CORNWALL INSIGHT

CREATING CLARITY

Review of deployment of long duration energy storage in the electricity sector in Ireland

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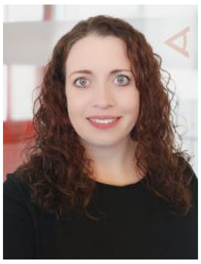

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2. Summary for all

This report seeks to assess the potential for Long Duration Energy Storage technologies (LDES) in Ireland, focusing on barriers and opportunities for the sector. The report focuses on policy, regulatory and market based opportunities and challenges, as the first step in understanding the market landscape for the sector. In our report we have:

Assessed seven LDES technologies identified by the system operator in Ireland, EirGrid: While there are technical and geographical constraints for certain technologies, three technologies suitable for implementation in Ireland are battery storage in the short term, pumped storage hydro in the medium to long term and hydrogen storage in the long term.

International examples Ireland can learn lessons from: Countries which have a successful track record of LDES deployment have ensured there are tangible targets backed by policy, financial incentives and routes to market for LDES technologies, especially more nascent technologies. In addition these countries have taken advantage of their natural resources.

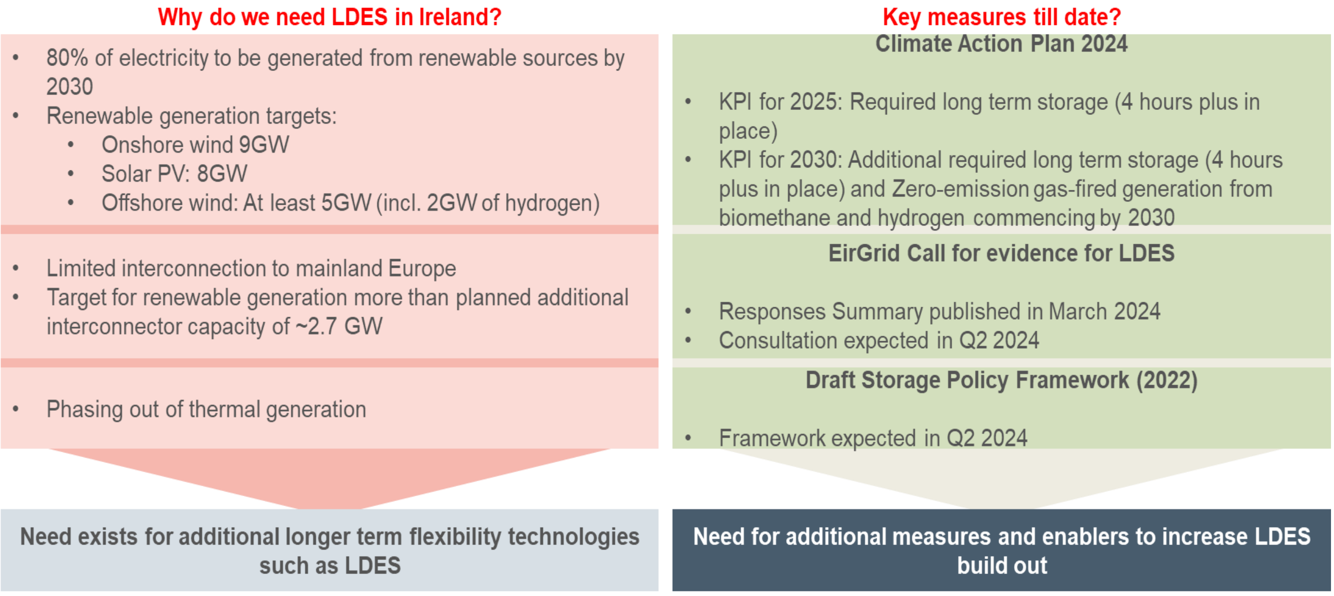
There are both opportunities and challenges for the LDES sector: There is a clear system need for technologies which provide low carbon flexibility and stability services, which has a growing share of intermittent variable renewable generation on it driven by national target of 80% share by 2030. But there are no policy, regulatory or commercial drivers to incentivise investment in LDES capacity.

We have identified key areas of consideration and further evaluation: We developed a suite of considerations across three key focus areas, namely, strategy and policy landscape, understanding the capabilities of different LDES technologies and incentivising development of LDES, with proposed actions under each area to drive uptake in the LDES sector

3. Executive Summary

The transition to a low carbon economy requires significant changes to our power system. To date the government has established targets and initiatives to incentivise the development of renewable generation. There are also plans to close the existing aging fossil fuel based thermal generation. In order to facilitate this and ensure the power system can remain secure, Ireland must develop flexible generation to complement the renewable generation that is connecting to our power system (Figure 1). There are a range of types of flexible capacity, but one key form that will be needed is long duration energy storage (LDES), which we define as storage with a duration of at least four hours. LDES has the distinct advantage that it can provide a range of different services to the grid, such as frequency support, voltage support, resilience, security of supply and congestion and constraint management services.

Figure 1: LDES - setting the context in Ireland



This independent report has been prepared by Cornwall Insight Ireland on behalf of the *Climate Change Advisory Council* (CCAC) with the purpose of analysing the market opportunities and challenges for LDES in Ireland's electricity sector and to provide considerations and areas of further development to incentivise its deployment.

Market Landscape

In order to understand the opportunities and challenges for LDES in Ireland, it is important to identify the need for LDES within the current and forecast electricity market landscape. This includes understanding both demand and supply within the sector to understand the needs that LDES can address. Thus, we included a review of the forecast demand and generation capacity for Ireland based on our All-Island wholesale power market model, the Single Energy Market (SEM) Benchmark Power Curve. This showed that there is an increasing need for flexibility for a range of reasons, including increasing intermittent renewable capacity, limited levels of interconnection to Europe, climate neutrality targets and increasing demand in Ireland. LDES technologies can provide this flexibility as they can quickly respond to events and are typically available at times of low and high renewable output. This means they can facilitate security of supply but also aid with congestion management by providing an alternative to grid reinforcement, thereby allowing a greater amount of renewables to connect and export. Our assessment of the market environment for LDES showed there are currently very limited incentives for LDES developers in Ireland and there are a number of barriers to participation in the schemes and markets that are available.

