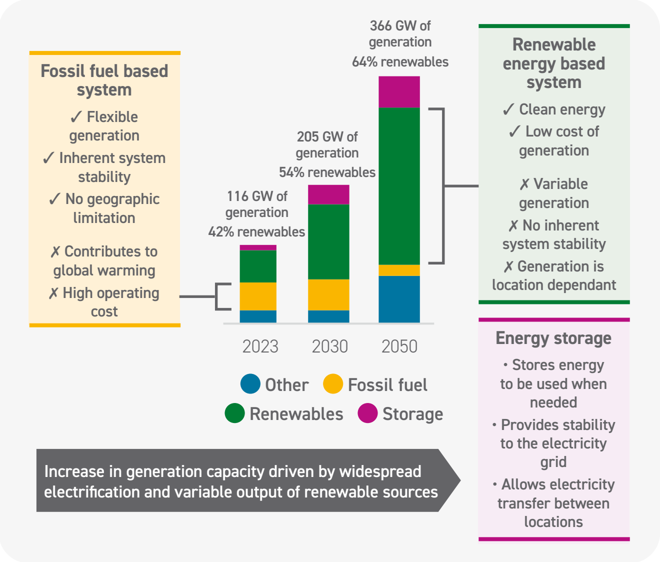
The role of energy storage

Energy storage is being widely deployed to address the challenges of a renewable energy-based system by providing additional flexibility.[8] Energy storage systems will be deployed across three main applications:

- Energy supply: Storing excess renewable energy in times of over-generation to be supplied at times of under-generation or peak demand.
- Grid stability: Providing ancillary services to help maintain stability.
- Local flexibility: Managing transmission and distribution network constraints.

Energy storage can be installed as front-of-the-meter (FTM), behind-the-meter (BTM) or off-grid systems. FTM applications refers to storage systems connected to the transmission and distribution networks or co-located with renewable electricity generation. BTM applications refers to storage systems installed behind the utility meter of commercial, industrial or residential consumers,[9] sometimes referred to as distributed energy.[10] In these cases, the system is owned and operated by the consumer for their own benefit, typically to provide resilience or reduce energy bills by utilising on-site renewable generation. Off-grid refers to systems or locations that are not connected to the main electricity grid, relying on autonomous power generation and management.[11] Examples include remote communities, rural industries, or isolated systems (e.g., telecoms).

Figure 1: UK installed electricity generation and potential UK electricity generation stack in 2050



Source: ESO - Future Energy Scenarios 2024. Based on the Future Energy Scenarios "Holistic Transition" scenario. Numerical data for figures.

(i) Energy supply applications for energy storage involve providing electricity to the grid to help meet demand. Such applications are typically broken down into short duration (less than 6 hours), long duration (between 6 and 160 hours), and seasonal storage applications (+160 hours) (Table 1).[12] It should be noted that the duration of an energy storage system represents over how long the energy could be provided to the electricity grid, not how long the energy will be stored for.

In short duration energy storage (SDES), energy storage systems are charged during periods of excess renewable energy generation (and therefore low electricity prices), or during periods of low demand. This energy is then supplied back to the electricity grid when demand exceeds supply.[13] Such applications can be referred to as energy arbitrage,

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[8] 'Energy storage' is a broad concept encompassing various methods of storing energy in different forms, including 'electricity storage' where electricity from the grid or renewables is stored for later use. In this insight, 'energy storage' specifically refers to 'electricity storage'.

[9] BNEF - Scaling the Residential Energy Storage Market (November 2023).

[10] Current News – Why distributed energy matters now more than ever (September 2024).

[11] U.S. Department of Energy - Off-Grid or Stand-Alone Renewable Energy Systems.

[12] Energy supply applications are defined by discharge duration, however these are not set definitions. In this report, a combination of definitions were used. In the UK, the Department for Energy Security and Net Zero have defined LDES as having a discharge duration of greater than 6 hours. In the US, the Department of Energy defined seasonal storage as having a discharge duration of greater than 160 hours. Different industry stakeholders may quote different values.

[13] Power Sonic - The Power of Peak Shaving.

Table 1: Basic definition and requirements for short, long and seasonal energy storage

Parameter	Short duration energy storage	Long duration energy storage	Seasonal energy storage
Discharge duration	0 to 6 hours	6 to 160 hours	+160 hours
Cycling requirements	Daily cycling	~ 10 to 200 cycles per year	Less than 5 cycles per year
Energy and power requirements	Low volume of energy storage, high power delivery	Medium volume of energy storage, medium power delivery	High volume of energy storage, low power delivery

Source: Faraday Institution research.

helping optimise electricity use. SDES is often co-located with renewable energy sources, typically solar rather than wind as the short discharge duration is well suited to the daily cycle of solar energy. SDES require daily cycling of the storage system, in some cases up to twice per day to ensure economic viability. Batteries are currently the dominant technology for these applications.

A large amount of long duration energy storage (LDES) will need to be deployed to help cope with lengthy periods of low wind or solar supply known as dunkelflaute. An analysis of historical weather data from the North and Baltic Seas found that such events occur most frequently from November to January, with 50 to 100 hours of dunkelflaute occurring in each of these months.[14] Although LDES applications will require fewer number of cycles than SDES, ranging from a few cycles per week to a few cycles per month, the amount of energy stored will be significantly larger than in SDES. A wide range of technologies are being pursued for LDES including mechanical-based systems (pumped hydro, compressed air and liquid air) and battery technologies such as redox-flow and metal-air.

Seasonal storage is expected to be used to correct for seasonal imbalances in demand between winter and summer. Chemical energy storage solutions such as hydrogen are mainly being considered for seasonal storage.[15] Although the technology is still under development, excess electricity from renewables could be used to produce hydrogen through electrolysis. This hydrogen can then be stored and used to produce electricity when required, either using a fuel cell or used as a conventional fuel in thermal power plants.[16]

In theory, seasonal storage systems and LDES could be used to respond to short duration energy imbalances. However, in practice this is difficult to achieve with existing technologies under development, as longer discharge duration technologies tend to have slower response times and lower efficiencies.

The combination of SDES, LDES, and seasonal storage is essential for creating an efficient, flexible, and cost-effective electricity grid that can respond to short-term fluctuations and seasonal energy shortages.

(ii) Ancillary services refer to a broad array of services that keep the electricity grid within its operational frequency requirements and ensure system stability (Table 2).[17] These

Table 2: A brief description of ancillary services that can be provided by energy storage in the UK

Application	Description	Typical discharge durations	Equivalent annual cycles
Frequency response	Ensuring that frequency levels are maintained throughout the grid.	0.5 hours	Up to 100
Reserve services	Providing a correction to imbalances between supply and demand.	0.5 to 2 hrs	Up to 300
Restoration services	Ensuring the power grid can be re-established following an outage.	1 hr	Less than 10
Voltage support	Ensuring that voltage levels are maintained throughout the grid.	n/a	Up to 800

Source: Rho Motion Energy Storage Market Assessment 2023. Values to be taken as estimates. Equivalent annual cycles quoted as certain applications will not use full charge/discharge cycles of the cells.

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[14] Bowen Li et. al., A Brief Climatology of Dunkelflaute Events over and Surrounding the North and Baltic Sea Areas, Energies (2021).
[15] The Royal Society - Large-scale electricity storage (September 2023).
[16] Hydrogen Europe - Hydrogen Horizons: Empowering the Power System with long-term seasonal storage.
[17] Aurora - Long Duration Energy Storage Report (April 2023, page 20).

include frequency response and reserve services, which ensure that the grid operates within the correct frequency range at all times.[18] In the event of a partial or total electricity grid shutdown, restoration services are used to restore power to the grid. Finally, voltage support services help ensures operational stability. A more detailed description of these services is provided in the glossary.

(iii) Local flexibility aims to alleviate and manage grid constraints on the transmission and distribution networks. These services are required when connections between sections on the grid are operating at maximum capacity and are unable to transmit enough power to meet demand. Operating the transmission and distribution networks near maximum capacity can result in network failures and power outages, as well as requiring renewable energy production to be curtailed (i.e., asked to stop generating) due to constraints on the transmission and distribution networks preventing the transport of all the generated electricity. Historically, grid constraints have been managed by building additional transmission or distribution capacity, or by paying power plants or wind farms to reduce supply. Energy storage provides an alternative to these solutions by shifting electricity usage from peak to off-peak periods. The demand for constraint management is location dependent, such as along the B6 boundary in the UK,[19] which separates large wind farms in the north of the UK from demand centres in the south.[20]

The role of battery energy storage systems

A battery is a device that converts chemical energy to electrical energy through an electrochemical reaction. For the types of batteries used in grid applications, this reaction is reversible, allowing the battery to store energy for later use. Batteries are installed as battery energy storage systems (BESS), where individual battery cells are connected together to create a large energy storage device (Box 1). The size of a BESS is defined by its power capacity and its stored energy capacity (Box 2).

