Techno-Economic Analysis of the Energy Storage Market in Scotland

Final Report
Scottish Enterprise
May 2025

Public Report

J3492

Executive Summary

The demand for grid-scale energy storage capacity is driven by several factors. The move towards Net Zero is resulting in increases in the amount of renewables generation being connected to electricity grids. This increases the need for flexibility within the system to deal with intermittent generation from wind, solar, etc. Governments are also implementing policies to improve energy security by reducing reliance on fossil fuels for energy generation. These policies also seek to protect consumers from fluctuations in energy costs caused by global events. These drivers to increase the renewable generation capacity are also driving the need for energy storage systems.

The global grid-scale energy storage capacity is expected to increase from 240 GW in 2023 to between 850 GW and 1,300 GW by 2030, an increase of between 250% and 440%. Approximately two-thirds of this growth will come from newly installed battery energy storage systems (BESS), typically based on lithium-ion chemistry. The remaining growth in capacity will mainly come from newly installed pumped storage hydro (PSH) facilities. There will also be opportunities for other technologies such as flow batteries, liquid air energy storage (LAES), thermal storage, compressed air energy storage (CAES) and gravity energy storage, for example.

The electricity infrastructure serving the demand in Great Britain (GB) will also require a significant increase in grid-scale energy storage capacity. Current capacity is 7.4 GW and this is projected to increase to between 27 GW and 33 GW by 2030 and between 29 GW and 39 GW by 2035. Most of the growth will occur with the next five years to 2030 where the increase in capacity will be between 260% and 350%. As with the global outlook, the growth in GB grid-scale energy storage capacity will mainly be achieved through deployment of BESS.

In Scotland, the battery storage capacity is projected to grow from a current capacity of 0.4 GW to projected capacities of 7.5 GW in 2030 and 7.6 GW in 2035. This is a growth rate of approximately 1800%. Long duration energy storage (LDES) capacity in Scotland is currently 0.7GW, all of which is provided by PSH. There are no specific LDES targets identified for Scotland but the GB target is to increase by between 1 and 3 GW by 2030 and between 2 and 7 GW by 2035. Estimates from this study suggest there is currently 13.4 GW of energy storage systems (mainly BESS but also some flow batteries, LAES and gravity storage) and 11.1 GW of PSH at various stages of the development pipeline in Scotland. It is clear that the supply of grid-scale energy storage capacity, in development, significantly exceeds what is likely to be required up to 2035.

In this context of significant market growth for grid-scale energy storage systems, there is an economic development opportunity to maximise supply chain involvement and create jobs and Gross Value Added (GVA). This is the motivation behind this study, commissioned by Scottish Enterprise and the subject of this report. The study investigates and maps several segments of the grid-scale energy storage supply chain in Scotland, including developers; parts, components and systems; original equipment manufacturers (OEM); project design engineering and project management; systems installation, commissioning, operation and maintenance and; decommissioning.

The Scottish grid-scale energy supply chain, covering these segments, consists of 76 companies active, or having the potential to become active, across technologies such as lithium-ion BESS, PSH, flow batteries, thermal storage, CAES, LAES and gravity energy storage systems.

These companies directly employ 1,000 FTEs active in grid-scale energy storage, with an annual GVA of £69 million. Feedback obtained during this study suggests that, by 2035, direct employment will have increased to 3,500 FTEs and annual GVA will increase to £304 million.

Many more temporary jobs will be created in companies outside of the supply chain defined for this study. For example, our analysis of a report, produced by Biggar Economics for Scottish Renewables, suggests that, between 2025 and 2035, civil engineering construction jobs associated with the development of PSH projects could peak at between 5,000 and 6,000 jobs and contribute between £2.3 billion and £3.2 billion in GVA over the period (direct, indirect and induced). Separate analysis carried out for this study also highlights that BESS construction, over the same period, could support between 5,000 and 6,000 temporary jobs and the construction of a LAES facility, planned for Hunterston, is projected to support 1,000 temporary construction jobs and an additional 650 in the supply chain.

It is clear that there is a significant economic opportunity for the Scottish supply chain in the domestic market. Additional opportunities also exist in the rest of the UK and in export markets, the latter where there are exportable products and services able to be sold into overseas markets.

There are several barriers, identified by companies in the supply chain, that may impede growth in the grid-scale energy storage market. These include: time consuming planning and consenting processes; uncertainty caused by the NESO reforms of the connection queue system; skills shortages in areas such as electrical engineers and electrical technicians with high voltage experience; significant lead times for bespoke equipment for PSH equipment, of up to four years; competition for international civil engineering main contractors for PSH; uncertainty about how the long duration energy storage cap and floor mechanism will work and the timing of its introduction; lack of knowledge of the Scottish supply chain capabilities amongst developers and technology developers and lack of funding to support companies move from demonstration scale to commercial scale, where the technologies are not currently at TRL 9.

Table of Contents

Prepared By: John Taylor, Hayley Welsh & Grace Crawford	**Date:** 29/05/25
Approved By: Deborah Creamer	**Date:** 29/05/25

1 Introduction

This report is one of the outputs of a study, commissioned by Scottish Enterprise, to better understand the scope, scale and economic contribution of the Scottish grid-scale energy storage supply chain. The study also seeks to investigate the current and future market opportunity for different technologies in this supply chain.

In addition to this report, outputs also include a database of companies active in the supply chain and those that have the potential to be active, categorised by segment of the supply chain and energy storage technology. There is also a database of energy storage research areas within Scottish universities.

1.1 Study scope and objectives

1.1.1 Scope

The scope of this study focuses on several technologies relevant to grid-scale energy storage. These were identified by Scottish Enterprise and included in the study brief. The technologies investigated are shown in Table 1, below.

Energy Storage Area
Pumped Storage Hydro
Battery - lithium ion
Battery - sodium sulphur
Battery - Flow
Thermal
Liquid Air
Compressed Air
Gravity
Superconducting magnetic energy storage
Flywheel
Cryogenic
Supercapacitors

Table 1: Energy storage technologies included in study

The study only includes technologies used in centralised facilities and does not include consumer-led flexibility, where decentralised assets are aggregated to create a virtual power plan. Therefore, technologies such as Vehicle to Grid are not included. The use of hydrogen to capture excess grid electricity and supply back to the grid at periods of low supply, is also not included in scope. This is to avoid duplicating efforts of other teams withing Scottish Enterprise.

The scope to the supply chain, defined in the brief and refined at the project inception meeting focused on the following segments:

- Developer
- Parts, components or systems
- Original equipment manufacturer
- Project design engineering and project management
- System installation, commissioning and operation & maintenance
- Decommissioning

Notably, this does not include the whole supply chain. For example, civil engineering services are not included, although in the economic impact assessment the jobs associated with facility construction is discussed and quantified in section 6.3.

1.1.2 Objectives

This study seeks to:

- Identify commercial opportunities arising from deployment of grid scale energy storage facilities, domestically and internationally, in terms of scale, storage technology type and timing
- Understand Scottish company and university R&D capability relevant to energy storage projects (including technology development, components/materials, site selection and systems integration) at a detailed company and organisational level
- Develop a geographical map of existing and future energy storage projects in Scotland to demonstrate and communicate domestic market potential
- Identify the extent to which Scottish company capability aligns with identified market opportunities, including which companies are already active and which have the potential to become active
- Identify state of the art technology developments in Scotland and understand the extent to which these could align with the projected market demand
- Understand the potential jobs and Gross Value Added (GVA) involved in the energy storage supply chain in Scotland
- Improve understanding of the place of Scottish companies in the overall supply chain and where key gaps in capability exist
- Better understand the barriers to deployment and, more generally, market failures that may restrict the growth of grid storage facilities and the involvement of the Scottish supply chain, with a view to using this information as evidence to develop or modify company support interventions
- Support the communication of the commercial opportunity in grid scale energy storage for the Scottish supply chain and how this can facilitate the growth in intermittent renewables to power grid electricity

1.2 Research method

The research was carried out between December 2024 and March 2025. An initial phase of desk research was carried out to identify potential supply chain companies, market information, university and research organisation R&D capabilities and the strategic and policy landscape. A format for the company database was discussed and agreed with the client before being populated.

Stakeholder interviews were carried out during February and March. A target interviewee list was developed and agreed, along with a study briefing note and series of discussion topics. A total of 96 target interviewees were approached by email and 20 interviews (21%) were carried out, via MS Teams.

The information gathered was then analysed and the report written.

2 Background and context

2.1 Key drivers

The key drivers of the energy storage market are the achievement of net zero, energy security and protecting consumers from volatile global energy markets.

Following on from the Paris Agreement, each signatory country prepares Nationally Determined Contributions every five years. These documents provide details of the steps the country is taking to reduce greenhouse gas emissions, including from electricity generation. This is important as the strategies to decarbonise other sectors of the economy often rely, to some extent, on electrification of energy supply to displace fossil fuel use. Therefore, the demand for electricity is set to increase significantly. Decarbonising grid electricity supply involves, in part, the construction of new renewable power facilities, including wind (offshore and onshore), solar, etc. These sources of power can be intermittent, in some situations producing more than is required and in other cases less. Grid electricity networks, therefore, frequently rely on fossil fuelled power plants to provide the flexibility to cope with the intermittency of renewable energy generation. However, as countries move towards net zero, there is a requirement to reduce this fossil fuel use. One of the solutions to providing flexibility is by using grid-scale energy storage systems to store electricity when supply exceeds demand and produce electricity when demand exceeds supply.

In addition to net zero, a key driver of the increased use of renewable energy and energy storage is energy security. The International Energy Agency (IEA) is clear about the need for energy storage to contribute to greater energy security.

'Electricity security is high on the agenda as increasing demand and more variable generation sources highlight the importance of secure, resilient and flexible power systems. Batteries are rapidly scaling up to provide short-term flexibility; demand response can provide short-term and some seasonal flexibility while also helping to keep costs down; thermal power and hydropower are the main sources of seasonal flexibility today and are set to remain so through to 2050'

The IEA also states that *'clean energy transitions can help to reduce household bills'*. Reducing fuel poverty is also a stated aim of the UK Government via the Clean Power 2030 Action Plan, where it argues that reliance on fossil fuel for energy has left consumers vulnerable to global price increases arising from events outside of UK control. By moving to a situation where more clean power is generated from assets located within the UK territorial area, this will reduce exposure to volatile global energy markets and provide more price stability.

2.2 Global opportunity

In 2023, the IEA reports that global installed capacity of grid-scale energy storage (not including hydrogen electrolysers) is 239 GW. Based on an 'implementation of stated policies' scenario, this is projected to increase to 839 GW by 2030. Alternatively, based on a 'Net Zero emissions by 2050' scenario, the global installed capacity of grid-scale energy storage is projected to increase to 1,300 GW. The breakdown of these current and future global capacities, by technology is shown in Table 2, below.

Technology	Current (2023) (GW)	2030 – Existing Policies (GW)	2030 – Net Zero by 2050 (GW)
Pumped Storage Hydro	181	249	293
Grid-scale battery	54	585	1,001
Other	4	5	6
Total	**239**	**839**	**1,300**

Table 2: Current and future projections of global grid-scale energy storage capacity (*source: International Energy Agency, 2024*)

The global market for grid-scale energy storage systems is clearly projected to grow significantly to 2030 and beyond, driven by the increasing integration of renewable energy sources and the need for grid stability as well as technological advancements and supportive policy frameworks and measures. Its market value, however, is challenging to quantify due to the different methodologies, market definitions and the scope of the technologies used by researchers and analysts. All agree, however, on one fundamental trend – that the global energy storage systems market is set for significant expansion, with investments accelerating across multiple technology areas.

To provide some context, the grid-scale segment of the total energy storage systems market was valued by one source at approximately $181.5 billion in 2023. The wider market (including grid-scale, domestic, commercial and industrial segments) is expected to more than double over the period to 2033, growing at a Compound Annual Growth Rate (CAGR) of around 8.9%. The grid-scale segment is expected to maintain its dominant position and, if it retained the same share of the overall energy storage systems market, then this would result in a global market value of around $415.7 billion by 2033.

The energy storage systems market is made up of several technologies, with the most prominent being battery energy storage, pumped hydro storage, thermal energy storage, and flywheel energy storage.

It is evident from the research, however, that pumped storage hydro and grid-scale battery storage systems dominate within the global grid-scale energy storage market, as also noted in the IEA data projections in Table 2. For this reason, and due to the difficulty in defining a total market value, the markets for these technology areas are considered to demonstrate projected growth rate and market value.

Figure 1 provides a range of market estimates for each technology area to (i) demonstrate the differences across various sources, and (ii) highlight the projected growth rate of these technologies and markets. For pumped storage hydro, estimates for 2023 vary greatly, from as low as $45.95 billion to around $224 billion. This large discrepancy arises, primarily, due to differences in whether reports consider existing operational facilities or only new installations and refurbishment projects, and how broadly they define the market scope geographically. Nonethless, the projected growth for all sources is at least double existing market values by 2030, demonstrating robust growth in this segment.

Grid-scale battery storage, while currently smaller than pumped storage hydro in absolute market size, consistently exhibits much higher projected annual growth rates, ranging from 18% to 27% CAGR. This rapid growth is fuelled by technological innovations, rapidly decreasing battery prices, shorter development timelines, and strong policy incentives aimed at integrating renewable energy. These factors make battery storage especially attractive for grid-scale projects seeking quick deployment and operational flexibility.