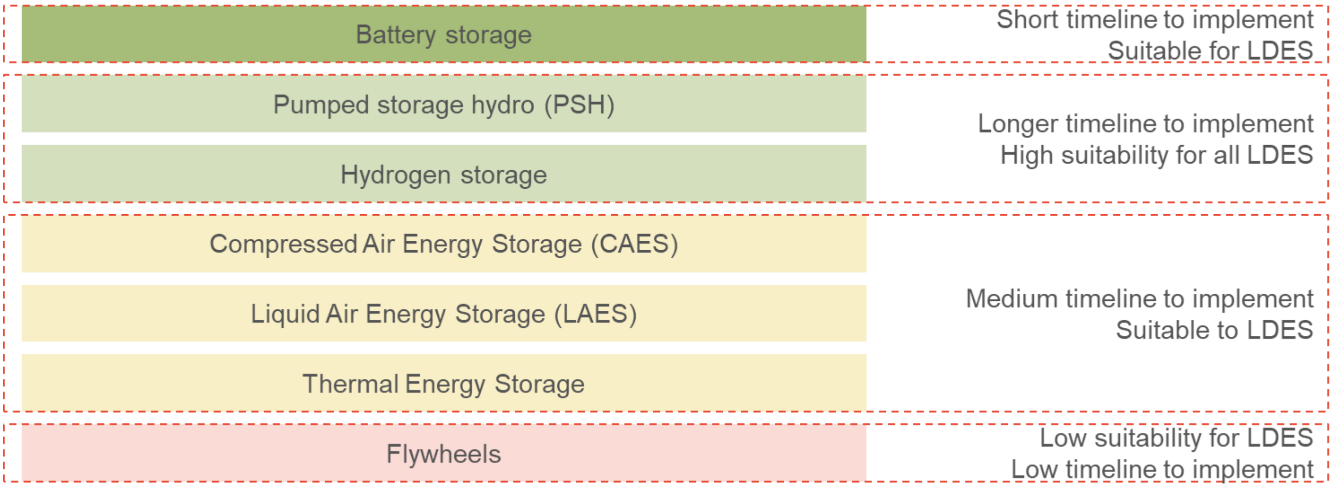
LDES technologies

We assessed seven different LDES technologies, as shown in Figure 2, based on:

- Their ability to reduce emissions
- Geographic requirements
- Lifespan
- Environmental Impact
- Level of establishment
- Timeline to become operational
- Storage duration
- Discharge duration
- Suitability for Ireland

There are benefits and challenges of each technology, and it is crucial that key stakeholders are cognisant of the nuances for different LDES technologies when designing market mechanisms and initiatives to incentivise LDES in Ireland. We have identified three key technologies as shown in Figure 2, namely battery storage, which has a short lead time, is suitable for LDES but typically only effective at durations up to six hours and hydrogen and pumped storage which have longer lead times but have a high suitability and potential longer duration as LDES technologies.

Figure 2: Technology assessment



International case studies

We assessed the following five countries that have different LDES technologies either deployed or in development: Great Britain (pumped hydro), Norway (dammed hydro), France (hydrogen), Germany (compressed air storage), and Spain (molten salt thermal storge).

We reviewed their market landscape for and initiatives towards LDES deployment, the types of LDES technologies that exist within these jurisdictions and assessed their readiness to enter the Irish market. From this we determined a number of lessons learned (as shown in Figure 3) that can be applied in an Irish context, which we then used to inform our assessment of the key opportunities and challenges that exist for LDES in Ireland.

Figure 3: International lessons

Key lessons from other jurisdictions		How can Ireland implement?
Making use of the country's natural resources	**Norway** **Spain**	• High offshore wind potential • Lends itself to hydrogen production
Pilot or demonstration projects for new technologies	**GB** **Germany** **Spain**	• Identify key technologies to trail • Finance pilot project for identified technology
Mechanism specifically to encourage LDES uptake	**GB** **Spain**	• Auction or criteria specific mechanism to help build LDES capacity
Specific LDES targets and initiatives with clear timelines	**Germany**	• Ensure the new storage policy does not fall short of setting clear targets and timelines

Opportunities and challenges for LDES

Specifically looking at the opportunities in Ireland, we see that based on the Climate Action Plan (CAP) 2024 targets, the generation mix will significantly change from baseload thermal and gas to intermittent renewable generation, and the need for flexible generation will be key. This is echoed across a number of areas, as the National Energy Security Framework requires system security to be provided by low carbon sources, such as LDES, and the Offshore Renewable Electricity Subsidy Scheme (ORESS) is introducing a requirement for hydrogen production and storage to be included in development of offshore wind sites. There is significant potential for LDES to co-locate with renewable assets to complement their operation at times of both high and low renewable output. Further to this, standalone LDES can also assist with managing renewable output through congestion management services, which are now being designed for both the transmission and distribution systems.

There are still challenges to the development of the LDES sector in Ireland. Crucially the lack of clear policy and targets for LDES are impacting the development of the sector. The lack of a policy and regulatory pathway to LDES development has a knock-on impact on the development of incentives and assessment of market barriers. Many LDES technologies have significant capital costs to develop, thus they need as much revenue certainty as possible, for which a stable regulatory backdrop is a prerequisite. In many instances LDES are hindered from full participation in the revenue streams that do exist through regulatory and market design limitations, where the Commission for Regulation of Utilities (CRU), SEM Market Operator and System Operator EirGrid are responsible for driving relevant change. Development of specific targeted revenue streams, especially those which alleviate identified challenges, is essential so that the potential of and need for LDES can be realised in Ireland.