It is worth highlighting that BESS are not typically used for a single application, especially in FTM installations. To increase their economic viability, multiple services can be provided from the same asset, known as revenue stacking. This approach enables flexible assets such as BESS to collect revenues from different products, services and markets, increasing overall profitability.[21]

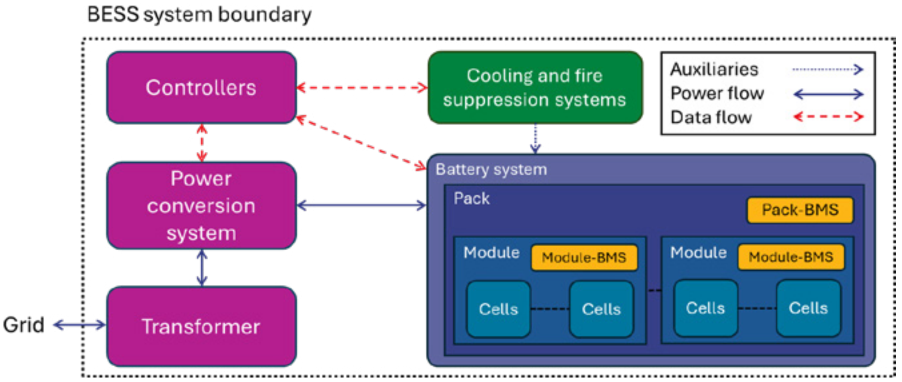
The economic importance of different applications for a particular BESS will largely depend on the discharge duration of the system.[22] BESS primarily aimed at providing

Box 1: Overview of a battery energy storage system

A battery energy storage system (BESS) is a device that allows electricity from the grid or renewable energy sources to be stored for later use. BESS can be connected to the electricity grid or directly to homes and businesses, and consist of the following components:[23]

- **Battery system:** The core of the BESS where energy is stored and distributed. Individual battery cells are connected into modules, which are then connected into packs. Multiple packs can be combined to reach the required system size.
- **Battery management system (BMS):** The "brain" of the BESS, responsible for ensuring that critical parameters of the battery (e.g., voltage, temperature) are operating within pre-determined ranges.
- **Power conversion system (PCS):** Since batteries operate using DC, while the electricity grid runs on AC, a PCS is required for the battery to convert between the two. This allows the battery to charge from and discharge to the grid.
- **Controllers:** These monitor, control, protect, and communicate with the key systems of the BESS. They ensure optimal operation and regulate the flow of electricity to and from the grid.
- **Cooling systems:** Certain battery technologies require temperature control to ensure efficient and safe operation of the battery.
- **Fire suppression system:** Depending on the battery technology used, a fire suppression system may be deployed to contain the spread of the fire to the rest of the BESS in the event of a thermal runaway.

Figure 2: Schematic of a typical BESS layout



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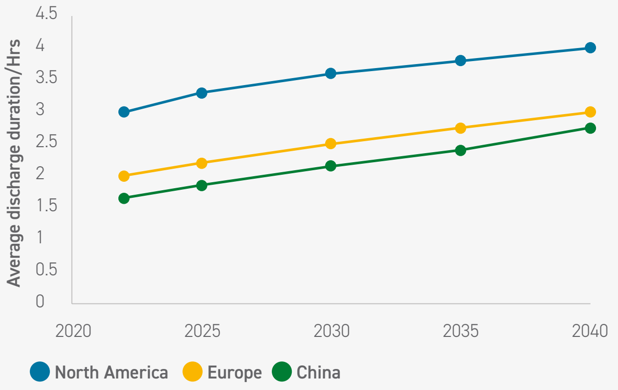
[18] ESO - Introduction to energy system flexibility.
[19] The B6 boundary separates the transmission network roughly along the border between Scotland and England. For more information, visit ESO - Scottish boundaries.
[20] Current News - National Grid ESO and Piclo to develop Local Constraint Market (December 2022).
[21] ESO – Markets Roadmap (March 2024).
[22] Modo Energy - Untangling the impact of BESS duration (December 2021).
[23] Power Sonic - Battery Energy Storage System Components.

ancillary services will typically require discharge durations of around one hour, while longer discharge durations are better suited to energy supply applications. There is a global trend in recent years of BESS being deployed with increasingly longer discharge durations, which is expected to continue beyond 2030 (Figure 3). This trend is driven by falling battery costs and the emergence of new revenue opportunities. However, most BESS installed to date fall in the bracket of SDES systems (less than 6 hours discharge duration).

Figure 3: Projected average BESS discharge duration across North America, China, and Europe



The average discharge duration of BESS will increase towards 2040, driven by falling battery costs and the emergence of new revenue opportunities.

Source: Rho Motion Energy Storage Market Assessment 2023.

Box 2: Power capacity versus stored energy

A BESS is defined by its nominal power capacity and nominal stored energy capacity, where:

- **The nominal power capacity (MW)** is the amount of power that the system can provide or absorb. This will be the power limit imposed by the inverter rating and system design.
- **The nominal stored energy capacity (MWh)** is the amount of energy that the system can supply or store, based on system design.

Power and energy are closely related but distinct concepts within energy systems:

- **Power capacity** refers to the maximum amount of power that a system can deliver or transfer at any given moment, measured in units of watts. It represents the system's potential for energy production.
- **Energy capacity** refers to the actual production of energy over a period, measured in units of watt-hours. It is a measure of how much power is being generated over time.

The discharge duration of the system can be inferred from these parameters as the amount of time that a system takes to discharge its nominal stored energy capacity at its nominal power capacity. In practical terms, a 10 MWh energy storage system can deliver 10 MW of power for 1 hour, or 5 MW for 2 hours. This concept can also be applied to renewable energy generator: a 1 MW wind turbine turning at full power for 1 hour produces 1 MWh of electricity, and 24 MWh of electricity if it continues at this rate for a whole day.

In short, power capacity defines a system's capability, while energy capacity reflects its performance in converting resources into usable energy. For an electricity grid to function, there must be sufficient power capacity (to meet peak demand) and energy capacity (to meet ongoing requirements). This is why both values are typically provided in the context of energy storage.

Global and UK Energy Storage Outlook

Global market outlook

The world has a significant amount of existing energy storage, with 272 GW of capacity installed globally as of 2023 (Figure 4). Most of the installed energy storage is pumped hydro and batteries, accounting for 181 GW and 87 GW of total capacity, respectively. However, existing energy storage is insufficient to support a transition to a renewable energy-based system.

By 2030, the global demand for energy storage could reach up to 1,500 GW.[25] This could include over 1,200 GW of battery energy storage. Assuming an average discharge duration of 2.7 hours for BESS in 2030 (based on data from Figure 3), this equates to over 3,200 GWh of batteries installed in energy storage applications globally by 2030. Around 85% of the battery capacity installed globally in 2030 is projected to come from lithium-ion batteries.[26] For comparison, the average discharge duration of a pumped hydro system is around 10 hours, meaning pumped hydro storage will provide around 2,900 GWh of energy storage in 2030.

Between 2010 and 2022, renewables have increased their contribution to electricity generation globally from 4,200 TWh to 8,600 TWh and could reach 68,400 TWh by 2050 to keep in line with net-zero targets.[24] To enable this transition, a target of deploying 1,500 GW of energy storage by 2030 is set to be proposed at COP29 in 2024.[25]

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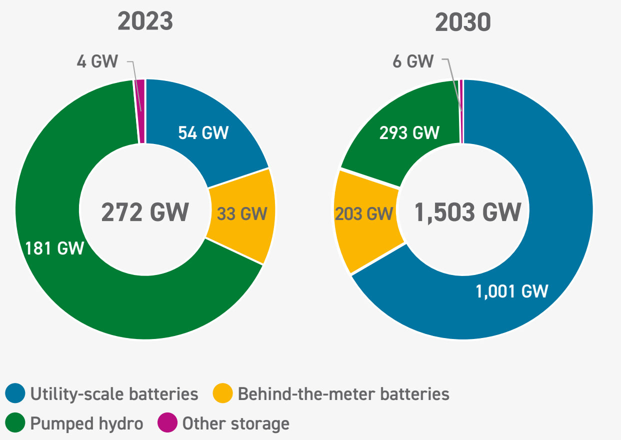
[24] International Energy Agency – World Energy Outlook 2023.
[25] ETN News - COP29 summit to propose 1,500 GW energy storage target by 2030 (September 2024).
[26] BNEF (2023). Energy Storage Market Outlook 2H 2023.