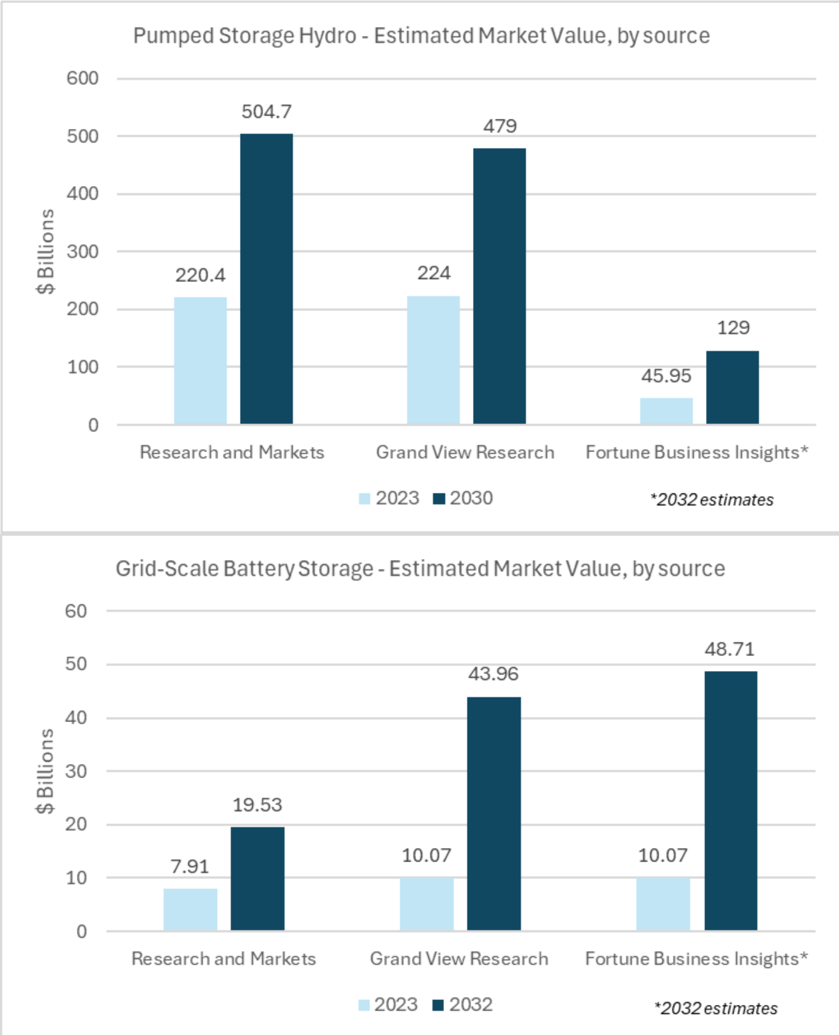

Figure 1: Range of market value estimates for pump storage hydro and grid-scale battery storage

The global energy storage systems market is clearly experiencing significant growth, with both grid-scale battery storage systems and pumped storage hydro playing pivotal roles. While grid-scale battery storage is expanding rapidly, pumped storage hydro remains a cornerstone of large-scale energy storage infrastructure, offering substantial capacity and reliability. Collectively, these technologies are essential for supporting the global transition to renewable energy and ensuring grid stability.

3 Grid energy storage technologies

The range of grid-scale energy storage technologies investigated is provided in earlier Table 1. These technologies are discussed in detail within this section and are prioritised in Section 7, taking into account the findings of this study.

3.1 Overview of grid energy storage technologies

Grid energy storage facilities can be classified as either Long Duration Energy Storage (LDES) and Short Duration Energy Storage (SDES). This refers to the minimum duration over which the facility can discharge to the grid at full power. LDES provides a back up to grid balancing during periods where outputs from renewable generation connections can be low, for example solar PV panels at night or wind turbines when there is insufficient wind to turn the blades.

Annex 1 of the NESO Clean Power 2030 report highlights that the installed capacity of LDES is just under 3 GW in Great Britain (GB). This is mainly from pumped storage hydro facilities in Scotland and Wales, with around 0.01 GW of new and innovative LDES (for example the Highview Power 5MW Liquid Air Energy Storage facility in Bury, England). The report states that the LDES generation mix to 2030 is assumed to be achieved through pumped storage hydro and liquid air energy storage. Other potential LDES technologies include compressed air energy storage (CAES), gravitational technology and flow batteries.

LDES is also, typically, provided by natural gas-powered generation. However, the ambition of the UK Government's Clean Power 2030 Action Plan is to use less than 5% natural gas, so other current and emerging non-fossil fuel technologies must be deployed at greater scale. To support this move, the UK Government (DESNZ) is working with Ofgem to develop a 'cap & floor' regime that will set minimum and maximum levels of market price paid for electricity generated by LDES facilities. This will reduce risk for investors in LDES facilities. At the same time the cap will protect consumers from excessively high market prices for electricity provided by the LDES facilities.

In the UK Government's response to the consultation on LDES, which ran between January and March 2024, it is proposed that there should be two routes to the cap and floor scheme. The first route will focus on established technologies, with a Technology Readiness Level (TRL) of 9 and power rating of at least 100 MW. The second route will focus on supporting emerging technologies at TRL 8, with a power rating of at least 50 MW (please see Appendix A for definitions of TRLs). The response also highlighted the different views on the minimum number of hours required to be classified as LDES, with consultee feedback ranging from 4 to 12. Reflecting on this feedback the UK Government stated that setting a higher minimum duration also reduces the potential supply of LDES the scheme could deliver and that this downside must be weighed against the benefits of restricting the scheme to higher duration storage only. In the subsequent call for input on the LDES cap and floor regime, published by Ofgem in December 2024, it is stated that Ofgem and DESNZ are considering a longer minimum duration, based on their analysis that longer storage provides greater system benefits, of 8 to 10 hours, for the first cap and floor route only (i.e. the one focused on proven technologies). The technical decision document for the long duration energy storage cap and floor regime, published in March 2025, defines the requirement to be eligible for the cap and floor regime as *'8 hours continuous output at full power, and maintain this capacity over the full cap and floor regime duration (i.e. 25 years').*

The current installed base of lithium-ion battery energy storage facilities in the UK typically consists of systems of 1-hour duration or less, although it is reported that the overall market is moving towards 2-hour systems. However, there is evidence of lithium-ion Battery Energy Storage System (BESS) facilities being deployed with an 8-hour duration, such as the Quinbrook Infrastructure Partners and CATL project in New South Wales, Australia.

Although the emerging cap and floor scheme to support LDES is technology agnostic, the UK Government does stress that only projects that would not otherwise move forward to investment decision should be supported. Therefore, there is some ambiguity about whether a lithium-ion based BESS, which can achieve higher durations of discharge at full power, could apply to the scheme, if it were commercially viable without the cap and floor support.

Each of the specific energy storage technologies is now assessed, considering factors such as alignment with market demand, technology maturity in grid applications, ease of market entry and relative scale of Scottish supply chain presence.

3.1.1 Pumped Storage Hydro

PSH is a mature technology that accounts for most of the LDES deployed in the UK with a TRL of 9 as it is fully commercialised and widely deployed globally. It has a round trip efficiency of between 65% to 87% and response time of less than 60 seconds. There are four existing PSH facilities in the UK, two in Scotland and two in Wales, with a combined installed capacity of 2.8 GW. These facilities have two reservoirs at different heights. During periods of excess electricity in the grid, the water from the lower reservoir is pumped up to the higher reservoir, creating potential energy. When electricity is required by the grid the water flows down a pipe in the opposite direction, passing through a turbine which rotates to generate electricity.

This technology is specifically mentioned as a key future provider of additional LDES in the GB electricity network in the Clean Power 2030 Action Plan. A report by Biggar Economics, for Scottish Renewables, identifies six potential PSH projects with combined capacity of 4.9 GW. All of these projects are located in Scotland. This will require a total of £6 to £8 billion in investment (£1.2m to £1.6m per MW installed) and take between 3 and 5 years for construction and additional time for the initial design, feasibility and consenting. The financial barriers to entry for developers of such facilities are significant. The supply chain for these types of facilities is almost entirely based outside of Scotland for the equipment and the main contractors, as no new PSH facility has been constructed in the UK for over 40 years. The main supply chain opportunities are in civil engineering sub-contracting to the main contractor, and this is the area where most economic impact will occur, in terms of employment. The day-to-day operation and maintenance is, typically, carried by direct employees of the asset owners. The lifetime of PSH facilities can be from 30 year to 100 years, with refurbishments.

The Scottish supply chain contains capabilities in the operation and management of PSH facilities. It also includes companies active in developing proposals for new PSH, with associated design engineering expertise, either in-house or through partnering with specialist engineering services suppliers. However there are no main equipment manufacturers for PSH. There is some presence of asset optimisation capability in the Scottish supply chain, which are typically technology agnostic. Examples of companies in this supply chain include ILI Group, Drax Hydro and SSE Renewables. Note that there is a variation to PSH, which is at an experimental stage. PSH using high density liquids is currently being developed by UK based company RheEnergise. By using higher density fluids the PSH projects can be 2.5 times smaller, compared to water based PSH, and operate in topographies with shorter height differences between lower and upper reservoirs. This reduces build cost and expands the locations where a facility can be constructed. The company is developing a pilot site in Devon with a view to having its first grid-scale project operational by 2026. No Scottish based supply chain capability was identified in this emerging area.

3.1.2 Battery – lithium-ion

BESS, using lithium-ion batteries, is a mature technology with a TRL of 9, given its widespread commercial adoption. The most common lithium-ion chemistry used for BESS is lithium iron phosphate (LFP), due to its higher safety performance, longer lifespan and lower cost, relative to other chemistries. Although LFP has a lower energy density compared to other lithium-ion chemistries, this is not a key factor in stationary applications, such as energy storage. It has a round-trip efficiency of 85% to 90% with response time of 0.15 to 1 second and is typically, but not exclusively, used for short duration energy storage (SDES) and also provides other commercial services to the grid, including frequency regulation. It is the most common form of SDES on the GB electricity grid with 4.5 GW of capacity already deployed. The approximate investment cost is just under £0.6m per MW installed, for a typical 2 hour duration battery and construction time is typically 1 to 2 years. Barriers to entry are lower than PSH due to lower investment costs. The supply chain for BESS is usually located in the Far East, with China being a key location for battery manufacturing. The main opportunity for the supply chain in Scotland is in the civils and construction work required. The sites are usually unmanned after development and commissioning and the operation and maintenance will be carried out by sub-contractors, which also offers a modest opportunity for the Scottish supply chain. Feedback from stakeholders suggested that the operation and maintenance can often be contracted by the BESS equipment supplier and sold to the asset owner as part of a warranty package included in the BESS system purchase price. Asset optimisation is also carried out remotely to maximise the revenue generating potential of the system across different grid services. The average lifetime of a BESS system is a minimum of 15 years with some developers claiming up to 50 years. There are a small number of companies in the supply chain that manufacture parts, components and systems for BESS. However, the main strength of the supply chain for this technology is in the developer and project design engineering segments. There are also several companies with operation and maintenance capabilities. Examples of companies in this supply chain include OnPath Energy, ILI Group, SAE Renewables, Apatura, Dukosi, Powertek Utilities and Norco Energy. In addition to this, Edinburgh based company, Flexitricity, offer various energy flexibility services, including asset optimisation for BESS and other energy storage technology assets.

3.1.3 Battery – sodium sulphur

This type of battery can provide LDES services of 6 or more hours. It is a high temperature rechargeable battery, storing energy in an electrochemical cell using molten electrolyte (sodium sulphur). The operational efficiency is 80% to 90% and the response time is between 0.5 and 1 second. The TRL is 9, with systems having been commercially deployed for over 20 years in Japan. One disadvantage of this technology, compared to lithium-ion BESS, is the high operational temperature of sodium sulphur batteries, introducing increased safety risks.

Sodium sulphur energy storage battery technology has mainly been developed and deployed in Japan, where the main sodium sulphur battery manufacturer, Nagoya, is located. In total, approximately 720 MW of sodium sulphur battery systems have been deployed worldwide. In addition to Japan the deployments have been in Germany, Bulgaria and Australia. There are no systems deployed in the GB grid.

BASF Stationary Energy Storage is partnering with Nagoya to develop an advanced version of the sodium sulphur battery to reduce the total cost of ownership and achieve a smaller footprint of installations. The average lifetime of sodium sulphur systems is 15 to 20 years.

No Scottish supply chain companies were identified as being active in this specific technology area.

3.1.4 Battery – flow

Flow batteries can provide LDES services to the grid and there are examples of it being commercially deployed, albeit at a relatively small scale compared to PSH and lithium-ion BESS. A policy briefing on 'Large Scale Electricity Storage' by the Royal Society states that the TRL of redox flow batteries is 7-8, due to the small scale of current deployments. A flow battery stores electrical energy in two liquid solutions that flow through separate tanks and interact with one another in a central reactor, known as a cell stack. The liquids are chemical solutions that store energy and the charging phase causes an electrochemical reaction in the solutions resulting in energy storage. To discharge the battery the two liquids are mixed in the cell stack and an electrochemical reaction takes place that releases electrical energy. The process is typically 70% to 80% efficient and the response time is between 0.5 and 1 seconds.

Different chemical solutions can be used in flow batteries, with the most common being based on either vanadium, lithium sulphur or zinc bromine. The benefits of flow batteries include the ability to operate at higher temperatures without cooling systems and low risk of fire. The capacity of flow batteries is increasing, with one recent announcement describing an 800MW flow battery to be developed in Switzerland. As deployment increases it is expected that technology costs will decrease.The lifetime of a flow battery is typically 15 to 20 years and they can be recycled at the end of life The supply chain is strongest in the manufacturing segment with three companies present in Scotland: Mhor Energy, Invinity Energy Systems and StorTera.

3.1.5 Thermal

Two types of thermal energy storage are discussed in this section. One is thermal solar energy storage, which is a proven technology deployed at grid scale, involving concentrated solar power and a medium such as molten salt. Another is pumped thermal energy storage (PTES), which uses excess electricity to compress an operating gas and the heat arising from this is used to charge a thermal storage material. When electricity is required, the heat from the thermal storage material is released and used to generate electricity.