Figure 4: Key opportunities and challenges

Opportunities identified	Challenges identified
Evolving generation mix with high intermittent renewables, increases need for long term flexibility	Lack of clear policy and targets for LDES
Move towards low carbon system	Lack of financial incentives
Opportunity of co-location of renewable and storage assets, to optimise renewable generation and reduce dispatch down	Systemwide delays in planning permissions and grid connection permits for new assets
Congestion management services	System service mechanism is changing and LDES assets will have uncertainly regarding route to Market at present
Storing offshore wind output using technologies such as hydrogen storage to fully utilise potential	Technical viability of certain technologies
Self reliant system despite having low interconnection to mainland Europe	Behavioural aspects of stakeholder groups
	Development and buildout timelines of certain technologies
	Geographical considerations needed for certain technologies as they are not modular and location agnostic
	Capacity market changes needed to incentivise storage

Areas for consideration and further evaluation

We have developed a suite of considerations across three key focus areas:

- Strategy and Policy Landscape
- Understanding the capabilities of different LDES technologies
- Incentivising development of LDES

These considerations range from short to long term actions and are designed to enable the growth of the LDES sector in Ireland to facilitate the transition to a low carbon economy. These considerations are:

Figure 5: Areas for consideration and further evaluation

Strategy and Policy Landscape	Understanding the capabilities of different LDES technologies	Incentivising development of LDES
LDES specific focus in the planned Storage Policy Framework	Develop a mechanism, either auction or tariff based, to trial 'new to Ireland' LDES technologies	Develop a consultation to implement a change as needed in the application of demand network tariffs to storage assets
If planned Storage Policy Framework does not include LDES adequately; develop an LDES specific strategy	Conduct analysis to understand LDES technologies' capabilities and align with routes to market and business cases to ensure full participation of LDES in Ireland	To implement a support scheme for LDES in Ireland review requirement details and constraints/risks and develop a consultation
		To implement a support scheme for LDES in Ireland review requirement details and develop a consultation
Develop a strategy for approaching resourcing within key stakeholder organisations, to meet resourcing requirements for 2030	TSO's current review of System Service requirements and volumes for the Future Arrangements of System Services needs to consider LDES capabilities and constraints.	Conduct a new review into storage asset derating factors in the Capacity Market with a specific focus on LDES assets

In conclusion LDES technologies have strong potential to support decarbonisation of the Irish electricity system. However, there are significant challenges in policy, regulatory and market enablers which have to be addressed to drive growth in the sector. Policy makers, regulators, system operator and market operator all have a significant role to play in creating mechanisms and an environment which sends the right investment signals to developers and investors, to encourage LDES development.

4. Background

In this section we describe the policy signals and the initiatives that set out the importance and need for LDES in Ireland as a part of the energy generation mix as we move to a system with higher intermittent renewable generation and therefore a higher need for flexibility.

4.1. Understanding LDES

The power system in Ireland is continuing its transition to a low carbon system in line with the national target set in CAP 2024, of 80% of electricity to be generated from renewable sources by 2030 and further to achieve net zero by 2050. With most of this renewable generation coming from intermittent sources such as wind and solar, flexibility will become more important. This flexibility requirement will need to be fast acting, able to store excess energy for long periods of time, and carbon neutral. Longer duration storage can provide this type of flexibility and can be a very attractive tool for the Transmission System Operator (TSO), EirGrid, who are responsible for maintaining the security of the power system day to day. At present there is only 0.3 GW of LDES on the Irish grid.

The Irish Government have acknowledged the need for LDES in the CAP and it sets out Key Performance Indicators (KPI) for 2025, 2030 and 2031 - 2035 that specifically reference LDES, as shown in Figure 6.

Figure 6: Climate Action Plan 2024 KPI's for LDES

2025 KPI	• Required long term storage (4 hours plus in place)
2030 KPI	• Required long term storage (4 hours plus in place) • Zero-emission gas-fired generation from biomethane and hydrogen commencing by 2030
2031-2035 measures	• Required additional long duration storage technologies in place

Source: CAP 2024

In addition to the CAP, EirGrid has acknowledged the importance of LDES in their *Shaping Our Electricity Future (SOEF) Roadmap* in July 2023, stating, "A key output of the new iteration of Shaping Our Electricity Future is that there is a need for Long Duration Energy Storage (LDES). Industry feedback is that there is a remuneration gap for investors to develop LDES." The SOEF has also estimated the additional LDES requirement to be at ~2.4GW for 2030.

The Distribution System Operator (DSO), ESB Networks (ESBN) has also recognised the important role LDES can play to aid them in their need to manage their networks, especially to alleviate congestion within the network.

Whilst these three entities are aligned in the need for LDES, in more general terms a definition of LDES is required.

Currently, various entities define LDES differently based on system needs. In Ireland there are multiple definitions at present.

- CAP 2024, which is the key policy behind the country's net zero goals, defines LDES as technologies capable of at least four hours of storage
- EirGrid's Call for Evidence on the Market Procurement Options for Long Duration Energy Storage in October 2023 defines LDES technologies as capable of at least eight hours of storage. This is however at a call for evidence stage and opinion has been sought on whether this definition is acceptable and accurate
- ESBN defines at least four hours of storage as medium term storage, with six to eight hours categorised as longer duration storage

For the purpose of this report, we will be using the CAP definition of LDES i.e. over four hours of storage.

The majority of storage assets operational in Ireland at this time are shorter duration batteries of two hours or less, with one 292MW LDES asset operational at Turlough Hill and another 300MW LDES asset planned for Silvermines in Tipperary.

Despite these two sites, it is widely acknowledged that developing a business case for LDES in Ireland is challenging. To improve this, there needs to be policy and regulatory intervention, starting with recognition of what is to be defined and considered as long duration. Along with the need to address policy, regulatory and market design concerns, there are several other factors influencing the way forward for LDES technologies as a whole and to understand which specific LDES technologies will be suitable for Ireland. However, while this report recognises these other issues, as listed below, it focuses on policy, regulatory and market based challenges and enablers as these form the foundation for any progress in the LDES sector:

1. Financial burden of implementation: The cost of commissioning LDES capacity and whether recovering these costs place any burden on the consumer needs to be understood. Also key is understanding where the investment into these technologies are expected to come from; whether state (public) or private funding, and the enablers that will be needed to drive this investment
2. Geographical concerns: There are certain technologies, as described in section 6, which have certain geographical restrictions or requirements. *Energy Storage Ireland in 2019* recognised that solutions such as Pumped Storage Hydro (PSH), Liquid Air Energy Storage (LAES), Compressed Air Energy Storage (CAES) and others require locations with specific geographical characteristics which are not particularly common on in Ireland. So, while they may offer a solution it is likely to be limited in scale
3. Behavioural aspects: There are various entities involved in commissioning a LDES asset, including particularly sensitive aspects such as public opinion and community buy-in. These need to be understood, accounted and planned for before LDES technology growth can be implemented. A key part of understanding the behavioural aspect is carrying out stakeholder interaction across various stakeholder groups such as government entities, industry bodies, developers, investors and consumers
4. Technology maturity: Different LDES technologies are at different stages of maturity and as such will only be implementable economically in the medium to longer term. This needs to be understood from a current and future perspective before promoting specific technologies