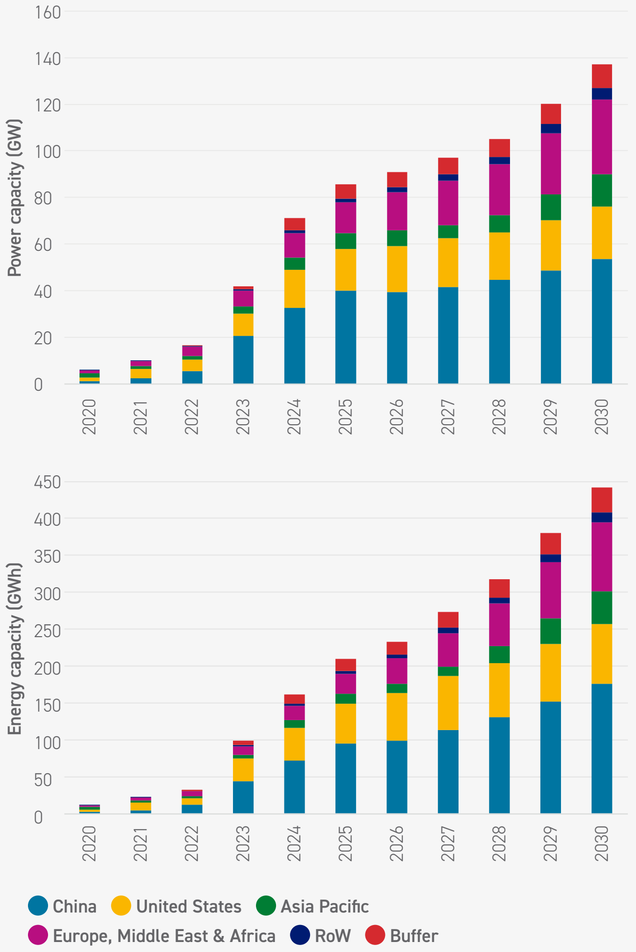
Figure 4: Proposed target for global power capacity of energy storage by technology in 2023 and 2030



Between 2023 and 2030, batteries will overtake pumped hydro as the most widely deployed storage technology.

Source: International Energy Agency. The values for 2030 are from the IEA Net Zero Emissions scenario. Numerical data for figures.

Figure 5: Global annual energy storage installations by power (top) and energy (bottom) since 2020



China is currently leading the deployment of energy storage globally, followed by the US and Europe, Middle East and Africa.

Source: Source: BNEF, Faraday Institution research. The buffer addresses forecast uncertainties.

The demand for energy storage is expected to grow steadily towards 2030 (Figure 5). This demand is driven by the integration of energy storage with sources of renewable energy, decarbonisation goals and supportive government policy. By 2030, over 130 GW of storage capacity will be being installed annually. In 2030 China will be the largest market for energy storage, accounting for a 41% share of the global total, followed by the US with 24%, and 17% in Europe, Middle East and Africa. This growth is expected to continue towards 2050 as energy storage becomes increasingly important to providing system flexibility.[27]

UK market outlook

As of 2023, the UK has 7.4 GW / 33.8 GWh of energy storage capacity installed. Batteries and pumped hydro account for

Box 3: Examples of BESS installations in the UK

Pillswood, East Yorkshire: A 98 MW / 196 MWh BESS that is currently one of the largest in operation in the UK, developed by Harmony Energy. It is connected to the same substation as the Dogger Bank wind farm and provides mainly SDES energy supply applications.[28]

Energy Superhub Oxford, Oxfordshire: A hybrid BESS system combining a 50 MW / 50 MWh lithium-ion BESS and a 1.25 MW / 5 MWh vanadium redox-flow battery BESS in the same installation. This BESS was developed by EDF Renewables and Pivot Power and was the first in the UK to connect to the high-voltage transmission network.[29]

Neilston Greener Grid Park, Scotland: A 50 MW BESS that was delivered as part of Phase 2 of the ESO Stability Pathfinder programme and delivered by Fluence. The BESS will seek new ways of increasing transmission network stability by providing local flexibility services to the grid.[30]

Further examples of BESS projects in the UK have been compiled by Bessanalytics.[31]

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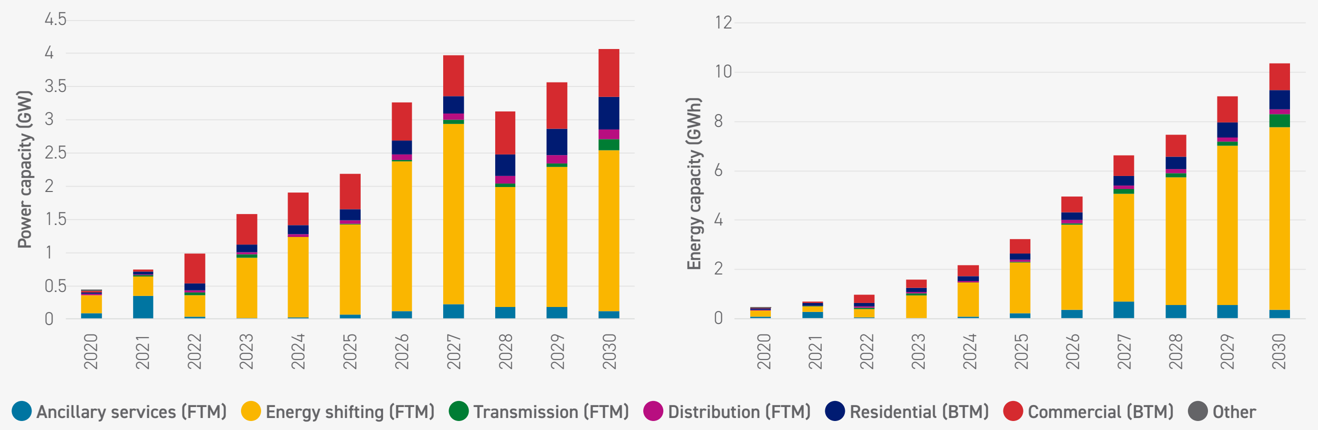
[27] Latitude Media - Battery storage capacity needs to jump 50 times by 2050 (May 2024).
[28] Energy Storage News - How we delivered the 98MW/196MWh Pillswood BESS Project (August 2023).
[29] Energy Storage News - 'Encouraging numbers' from world's largest lithium-vanadium hybrid BESS (August 2023).
[30] Fluence - Statkraft and Fluence's latest project will help lower overall energy cost and increase energy security (August 2023).
[31] Bessanalytics - Projects.

Figure 6: UK annual energy storage installations by power (left) and energy (right) since 2020



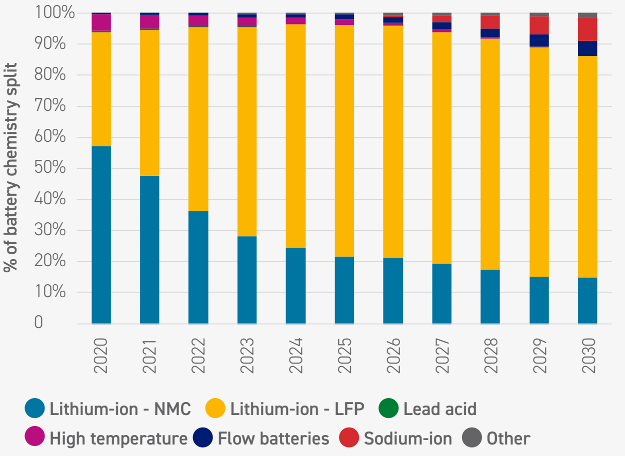
BESS in the UK are primarily used for energy shifting applications.

Source: BNEF, Faraday Institution research.

4.7 GW / 5.8 GWh and 2.7 GW / 28 GWh respectively. While pumped hydro capacity is concentrated in more mountainous areas, BESS have been installed across the UK (Box 3). By 2030, a further 22 GW / 44 GWh of stored energy capacity could be installed in the UK (Figure 6). The majority of these new installations will be from lithium-ion BESS in SDES installations.[7]

FTM applications will dominate overall installations, accounting for around 80% of storage systems by 2030 (Figure 6). However, demand for BTM energy storage could increase further as the electrification of transport and residential heat and hot water continues. Applications in energy supply and residential and commercial sectors will all see substantial growth. Energy shifting will be the most important application of energy storage, accounting for 67% of UK capacity by 2030. Other applications will represent a smaller but meaningful segment of the market, with commercial and industrial applications accounting for 13%, residential applications at 7%, and ancillary services at 8%. Note that these market projections do not include vehicle-to-grid technology, which is discussed later in this Insight. Lithium-ion batteries, which include both lithium nickel manganese cobalt oxide (NMC) and lithium iron phosphate (LFP) chemistries, are anticipated to be the technology of choice for SDES and BTM BESS installations. However, LFP, which has a lower upfront cost than NMC, is becoming the technology of choice for BESS applications (Figure 7). This is a global trend, with BNEF predicting an energy storage market share of 1% for NMC type batteries globally by 2030.[32] New technologies such as sodium-ion are expected to gain significant market shares in the future, using cheaper raw materials to further reduce up-front costs.

Figure 7: Projected split in battery technologies used in stationary storage applications in the UK



LFP will become the most widely deployed battery chemistry in BESS applications in the UK by 2030.