Thermal solar energy storage can use concentrated excess grid electricity or concentrated solar power (CSP) to heat and melt salt, storing the resulting thermal energy. The molten salt can then, as required, be used to generate electricity, using the heat to power a turbine. Such systems have been commercially deployed in China, Australia and the USA and, therefore, have a TRL of 9. Connected to the grid, these systems have a typical efficiency of 65% to 70%, response time of 10+ seconds and can be used to provide LDES services with 8+ hour duration. There have been no deployments of this technology on the GB grid. The lifetime of thermal solar energy storage is approximately 30 years.

PTES can provide LDES services and some applications are at TRL level 7-8. For example, a planned grid connected PTES project developed by Westinghouse in Alaska is capable of continuous output of 50 MW for 24 hours. The project will use low cost, concrete blocks to store heat alongside a low cost, low temperature ice reservoir to store cold.

A Scottish based technology developer, SynchroStor, is developing a PTES system utilising its multi-cylinder reciprocating technology.

3.1.6 Liquid Air

Liquid air energy storage (LAES) technology uses compression to convert ambient air to a liquid which is stored in tanks. This can be carried out during periods of excess electricity on the grid and the resulting thermal energy, released during the compression process, is stored. When electricity is required, the liquid air is warmed, using the heat from the thermal store, and the resulting expansion from liquid to gas drives a turbine which produces electricity. The TRL of LAES is 9 for smaller scale demonstrator systems but 7-8 for larger scale more complex systems under development. In some reports, LAES is classed as a thermal storage technology.

LAES has reported efficiency of 80% and provides LDES of over 6 hours, with a company website claiming 12.5 hours.

One of the leading technology developers in LAES is Highview Power, based in England. . The company plans to design and build a 200 MW LAES at Hunterston in Scotland. The lifetime of a LAES system is approximately 35 - 40 years.

3.1.7 Compressed Air

Compressed air energy storage (CAES) facilities typically use an underground reservoir, such as a disused salt mine, to store pressurised air. In periods of excess electricity a compressor is used to push air into an underground cavern, where it can be stored. When required by the grid, the compressed air is released and drives a turbine to generate electricity.

There are three main types of CAES. Diabatic CAES requires natural gas (or similar fuel) to be used in the system, alongside the compressed air. These systems have relatively low efficiencies (~ 50%) as heat is lost to the environment. They have a response time of less than 60 seconds. This uses mature technology, with examples of commercial deployment of such systems in Germany and the USA, but none identified in the UK. Adiabatic CAES is a less mature technology, at TRL 7-8, which does not require natural gas to be used but requires higher capital cost compares to diabatic CAES. It can achieve efficiency levels of ~ 70%. Isothermal CAES uses heat exchange technology to increase process efficiency, with potentially higher levels of efficiency than the other technologies. However, it is less well developed that adiabatic CAES.

There are no examples of CAES systems being connected to the GB grid. However, the NESO Future Energy Scenarios for 2024 highlight that CAES is forecast to play a significant role in increasing installed LDES capacity from 2030 to 2050, alongside BESS, PSH and LAES.

3.1.8 Gravity

This category of energy storage works on the principle of converting excess electrical energy into potential energy by raising a heavy block and then lowering it to drive a turbine and generate energy at periods of low electricity availability. There are several pilot and demonstrator projects, including the Port of Leith project, operated by Scottish based technology developer, Gravitricity. The technology offers high levels of efficiency, under 1 second response rate and a lifetime of 50+ years. Gravitricity is the main company active in this supply chain in Scotland. At a global level, the US based company, Energy Vault, has connected a commercial scale gravity energy storage system to the grid in China. Compared to PSH, gravity energy storage systems claim a smaller environmental impact.

3.1.9 Superconducting magnetic

Superconducting magnetic energy storage systems store electrical energy in the magnetic field generated by the direct current in a superconducting coil. The coil is cryogenically cooled to a temperature below its superconducting critical temperature. Efficiency is high and the response rate is very fast. The main applications are improving power quality and grid stability at local level. No commercial deployment of grid scale superconducting magnetic energy storage has been identified. The technology is at TRL 7.

No Scottish supply chain companies were identified as being active in this area.

3.1.10 Flywheel

Flywheel energy storage systems can store excess electricity in the form of kinetic energy through the use of a rotating mass. To minimise friction, which leads to energy losses, the rotating mass is typically stored in a vacuum and magnetic bearings are used. Response time is within milliseconds and the equipment has a long lifespan. The technology is mature with a TRL of 9, with examples of commercial deployment including a 20 MW capacity flywheel in New York State, installed by Beacon Power. However, the primary purpose of this is frequency stabilisation rather than bulk energy storage. The capital costs of a flywheel energy storage system for bulk energy storage is high, relative to PSH and BESS.

No Scottish supply chain companies were identified as being active in this area.

3.1.11 Cryogenic

Cryogenic energy storage includes LAES. The Highview Power LAES system lists one of its component parts as a 'CRYOBattery'. LAES has already been discussed in section 3.1.6.

3.1.12 Supercapacitors

Supercapacitor (also known as ultracapacitors) systems involve storing excess electricity in the form of static discharge on the surfaces between an electrolyte and two conductor electrodes. It delivers an instantaneous response but is only able to provide power for a short duration (minutes), therefore, is used for very short-term energy supply. It is a mature technology. An example of a commercially available supercapacitor for grid-scale energy storage is provided by US company, Skeleton Technologies, which offers power quality and short term back-up power services.

No Scottish supply chain companies were identified as being active in this area.

4 Strategy and policy

The need for large scale energy storage capacity, to support a decarbonised electricity grid, is recognised by industry, government and regulators. It is essential to enable the economic benefits of investments in renewable energy generation, to increase security of energy supply and help insulate the UK from price spikes caused by external global factors. In the drive towards these objectives, a number of key strategies and policies are being developed and implemented to focus effort, overcome barriers and secure economic opportunities. A summary of some of the key strategies and policies are provided in the following section.

It is noted that energy (including electricity) is a specific reserved matter to the UK Parliament. As such, the regulation of electricity markets and the national grid and interconnectors is controlled by the UK Parliament. However, the Scottish Parliament does have control over setting renewable energy targets and policies, which is a key driver of demand for grid energy storage capacity. The Scottish Government also controls planning and consenting for energy infrastructure. At a local government level, the application of planning regulations takes place in the context of agreed spatial planning strategies.

4.1 UK Government

The Clean Power 2030 Mission is the key strategic energy plan, developed by the UK Government, aimed at increasing the security and affordability of energy, to help create new jobs in the energy sector and supply chain and reduce greenhouse gas emissions. It identifies the potential future grid capacities of different technologies and the actions required to help achieve them. The scope is the GB electricity grid, including Scotland, England and Wales.

The Clean Power 2030 Action Plan, published in December 2024, states the need for significantly higher levels of flexible storage capacity as a key objective. Along with new offshore wind, onshore wind and solar generation capacity, grid scale battery energy storage and long duration energy storage will be required alongside other flexibility technologies such as gas carbon capture utilisation and storage, hydrogen and consumer-led flexibility via virtual power plants. Overall, the action plan estimates that £40 billon of investment, on average, will be required per year between 2025 and 2030. Of this, £30 billion, on average per year, will be required for investment in generation assets and £10 billon for investment in electricity transmission network assets.

The action plan ambitions for increased capacity are set in the context of two potential pathways for future demand developed by NESO in its report, Clean Power 2030, commissioned by the Department for Energy Security and Net Zero (DESNZ). The two scenarios are established to meet the objective of a Clean Power grid by 2030. They are:

- New Dispatch
  - Growth in renewables but at a lower level compared to Further Flex and Renewables
  - Deployment of new low carbon dispatchable power (carbon capture and storage and hydrogen) alongside highest nuclear capacity
- Further Flex and Renewables
  - Highest levels of societal engagement with higher residential and industrial demand flexibility and more storage
  - Fast deployment of renewables (50 GW offshore wind), but no new dispatchable power

The estimated scale of future storage capacity requirements under each of these scenarios is shown in Table 3.

Technology	Current installed capacity	NESO 'Further Flex and Renewables' Scenario	NESO 'New Dispatch' Scenario	DESNZ 'Clean Power Capacity Range' (2030)	2035 FES-derived Capacity Range
LDES	2.9	8	5	4 to 6	5 to 10
Batteries	4.5	27	23	23 to 27	24 to 29

Table 3: Installed GB storage capacity in 2030 in the NESO Scenarios and the DESNZ 'Clean Power Capacity Range', compared to the current installed capacity (GW)

A technical annex to the Clean Power 2030 Action Plan quantifies the 'Clean Power Capacity Range' for LDES and battery storage for 2030 and also includes an estimate of the likely capacity required by 2035 (shown in the above Table 3). The 2035 figures are based on data published in the NESO Future Energy Scenarios 2024, with some modifications to projected onshore wind capacities to reflect the lifting of the moratorium on new developments in England. The 2035 capacities are interim estimates to help clarify the scale of projected capacity requirements post 2030. The technical annex also estimates the proportion of the new battery capacities likely to be located in Scotland:

- By 2030, it is estimated that installed battery storage in Scotland will be 7.5 GW (28% of the estimated total GB battery capacity, in 2030, of 27.1 GW)
- By 2035, it is estimated that installed battery storage in Scotland will be 7.6 GW (26% of the estimated total GB battery capacity, in 2035, of 28.7 GW)

No estimates were identified for the LDES capacity that expected to be installed in Scotland (Table 3 data relates to GB capacity), for 2030 and 2035. It is reasonable to assume that a significant majority of PSH capacity will be based in Scotland as most of the potential PSH projects are planned for Scottish locations. LAES investments are, relatively, more mobile than PSH as they do not require specific topography to be constructed.

The Clean Power 2030 Action Plan also compares the capacity of projects in the grid connection queue with current installed capacity and the capacity required under both NESO scenarios. This is summarised in Figure 2, below. It should be noted that this snapshot of the grid connection queue represents the situation prior to the planned reforms to the queuing system being developed by NESO. These reforms include proposals to introduce a Progression Commitment Fee, which would start at £2,500 per MW and increase by £2,500 every six months, capping at £10,000 per MW. This is intended to incentivise progress or exit from the connection queue.

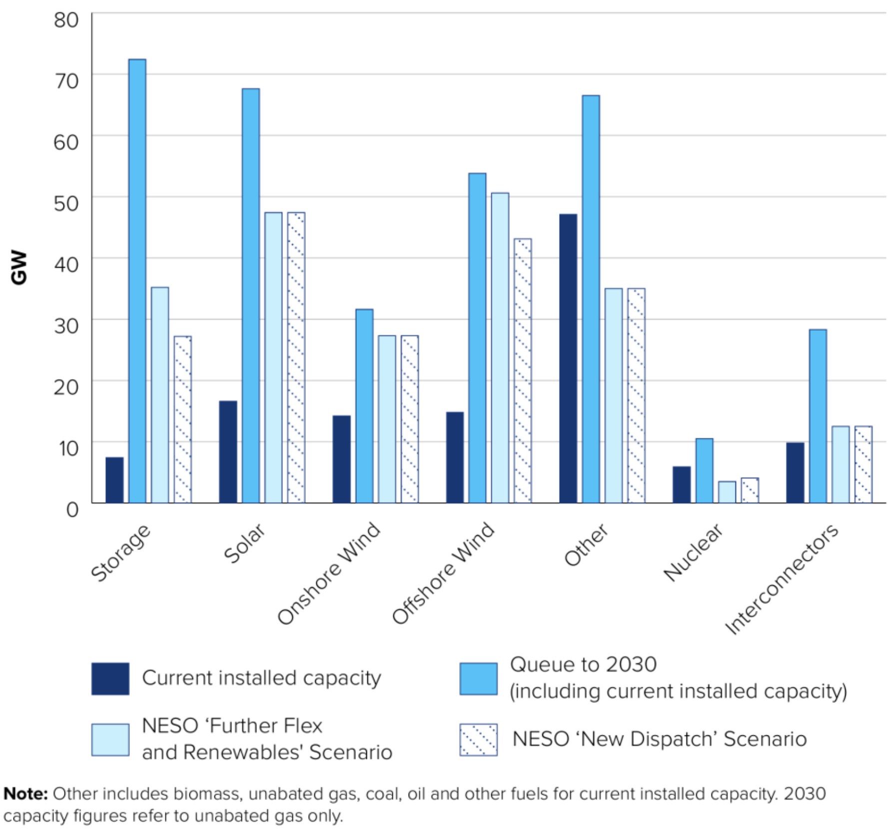

Figure 2: Current connections queue compared to current installed capacity and NESO Scenarios (GW) (Source: DESNZ, DUKES and NESO)

The connection queue to 2030 for storage is at least double either of the two NESO 2030 scenarios for storage capacity installed. Since there is significantly more planned capacity than either of the two future scenarios require, then it is reasonable to assume that not all planned storage projects will proceed.

The key enabling issues, acting as barriers to achieving the Clean Power 2030 Action Plan objectives, includes reforming the connection queue. This, and other issues, are summarised below.

Markets and investment

A consultation was launched in early 2024 about a cap and floor pricing mechanism. This seeks to guarantee a minimum and maximum revenue to LDES projects to lower investor risk and the subsequent cost of capital.

The consultation proposal to exclude lithium-ion from LDES is opposed by some in the industry who claim that lithium iron phosphate (LFP) can be competitive at this duration due to expected continuing reduction in the cost of LFP systems. One report states that LFP BESS has the potential to provide long duration storage of up to 10 hours by 2030. The NESO Clean Power 2030 report states that some of the stakeholders that were consulted anticipated that, with the reduction in battery costs, there could be BESS developed that can operate beyond a 2 to 4 hour duration. These stakeholders requested a clear definition of long duration energy storage in this context.