While it is evident that there is consensus on the need for increased levels of LDES in Ireland in the transition to net zero, there is significant work that needs to be done to incentivise uptake and it needs to be done with urgency so that Ireland can seek to achieve the CAP targets for 2030 and beyond

In Ireland, however, there have been some initiatives that have been started to encourage uptake of LDES:

- *EirGrid's Call for Evidence on the Market Procurement Options for Long Duration Energy Storage*: In October 2023 EirGrid published a call for evidence to understand how they could procure LDES. The responses on the call for evidence have been published as of March 2024, however, no decisions have been taken to date.
- *ESB Networks' (ESBN) demand flexibility product proposal*: In December 2023 ESBN published a consultation on their need to procure additional demand flexibility to manage distribution system needs. They are proposing to carry out a criteria-based or price-based auction to procure this capacity that will provide support for a minimum of four hours.
- *Department of the Environment, Climate and Communications (DECC), Consultation on Developing an Electricity Storage Policy Framework for Ireland*, November 2022: The consultation for the policy enabling storage technologies in Ireland was published in 2022, however, there was no specific clarifications around LDES, in it. There have also been delays in publishing the final decision which is now expected in Q2 2024.

Thus, while it is evident that there is consensus on the need for increased levels of LDES in Ireland in the transition to net zero, there is significant work that needs to be done to incentivise uptake and it needs to be done with urgency so that Ireland can seek to achieve the CAP targets for 2030 and beyond.

With that in mind, this report prepared by Cornwall Insight Ireland on behalf of *CCAC*, seeks to assess the potential for LDES in Ireland and the next steps that need to be taken to alleviate any barriers and crystalise opportunities. CCAC is an independent advisory body providing evidence-based advice and recommendations on policy to support Ireland's just transition to a biodiversity rich, environmentally sustainable, climate neutral and resilient society. In this report:

- *Section 4* looks at the market landscape in Ireland in terms of the evolving generation and demand mix, the need for flexibility and how LDES can provide it
- *Section 5* assesses the technologies that can provide LDES and their suitability to provide LDES in Ireland
- *Section 6* highlights international comparisons of where different LDES technologies are developed and how the market accommodates them
- *Section 7* looks at the specific opportunities and challenges for LDES in Ireland
- *Section 8* sets out a table of areas of consideration and further evaluation to provide the way forward for developing the LDES market in Ireland

For the purpose of this report when we reference energy storage we are referring to the storage of electricity to be used in either the same or a different form at a later point in time. We are not referring to forms of strategic energy stores, such as the strategic oil reserves.

The overall report focuses on providing a curated repository of information for possible LDES technologies; existing examples that Ireland can learn from; and an assessment of current opportunities and challenges to implementation in Ireland. The goal of this study is to identify the "big wins" to support the development of the LDES sector in Ireland.

5. Market Landscape

Flexibility is a key technology type required for the transition to a low carbon electricity system. In this section we set out the generation and demand mix changes that will drive the need for flexibility, the role that flexibility, and especially LDES flexibility, can play in the power system, followed by the challenges that are currently faced by LDES developers and investors in creating a business case for the development of LDES in Ireland.

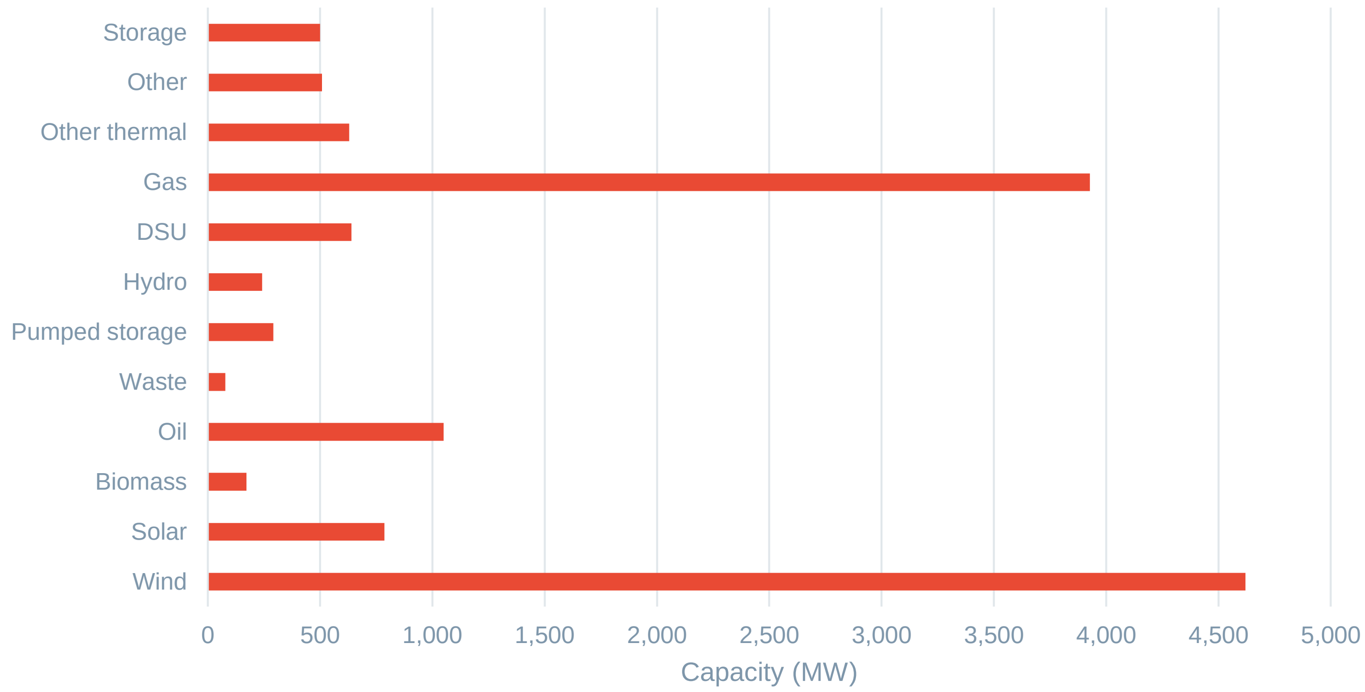
The electricity generation mix of Ireland has evolved significantly over the past decades, shifting from a system dominated by thermal generation to one with significant levels of intermittent renewable capacity. This trend is expected to continue with large amounts of additional renewable capacity forecast, incentivised and driven by government schemes and targets as seen in Figure 8. Currently, as shown in Figure 7 there is ~13.4GW of generation capacity in Ireland, of which ~5.4GW is intermittent renewable. There is also ~0.5GW of short duration storage and ~0.3GW of LDES (the Turlough Hill pumped storage site). Due to the intermittent nature of the dominant renewable technologies (wind and solar) and the phasing out of thermal generation which can deliver constant baseload power, it is key that flexible technologies that have one or more of the following capabilities are brought on to the grid to ensure security and stability is maintained:

Overall we expect a significant growth in renewable capacity and greater levels of demand, both of which will necessitate the development of flexible technologies such as LDES.