Source: BNEF, Rho Motion Energy Storage Market Assessment 2023, Faraday Institution research.

Long duration energy storage market outlook

While the demand for energy storage is growing globally, the vast majority of new capacity is for SDES. The development of LDES and seasonal storage systems, which are crucial to ensuring security of supply in a renewable energy-based

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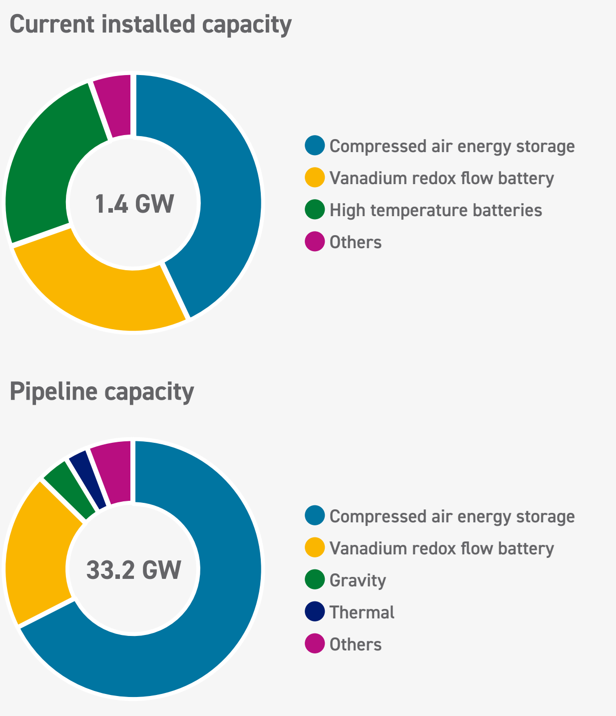
[32] BNEF - Global Energy Storage Market Records Biggest Jump Yet (April 2024).

system, is slow. Excluding lithium-ion and pumped hydro energy storage, the global capacity for LDES installations is 1.4 GW, with a further 33.2 GW of projects currently planned (Figure 8). As with SDES, the demand for LDES energy storage is being led by China. Although demand is growing for LDES storage systems, many challenges remain, including establishing market and regulatory frameworks as well as demonstrating the performance capabilities of LDES technologies.

Figure 8: Current and planned LDES capacity globally



Existing and future installations of LDES capacity is currently dominated by redox-flow batteries and compressed air energy storage globally.

Source: BNEF. Note that these figures exclude pumped hydro and lithium-ion batteries.

There are similar challenges in the UK. The UK is considered a world leader in the deployment of BESS with a growing industry across a number of market segments, from developers to investors to operators. As of April 2024, the UK has over 90 GW of battery storage projects in the pipeline.[33] This pipeline represents ample capability to deliver the projected SDES system flexibility for 2030 and beyond.[1] However, development of LDES and seasonal storage capability in the UK is lacking.

The UK currently has no significant LDES or seasonal storage capacity aside from pumped hydro installations. While efforts to increase this capacity are under way, including hydrogen storage[34] and liquid air energy storage,[35] these still fall short of the volume the UK requires. The ESO's Future Energy Scenarios 2024, which model possible pathways to net zero, estimate that up to 5.9 GW / 80.9 GWh of compressed-air, liquid-air and pumped hydro storage would be required by 2030. By 2050, this increases to 15.3 GW / 203.9 GWh. Up to 44.5 GW of electricity generation capacity could be required from hydrogen by 2050, a seasonal storage candidate technology.

To meet LDES and seasonal storage capacity targets, an array of storage technologies will be required. Although mechanical and chemical based storage technologies tend to be focused on for these applications, batteries could also play a role in this space.

While lithium-ion batteries have been established as the technology of choice for SDES applications, 6-hour lithium-ion BESS are under development in the UK.[36] Other battery technologies such as flow batteries or metal-air batteries will play a role in discharge durations of up to 100 hours. For example, US-based Form Energy recently announced that it had received funding as part of a major project to upgrade New England's electricity grid in the US. The company will install a 100-hour, 85 MW / 8,500 MWh iron-air battery at a former paper mill site.[37]

Battery Technologies for Energy Storage

Performance and operational parameters of battery technologies

The key performance parameters for battery technologies for BESS are safety, cost and cycle life. These three parameters are crucial when assessing the viability of a particular battery technology. Other parameters described in Table 3 are less critical overall but can also indirectly influence the three key parameters.

Safety is a priority for BESS as they are often deployed close to communities or within homes. Lithium-ion batteries are already safe and accidents are very rare. However, they can occur if the battery is damaged or improperly managed.[38] The main causes of lithium-ion battery damage are:

- Mechanical stress (e.g., manufacturing defects or external damage);
- Thermal stress (e.g., overheating);
- Electrical failure (e.g., overcharging due to BMS failure).

Safety concerns are prominent due to several high-profile fire incidents in recent years. However, lessons learnt have led to improvements in the manufacturing of battery cells and modules, better monitoring of BESS during operation, and more robust sensing and monitoring of BESS. The Faraday

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[33] Renewable UK - Pipeline of UK energy storage projects grow by two-thirds over last 12 months (December 2023).
[34] INEOS - Keuper Gas Storage Project.
[35] Highview Power - UK Infrastructure Bank, Centrica & Partners Invest £300M in Highview Power Clean Energy Storage Programme to Boost UK's Energy Security (June 2024).
[36] Energy Storage News - Statera wins planning consent for 6-hour, 1.7GWh battery storage project (March 2024).
[37] Energy storage news - Funding for US grid upgrades includes US$147 million for 8.5GWh 'multi-day' battery storage (August 2024).
[38] House of Commons Library – Battery energy storage systems (April 2024).

Table 3: Performance parameters to consider for battery technologies in BESS applications

Parameter	Unit	Priority	Description
Safety	-	High	Relates to the risk of system malfunctions during use. Will be highly technology dependent.
Specific energy cost	£/kWh	High	The cost of components that enable the storage of energy (e.g., battery cells).
Specific power cost	£/kW	High	The cost of components that enable the input or output of energy from a storage system (e.g., power electronics).
Cycle life	-	High	Number of charge-discharge cycles the system can undergo before end of life. This will be dependent on the system application.
Roundtrip efficiency	%	Moderate	How much energy is lost during a full charge-discharge cycle. Will be variable, based on the battery technology.
Response time	s	Moderate	The amount of time it takes to ramp to full power delivery from idle. Importance will vary based on application.
Self-discharge rate	%	Moderate	The rate at which the battery will lose charge when left idle.
Operating temperature range	°C	Moderate	The temperature window within which the technology must be operated. Influences the system efficiency and safety.
Energy density	Wh/kg Wh/L	Low - moderate	Relates to the amount of energy stored in a battery divided by the battery mass or volume. Will influence the size of the system footprint.
Power density	W/kg W/L	Low - moderate	Relates to the amount of power the battery can deliver divided by the battery mass or volume.
End-of-life cost	$	Low	The cost of system disposal. Legislation exists stating minimum recovery requirements at the end of its useful life.
Typical discharge duration	Hours	Low	The range of discharge duration that best fits the technology in question. Will be dependent on all other technology parameters.

Source: Faraday Institution, Rho Motion Market Assessment.

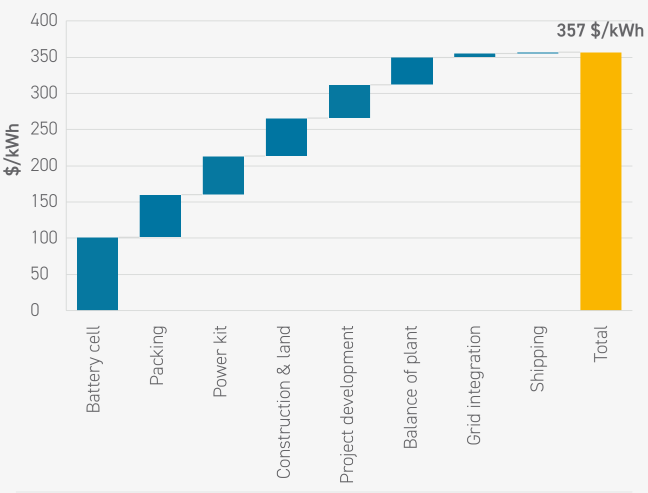
Institution's SafeBatt project is focused on understanding the science of battery safety (Box 4).

Cost is a key consideration for BESS, usually segmented into specific power cost (£/kW) and specific energy cost (£/kWh). This breakdown reflects the inherent performance of a particular technology, allowing for a more nuanced understanding of the capabilities and limitations of different battery types. The cost of a storage technology can also be measured over its lifetime using the levelised cost of storage, which considers both the cost and performance by including key parameters as well as accounting for construction, operational and end-of-life costs.[7] Figure 9 shows the typical cost breakdown for a lithium-ion BESS system demonstrating the contributions of each component.