This projected reduction in battery cost could represent an investment risk for LDES projects using PSH or LAES technology, depending on the economic return of each project. However, some stakeholders consulted for this study highlighted additional grid services that PSH and LAES could provide that are not available from BESS. For example, the rotating equipment (turbines) used in PSH and LAES provide inertia services to stabilise the grid, something which BESS does not provide in the same way.

The technical decision document for the long duration energy storage cap and floor regime was published by the DESNZ and Ofgem in March 2025. This states that Ofgem expects to open the first application window in April 2025, with an indicative overall capacity range of 2.7 and 7.7 GW, coinciding with NESO's assessment that this range of LDES will be required by 2035. There will be two streams for applicants. Stream 1 is for proven technologies (TRL 9) with minimum project level capacity of 100 MW. Stream 2 is for emerging technologies (TRL 8) with minimum project capacity of 50 MW. The period of minimum duration has been set at 8 hours of continuous output at full power over the full cap and floor duration of 25 years.

Planning, consenting and communities

PSH facilities can have construction times of between three and seven years. The time taken to progress through the planning and consenting system is in addition to this and the concentration of potential PSH facilities in the Highlands of Scotland could be a potential constraint to planning applications progressing. Note that these developments are over 50 MW capacity so would be assessed by The Scottish Government Energy Consents Unit rather than Highland Council.

BESS have a typical deployment time of 12 to 24 months, once planning is approved and construction commenced. Timescales from submission of planning to operation are, on average, 42 months for standalone BESS and 36 months for projects collocated with renewables.

Connections reform

The grid connection queue is currently oversubscribed, compared to the projected energy storage requirements. As part of the Clean Power Action Plan, there has been a pause in new entrants to the queue whilst a revised policy is developed to reorder it to better meet the strategic objectives of Clean Power 2030. The queue was previously ordered in a 'first come, first served' basis. However, Ofgem and NESO have been tasked to reform the connection queue so that it is aligned with the strategic mix of technologies described in the Clean Power 2030 Action Plan. In April 2025, NESO reported that Ofgem had approved the connection reforms it had proposed in December 2024.

Availability of supply chain and workforce

PSH is a mature technology with established supply chains for equipment and civil engineering activity. However, there has been no PSH facilities constructed in the UK in over 40 years, so the main Teir 1 suppliers are all located outside of the UK. Industry stakeholders report that current global demand for PSH facilities is high and this is leading to lead times of up to four years for bespoke turbines to be supplied. The civil engineering work will require the use of local labour and this could be a constraining factor in the Highlands of Scotland, as there is projected to be several PSH projects ongoing at the same time.

LAES facilities are a relatively new solution and there is an opportunity to develop both supply chains and workforce in the UK that could benefit from growing global demand in future.

Stakeholder feedback suggests that BESS are typically sourced from the Far East and that it is difficult to find a cost competitive solution in Europe. There is, however, a supply chain opportunity in peripheral systems such as fire suppression and site security. As with the PSH opportunity, the jobs impact potential of BESS is in construction of the site, which is then unmanned except for a few visits per annum for operation and maintenance. There are supply chain opportunities in virtual optimisation of the BESS assets but these require remote operation and could be based in any location within or outside the UK.

Other activities being developed to support the delivery of the Clean Power 2030 Action Plan include:

- The Strategic Spatial Energy Plan – commissioned by the UK, Scottish and Welsh Governments, this GB wide plan is being developed by NESO to map potential locations, technologies and types of infrastructure (including storage) over time
- The Centralised Strategic Network Plan – a framework for identifying and assessing transmission investment options
- The Regional Energy Strategic Plans – NESO will co-ordinate regional energy network planning. By 2025/26 these will inform DNO business plans for 2028-33

4.2 Scottish Government

As mentioned previously, The Scottish Government has devolved responsibility for setting renewable energy policy and targets. Higher levels of renewable energy generation connected to the electricity grid is a key driver of increased demand for energy storage. In the Draft Energy Strategy and Just Transition Plan, published in 2023, The Scottish Government states an ambition for an additional 20 GW of renewable electricity to be developed by 2030. It also identifies energy storage as being an important element of the development of Scotland's own energy resources. It calls on the UK Government to support the development of PSH through a market mechanism and to make ancillary markets (e.g. frequency response services) more accessible for BESS ahead of fossil fuel powered alternatives.

The Scottish Government also has responsibility for planning and consenting of electricity infrastructure developments over 50 MW capacity, through the Electricity Act 1989. The Clean Power 2030 Action Plan states that the UK Government will seek to reform the current legislative framework for electricity infrastructure consenting with changes deployed by the Scottish Government. For example, amendments to The Electricity Act 1989 could help modernise and remove inefficiencies whilst giving communities and statutory consultees meaningful opportunities to influence applications for consent. In October 2024, The UK Government published proposals for reforming the consenting processes in Scotland under the Electricity Act 1989. This is being carried out in collaboration with The Scottish Government and outlines a multifaceted range of actions to efficiently and effectively improve the processes involved.

In addition, The Scottish Government has, in December 2024, published a consultation on community benefits from Net Zero energy developments. This consultation highlights examples of community benefit funds and proposals associated with PSH and BESS developments. It does note that BESS projects are not explicitly mentioned in the current Good Practice Principles for onshore renewable energy developments.

The Scottish Government is also responsible for national planning policy with the National Planning Framework (NPF4) setting strategic priorities. The stated policy intent of NPF4, in relation to energy is *'To encourage, promote and facilitate all forms of renewable energy development onshore and offshore. This includes energy generation, storage, new and replacement transmission and distribution infrastructure and emerging low-carbon and zero emission technologies including hydrogen and carbon capture utilisation and storage'*. This is aimed at achieving the policy outcome of *'Expansion of* *renewable, low-carbon and zero emissions technology'*. PSH and BESS are specifically identified, in Policy 11 of NPF4, as technologies to be supported.

For energy infrastructure developments under 50 MW capacity, the local authorities are responsible for planning and consenting, through the Town and Country Planning (Scotland) Act 1997. In February 2024, The Scottish Government published a consultation on Investment in Planning, setting out a range of options to improve the capacity of the Scottish planning system. This document highlights that Net Zero commitments are driving the need for planners to increasingly develop an understanding of new technologies and their impacts. It proposes the development of a centralised 'Planning Hub' resource to enable access to a variety of specialist and technical skills in new and evolving areas, including energy.

4.3 Local Government

Local authorities develop Local Development Plans that align with the National Planning Framework and also take into account strategic land use, zoning and infrastructure needs. These Local Development Plans provide an important reference document when assessing planning and consenting applications for energy infrastructure development for assets with capacity under 50 MW.

In some local authority areas the current Local Development Plans have yet to be fully updated (in the public domain) to reflect the policy intentions and outcomes of NPF4. In these cases, there is typically support for renewable energy but no specific mention of energy storage. Examples of this include the Local Development Plans for:

- Highland Council - Highland-wide Local Development Plan (2012)
- Glasgow City Council – Glasgow City Development Plan (2017)

There are also examples of Local Development Plans that have been updated to align with NPF4 and also specifically mention energy storage. For example, the Scottish Borders Local Development Plan 2, includes Economic Development Policy 9 'Renewable Energy Development'. This policy states that development proposals for energy storage, such as battery energy storage and pumped storage hydro will be supported.

It is reasonable to assume that, over time, all local authorities will update and publish Local Development Plans that align with NPF4 and be supportive of energy storage developments, either in the documents themselves or in supplementary planning guidance.

4.4 Industry

Transmission Network Operators (TNO) are responsible for the infrastructure that transports high voltage electricity from electricity generators to substations within their regional areas and between other UK transmission networks.

The business plans of TNOs commit to planning investment to align with the pathways to Net Zero modelled by NESO and UK and Scottish Government ambitions for renewable energy deployment. Examples of these TNO business plans include the SP Energy Networks (Central and Southern Scotland region) 2026 to 2031 plan, 'How we get there – 5-year plan for transforming what our transmission network delivers' and the Scottish & Southern Electricity Networks (Northern Scotland) 2026 to 2031 plan, 'Delivering a Network for Net Zero: The Pathway to 2030'. These business plans are aligned with the Clean Power 2030 mission.

Investment in specific energy storage facilities is funded and carried out by various companies in the private sector. They are responsible for identifying sites, carrying out feasibility studies, producing detailed designs, raising finance, procuring equipment and services and constructing and operating energy storage assets. Typically, this involves collaborations across the supply chain. These companies will have their own internal business strategies but these are usually confidential and not available in the public domain. However, the over-subscription to the NESO connection queue suggests a very buoyant market for energy storage in the UK and globally.

5 Nature and scale of the market

The nature and scale of the market is assessed at global, GB and Scottish levels.

5.1 Global market

The global grid-scale energy storage market is experiencing rapid growth, driven by the increasing integration of renewable energy sources and the need for grid stability and reliability. This expansion varies across different regions and is influenced by local policies, technological preferences, and market dynamics.

In terms of technology area, PSH was the largest segment of the global market in 2023, with an installed capacity of around 180 GW. The International Hydropower Association (IHA) estimates that a growth rate of 26 GW per year is required to stay on track with net zero targets. In terms of market value, this varies between sources, as noted previously, with estimates ranging between $45.95 billion and $224 billion, however, all agree that the segment is projected to at least double in market value over the period to 2030.

Battery energy storage, however, is expected to be the fastest growing segment of the energy storage systems market going forward. The global grid-scale battery for energy storage systems market was valued at around $10.07 billion in 2023 and is estimated to be worth around $48.71 billion in 2032, a CAGR of 19.14%. This represents significant growth opportunities for companies and supply chains.

The global thermal energy storage market was valued at $4.94 billion in 2023 and is estimated to grow to $7.8 billion by 2028, an increase of 59% on 2023 figures[1]. Grid-scale systems are, however, the smallest segment, at around 28.6% of the overall market in 2023, but is expected to increase its share slightly by 2028. The market is made up, primarily, of molten salt energy storage and phase change materials, with molten salt energy storage dominating the market with almost 85% market share in 2023. This share, however, is expected to decrease to around 83.6% of the global thermal energy storage market by 2028.

Another relevant segment of the market is flywheel energy storage, the value of which varies by source ranging from $396 million[2] to $431 million in 2023 but is widely expected to grow, reaching around $620 million by 2028 and up to $1.5 billion by 2032. These systems serve various applications, including grid stability, renewable energy integration, uninterruptible power supplies (UPS), transportation, and data centres. In 2024, the grid-scale segment is believed to have accounted for around 56% market share.

[1] Global Thermal Energy Storage Market 2024-2028 (Technavio, 2024)

[2] Global Flywheel Energy Storage Market 2024-2028 (Technavio, 2024)

The global adoption of these grid-scale energy storage systems is being shaped by a range of different factors, from the rapid expansion of renewable energy to advancements in battery technology, grid modernisation, regulatory reforms, and the increasing need for energy security. While many of these drivers apply universally, Europe and the UK, for example, have specific regulatory, economic, and energy system factors that create unique demands for different storage technologies.

At a regional level, Asia-Pacific is currently the largest region in the wider energy storage systems market, accounting for around 47% share, with countries like China, South Korea and India driving demand due to their growing renewable energy sectors and energy storage needs. China not only leads the world in battery capacity and development, but it is also building out large amounts of thermal energy storage linked to concentrated solar power plants. China's grid-scale battery storage capacity experienced significant growth between 2022 and 2023, increasing from 7.8 GW in 2022 to 27.1 GW in 2023, an addition of approximately 19.3 GW within that period. This substantial growth reflects China's aggressive renewable energy targets and governmental support for energy storage initiatives. China also maintains global leadership in PSH, operating approximately 50 GW of capacity in 2023, with ambitions to increase this capacity to 120 GW by 2030.

The United States leads the North American market in lithium-ion battery storage, driven by federal incentives like the Inflation Reduction Act (IRA) and ambitious state-level renewable energy targets. As of 2023, the U.S. has 575 operational battery energy storage projects totalling 15.9 GW of rated power. Projections indicate that U.S. battery energy storage capacity could reach nearly 150 GW by 2030. PSH remains significant but faces limited new developments due to environmental permitting challenges and geographical constraints.

Europe's grid-scale energy storage landscape is diverse, influenced by varying national policies and renewable resource availability. Pumped storage hydro remains significant in countries like Norway, Austria, and Switzerland, benefiting from favourable topography and established hydropower infrastructure. Norway, for instance, has installed capacity for PSH of approximately 1.37 GW, as of the latest available data[3]. However, it's important to note that Norway has significant technical and geographical potential to substantially increase its PSH capacity, leveraging its extensive natural reservoir systems and hydropower infrastructure. Austria's PSH capacity stands at around 3.48 GW, while Switzerland's is approximately 1.44 GW.

The uptake of battery storage in Europe has expanded rapidly, particularly in Germany and the UK, driven by ambitious renewable energy goals. Germany's Energiewende policy, for example, has significantly boosted battery storage deployment to support renewable integration and grid balancing. In 2024, Germany increased its grid-connected battery capacity by 30% to compensate for fluctuations caused by the rise in renewable energies, which supplied 60% of the country's electricity in the first half of that year. Southern European markets, on the other hand, including Spain and Italy, tend to prioritise thermal energy storage (TES) and lithium-ion battery solutions primarily for solar energy storage, due to high solar irradiance and corresponding energy storage needs during evening peaks.

In Africa, grid-scale battery storage is being deployed, primarily in renewable energy projects, notably in South Africa and Morocco, although at relatively small scale compared to other regions. The Middle East, particularly the UAE and Saudi Arabia, increasingly integrates battery and thermal energy storage

[3] Global Battery for Energy Storage Systems (ESS) Market 2024-2028 (Technavio, 2024)

solutions within large-scale solar power developments to enhance grid stability and ensure reliability during peak demand periods. East Africa, on the other hand, holds significant pumped storage hydro potential, yet it remains largely unexploited due to infrastructure, economic, and regulatory challenges.