- Low carbon or carbon neutral technologies to ensure that the '*CAP 2021*' goal of a "climate neutral economy by no later than the end of the year 2050" is not compromised
- Ability to provide a fast response in the event of a sudden increase or decrease in the frequency of the electricity network. This is caused by electricity generation not matching electricity demand
- Ability to absorb significant amounts of power during periods of excess renewable generation and export it back to the grid over a prolonged period of time when renewable generation levels are low. This can reduce the levels of dispatch down of renewable generation

There are a number of potential solutions to this problem, some of which align with Ireland's energy strategy and some less so, but nonetheless are options to facilitate the increase in renewable capacity. While there are a number of options, one of the best low-carbon solutions is LDES. With multiple technologies capable of providing LDES, some at a relatively advanced stage of uptake, it is a solution which needs to be explored and its adaptability and suitability understood in an Irish context. In this section we set the scene for LDES in Ireland before providing an in-depth review of the types of technologies that may be suitable for adoption.

Figure 7: Generation capacity (MW) in Ireland in 2023



Source: EirGrid Ten Year Generation Capacity Statement 2023-2032 *and* DECC

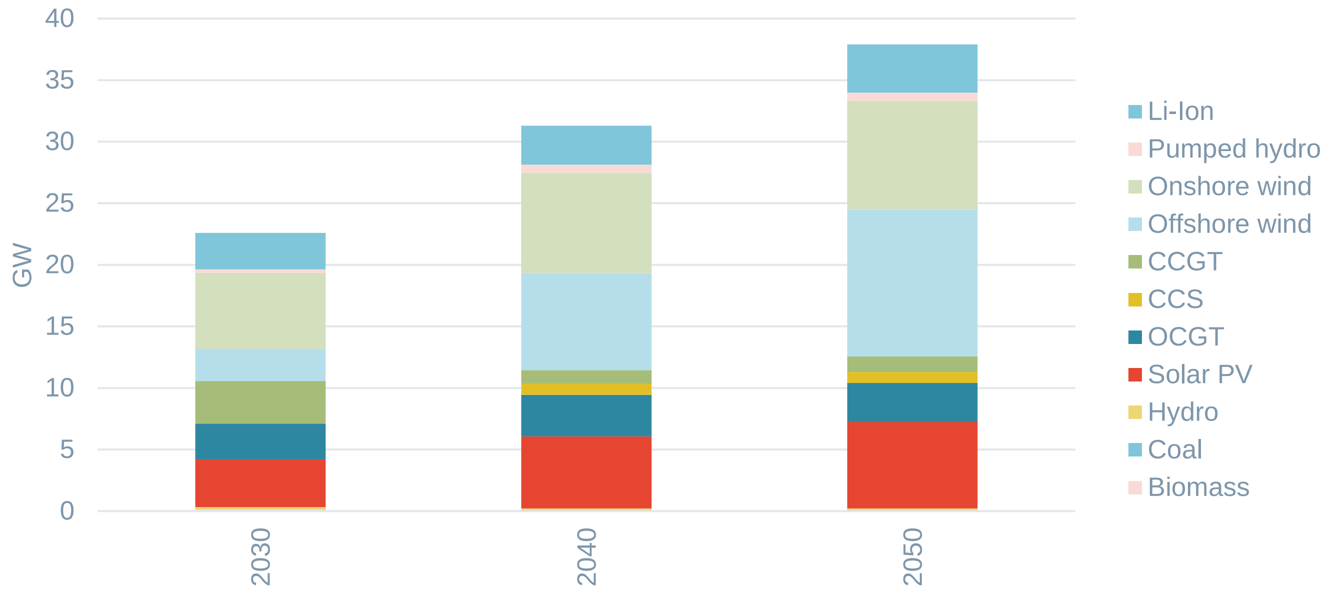
In sections 5.1 and 5.2 we discuss our forecasts of the SEM, All-Island system focusing on electricity generation capacity and demand out to 2053-54. In these two sections we have provided an overview of the trends that we see in our forecasts that highlight the increased need for flexibility in Ireland as well as why specifically LDES can support the energy transition that we are forecasting. The modelling methodology utilised in our SEM Benchmark Power Curve is included in Appendix 3: Cornwall Insight SEM Benchmark Power Curve modelling methodology for reference.

Sections 5.3 and 5.4 discuss the need for flexibility and how LDES can provide that flexibility in Ireland. Whilst section 5.5 looks at the revenue opportunities for LDES in Ireland.

5.1. Forecast electricity generation capacity

Our SEM Benchmark Power Curve (BPC) forecasts a significant increase in generation capacity in Ireland, primarily as a result of a growth in renewable generation capacity. This is despite the current planning and grid issues that are currently materially impacting renewable projects, which risk the government's renewable energy targets being missed. While these issues are impacting short-term renewable deployment, work is currently underway by the government to overhaul the existing planning system via the *Planning and Development Bill 2023*. We therefore still see major growth in both offshore wind and solar capacity to meet the 80% renewable electricity target in 2030. These technologies reach >2.5GW and nearly 4GW respectively by 2030.

Figure 8: Forecast Ireland generation mix (CI central forecast)



Source: Cornwall Insight SEM BPC (Q1 2024)

Our forecasts of renewable capacity (offshore wind, onshore wind and solar) are significantly impacted, particularly in the short-to-medium term, by the Irish government's Renewable Electricity Support Scheme (RESS) and Offshore Renewable Energy Support Scheme (ORESS). Support under RESS and ORESS is awarded via competitive auctions and contracts are designed to provide long-term investor certainty for renewable projects and support the achievement of the 80% renewable electricity target by 2030.