Cycle life is a high priority parameter as it defines the overall lifetime of a BESS system. Due to the high costs involved in deploying energy storage technologies, it is important that BESS systems have long lifetimes to spread the cost over many years.

While safety, cost and cycle life are critical parameters for BESS, they are influenced by other battery parameters during operation. These relationships need to be considered during system design and when evaluating which technology is best suited to a particular application. For example, response time is critical for ancillary services, as power needs to be delivered at sub-second intervals, while self-discharge rate will be important for energy supply applications.

Figure 9: Breakdown of system level costs for a 100 MW / 200 MWh lithium-ion BESS



The battery cells are currently the most expensive system component for a lithium-ion BESS.

Source: Rystad Energy – Energy Transition Report: Battery Market Outlook (March 2023). Costs have since dropped further in 2024. Numerical data for figures.

Current generation BESS technologies

Although recent deployments of BESS have been dominated by lithium-ion batteries, legacy battery technologies such as lead-acid, flow batteries and high-temperature batteries continue to be used in energy storage.

Lithium-ion batteries were first used in portable electronics in the early 1990s and are now widely used in electric vehicles (EVs) and stationary energy storage. These batteries operate by shuttling lithium ions between the cathode and the anode as the battery is cycled. They are characterised as having high energy and power densities, high cycling efficiency and good cycle life. While graphite is the most used anode material, there are two main families of cathode materials currently in commercial use: NMC and LFP.[39] NMC batteries offer higher energy and power densities at the cost of cycle life, while LFP batteries offer higher cycle lives and lower costs, making it the chemistry of choice for energy storage applications. The majority of lithium-ion batteries are made in China,[40] but there are substantial efforts in the UK, EU and North America to develop local supply chains.

Lead-acid batteries are widely used in the automotive sector as starting, light and ignition batteries and have also been deployed in energy storage applications. The battery chemistry is based on the reversible chemical reaction between lead and sulfuric acid. Despite various cell designs, the chemistry has remained unchanged since its invention in 1860. Lead-acid was once the cheapest rechargeable battery technology available due to widespread deployment in the automotive sector, although it has now been surpassed by lithium-ion. Lead-acid batteries are robust, highly recyclable, offer good power density, and are widely available globally. However, they have limited energy densities and low cycle life.

Redox-flow batteries cover a range of chemistries that all operate on the same principle: storing energy in electrolyte solutions contained in separate tanks. During charge and discharge, pumps flow the electrolyte through a cell stack separated by a membrane, storing or releasing energy.[41] A unique feature of flow batteries is the decoupling of specific energy and power: energy is controlled by the size of the electrolyte tanks, while power is determined by the surface area of the electrodes in the cell stack. These systems have very low energy and power densities due to the size and mass of the electrolyte tanks, but they offer high cycle lives and reasonable roundtrip efficiencies. Most commercial flow battery systems today are vanadium based. A world leader of flow-batteries is UK-based Invinity, who was awarded £11 million to build a 7 MW / 30 MWh for the UK grid in 2023.[42]

As with redox-flow batteries, **high temperature batteries** refer to a range of different battery chemistries that operate on a similar principle. These batteries use molten electrodes separated by a solid ceramic electrolyte separator that conducts ions between the electrodes. As the electrodes must remain in a liquid state for the battery to function, these systems operate at temperatures over 250°C, which could make them more suitable for operation in hotter climates. The only high temperature battery technologies that have been commercially deployed at scale are sodium-sulfur

Box 4: Faraday Institution research relevant to energy storage applications

The Degradation project is focused on developing a comprehensive mechanistic understanding of the relationship between external stimuli (such as temperature and cycling rate) and the physical and chemical processes occurring inside the battery that lead to degradation.[43] This research is being carried out on a number of different battery chemistries including LFP- and NMC-type batteries.

The Multi-scale Modelling project is focused on advancing the modelling of lithium-ion batteries.[44] The project aims to create accurate battery models to extend the lifetime and performance of battery packs and to contribute to the electrification of the automotive industry and other key sectors of the economy.

The SafeBatt project explores the science of lithium-ion battery safety.[45] It aims to understand underlying causes of failure in lithium-ion cells, allowing industry to design safer battery packs and simplify safety systems. Through investigations on degradation, failure propagation, and environmental consequences of battery fires, SafeBatt provides insights crucial for industry advancements in battery safety.

NEXGENNA is seeking to develop the next generation of sodium-ion batteries.[46] The project is led by the University of St Andrews and aims to improve the performance of sodium-ion while maintaining safety and cost advantages. The project focuses on active material design, electrolyte development, and scale-up demonstrations.

As part of the Ayrton Challenge on Energy Storage,[47] the Faraday Institution is also leading battery research funded by the Foreign, Commonwealth and Development Office, with the aim of developing improved and lower cost battery technologies tailored for deployment in emerging economies. These projects focus on researching low-cost alternative chemistries, recycling battery waste and optimising systems to maximise performance. energy storage.

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[39] For more information on the different types of lithium-ion cathode chemistries, download Faraday Insight 18.
[40] Volta Foundation – Annual Battery Report 2023.
[41] DiLiCo Engineering - Redox Flow Battery.
[42] Invinity - Invinity to Build the Largest Grid-Scale Battery Ever Manufactured in the UK (April 2023).
[43] Faraday Insight 10 - Why Batteries Fail and How to Improve Them: Understanding Degradation to Advance Lithium-Ion Battery Performance (March 2021).
[44] Faraday Insight 15 - The Value of Modelling for Battery Development and Use (December 2022).
[45] Faraday Insight 17 - Improving the Safety of Lithium-ion Battery Cells (July 2023).
[46] Faraday Insight 11 - Sodium-ion Batteries: Inexpensive and Sustainable Energy Storage (May 2021).
[47] Faraday Institution to lead UK Government's Ayrton Challenge on Energy Storage (August 2023).

batteries, which use molten sodium and sulfur electrodes. Although they offer high energy density, their commercial uptake has been limited by safety issues. As of 2024, Japan-based NGK is the only company offering this technology commercially.[48]

Next-generation BESS technologies

In addition to lithium-ion and other legacy battery technologies, several next-generation battery chemistries are under development for energy storage applications.

Sodium-ion batteries operate similarly to lithium-ion batteries but have lower energy densities due to the higher atomic mass of sodium. They offer a lower cost alternative by relying on abundant sodium resources, reducing potential supply chain constraints. Thanks to their similar performance, sodium-ion technology has the most potential to compete with lithium-ion batteries for market share in SDES and LDES applications. Sodium-ion batteries also provide better cold temperature performance than lithium-ion and could offer improved safety characteristics. Many battery manufacturers are developing this technology at scale for both automotive and energy storage applications.[40] Sodium-ion batteries are just beginning to be deployed for large storage projects, with the first large scale installation put into operation in China in May 2024.[49] In the UK, Faradion, a world leader in sodium-ion batteries, has been developing the technology for over a decade.[50] The Faraday Institution NEXGENNA project was set-up to develop the next generation of sodium-ion batteries (Box 4).

Metal-air batteries generate and store electricity through the reaction of a metal anode with oxygen from the air. The anode can be made from metals such as lithium, aluminium, zinc and iron, while the cathode is typically made from a porous electronically conductive carbon that acts as a catalyst to accelerate the reaction. Metal-air battery systems can offer low costs but suffer from low energy efficiencies and low cycle lives. Form Energy, a US-based company, is developing large-scale iron-air based batteries for LDES applications and is currently building a manufacturing facility in West Virginia.[51]

Redox-flow and **high-temperature battery** technologies are already being deployed commercially. However, new battery chemistries from these technology families are emerging. Novel flow battery chemistries are being developed in a bid to move away from vanadium-based systems (which have toxicity issues and high costs), including zinc-bromide and organic based systems. The Faraday Institution is also funding research into low-cost flow battery chemistries, with potential applications in developing countries (Box 4). In high-temperature batteries, an alternative chemistry to sodium-sulfur is being commercialised in the UK by LiNa Energy, that have developed and deployed a pilot sodium-nickel-chloride-based BESS installation in India.[52]

Although not explicitly a distinct battery chemistry, vehicle-to-grid technology (V2G) is also being researched as a possible technology for energy storage. V2G involves using the battery of an EV to provide energy to the electricity grid for flexibility (Box 5).

Box 5: Vehicle-to-grid technology

Vehicle-to-grid (V2G) technology allows EVs to interact with the electricity grid by both drawing electricity from it for charging and feeding electricity back into it when needed to meet demand at peak times.