The global grid-scale energy storage market is clearly growing rapidly, with regional technology preferences influenced by national policies, renewable energy goals, economic incentives, and geographic considerations. While PSH remains significant, battery technologies, especially lithium-ion, increasingly dominate new installations. Long-duration storage solutions continue to gain momentum, reflecting the need to manage renewable intermittency and seasonal energy demands effectively.

5.2 GB market

The UK is expected to see substantial investment in grid-scale energy storage systems by 2030, with total investments in UK utility scale battery storage anticipated to reach approximately £16.15 billion ($20 billion). It is believed that this level of expansion will give the UK around 9% share of all global capacity installations, sitting behind China, the US and Germany. The UK's ambitious energy storage targets and the installation of more solar and wind energy infrastructure increases the need for reliable storage solutions to deal with the intermittent nature of these renewable sources. Within the battery energy storage system market, lithium-ion batteries are expected to dominate due to their cost-effectiveness and improved life-cycle. It is anticipated that lithium-ion batteries will make up around 90% of grid-scale installations by 2030.

According to NESO's most recent Future Energy Scenarios, GB currently has an operational battery storage capacity of 4.7 GW, whereas for long duration storage there is an installed capacity of 2.7 GW. Long duration storage is predominantly driven by PSH systems. This gives a total current capacity for energy storage in GB of 7.4 GW.

The current GB connection queue for energy storage has projects with total capacity of approximately 65 GW. This is more than double the projected additional power capacity range required by 2030, defined by DESNZ, of between 19.6 and 25.6 GW (combined battery and LDES). It is also important to note the NESO connection queue does not include all grid-scale energy projects in the pipeline. During our research, we compared the projects with the NESO connection register for Scotland with the grid-scale energy storage projects identified by the Global Data Power database, accessed via Scottish Enterprise. There were a significant number of grid-scale energy storage projects found in the Global Power Database that were not in the NESO connection register. The Global Data Power database captures projects at an earlier stage of development, prior to them approaching NESO with a request to be added to the queue. This means that the statements of overcapacity in pipeline grid-energy projects actually understates the true value of all such projects in the pipeline.

5.3 Scottish market

Data for installed and upcoming grid-scale energy storage in Scotland was taken from the NESO embedded register and the Global Data Power database made available from Scottish Enterprise[4]. Projects were deduplicated between the two data sources and a combined spreadsheet of grid-scale

[4] The Global Data used for this project was supplied directly by Scottish Enterprise and is not available in the public domain

energy storage projects was analysed. This section analyses data on both current capacity and future capacity.

5.3.1 Current capacity

The current installed capacity of Scottish energy storage was valued at 1,134 MW. It is noted that a small number of records did not have data for installed capacity. This, however, only impacted 2.3% of projects, therefore the data presented can be regarded as reasonably accurate.

The current installed capacity, by technology, is shown in Figure 3, below.

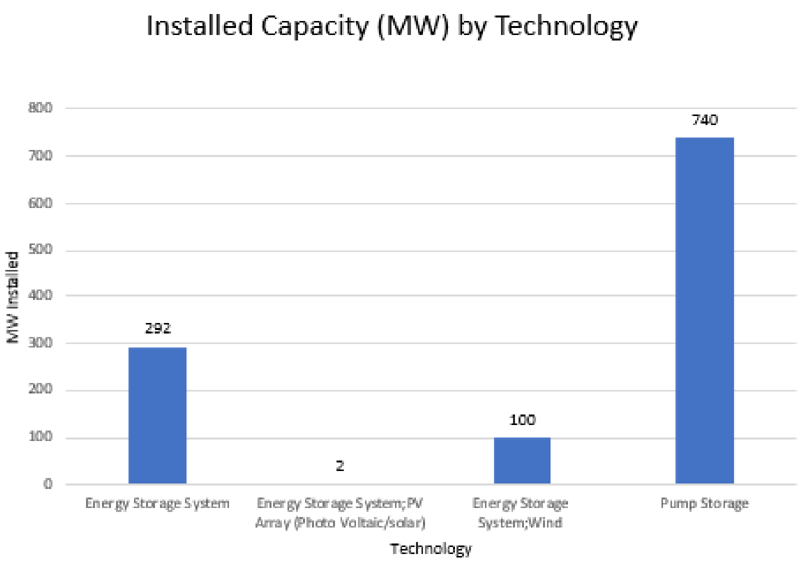

Figure 3: Current installed capacity in Scotland by technology type

PSH technology currently contributes the highest number of MW by a significant margin, making it the dominant form of energy storage. In this context, the term "Energy Storage System" specifically refers to battery storage solutions, which are typically lithium-ion battery systems. There are some small capacity exceptions to this, including three flow battery systems and one gravity storage system, including the Isle of Gigha Flow Battery Project at 0.1 MW and the Leith Gravity based Energy Pilot Project at 0.25 MW. In addition, as evident from Figure 3, there are also operational systems that integrate battery storage with other renewable energy generation technologies, such as solar PV and wind energy, creating hybrid solutions.

5.3.2 Future additional capacity

The total capacity of pipeline projects, identified in Scotland, is 24.6 GW, with the total capacity by 2036, therefore, coming to 25.7 GW, which includes PSH, energy storage systems, and energy storage systems combined with renewables. The capacity of projects in the pipeline for energy storage systems and PSH systems is shown in Table 4, below.

	Current Installed Capacity (MW)	Current Pipeline Capacity (MW)	2036 Total Capacity (MW)
Energy Storage System	292	11,962	12,254

	Current Installed Capacity (MW)	Current Pipeline Capacity (MW)	2036 Total Capacity (MW)
Pumped Hydro Storage	740	11,093	11,833
Energy Storage Systems with Renewables	102	1,519	1,621
Total	**1,134**	**24,574**	**25,708**

Table 4: MW capacity figures for current installed capacity, current pipeline capacity and projected total capacity by 2035 (if all pipeline capacity is installed)

Most (77%) of the data gathered on future grid-scale energy storage projects includes the year it is projected to become operational. The stage of the projects is also defined as either 'scoping' or a more advanced stage of 'planning/planned'. The annual capacity coming online, by current project stage, is shown in Figure 4, below.

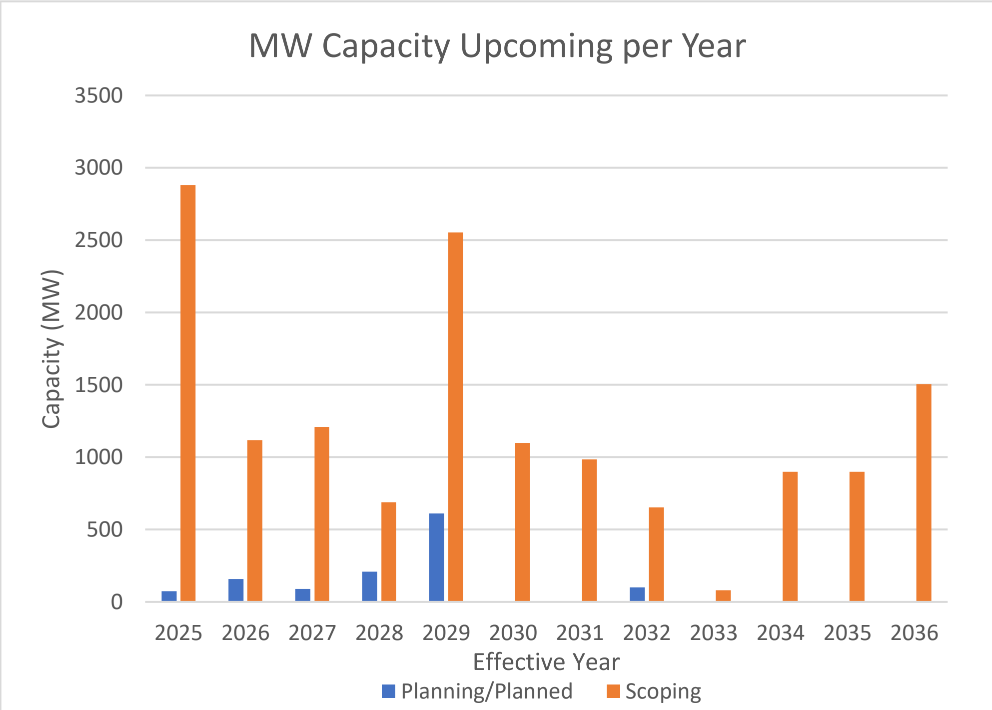

Figure 4: MW Capacity increase from projects per year by project stage

It is clear from this that a substantial amount of energy storage is set to come online starting in 2025, through to 2036. As can be seen from the graph, there is a spike in capacity in 2029, which can be partially attributed to the Coire Glas project, phases 1 and 2, which are due to come online that year.

The annual projected connection capacity can also be shown by technology type, as illustrated in Figure 5, below.

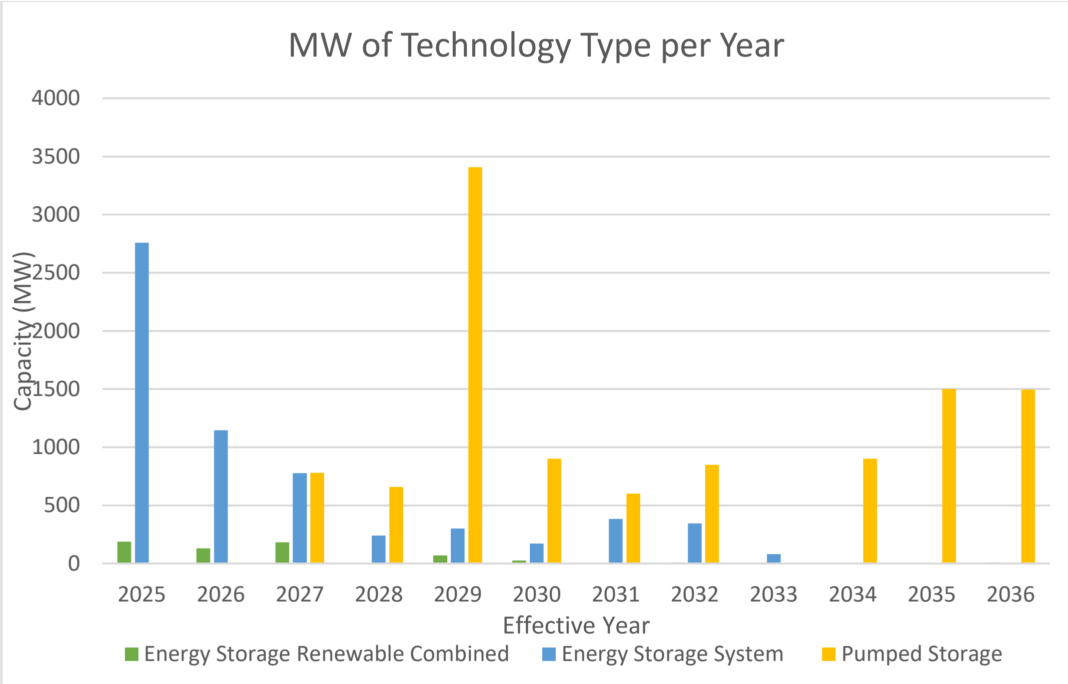

Figure 5: MW Capacity increase from projects by Technology Type

Figure 5 demonstrates that energy storage systems, which are predominantly lithium-ion BESS systems, will come online faster than the PSH projects. This is consistent with earlier Table 3, showing the Clean Power 2030 Action Plan estimates for timing of additional capacity for LDES and BESS.

Projects can also be mapped according to the Local Authority area in which they are, or will be, connected. According to the data, current installed capacity of energy storage is distributed across Scotland, with the areas with the highest installed capacity being the Highlands, Argyll and Bute, and Fife, shown in Figure 6. In the Highlands, this can be largely attributed to the Foyers Hydro Scheme operated by SSE Renewables. In Argyll and Bute, the Cruachan 1 project, operated by Drax Global, is a significant contributor. This project is due to be expanded with the 600MW Cruachan Expansion, by 2030.

Other local authorities including Shetland Islands, West Lothian, Perth and Kinross and Dundee City also have installed capacity as of 2025.