ORESS will be the primary support mechanism for the deployment of offshore wind, but we are also aware that some windfarms may look to enter into Power Purchase Agreements (PPA) rather than enter the ORESS auctions. New offshore wind turbines will have higher load factors than older models, and the cost of deployment is expected to fall as the technology matures. These factors combined improve the business case for investing in offshore wind assets, which further supports the growth of additional offshore wind capacity.

ORESS 1, the first subsidy auction for offshore wind projects in Ireland, closed in May 2023 with four successful projects totalling over 3GW of capacity. ORESS 2.1 which is planned to be launched mid-2024, is set to procure 900MW of capacity. This capacity is due to come online by 2030, with ORESS 2.2 following to help meet CAP 2023 goals of at least 5GW capacity by 2030 with an extra 2GW set aside for hydrogen production. The Government released a *consultation* in January 2024 setting out its pathway to increase offshore wind capacity to 20GW and 37GW by 2040 and 2050 respectively. Like in the CAP, some capacity is expected to be used for hydrogen production.

Our forecasts suggest that the ambitious 5GW offshore wind target by 2030 in Ireland will be missed, with capacity not reaching this level until the mid-2030s. We see the 2040 and 2050 target for offshore wind generation missed by a greater level. Despite missing these targets this would still make offshore wind the dominant source of electricity generation from the 2040s onwards.

In our forecasts we see solar capacity growing steadily and continuously, reaching ~4GW by 2030 and rising to ~6GW by 2040 and ~7GW by 2050. This would be behind CAP 2023 targets of 5GW of solar by 2025 and 8GW by 2030[1].

Onshore wind is one of the key technologies in our modelling for meeting additional demand and carbon targets in the Irish market, as it is one of the cheapest forms of new generation capacity. The main constraints on its deployment are the available network connections and competition with other low-carbon sources of power, such as solar and offshore wind as well as falling wholesale prices.

The second RESS auction for onshore capacity (RESS 2) awarded contracts to over 400MW of onshore wind with delivery required by 2025. RESS 3 took place in September 2023 for delivery by 2027 and procured 150MW of wind capacity and 500 MW of solar capacity.

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[1] *We note that these targets include 1GW and 2.5GW of non-grid solar respectively, which is not included in our forecast capacity values*

Onshore wind capacity increases <5GW in 2023 to just over 6GW by 2030, missing the government target of 9GW by 2030. As older wind farms begin to retire, there is a replacement programme that keeps onshore wind capacity above 8GW throughout the 2040s. This is why we see a significant amount of onshore wind in our modelling, but less material increases than are seen with solar and offshore wind.

For both onshore and offshore wind and solar, the main reason our forecasts show that Ireland will not reach the targets that have been set, is the challenges around securing planning permission and grid connections. We are also aware that there are some concerns amongst industry that the capacity that has already been successful through previous RESS and ORESS auctions may face delivery challenges, and therefore will not be on the system in time for the 2030 target.

Alongside this major growth in renewable capacity, we are forecasting a reduction in dispatchable thermal generation. We see coal plants cease day to day operations by 2025 (although Moneypoint may be available as a generator of last resort until 2029 after converting from a coal fired generator to one powered by oil) and Combined Cycle Gas Turbine (CCGT) capacity is expected to peak in the late 2020s (at >3GW) before a steady decline. Additional CCGTs are expected to come online towards the end of the 2020s as older plants start to retire and new capacity is required to help meet demand during the transition towards renewable generation. The flexibility offered by CCGTs is also a crucial part of balancing the system at this time, as acknowledged in CAP 2023, which targets the addition of at least 2GW of flexible gas generation by 2030.

This reduction in thermal capacity, combined with the expected increase in renewable capacity discussed earlier in this section, means that in our modelling we see a number of technologies deployed to provide additional flexibility, such as battery storage, Open Cycle Gas Turbines (OCGTs), Demand Side Response (DSR) and interconnectors. These technologies are vital for ensuring system security. However, they do not offer a solution to Ireland’s need to store renewable power during periods of excess production and export it again during periods of low renewable output.

In our modelling, investment in grid-scale batteries reaches just under 3GW by 2030 as battery costs fall and lithium-ion batteries help meet increased requirements for system support. Battery capacity continues to grow, following the growth of renewable generation. The level of transport electrification from EVs partly reduces the deployment of utility-scale and domestic batteries as the system can rely on a level of “free” response from flexibility-enabled electric vehicles (EVs), as it is an inherent service provided without a procurement mechanism associated with it.

OCGT capacity grows to maintain system security (such as minimum reserve level requirements and Loss of Load Expectations) because it has better dynamic characteristics and is cheaper to deploy than other thermal generation. As peaking plant, they have low load factors but will often capture a premium given their high degree of flexibility to respond to market prices. OCGTs maintain very low load factors and have high marginal costs reflecting the value of power – they are used sparingly to provide reserve services as they are displaced from running by lithium-ion battery storage projects over most peak demand periods. Despite running relatively little, around 2.5GW is expected to stay online to provide essential system stability as the system connects more renewable generation.

DSR is the ability of electrical loads to reduce or move consumption to minimise the customer’s exposure to high prices, or to secure value by offering the capacity into other markets (the revenue streams that are available in Ireland are discussed later in this report). This response can range from true demand response (such as turning down commercial freezers), customers’ onsite generation to displace consumption from the wider system (such as an on-site diesel generator), to demand disconnection by the system operator. In our modelling we see DSR capacity grow steadily from ~0.75GW currently to nearly 2GW by the late 2030s.

As it represents a wide range of customer responses, the price of operating DSR is also similarly varied, depending on the value to the customer of the task being performed by the electrical equipment.