V2G technology can increase grid flexibility while leveraging the growing adoption of electric transportation. With up to 40 million EVs expected to be on UK roads by 2050, this could provide 2,400 GWh of potential stationary storage capacity (assuming an average battery pack size of 60 kWh). Although only a small proportion of this capacity would be available at any given time, the potential for grid flexibility remains significant, with ESO modelling a maximum of 65 GW of capacity from V2G in 2050.[1] In addition, recent studies show participation in V2G schemes does not increase battery degradation beyond normal use.[53]

V2G has demonstrated financials savings for consumers,[54] but current deployment costs are too high for widespread adoption.[55] Moreover, the majority of EVs produced today lack bi-directional charging capability. For V2G to be widely utilised, both new EVs and EV chargers must have bi-directional capability. Standards and protocols have been developed to help facilitate standardisation in this area, but they are not yet widely implemented. Cost decreases and further research is needed to help support the implementation of an optimised smart grid and to maximise the viability and benefits of V2G applications.

While this technology is still nascent, there are a number of ongoing trials across the globe. In 2022, Hyundai deployed a fleet of 25 IONIQ 5 EVs in Utrecht alongside mobility provider We Drive Solar for a new V2G-powered mobility service.[56] In February 2024, Octopus launched what it claimed to be the UK's first mass-market-ready V2G tariff for customers with a qualifying EV and EV charger.[57]

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[48] NGK Insulators - NAS Batteries.
[49] CNEV Post - China's 1st large-scale sodium battery energy storage station put into operation (May 2024).
[50] Faradion website.
[51] Form Energy website.
[52] LiNa Energy website.
[53] Jingyu Gong et. al., Quantifying the impact of V2X operation on electric vehicle battery degradation: An experimental evaluation, eTransportation (2024).
[54] Current News - Cornwall Insight: V2G could reduce electricity spend by 70% (September 2024).
[55] Energy Systems Catapult: V2GB - Vehicle to Grid Britain.
[56] Hyundai - Hyundai and We Drive Solar launch energy system of the future in Utrecht (April 2022).
[57] Electrive - Octopus launches V2G tariff as a UK-first (February 2024).

Battery Technology Targets and Applications

Typically, energy storage applications are defined by discharge durations. While there is no standard discharge duration for a particular technology (as it is a flexible parameter varied through system design), each technology will have a typical discharge duration (determined by its inherent performance parameters) making it suitable to certain applications (Figure 10).

Lithium-ion has successfully displaced lead-acid as the battery technology of choice for BESS and is likely to dominate SDES applications and ancillary services towards 2030. The combination of high performance, low-cost and wide availability make it difficult for other battery technologies to compete in these markets. The average discharge duration of lithium-ion BESS is increasing, with several 6-hour duration BESS being recently given planning permission in the UK.[58] However, system costs would need to continue to fall before lithium-ion could become applicable across longer discharge durations in LDES markets, with other technologies having an average capital expenditure lower than lithium-ion for LDES (in terms of £/kWh).[59]

Sodium-ion batteries will likely be deployed across similar applications to lithium-ion, with lower up-front costs offsetting the slight loss in energy density. Sodium-ion batteries have a lower potential cost than lithium-ion, providing opportunities for them to be used in certain LDES applications. Redox-flow batteries, high temperature batteries, and metal-air batteries all have characteristics making them contenders for LDES storage applications. However, the capital cost of these technologies is currently too high for them to be deployed at the scale required in the UK. In addition, these markets are not yet well established, making it difficult for such systems to be prototyped, a crucial step in the development of any new technology.

Why is lithium-ion technology so dominant?

There are three main reasons why lithium-ion technology is so dominant:

i. Ease and speed of deployment;

ii. Strong performance characteristics;

iii. Decreasing cost of manufacture.

Although there are a wide range of different battery technologies available for energy storage applications, lithium-ion will be the most widely deployed energy storage technology globally by 2030.

(i) Lithium-ion can be deployed quicker than other storage technologies. Lithium-ion BESS are mature technologies that can be installed in modular shipping container units, typically taking a year to build and commission once permits have been received.[7] In addition, lithium-ion systems can be deployed in most locations. In contrast, pumped hydro must be placed in geographically suitable locations and requires longer installation and site development times than lithium-ion.[7]

(ii) Lithium-ion batteries are higher performing than other battery chemistries. While energy density is often highlighted as a key metric for battery technologies, power density is crucial in energy storage applications. Lithium-

Figure 10: Suitability of energy storage technologies for different applications.

	Battery technologies							Other storage technologies	
Application	**Lithium-ion (LFP)**	**Lead-acid**	**Redox-flow**	**High-temperature**	**Sodium-ion**	**Metal-air**	**V2G**	**Pumped hydro**	**Liquid air**
Short duration	🟢	🟢	🟡	🟡	🟢	🔴	🟡	🟡	🟡
Long duration	🟡	🔴	🟢	🟢	🟡	🟢	🔴	🟢	🟢
Seasonal storage	🔴	🔴	🔴	🔴	🔴	🟡	🔴	🟢	🔴
Ancillary services	🟢	🟡	🟡	🟡	🟢	🔴	🟢	🟡	🟡
Constraint management	🟡	🔴	🟡	🟡	🟡	🟡	🟡	🟢	🟢
BTM applications	🟢	🟢	🟢	🟢	🟢	🔴	🟡	🔴	🔴
Off-grid applications	🟢	🟢	🟢	🟢	🟢	🟡	🟡	🟡	🟡

🟢 Suitable 🟡 Suitable in some cases 🔴 Not suitable

Source: Faraday Institution research.

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[58] Solar Power Portal - Dorset Council approves 2.4GWh battery energy storage project (August 2024).

[59] BNEF - Lithium-Ion Batteries are set to Face Competition from Novel Tech for Long-Duration Storage (May 2024).

ion is the most power dense battery technology available today, capable of operating through a wide range of charge / discharge durations, including very short (i.e., <1 hour) cycles. Lithium-ion also demonstrates much higher round-trip efficiencies compared to other battery chemistries.

(iii) Lithium-ion batteries have benefitted from significant cost reductions through rapid technological innovation. The widespread uptake of EVs has delivered substantial performance improvements along with reductions in the cost of lithium-ion batteries. Since 2010, lithium-ion cell costs have decreased ten-fold, from ~1,050 £/kWh to around ~105 £/kWh in 2023, one of the fastest cost decreases of any energy technology.[60] This development led by the automotive industry has permeated to other systems including BESS, leading to significant improvements in system design. In September 2024, Envision unveiled an 8 MWh BESS packaged in a 20ft container at the Energy Storage Exhibition,[61] representing a 20-times increase in system level energy density over a decade. These gains are attributed to the development of energy-dense, large-format LFP cells.

As lithium-ion technologies continue to be more widespread, having detailed insight into how these batteries work is key. Understanding how lithium-ion batteries degrade over time (and how degradation can be prevented) is becoming increasingly important for BESS. To maximise the economic viability of a system, short duration BESS systems are often cycled multiple times per day, putting stress on the battery. There is a delicate balance between prolonging system health and maximising revenues, which requires an in-depth understanding of degradation mechanisms and modelling charge / discharge cycles of lithium-ion batteries. The Faraday Institution funds research on these themes through the Degradation and Multi-Scale Modelling projects (Box 5).

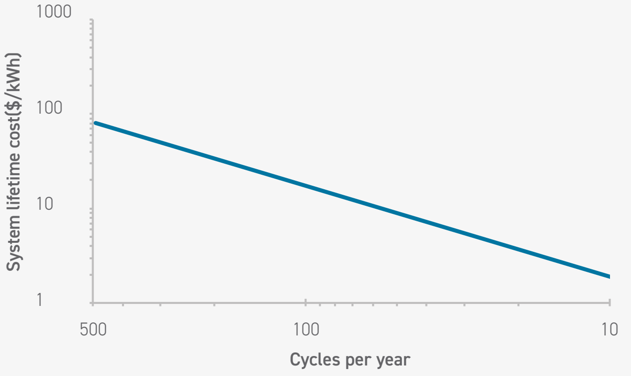
Targets and requirements for batteries in SDES and LDES applications

LFP-based lithium-ion batteries are set to be the technology of choice for SDES applications, setting the benchmark for any new technologies to reach. However, these systems lack a localised supply chain. Analysis from Modo Energy has shown that as of April 2024, 19 different companies have installed almost 5 GWh of BESS systems in the UK, the most important being Tesla, BYD, and CATL. Over 70% of the cells supplied for these BESS were sourced from China, while only 1% of cells were sourced from Europe.[62] Lithium-ion BESS deployed in SDES applications will become crucial in maintaining the stability of the UK energy system.

By 2030, the demand for UK-produced batteries for stationary storage applications could rise to 10 GWh per annum. Due to the differences in battery chemistry and pack assembly design requirements, this could potentially justify the development of a dedicated gigafactory for energy storage cells.[63]

The ideal technologies for LDES applications are yet to be determined. For next-generation battery technologies to be competitive in this space, certain economic and performance targets will need to be met. Recent reports show that energy storage technologies would need to achieve specific energy costs of ~ 7 £/kWh or less to be viable at discharge durations of 100 hours.[64] However, the target price point, as well as the performance targets, will vary depending on the discharge duration and expected number of cycles over the system lifetime.