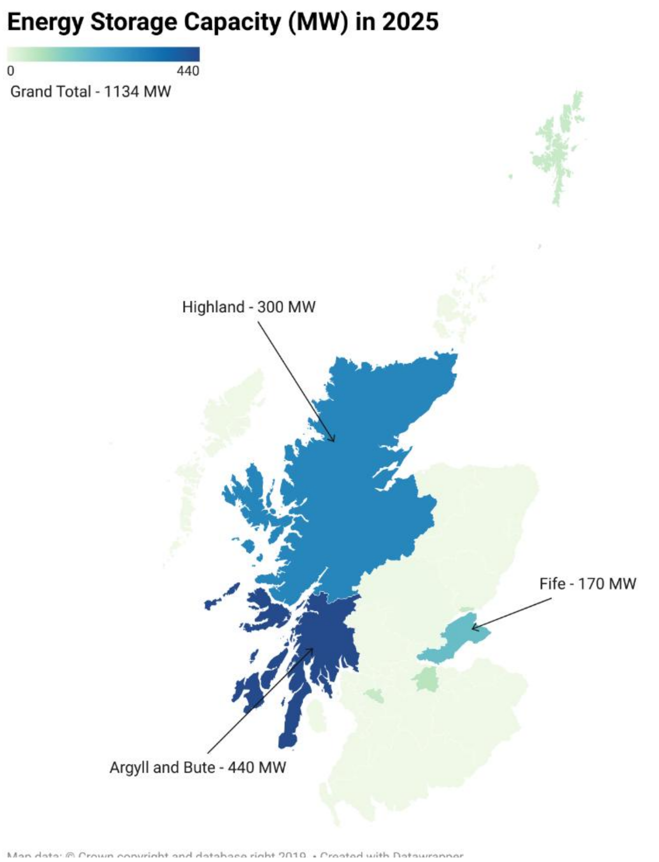

Figure 6: Map of Scotland showing current energy storage capacity by Local Authority areas

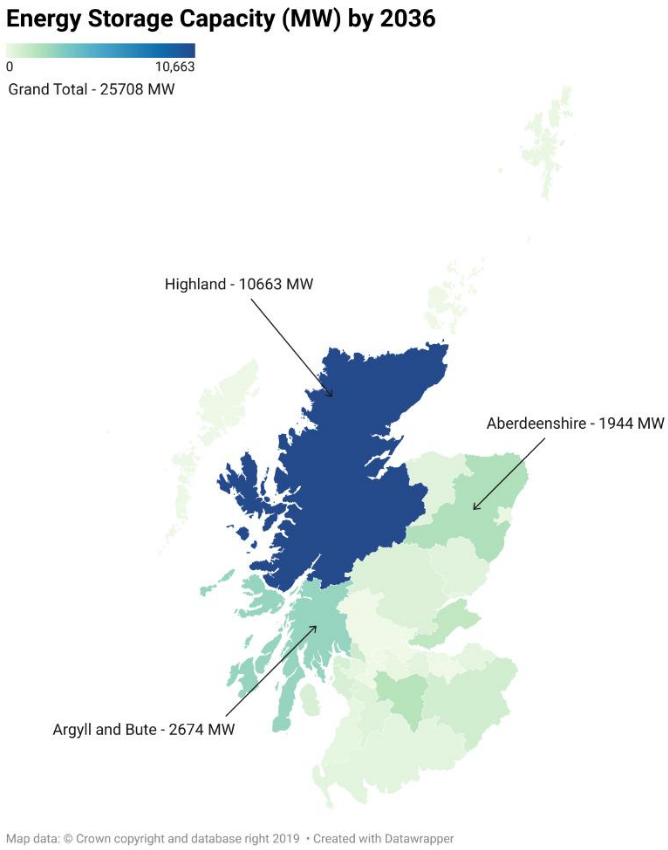

Figure 7: Map of Scotland showing energy storage capacity by 2036 by Local Authority areas

Grid-scale energy storage projects will continue to be developed, across many different local authority areas. Looking ahead to 2036, a further map has been developed to illustrate the projected capacity, by local authority. It should be noted that the location of the anticipated grid network connection station has been used to allocate a project to a particular local authority area, rather than the location of the energy storage facility. This was necessary due to a significant lack of information about the actual location of planned facilities.

By 2036, energy storage capacity is expected to increase significantly across all local authorities. While storage capacity by 2036 will be widespread, Highland Council is set to have the highest overall capacity. Argyll and Bute, Aberdeenshire and several other areas, are also projected to see significant growth.

6 Energy storage as an opportunity for the Scottish economy

This section examines the supply chain companies with locations in Scotland, the Scottish academic and research organisation research and development capabilities, relevant to grid-scale energy storage and an analysis of the potential economic impact over the next ten years.

6.1 Scottish company supply chain capabilities

Research has identified 76 energy storage supply chain companies with locations in Scotland. The capabilities of each have been categorised in terms of the energy storage technologies they are active in, or have the potential to become active in, and the segments of the supply chain they occupy. Please note that the numbers in Figure 8, below, do not sum to 76, as some companies are involved in more than one technology area and/or are in more than one segment of the supply chain.

To aid the interpretation of Figure 8, it is important to note the following:

- Some companies included in the database of supply chain companies are only involved in grid energy storage. More typically, grid energy storage formed only part of the revenue streams of the company
- The data relates only to numbers of companies and does not reflect their size

- The data includes companies that are both already active in grid energy storage and those with the potential to become active in future. The majority of entries relate to companies that are confirmed as already active in grid energy storage

Energy Storage Technology	Supply chain segment (numbers of companies)						
	Parts, components or systems	Original Equipment Manufacture	Developer	Project design engineering, project management	System installation, commissioning, operation & maintenance	Decommissioning	Other
Pumped Storage	0	0	8	9	4	0	1
Battery - lithium ion	4	4	33	26	16	3	5
Battery - sodium sulphur	0	0	0	0	0	0	1
Battery - Flow	0	3	0	4	3	0	1
Thermal	1	1	1	2	2	1	1
Compressed Air	1	0	0	2	1	1	1
Liquid Air/Cryogenic	1	0	1	1	1	1	1
Gravity	0	1	0	1	0	0	1
Superconducting magnetic	0	0	0	0	0	0	1
Flywheel	0	0	0	0	0	0	1
Supercapacitors	0	0	0	0	0	0	1

Key:

No companies
1 to 2 companies
3 to 10 companies
11 to 19 companies
Over 20 companies

Figure 8: Number of Scottish supply chain companies by segment and technology

By inspection of the above figure, it is clear that the supply chain for lithium-ion battery grid-scale energy storage systems is the most well populated, compared to other technology supply chains. There is strong company presence in the service aspects of this supply chain, such as developers and project design engineers/project managers. There are also some capabilities in manufacturing of parts, components, systems and original equipment.

Pumped storage hydro also has some presence in the service aspects of its supply chain but no manufacturing capabilities were identified.

The flow battery supply chain can be regarded as emerging and the presence of three manufacturers is encouraging, from and economic development perspective.

6.2 Scottish academic and research organisation R&D capabilities

Significant research is being carried out into energy storage across universities and other research centres in Scotland. The UKRI funding database, Gateway to Research, was utilised, using keyword searches including "battery" "supercapacitor" and "flywheel", amongst others, to identify the key researchers and universities within the space. Through this, a list of key universities was identified, which had either carried out, or were currently carrying out, UKRI funded research into relevant technologies. The universities that had the highest number of projects were the University of Glasgow; the University of Edinburgh; the University of St Andrews; the University of Strathclyde; Heriot Watt University; and the University of Aberdeen. Further detail about these research capabilities is included in an Excel-based dataset that accompanies this report.

Each university has its own focus and methods for research into energy storage. The University of Glasgow, for example, has a range of research groups focusing on innovations to combat climate change. Research from the Gregory Group is focused on the design and discovery of new energy materials with applications in batteries, fuel storage, gas purification/capture and thermoelectric devices. Further, the Glasgow Electrochemistry on Solids (GECOS) Group works on solid state materials, investigating their potential use in energy conversion and storage, including electrocatalytic water splitting, battery applications and CO_2 conversion.

The University of Edinburgh highlights "Energy Storage and Carbon Capture" as one of its key Research Themes within its School of Engineering. The aim of this theme is to develop cost-competitive technologies for electricity and thermal storage. Work ranges from developing new storage technologies to integration of technologies into the wider energy system. Storage technologies that are, or have been investigated, include CAES, ocean renewable energy storage (ORES), power-to-fuel and thermal energy storage.

The University of St Andrews hosts the JTSI Group, which has a diverse, but unifying, theme in Energy Materials. Current areas of research include electrochemistry, batteries, fuels cells, and materials, amongst others, with the aims of tackling global warming and energy security. The group states that a critical component of the solutions to these issues is the implementation of new, disruptive energy technologies, reshaping the energy economy. From the UKRI database a significant amount of research is being, or has been, carried out into batteries and battery materials. The University of St Andrews' Eden Campus is home to a fuel cell development and production site, a rapid prototyping centre, as well as a battery scale up facility.

The University of Strathclyde has set up the Energy Systems Research Unit (ESRU), which is a cross-disciplinary research group concerned with new approaches to built environment energy utilisation and the introduction of sustainable energy at various scales. The university has significant capability and carries out research across various areas including energy resources and conversion.

Heriot Watt University is home to the Electrochemical Energy Conversion and Storage Lab (EECS Lab), which is part of the nESSI research group at the Institute of Mechanical, Process and Energy Engineering. Research topics include electrochemical energy storage and conversion system and device design, for example solar-rechargeable redox flow batteries (SRFB), redox flow batteries with thermally regenerative electrochemical cycles (TREC), and photo and electro-chemical device architecture. Heriot Watt also runs the Research Centre for Carbon Solutions (RCCS), which largely focusses on carbon capture, utilisation and storage, but also has a research theme focusing on energy materials and technology. In this group, researchers focus on manufacturing nanoscale materials and composites for use in a wide range of energy conversion and storage devices, alongside integration with energy systems.

Finally, as part of their Interdisciplinary Institute, the University of Aberdeen sets out multiple interdisciplinary challenges - including Energy Transition. This research challenge provides a focus for all areas of energy related research, with an emphasis on supporting industry and policy makers in the transition to clean, sustainable energy and renewables.

There are also groups that bring together expertise across academia and research in Scotland, that are not aligned with one specific university. The Scottish Universities Physics Alliance (SUPA) is a group made up of academics, research staff and post-graduate students across nine universities in Scotland. The group has multiple research themes, one of which is energy. This includes energy storage. Scotland Beyond Net Zero is another alliance of Scottish universities. This coalition is designed to catalyse research collaboration across all academic disciplines, with multiple research themes including energy.

Scotland is also home to multiple research groups and facilities that build capability in energy storage research and development. The Power Networks Demonstration Centre (PNDC) is part of the University of Strathclyde, with its aims being the advancement of power networks, decarbonisation of transport, and decarbonisation of heat. The PNDC is a whole energy system research, test and demonstration facility supporting material contributions to the realisation of net zero emissions. It is an open-access facility and engages with the wider innovation infrastructure through various collaborative models, working closely with government, industrial and academic partners.

The Energy Technology Centre provides support across the low carbon energy sector, including energy storage, and runs the Renewable and Low Carbon Energy Test Facility. This is a testing facility for a range of new technologies across renewables and sustainability, with capabilities in energy storage development.

6.3 Economic impact potential

The projected growth of grid-scale energy storage will have positive impacts on Scottish jobs and gross value added (GVA). In seeking to quantify the scale of these economic benefits, two different methods have been used.

Firstly, a '**top-down**' approach, where illustrative data about jobs and GVA associated with PSH construction and operation is summarised from a detailed report produced by Biggar Economics for Scottish Renewables. This report describes the economic impacts associated with six potential new PSH facilities that are planned for construction by 2034 and have a total output capacity of 4,900MW. Estimates of jobs impacts associated with BESS construction are also made using data identified on 'jobs per MW capacity installed' for a sample of BESS projects. Finally, an estimate of construction jobs associated with LAES is also provided, based on public data about the proposed development at Hunterston.

Secondly, a **'bottom-up'** approach was used, taking current and projected company level jobs data from our study survey sample and using this to estimate jobs and GVA impact for the total population of companies identified in the supply chain. This approach is based on a supply chain that does not include jobs associated with civil engineering. Instead, it focuses on companies involved in: parts, components and systems manufacture; original equipment manufacture; project design engineering/project management; system installation/commissioning/operation & maintenance and; decommissioning. The GVA estimates are generated from the jobs data, combined with company level GVA per head data, published by the Scottish Government.

The estimates derived from these two approaches is discussed below.

6.3.1 Top-down jobs and GVA estimates – including civil engineering

A report by Biggar Economics, for Scottish Renewables, on the estimated economic impacts of six potential new PSH facilities in Scotland, provides useful insights into jobs and GVA impacts. Key findings relevant to this study include:

- The combined output capacity of the six PSH projects investigated equates to 4,900MW
- Typically, the development and construction capital expenditure is, mainly, focused on civil engineering contracts (69% of capital expenditure), with other contracts including development and planning (<1%), equipment (19%) and other spending (12%)
- Most of the civil engineering expenditure (77%) is estimated to be spent in Scotland, with development and planning expenditure also being, mainly, spent in Scotland (77%). 60% of other spending but only 4% of the overall equipment expenditure will also be spent in Scotland. This low level of Scottish equipment expenditure indicates a reliance on imported equipment and is reflective of the lack of new build PSH facilities in the UK in the last 40 years. Instead, the turbine, and most other equipment manufacturing, takes place overseas. Even though more than three quarters of the civil engineering expenditure takes place in Scotland, stakeholder feedback is that the main contractors will, typically, be based outside of the UK and will utilise local sub-contractors to carry out activities such as spoil removal and transport from site
- During the construction period of the six PSH projects, the total number of temporary jobs would peak between around 5,000 and 6,900 (rounded to the nearest hundred). This includes direct jobs in contracted companies, additional jobs in their supply chains arising from the PSH development and construction work (indirect impacts) and the additional jobs created through increased spending of wages in the Scottish economy by these additional workers (induced impacts)
- During the construction period, the total additional GVA to the Scottish economy (direct, indirect and induced) is projected to be between £2,300 million and £3,200 million. It is reasonable to assume that the majority of jobs and GVA from the construction phase of the PSH facilities will be associated with the civil engineering work
- The operation and maintenance of the six PSH facilities would require 500 additional jobs on an ongoing basis. This is a mix of direct, indirect and induced employment
- During the operation and maintenance phase of the PSH facilities, the annual GVA (direct, indirect and induced) is projected to be £29 million

The additional PSH output capacity of 4,900MW, by 2034, from the six projects included in the Biggar Economics report, can be considered in the context of:

- The pipeline of PSH projects in Scotland, identified by our study, is 11,100 MW by 2036, with 5,700 MW of this anticipated to be online by 2030
- The NESO/DESNZ capacity ranges for increased long duration energy storage, at a GB level, of between 1,100 MW and 3,100 MW by 2030 and between 2,100 MW and 7,100 MW by 2035

Although there are other technologies capable of delivering long duration energy storage, PSH is likely to deliver the majority of this requirement. It is noted that the 4,900 MW additional output capacity described in the Biggar Economics report is at the approximate mid-point of the NESO LDES 2035 capacity range.

It is also noted that the level of PSH output capacity currently in the pipeline of 11,100 MW, identified during this study, far exceeds the top end of the NESO 2035 capacity range for LDES (7,100 MW). Therefore, it is very unlikely that NESO would grant connections to all the PSH capacity in the pipeline to the period 2035.