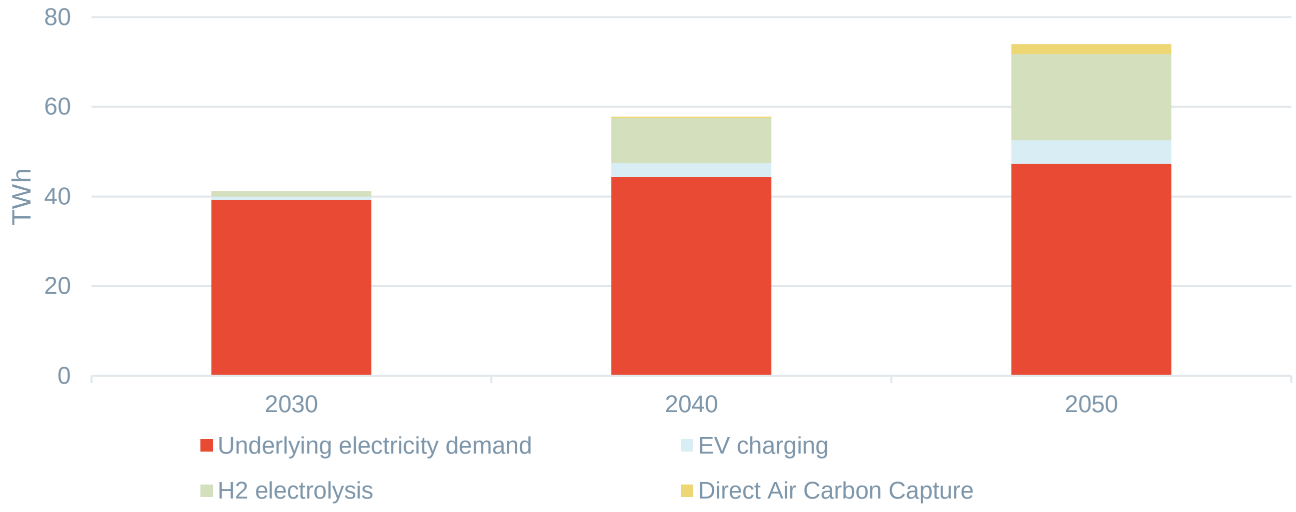
Interconnector capacity is forecast to increase from 0.5GW currently (IE to GB) to 1GW in the mid-2020s when the Greenlink interconnector to Wales is expected to become operational. This then rises to ~2.5GW by the late 2020s when we assume the planned MARES interconnector to Scotland from Northern Ireland and the Celtic interconnector to France respectively commission. While there are other interconnectors potentially coming online in Ireland, we have not modelled them as they are not sufficiently progressed to have any certainty on if and when they will connect.

5.2. Forecast demand

One of the main use cases for LDES is storing and shifting electricity from periods of high renewable output and low demand to periods of low renewable output and high demand. It is therefore important to consider how electricity demand is expected to change over the coming decades in the context of the changing electricity generation to understand the requirement for LDES on the system and why it is so important.

In our SEM BPC, we forecast a major increase in electricity demand, with annual consumption expected to more than double between 2024 and 2050, from ~35TWh in 2024 to ~44TWh in the early 2030s and nearly 74TWh by 2050. This is due to both an increase in demand requirements from both existing sources defined as underlying demand in Figure 9 below such as residential, commercial, and industrial and new sources, such as EV charging, heat, electrolysis, and carbon capture technologies. In our central forecast we see 2032 demand broadly in line with the Median scenario in EirGrid's latest Generation Capacity Statement (GCS) (~47TWh).

Figure 9: Ireland demand forecast (CI central forecast)



Source: Cornwall Insight SEM BPC (Q4 2023)

In the residential sector, this increase in demand is primarily driven by the electrification of heat and the move away from traditional fossil-fuelled heating. While overall demand is forecast to increase, commercial demand specifically is forecast to fall over the horizon as existing electric heating systems are replaced with more efficient heat pumps. Projections for industrial demand show an increase as the industrial fuel mix moves away from gas and other fossil fuels and becomes electrified.

Data Centre demand will also increase as the industry develops, with growth mostly concentrated in the next decade. Ireland has the largest cluster of Data Centres in Europe, and their electricity demand continues to grow, with a 31% increase in electricity consumption reported by the CSO between 2021 and 2022. There were approximately 75 operational Data Centres across Ireland in 2022, representing over 1GW of capacity. There is currently 300MW of capacity under construction and an additional *1,300MW with planning approved*, highlighting that the expansion continues rapidly.

Looking forward, Data Centre capacity is expected to rise to just under 2GW by the mid-2020s. Beyond this, we are anticipating a continued but more gradual growth based on information from *EirGrid's Tomorrow's Energy Scenarios*.

Electric Vehicles (EVs) are a crucial component of reducing carbon emissions to meet emissions targets in transport. However, the magnitude of the technology's impact on the electricity system is significant. By 2040 there will be an estimated 2.4mn EVs on the island of Ireland consuming nearly 5TWh, approximately 5% of total demand.

One important aspect of EVs is that they have the potential to offer the electricity system considerable flexibility, both in terms of vehicle-to-grid (V2G) discharging and smart charging. At the same time, the energy demand from EVs will be substantial and greater flexibility may be needed if consumers were to charge whenever it is convenient. With the widening deployment of EVs, it is unlikely that this greater flexibility in EV charging demand would be possible.

Our modelling shows that, in the absence of well-defined targets, hydrogen uptake will be slow in Ireland in the near term but is expected to increase sharply in the mid-2030s. The highest demand for hydrogen comes from the road transport sector due to the high share of road freight on the island and the efficiency of hydrogen Heavy Goods Vehicles (HGVs) for long-distance transport. However, the market share of hydrogen vehicles is minimal in the short term due to the strong competition from Compressed Natural Gas (CNG).

Demand for hydrogen feedstock is very limited in the Irish industrial sector. Therefore, hydrogen consumption in industry is limited to its displacement of fossil fuels in high-temperature processes in manufacturing industries. The adoption of hydrogen-based heating solutions in buildings is dependent on various factors such as connectivity to the gas network, efficiency of hydrogen heating solutions compared to other low-carbon heating solutions, and hydrogen supply. Hence, the building sector will have lower hydrogen consumption than other sectors.