Figure 11: Representation of the system lifetime costs at different cycling frequency when targeting a cost of 0.05 $/kWh per cycle



While system costs should always be minimised, the target price point for energy storage applications, as well as the performance targets, will vary depending on the discharge duration and expected number of cycles over the system lifetime.

Source: ARPA-E – Duration Addition to Electricity Storage (DAYS) Overview.

In the US, the ARPA-E DAYS program is pursuing the development of new LDES technologies, targeting a cost of electricity per cycle of 0.05 $/kWh.[65] Such a target allows for a range of system lifetime costs and performance parameters to be considered. In this case, system lifetime costs represent cost calculated on a levelised cost of storage basis, and thus represent the cost of the full system. While the DAYS program target is representative for a specific use case, Figure 11 demonstrates that the target cost and performance for technologies are on a sliding scale rather than being a fixed number. As cycling frequency decreases, lower system costs will be crucial to enabling economic viability.

Battery Energy Storage Policy in the UK

Changes to BESS grid connection policies and skip rates

The development of lithium-ion BESS projects in the UK has been hampered by difficulties in securing connection to the grid. Any installation wishing to connect to the UK transmission or distribution system must join a queue,

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[60] IEA – Batteries and Secure Energy Transitions (2024).
[61] ETN News - Envision unveils 8 MWh grid-scale BESS with superior energy density (September 2024).
[62] Modo Energy - BESS suppliers in Great Britain: Who is dominating the market? (April 2024).
[63] Faraday Institution Report, UK electric vehicle and battery production potential to 2040 (September 2024).
[64] N. A. Sepulveda et al., The design space for long-duration energy storage in decarbonized power systems, Nature Energy (2021).
[65] ARPA-E – Duration Addition to Electricity Storage (DAYS) Overview.

with some projects facing delays of 10 to 15 years to be connected. Battery energy storage projects in the queue are at different stages of development, which in some cases prevents projects at advanced development stages from being connected.

In 2023, Ofgem and the UK Government set out an action plan to reduce the average delay for viable projects from five years to six months. Actions include increasing the quality of projects applying for connections, removing stalled projects and better utilising and allocating existing network capacity.[66] This led to the ESO proposing a series of reforms to the grid connection process, suggesting the implementation of a "First Ready, First Connected" system to help accelerate the connection of viable projects.[67] These reforms will continue to be supported by Great British Energy and Mission Control to help accelerate the deployment of renewable energy generation and storage.[68]

Another issue facing the deployment of BESS on the grid are skip rates. In the UK, the National Energy System Operator (NESO) uses the Balancing Mechanism to balance energy supply and demand in real-time. A wide range of technologies, including batteries, are able to bid on the Balancing Mechanism to provide the services the NESO requires. However, batteries are currently overlooked roughly 30% of the time when they are cheaper than other technologies according to the NESO, with some sites being skipped over 90% of the time during constrained periods.[69] A coalition of battery storage developers recently wrote a letter to the UK Government and the NESO to highlight the issue of skip rates, which lead to higher energy bills and a lower use rate of renewable energy.

Policy developments for long duration energy storage

As the deployment of renewable energy continues at a steady pace in the UK,[70] more work must be done to develop an appropriate energy storage infrastructure to ensure system reliability beyond 2030. While the UK has a significant amount of both planned and connected SDES systems, LDES technologies must also be developed to ensure energy security in a renewables-based energy system.[71] However, pumped hydro storage remains the only mature technology in the UK for LDES to date. The biggest challenges facing longer duration systems include the significant capital outlay required and uncertain revenue streams due to lower cycling frequencies.

To address this issue, in January 2024 the Department of Energy Security and Net Zero (DESNZ) consulted on policy options to help enable LDES technologies, defining LDES as storage systems of six hours or more. The consultation recommends a cap-and-floor mechanism to guarantee minimum returns to keep projects viable and capping maximum revenue to protect costs to consumers, which the government has now confirmed it will implement.[72] Two streams of project support were established:

- Stream one for established technologies at a technology readiness level (TRL) of 9, delivering a minimum capacity of 100 MW; and
- Stream two for novel technologies at TRL 8, delivering a minimum capacity of 50 MW.

The response to the consultation states that eligible projects should be operational by 2030 to ensure they maximise system value for the UK. Importantly, DESNZ is proposing to exclude lithium-ion based systems from participating in the scheme. This decision was explained by lithium-ion already being a commercial technology that could be deployed at scale without subsidies, providing opportunities for other more nascent technologies to be tested.

In their response to the consultation, the House of Lords urged the Government to act quickly to ensure LDES technologies can scale up and contribute to reaching net zero.[73] They further recommended the UK Government expand pilot projects and outline clearer roles for redox-flow (along with iron-air) batteries in its industrial battery policy, including co-funding large-scale demonstrations with industry. While the cap-and-floor mechanism was welcomed, the report stated the need for explicit LDES capacity targets, and for the development of a large-scale strategic reserve of energy storage alongside commercially operated storage. Similar calls have been made by the National Infrastructure Commission, which recommended the UK Government develop a strategic energy reserve capable of generation 25,000 GWh of electricity to support system resilience,[74] as well as the Committee on Climate Change[75] and the Royal Society.[15] Such a storage reserve could include clean fuels and batteries, would only be required in extreme circumstances and could not be economically sustained even through the cap-and-floor mechanism.

The need for public engagement and safety standards for BESS

While the deployment of BESS in the UK has been largely successful, certain installations face public opposition, which can hamper project development.[76] Similar opposition has been faced in North America, leading to project cancellations.[77] Opposition to the deployment of BESS in communities typically stem from safety and environmental concerns in the unlikely event that a battery fire occurs. It is worth noting that global failure rates of BESS have dropped 97% between 2018 and 2023, as lessons learned

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[66] The Department for Energy Security and Net Zero Ofgem (November 2023). Connections Action Plan Speeding up connections to the electricity network across Great Britain.
[67] NESO - Connections Reform.
[68] The Department for Energy Security and Net Zero - Chris Stark to lead Mission Control to deliver clean power by 2030.
[69] Financial Times - National Grid blames old computer systems for sidelining batteries (September 2024).
[70] Current news - Awarded capacity triples, offshore wind returns: CfD AR6 results in detail (September 2024).
[71] ESO - Potential Electricity Storage Routes to 2050.
[72] DESNZ - Long duration electricity storage: proposals to enable investment (October 2024).
[73] House of Lords Science and Technology Committee - Long-duration energy storage: get on with it (March 2024).
[74] National Infrastructure Commission - Energy & Net-Zero Headline Recommendations (October 2023).
[75] CCC - Delivering a reliable decarbonised power system (March 2023).
[76] Shropshire Star - 'Potentially hazardous, noisy and unsightly!' Residents amp up opposition to battery energy storage scheme in village centre (April 2024).
[77] Energy Storage News - Local opposition leads to BESS project cancellations in North America (February 2023).

from previous incidents have been incorporated into system designs and safety protocols.[78]

In the UK, there are currently no laws that govern the safety of BESS specifically, although they "may need to adhere to product safety regulations".[38] In 2023, the UK Government stated that it considered BESS to be covered by "a robust regulatory framework", publishing guidance where it encouraged developers to consult their local fire and rescue service while preparing planning applications for BESS. Providing clarification in this area could help assure the public on local BESS installations.

Public engagement is essential in addressing safety concerns and building community support. Open forums and education campaigns can inform residents about risks and the stringent safety protocols that will be implemented during the installation and operation of BESS, while also highlighting localised benefits, such as potential reductions in energy costs. Additionally, listening to public concerns and incorporating their feedback into planning can help build trust and ensure community needs are met. Industry and government should focus on engaging with and providing communities and fire officials with up-to-date knowledge and training on BESS. In North America, which is seen to be the leader in developing standards for BESS, numerous standards exist including UL 1973,[79] which addresses safety and reliability safety standards for the BESS system in real-world conditions and NFPA855,[80] which deals with installation standards. Requirements should be robust, and fit-for-purpose for BESS, and it will be critical for the UK to ensure that the most appropriate standards of safety are enforced whilst not stifling innovation and development.

Conclusion

Batteries will soon be the most widely deployed energy storage technology globally, supporting the rapid increase in renewable energy generation as the technology of choice for SDES and BTM applications, thus helping to decarbonise electricity supply. Lithium-ion, and in particular LFP-type batteries, are driving this deployment, thanks to their low cost and long cycle life. Next-generation technologies such as flow batteries or sodium-ion will displace legacy battery technologies and could compete with lithium-ion batteries in certain market sectors. However, efforts must be made to continue to reduce capital costs of these technologies, opening up opportunities in LDES applications.