The PSH output capacity described in the Biggar Economics report provides better alignment with NESO 2035 capacity range for additional LDES. Therefore, the additional jobs and GVA associated with the six PSH projects described in the Biggar Economics report are indicative of the scale of Scottish economic impact that could arise from deployment of this energy storage technology, assuming most of the required additional LDES will be located in Scotland.

The other main technology expected to be deployed is BESS. Inspection of the pipeline of energy storage system projects identified during this study highlights that:

- There is an existing installed capacity of energy storage systems (mainly BESS) in Scotland of just under 300 MW
- There is 12,000 MW of energy storage system capacity, in Scotland, projected to be online by 2035, most of which will be BESS technology (lithium-ion). There will also be smaller levels other technologies in this total, such as flow batteries and LAES

It is useful to compare this with NESO capacity ranges for battery energy storage identified for Scotland:

- By 2030, Scotland is projected to have battery energy storage capacity of 7,500 MW (which is 28% of the total projected GB battery capacity of 27,100 MW)
- By 2035, it is estimated that installed battery storage in Scotland will be 7,600 MW (26% of the estimated total GB battery capacity of 28,700 MW)

From the above NESO projections, it is clear that almost all of the additional battery energy storage capacity is anticipated to be in place by 2030.

It is also clear that the 12,000 MW of energy storage systems in the pipeline for Scotland, identified during our study (mainly consisting of BESS), significantly exceeds the NESO projection for installed battery storage in Scotland of 7,600 MW. This means that it is very unlikely that NESO will consent to all of the 12,000 MW of energy storage systems being connected to the grid. This is the same situation as described earlier for PSH.

During the research on BESS for this study, a number of sources were identified from desk research that provided an indication of a job per MW installed for this technology. For example:

- Pacific Green 249MW BESS - 56 jobs in construction and operation, equivalent to 0.22 jobs per MW
- Teesworks 100MW BESS – 100 jobs during construction (12 months) 1 job per MW
- E.ON 115MW BESS – 140 jobs in 2024 (project started in 2023 and expected to be operational in first quarter of 2025) – 0.82 jobs per MW

There are a range of 'jobs per MW' factors identified. It appears that the higher the output capacity, the lower the jobs per MW figure. This is reflective of economies of scale as the system size increases. There is also a difference in two of the figures as one relates to 'construction' and one to 'construction and operation'. It is also not clear whether these estimates of jobs are based solely on direct impacts or whether they also include indirect and induced impacts.

The average BESS project identified during this study had output capacity of 85MW. This is lower than any of the examples provided above, but similar in size to two of them. An estimate of 0.89 jobs per MW installed has been used, based on the above examples combined with feedback received during the company consultations. This can then be applied to several capacity figures to provide an indicative, top-down, estimate of the numbers of jobs:

- Considering the total pipeline of energy storages system projects identified during this study (mostly assumed to be BESS) of 12,000 MW by 2035, then this would result in a total of 10,700 temporary construction jobs. Most BESS projects are 12-24 months in duration
- The Scottish pipeline of 12,000 MW is significantly higher than the NESO/DESNZ estimated Scottish additional BESS capacity by 2035 of 7,300 MW. If the 7,300 MW figure is used in conjunction with the 0.89 jobs per MW factor, then the estimated total number of temporary construction jobs required to deliver the BESS facilities is 6,500

Stakeholder feedback suggests that jobs associated with operation and maintenance of BESS facilities are limited, as there are typically no onsite staff required. Operations and maintenance requires service and maintenance visits on a few occasions per year, alongside landscape gardening activity. The asset optimisation services also contribute to employment, although this is carried out remotely and the Scottish content is unclear. There are, however, Scottish supply chain companies that do offer this service.

In addition to PSH and BESS, research also identified the new LAES plant that is planned for Hunterston. This will provide long duration energy storage capacity of 200 MW. Construction of the facility will create 1,000 jobs onsite and 650 jobs in the supply chain.

6.3.2 Bottom-up jobs and GVA estimates – not including civil engineering

In addition to the above top-down estimate of economic impacts, we also carried out a company survey to provide evidence for a bottom-up calculation of current and future jobs and GVA.

As previously discussed, the scope of this study does not include the civil engineering or construction activities of the energy storage facilities. The supply chain segments included in this study were described earlier in Section 6.1. Therefore, the results of the bottom-up jobs and GVA estimates are not directly comparable with the top-down analysis.

A total of 76 companies were identified as being part of the grid-scale energy storage supply chain, with office locations in Scotland. Of the 20 interviews carried out, data on current and future grid-scale full time equivalent (FTE) employment was obtained from a sample of 13 companies.

Jobs

Data from the sample of 13 companies was used to estimate an average (mean) number of jobs per company. This calculation removed outliers, to avoid companies with larger numbers of grid-scale energy storage employees skewing the calculated average. The average value was then multiplied by the total number of companies in the population, less the number of outliers. The total number of jobs in outlier companies was then added back to the calculation. Using this method, an estimate for the current FTE jobs in the grid-scale energy storage supply chain was calculated to be 1,000 (rounded to the nearest hundred).

During the survey, companies were also asked to estimate the number of FTE grid-scale energy storage employees ten years from now. The same methodology was used to estimate the future FTE jobs for the whole population. This resulted in an estimate of grid-scale energy storage FTE jobs in 2035 of 3,500 (rounded to the nearest hundred).

Comparing current and projected future FTE job figures identifies that Scottish grid-scale energy storage supply chain FTE jobs are forecast to grow by 247% over the ten-year period to 2035.

GVA

Using the company level jobs data, an estimate of the company level, annual GVA generated by the supply chain can also be made. For each company providing jobs data, the two digit Standard Industrial Classification (SIC) code was identified from Companies House. The Scottish Government's Scottish Annual Business Statistics (SABS) 2022 dataset was used to identify 'GVA per head' figures for each relevant two digit SIC code. An average for the sample was calculated, taking into account outlier data. The average was multiplied by the total number of companies in the population, less the number of outliers, and then the outlier data added back into the calculation. Using this method, an estimate of current GVA for the Scottish grid-scale energy storage supply chain was calculated to be £69 million.

The same methodology was used to estimate the future annual GVA for the whole population. This resulted in an estimate of grid-scale energy storage annual GVA in 2035 of £304 million.

Comparing current and projected future annual GVA figures identifies that Scottish grid-scale energy storage supply chain annual GVA is forecast to grow by 340% over the ten-year period to 2035.

Further details about the economic impact methodology used in this study can be found in Appendix B.

7 Grid energy storage technology priorities

The different grid-scale energy storage technologies can be prioritised, using a number of factors, to highlight which specific technology supply chains will provide the best return in terms of economic benefit to Scotland and contribution to Net Zero, by supporting higher levels of grid connected renewables. The factors used include:

- Market expectations about scale of adoption
- Level of technology maturity
- Presence of a Scottish supply chain
- Relative intensity of Scottish academic and research organisation R&D capability

Market expectations about the scale of adoption consider which technologies have the highest future market value forecasts and an interpretation of the qualitative findings of our desk research on which technologies are most frequently mentioned as being a solution to grid-scale energy storage.

Level of maturity ranks technologies that are commercially proven higher than those still at development, pilot or demonstrator stage as the risks of deployment and, therefore, business growth is lower.

Presence of a Scottish supply chain for each technology considers both the number of companies present and the breadth of coverage over different segments within the supply chain.

The relative intensity of the Scottish academic and research organisation R&D capability considers the extent of the evidence of university and research centre R&D for the different energy storage technologies.

Each factor is scored in relative terms, either high, medium or low. The combined factor scores are then used to prioritise the grid-scale energy storage technologies. This scoring is summarised in Figure 9, below.

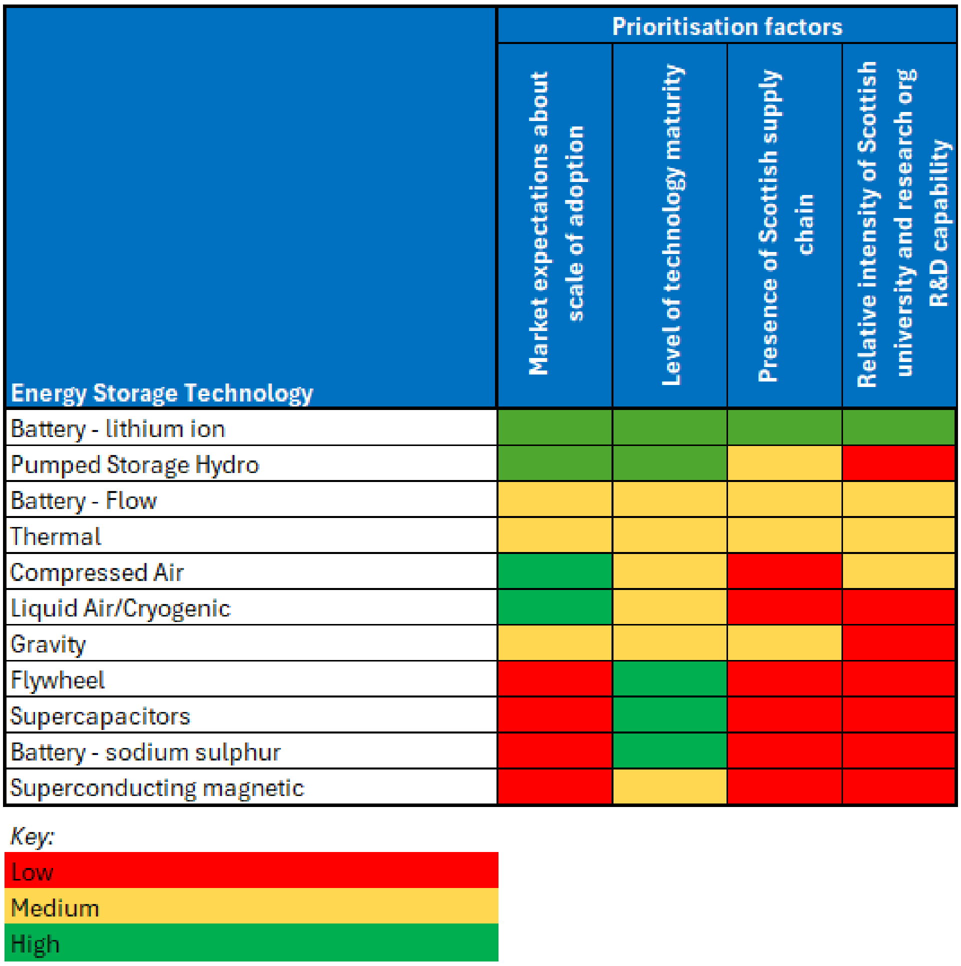

Figure 9: Relative prioritisation of grid-scale energy storage supply chains

Lithium-ion batteries, PSH, thermal and flow batteries are the top four grid-scale energy storage technology priorities in Scotland. In particular, lithium-ion batteries and PSH are mature technologies that are projected to meet the majority of the additional installed capacity required by 2035. An unpublished report, by Scottish Enterprise, into the Scottish battery supply chain provides more details on the companies active in this area. Flow batteries are also a relatively high priority as they provide a solution for long duration energy storage and there are three flow battery manufacturers in Scotland. There are several advantages claimed by developers of flow battery technology, relative to lithium-ion, including the non-flammable nature of flow battery electrolytes; lower levels of performance degradation over time and ability to operate in higher temperatures, reducing the need for air cooling systems. Thermal grid-scale energy storage is another relatively high priority technology, with currently one manufacturer identified in the Scottish supply chain. Compressed air energy storage and liquid air energy storage are also of interest as both are expected to provide significant long duration energy storage capacity in the period 2030 to 2050. However there are no Scottish-based manufacturers and the rest of the supply chain is also very limited. There is evidence of some university research on compressed air energy storage and there is an opportunity to develop a supply chain around the planned liquid area energy storage facility at Hunterston. Although the market opportunity for gravity energy storage appears to be relatively more modest than the other technologies, there is one manufacturer in Scotland so there is so there is potential for this to further contribute to the Scottish economy.

The remaining technologies: flywheel, supercapacitors, sodium sulphur batteries and superconducting magnetic, are assessed as lower priorities.

8 Conclusions, key findings and recommendations

This section contains the key conclusions from this study and also includes some recommendations for possible areas of support intervention, as identified by interviewed companies.

8.1 Conclusions and key findings

The key conclusions and key findings from this study are:

1. According to the International Energy Agency, total current global installed grid-scale energy storage capacity (2023) was 239 GW. PSH represented 76% of this total and BESS represented 23%, with 1% being 'Other'
2. The installed capacity of grid-scale energy storage systems is projected to experience significant growth over the next five years to 2030, reaching 839 GW. Even under the more modest scenario outlook, based only on existing policies being in place, the overall growth of installed grid-scale energy storage, between 2023 and 2030, is projected to be 250%. Within this, the installed BESS capacity is projected to increase ten-fold and PSH is projected to increase by 38%
3. This growth is being driven by the shift to Net Zero and the specific plans made by national governments to deliver their Nationally Determined Contributions, as part of the Paris Agreement, by electrifying significant elements of heat and transport energy demand. This shift to electrification is being accompanied by targets to decarbonise the grid electricity by increasing the use of renewable energy generation. To facilitate significant additional renewable electricity generation capacity, much of which can be intermittent, upgrades to the grid transmission and distribution networks are required, including energy storage facilities.
4. Estimates of the global market value for grid-scale energy storage systems varies significantly between different market research reports. For example, estimates of the global annual market for BESS, in 2033, range from $20bn and $49bn. This compares with 2023 estimates of annual global market value of between $8bn and $10bn. The market is, however, large and projected to experience significant growth
5. As energy supply is mainly a reserved power, it is the UK Government DESNZ's Clean Power 2030 Action Plan that includes the main targets and policy measures required to support and facilitate the increase in grid-scale energy storage. The Scottish Government is working with DESNZ on this plan and is also working on efficiency improvements to planning and consenting processes in conjunction with local authorities
6. The economic market for BESS functions efficiently with the market driving investment. The economic market for PSH and other LDES technologies, including some at pre-commercial stage, requires revenue support mechanisms. The UK Government is in the process of developing a 'cap and floor' mechanism to support investment in LDES. This will help to derisk projects and attract investment

7. Based on data in the Clean Power 2030 Action Plan, it is estimated that the maximum additional energy storage capacity required in Scotland, by 2035, is 7.1 GW of LDES (under a scenario that assumes all GB LDES will be located in Scotland) and 7.3 GW of BESS. Whilst it is unlikely that all LDES will be located in Scotland, it is feasible that a significant majority of PSH capacity will be. So, under this scenario, created for illustration, the total additional Scottish energy storage capacity by 2035 will be a maximum of 14.4 GW
8. At a Scottish level, 24.5 GW of planned energy storage capacity was identified through this study. This consists of 12 GW of energy storage systems (mainly lithium-ion BESS, but also a small number of flow battery and LAES systems), 11.1 GW of PSH and 1.5 GW of unspecified energy storage systems collocated with renewable generation assets. Comparing this to the maximum additional capacity scenario of 14.4 GW, described in the above point, this means that not all projects identified will proceed
9. The National Energy System Operator's (NESO) grid connection queuing process is undergoing reform, to move from a 'first-come, first-served' approach to an approach design to deliver the requirements of the Clean Power 2030 Action Plan. This is intended to ensure that the required mix of short and long duration energy storage facilities are constructed, in the optimal geographic locations. This connection queue reform process is reported to be creating uncertainty in the market, with projects being paused until more clarity is provided
10. There is some discussion, identified through desk research and stakeholder consultation, that lithium-ion battery pack cost reductions may mean that it is possible to deliver LDES in future, using BESS facilities. This is a potential risk for other LDES technology developers. An example of an 8-hour duration BESS, located in Australia, was identified. The LDES cap and floor regime appears to be technology agnostic but it is not intended for investments that could proceed without the support. Therefore, it is unclear whether this would exclude BESS by default
11. The BESS pipeline projects, identified in Scotland, are forecast to be constructed and connected between 2025 and 2032. The PSH pipeline projects are forecast to be constructed and connected between 2027 and 2036. This is consistent with the typical duration of BESS construction being 12 to 24 months, significantly shorter than the typical PSH construction phase of three to seven years
12. The local authority areas with the highest levels of planned energy storage capacity include Highlands (10.4 GW), Argyll and Bute (2.2 GW), Aberdeenshire, (1.9 GW), South Lanarkshire (1.7 GW), Fife (1.3 GW) and West Dunbartonshire (1.1 GW). The high values for Highlands and Argyll and Bute are driven by relatively large planned PSH projects
13. A total of 76 companies were identified as constituting the grid-scale energy supply chain in Scotland. This includes companies currently active in the supply chain and a small number of companies that are not yet active but have the potential to develop relevant products/services for the supply chain in future. The scope of this supply chain includes several segments: parts, components or systems; original equipment manufacturers; developers; project design engineering/ project management; system installation, commissioning, operation and maintenance and decommissioning. These companies all have office locations in Scotland, directly employ staff and contribute GVA to the Scottish economy
14. Analysis shows that the Scottish supply chain has relatively strong capabilities in lithium-ion batteries, PSH and a potential emerging strength in flow batteries. In lithium-ion batteries and PSH, the main capabilities are in the service segments of the supply chain. There are some niche and potential capabilities in lithium-ion battery parts, components and systems and original

equipment manufacturing. In the flow battery technology area there are three original equipment manufacturers, indicating growing capabilities in this area

15. There are individual companies with current or potential capabilities in other technology areas, including thermal, compressed air, liquid air and gravity. However, these are either at an early stage of development or are companies that are not currently in the energy storage supply chain but have the potential to diversify in future
16. No significant supply chain presence was identified (active or potential) in sodium sulphur batteries, superconducting magnetic storage, flywheels or supercapacitors
17. Although lithium-ion batteries and PSH are the two most significant technologies for grid-scale energy storage, there is a gap in the supply chain for the manufacture of most of the equipment used. Almost all parts are imported from the Far East, Europe or North America
18. There are some parts, components and systems and original equipment in the Scottish supply chain that are exported to markets in the Far East, Europe and USA
19. The main barriers faced by the supply chain include:
    a. Time consuming planning and consenting processes
    b. Uncertainty caused by the NESO reforms of the connection queue system
    c. Skills shortages including Senior Authorised Persons to supervise work in high voltage environments, experienced project managers, electrical engineers and electrical technicians with high voltage experience
    d. Significant lead times for bespoke equipment for pumped storage hydro equipment, of up to four years
    e. Competition for international civil engineering main contractors for pumped storage hydro
    f. Uncertainty about how the long duration energy storage cap and floor mechanism will work and the timing of its introduction
    g. For one technology developer the lack of knowledge of the Scottish supply chain capabilities was a barrier to maximising local content
    h. Lack of funding to support the shift from demonstrator deployment to commercial scale deployment of energy storage systems not currently at TRL 9
20. A range of Scottish academic and research organisation R&D and testing expertise was identified in several Scottish universities and technical support infrastructure organisations. The universities with the most significant expertise were the Universities of Glasgow, Edinburgh, St Andrews, Strathclyde, Aberdeen and Heriot Watt University. This included a mix of cross-cutting research and technology specific research relevant to lithium-ion batteries, flow batteries, thermal storage, and compressed air storage
21. A top-down approach to estimating economic impacts of grid-scale energy storage technologies was carried out for PSH and lithium-ion batteries. This approach used a broader definition of the supply chain to include civil engineering construction jobs and GVA. This approach estimated that:
    a. For pumped storage hydro, it was assessed that the detailed economic impact assessment carried out by Biggar Economics for Scottish Renewables is a reasonable basis to identify an indicative scale of jobs and GVA impacts that could be expected. The report is based on the construction of six pumped storage hydro facilities by 2035, with a combined capacity of 4,900 MW. This is approximately the mid-point of the long duration energy storage targeted range to 2035 of between 2,100 MW and 7,100 MW,

as outlined in the Clean Power 2030 Action Plan. The Biggar Economics report projected that:

i. During construction, temporary jobs would peak at between 5,000 and 6,900 (direct, indirect and induced)
ii. During construction, the total additional GVA contributed to the Scottish economy is between £2.3 billion and £3.2 billion
iii. At the operational stage, there is an annual requirement for 500 additional jobs (direct, indirect and induced)
iv. The annual GVA generated by the six pumped storage hydro facilities is projected to be £29 million

b. Based on the NESO/DESNZ estimate of additional battery energy storage system capacity in Scotland by 2035 and 'jobs per MW' factors identified during the research, it is projected that 6,500 temporary construction jobs would be required
c. Based on information in the public domain, the LAES facility planned for Hunterston is projected to provide 1,000 jobs onsite and 650 supply chain jobs during construction

22. A bottom-up economic assessment of jobs and GVA of the Scottish grid-scale energy storage supply chain was also undertaken. This used the study definition of the supply chain, which does not include the civil engineering segment. The data for this assessment was provided by the companies interviewed as part of the project. The key findings of this bottom-up approach are:
    a. The current supply chain of 76 companies supports an estimated 1,000 direct FTE jobs
    b. The current supply chain contributes £69 million of GVA, annually, to the Scottish economy
    c. Future (2035) job projections for the supply chain are estimated at 3,500 direct FTE jobs (a 250% increase from 2025)
    d. Future (2035) annual GVA projections for the supply chain is £304 million (a 340% increase from 2025)
23. Each energy storage technology was assessed using four factors: market expectations about scale of adoption; level of technology maturity, presence of Scottish supply chain companies and; relative intensity of academic and research organisation R&D capability. Based on this assessment the top priorities for Scotland are lithium-ion batteries, PSH, thermal storage and flow batteries. Compressed air, liquid air and gravity are also of interest due to either expected market growth or Scottish supply chain presence

Appendix A: Technology Readiness Level definitions

Technology readiness levels (TRLs) are a relative ranking of technological maturity. UK Research and Innovation uses the following, internationally recognised, definitions:

- TRL 1: basic principles observed and reported
- TRL 2: technology concept or application formulated
- TRL 3: analytical and experimental critical function or characteristic proof-of-concept
- TRL 4: technology basic validation in a laboratory environment
- TRL 5: technology basic validation in a relevant environment
- TRL 6: technology model or prototype demonstration in a relevant environment
- TRL 7: technology prototype demonstration in an operational environment
- TRL 8: actual technology completed and qualified through test and demonstration
- TRL 9: actual technology qualified through successful mission operations.

Appendix B: Methodology for assessing current and future economic contribution of grid scale energy storage

The approach to estimating current and future full time equivalent (FTE) jobs and gross value added (GVA) is aligned with Scottish Enterprise impact appraisal and evaluation guidance.

This appendix describes how the bottom-up calculation of economic impact, described in section 6.3.2, was carried out.

The initial step was to define the scope of the grid-scale energy storage supply chain to be included in the analysis. As described in section 1.1.1, the grid-scale energy storage supply chain includes:

- Developers
- Parts, components or systems manufacturers
- Original equipment manufacturers
- Providers of project design engineering and project management services
- Providers of system installation, commissioning and operation & maintenance services
- Providers of decommissioning services

The next step was to identify companies, with at least one office location in Scotland, that provided the above types of goods and services for one or more of the technology areas listed in earlier Table 1. This included companies where their sole focus was grid-scale energy storage and companies that were also active in other supply chains.

A spreadsheet database was constructed with details of each company were recorded, including:

- The two digit Standard Industrial Classification (SIC) code registered with Companies House to describe the nature of the business
- The 'GVA per head' average for each identified two digit SIC code, accessed from the Scottish Annual Business Statistics (SABS) 2022 report (the latest publicly available version)
- A contact name, position and email address, to facilitate the invitation to participate in the study research phase

A discussion topics list was drafted and then agreed by Scottish Enterprise. This contained questions about current and future FTE job numbers engaged in grid-scale energy storage supply chain:

- What is the estimated number of current FTE employees, based in Scotland, providing products/ services to the grid-scale ESS market?
- How many FTE employees, active in grid scale energy storage systems, might your company employ in Scotland in ten years time?

A briefing document, containing details about the scope of the study and the purposes for which the outputs would be used.

A total of 76 companies were identified and this was assumed to represent the total population of the grid-scale energy storage supply chain in Scotland. All 76 were contacted and invited to participate in the study. A further 20 stakeholders were contacted. This latter group consisted of university research stakeholders and grid-scale energy storage companies, based outside of Scotland, but had, or planned to use the Scottish supply chain in future.

A total of 20 interviews were carried out (21% response rate of the total 96 contacted). A total of 14 supply chain companies were interviewed and 13 of these provided data on current and projected future FTE jobs in grid-scale energy storage (17% of the total population of 76 companies).

The current and future job numbers were then converted to an estimate of GVA for each company. As described earlier, the SABS data is used to identify a 'GVA per head' ratio that can be applied to a number of jobs. Each two digit SIC code has a separate 'GVA per head' ratio in the SABS data and this is applied to the FTE job numbers identified from the company survey.

At this stage, the FTE jobs and GVA totals can be calculated for the sample of 13 companies. However, we are required to identify an estimate for the whole population of 76 companies. To do this, we carry out a series of calculations:

- The data for the sample is summed to calculate a total
- An average (mean) for this sample total is calculated
- The standard deviation of the sample is calculated (using the MS Excel formula 'STDEV.S')
- The standard deviation is doubled
- Any of the datapoints in the sample that are more than twice the standard deviation from the mean are classed as outliers. This is based on the 'Empirical Rule' that, in a normally distributed dataset, 95% of all the data will fall within two standard deviations around the mean
- The mean is recalculated for the sample data less the outliers
- If the number of outliers = n, then we multiply the recalculated mean by the 'total population (76) – n'
- The outlier data is then added back to derive an estimate of FTE jobs and GVA

There are data limitations to this approach. These include:

- There may be a response bias that means that companies with a greater proportion of their activity in grid-scale energy storage are more likely to respond to the invitation to participate in the survey, compared to those where grid-scale energy storage represents a low proportion of their business. In this case, the mean number of jobs and GVA could be higher than actual because the sample consists of the more active companies
- Whilst a significant amount of desk research was carried out, we may not have identified all companies with relevant capabilities. This would have the effect of underestimating the total population size and, therefore, the estimate of jobs and GVA

Appendix C: Glossary of Acronyms

BESS	Battery Energy Storage System
CAES	Compressed Air Energy Storage
CAGR	Compound Annual Growth Rate
CSP	Concentrated Solar Power
DESNZ	Department for Energy Security and Net Zero
ESP	Energy Skills Partnership
FTE	Full Time Equivalent
GVA	Gross Value Added
IEA	International Energy Agency
LAES	Liquid Air Energy Storage
LDES	Long Duration Energy Storage
LFP	Lithium Iron Phosphate
NESO	National Energy System Operator
OEM	Original Equipment Manufacture
OFGEM	Office of Gas and Electricity Markets
PNDC	Power Networks Demonstration Centre
PSH	Pumped Storage Hydro
PTES	Pumped Thermal Energy Storage
SDES	Short Duration Energy Storage
SIC	Standard Industrial Classification
TES	Thermal Energy Storage
TNO	Transmission Network Operators
TRL	Technology Readiness Level

Business Growth	Economic Development	Technology Commercialisation

Head Office:

Optimat Limited

100 West George Street,

Glasgow,

G2 1PP, United Kingdom

Tel: +44 (0)141 260 6260

Email: resource@optimat.co.uk

Web: www.optimat.co.uk