Ambitious targets have been set for the deployment of renewable energy generation in the UK, as the Government aims to make the UK a clean energy superpower.[81] Policies such as the Government's proposed cap-and-floor mechanism will help encourage the deployment of SDES and LDES systems. To ensure that battery energy storage meets the needs of a future grid, the following will be required:

- Reform grid connection processes by adopting a 'First Ready, First Connected" approach to speed up BESS deployment of SDES.
- Continue to support the installation of BESS in BTM applications to enable distributed energy systems across the UK.
- Reduce battery skip rates on the Balancing Mechanism to improve the use of BESS.
- Prioritise research into next-generation battery technologies, such as sodium-ion, redox-flow and metal-air, to lower capital costs for BESS, improve performance, and accelerate their deployment in SDES and LDES applications.
- Engage with fire safety services and the public to provide accurate information on the safety of BESS and procedures required to ensure their continued safety.
- Implement cap-and-floor financial mechanisms to de-risk investment in LDES and expand pilot projects for batteries and other technologies to demonstrate commercial scalability and market viability.
- Investment in LDES and seasonal storage technologies to deliver ~25,000 GWh of strategic reserve (significantly larger than the market size for EV batteries in the UK).

Given the importance of battery for grid stability and renewable integration, it will also be crucial to establish domestic battery manufacturing capacity to reduce reliance on imports and ensure security of supply. Although the UK is expected to have around 67 GWh of lithium-ion battery production capacity by 2030, this is to supply the UK's automotive sector. The demand for SDES could therefore justify the construction of a dedicated gigafactory.

Energy storage will be critical in ensuring a net-zero future by providing stability and flexibility to the electricity grid. While batteries will not be the only solution in providing LDES storage solutions, they could play a vital role in meeting the growing demand for energy storage across all durations. Continued investment, innovation, research and policy support will be essential to unlocking the full potential of battery technology for grid storage applications.

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[78] EPRI – Insights from EPRI's Battery Energy Storage System (BESS) Failure Incident Database (2024).

[79] UL1973, Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications.

[80] NFPA 855, Standard for the installation of stationary energy storage systems (2023).

[81] Labour - Make Britain a clean energy superpower.

Glossary of terms

Term	Description
Arbitrage	Arbitrage is one of the most important and simplest applications of BESS. It works on the simple premise of storing energy when prices are low and supplying it back to the grid when prices are high. Arbitrage allows energy to be stored and used in periods of higher demand. In FTM arbitrage applications, energy is traded on the wholesale market.
Balancing Mechanism	The Balancing Mechanism is an important tool that the NESO uses to balance electricity supply and demand in real-time. When electricity supply and demand are not in balance, NESO uses the Balancing Mechanism to purchase changes in supply and demand to correct the imbalance.
Battery energy storage system (BESS)	A battery energy storage system (BESS) is a device that allows electricity from the grid or renewable energy sources to be stored and used later. BESS can be connected to the electricity grid or directly to homes and businesses.
Battery management system (BMS)	A battery management system is an electronic system that ensure the safe use of a lithium-ion battery while monitoring the battery's state of health.
Behind-the-meter (BTM)	BTM refers to storage systems installed behind the utility meter of commercial, industrial or residential consumers. In these cases, the system is owned and operated by the consumer for their own benefit, typically to provide resilience or reduce energy bills by utilising on-site renewable generation.
Constraint management	Constraints can be categorised as capacity, voltage, or frequency constraints.[82] Historically, grid constraints have been managed by building additional transmission or distribution capacity, or by paying generators / consumers to increase / decrease their supply / demand for electricity. BESS provide an alternative to these solutions by adjusting the time of electricity use from peak- to off-peak periods, which helps minimise grid constraints.
Demand side response	Demand side response is a way to help align the demand of electricity with supply. This includes providing financial incentives to consumers to use electricity during specific time periods to help lower electricity demand during peak periods, for example charging an EV overnight. The UK has recently held trials with promising results. However, several barriers remain, particularly around the connectivity and reporting from smart chargers.[83]
Distribution network	The low voltage (<132kV) electricity network where electricity is distributed to consumers.
Frequency response	Frequency response services are used to manage small changes in frequency caused by continuous changes in supply and demand on the electricity grid.[84] As the generation capacity from renewable energy sources increases, there will be more frequent and faster frequency fluctuations, often requiring sub-second response times to mitigate them. BESS can provide frequency response by adjusting their active power to respond to changes in frequency on the grid, and are well suited to this application, thanks to their fast response time.[21]
Front-of-the-meter (FTM)	FTM refers to storage systems connected to the high-voltage transmission network, the low-voltage distribution network or co-located with renewable electricity generation.
Grid flexibility	Flexibility on the electricity grid refers to the ability to shift the supply or demand of electricity in time or location.
Inertia	Inertia refers to the energy stored within spinning generators and turbines and is a measure of the grids ability to resist changes in frequency.[85] If a generator fails, the inertia of the spinning turbine will slow the drop in frequency caused by the failure, giving the grid operator time to respond by deploying extra generation to make up for the shortfall.
Levelised cost of storage	A method of calculating the cost of a particular storage technology over its lifetime that considers both the cost (by including both up-front and maintenance costs) and performance (by including roundtrip efficiency and cycle life) of a particular technology.
Lithium iron phosphate (LFP)	Lithium iron phosphate is a cathode material used in lithium-ion batteries. LFP is widely used in electric vehicles today and for energy storage purposes.[39]
Long duration energy storage (LDES)	Energy storage required for discharge durations between 6 and 160 hours.
Mission Control	Mission Control is a government initiative to enable the UK to transition to clean energy by 2030. It will focus on accelerating the shift from fossil fuels to clean energy, enhancing Britain's energy independence and reducing costs. It aims to unite industry experts and officials to address obstacles and collaborate with key energy organisations, speeding up the connection of cleaner, cheaper power to the grid.
National Energy System Operator (NESO)	The electricity system operator for Great Britain.

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[82] Wattstor - What are Grid Constraints & Why Do They Cause Businesses Problems?

[83] UK Parliament POST - Demand side response: A tool for lowering household energy bills (February 2024).

[84] NESO – What is Frequency?.

[85] NREL - Inertia and the Power Grid: A Guide Without the Spin (May 2020).

Term	Description
Network interconnection	Network interconnectors are high-voltage cables that connect the electricity grids of neighbouring countries, allowing excess electricity to be traded. The UK currently has a number of European interconnectors, with a projected maximum interconnector capacity of 27 GW by 2050.[5]
Lithium nickel manganese cobalt Oxide (NMC)	Lithium nickel manganese cobalt oxide is a class of cathode active material used in lithium-ion batteries for electric vehicles and energy storage.[39]
Reserve services	Reserve services are used for a similar purpose to frequency response (maintaining the balance between supply and demand on the grid), but unlike frequency response, reserve services will be dispatched manually and are typically sustained over longer periods of time.[71]
Restoration services	Restoration services are required to restore power in the event of a partial or total electricity grid shutdown. These services are provided by assets that can self-start and generate electricity without an external power supply.[71] These assets will power up their local network, forming a power island, which will grow and connect to other power islands until power is restored to the whole grid. Energy storage technologies such as BESS are able to provide these services when combined with a grid-forming inverter. Events where restoration is needed occur rarely in the UK.
Seasonal storage	Seasonal storage will be used to correct the seasonal imbalance between energy supply and demand. Seasonal storage can be defined as requiring discharge durations of more than 160 hours.
Short duration energy storage (SDES)	Energy storage required for discharge durations of less than 6 hours.
Transmission network	The high voltage (>132kV) electricity network that transmits large quantities of electricity over long distances.
Vehicle to grid (V2G)	Vehicle-to-grid (V2G) is a bi-directional service where owners can plug in their battery-powered vehicle and energy from the onboard battery pack can be transferred back into the grid. This can collectively provide the grid with a surplus amount of energy capacity that can be managed to deal with spikes in demand during peak times or as an emergency backup. Car owners are compensated for allowing their EV batteries to be used to support the grid.
Voltage support	Voltage support involves absorbing or injecting reactive power onto the network to reduce or increase the voltage in the surrounding network. Unlike grid frequency, the need for voltage support is dependent on location. The instability bought by renewable energy sources will increase the levels of voltage support required on the grid.[71] BESS can provide voltage support quickly by absorbing or injecting reactive power without providing additional capacity onto the grid.

About the Faraday Institution and Faraday Insights

The Faraday Institution is the UK's independent institute for electrochemical energy storage research, skills development, market analysis, and early-stage commercialisation. We bring together academics and industry partners in a way that is fundamentally changing how basic research is carried out at scale to address industry-defined goals.

Our 'Faraday Insights' provide an evidence-based assessment of the market, economics, technology and capabilities for energy storage technologies and the transition to a fully electric UK. The insights are concise briefings that aim to help bridge knowledge gaps across industry, academia and government. If you would like to discuss any issues raised by this "Faraday Insight" or suggest a subject for a future Insight, please contact Stephen Gifford.

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