5.3. The need for flexibility

The combination of increasing demand, increasing intermittent renewable generation and a lower proportion of dispatchable thermal generation will make it more challenging to ensure that the electricity system can be safely operated in real time by SONI and EirGrid. These challenges include:

- Ensuring the frequency of the system remains within safe limits
- Maintaining security of supply, especially during periods of low renewable output
- Managing network constraints, particularly during periods of high renewable output

Flexible capacity offers solutions to these challenges and can come from a number of sources, including gas-fired generation, DSR and energy storage. We see all of these technologies deployed to different degrees as they are able to help address the challenges identified because they are:

- Able to respond quickly to frequency events
- Typically, available during periods of low renewable output
- An alternative to grid development or reinforcement
- Able to help manage peak demand, either by reducing demand or providing additional generation capacity

"The combination of increasing demand, increasing intermittent renewable generation and a lower proportion of dispatchable thermal generation will make it more challenging for the TSO to ensure that it is able to safely balance the electricity system"

The current fleet of batteries and those we are forecasting in our modelling are short duration (<4hr), which means they are well placed to respond quickly to frequency events and ensure frequency remains within safe limits. Batteries are currently remunerated for this via DS3 services, which we discuss in more detail later in this report. However, their limited duration means they are less well placed to manage system needs by absorbing excess renewable energy during periods of high output or producing power during extended periods of low renewable generation. Battery Energy Storage Systems (BESS) also offers the benefit of the flexibility provided being low carbon.

Similarly, DSR can respond quickly when needed and is typically low carbon, but as it relies on reducing demand, may not be able to be done for a prolonged period of time as the demand customer may have a requirement to consume their 'full' power again. Generally DSR has greater flexibility to reduce their consumption than to increase it.

OCGTs have different limitations. They are able to respond relatively quickly, although not as quickly as BESS or DSR, and as they burn gas to produce electricity, they can sustain their output indefinitely. However, due to their reliance on fossil fuels they are a relatively high carbon form of flexibility unless combined with carbon capture technologies. In addition, unlike the majority of the other technologies discussed in this section, OCGTs are only able to export power and are not able to alleviate constraints by absorbing excess renewable energy.

The flexibility provided by interconnectors is partly limited by the way in which capacity is traded on them.

This means that they are not always able to react to short term market signals. In addition, the carbon intensity of the flexibility provided is dependent on the generation mix of the market from which the power is flowing.

In summary, while there are a number of sources of flexibility available in the Irish market, they all have some form of limitation, which is why a mixture of technologies is required. This means that there is a gap in the market for a source of low carbon flexibility that is able to store power for a prolonged period of time during periods of high renewable output and low demand and export it again during periods of low renewable output and high demand. This is a role that LDES could fill, and we will discuss this in greater detail in the following section.

5.4. The role of long duration energy storage

Historically, flexibility has primarily been provided by large-scale, fossil-fuelled generation. However, in recent years climate change targets and emission limits have seen this capacity close and this flexibility be provided instead by other technologies, including battery storage. While battery storage offers a low carbon, fast responding form of flexibility, the length of time they are able to provide power is currently limited. Most batteries currently deployed in Europe have durations of less than two hours, which means they are unsuited to managing security of supply during prolonged periods of low renewable output, for example during an extended cold spell with low wind, often referred to as a "dunkelflaute[2]" event.

As levels of intermittent renewable generation increase and fossil-fuelled generation reduces there will be an increased need for Ireland to be able to absorb this energy during periods of excess renewable generation, store it for a prolonged period of time (days, weeks, or months potentially), and export it for a prolonged period of time during periods of low renewable output. Increased levels of intermittent renewable generation is also expected to result in greater levels of network congestion. This occurs when the physical electricity network is not sufficient for power to flow from where it is produced to where it is consumed. As more renewables connect it is likely that parts of the network will face greater levels of congestion. Currently, congestion is managed by the TSO, EirGrid, through the Balancing Market (discussed below) by instructing generators to increase or decrease their output to meet demand and avoid congestion.

"As levels of intermittent renewable generation increase and fossil-fuelled generation reduces there will be an increased need for Ireland to be able to 'absorb' this energy during periods of excess renewable generation, store it for a prolonged period of time, and export it for a prolonged period of time during periods of low renewable output"

Addressing these two issues are the key roles that long duration energy storage (LDES) will play if Ireland is to meet its decarbonisation targets whilst ensuring security of supply. This future role of LDES was highlighted by EirGrid in the Shaping Our Electricity Future Roadmap v1.1, where it noted that it assumed that 2.4GW of the 3.8GW of storage capacity it assumed would be on the system in 2030 would be long duration (>4hr).

LDES offers a number of system benefits, including:

- Supporting the increased penetration of renewable generation
- Reducing carbon emissions by reducing the need for fossil-fuelled capacity
- Reducing the level of renewable dispatch down due to location adaptability
- Reducing All-Island generation costs

Further, in order for LDES to be impactful and fit-for-purpose for the Irish electricity system it should also have the following characteristics:

- High efficiency
- Low loss of energy during storage

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[2] *A period of time when there is no wind or solar for generation.*

- Speed of response
- Ability to swiftly change direction of power flow.
- Ability to be scalable

LDES can operate alongside the existing and planned fleet of short (<4hr) duration storage assets, with the shorter duration assets providing quick response frequency services (similar to today), and LDES assets providing more sustained output. This would be similar to how dispatchable thermal assets currently operate.

5.5. The revenue opportunities for storage

One of the challenges that has been identified both by potential developers of LDES assets and reiterated by EirGrid in its *LDES Call for Evidence* is the lack of adequate investment signals currently being sent from the market for long duration storage. While there is currently an operational LDES asset in Ireland in the form of Turlough Hill, this was originally constructed as a system balancing asset rather than as a merchant generation station. As such it was able to be constructed despite the lack of revenue opportunities.

In Ireland there are four broad groups of revenue opportunities for electricity generators namely; the wholesale market, Balancing Market, System Services market and the Capacity Market. Currently the main source of revenue for storage assets is through the provision of System Services, but over time we expect storage assets to be able to secure greater value from arbitrage opportunities in the wholesale markets and Balancing Market. Currently storage assets, regardless of their duration, face challenges with participating in all of these markets to differing degrees:

> ***"Storage assets, regardless of their duration, face challenges with participating in all of these markets to differing degrees"***

- The wholesale electricity market
    - Participants are paid for the power they produce or pay for the power they consume at a rate determined by either bilaterally agreed contracts or via exchanges. Rules limiting storage assets' participation in the wholesale market, including limits on importing power, restrict the amount of value they are able obtain from this market. Work is underway to address this as part of the Scheduling and Dispatch Programme of Work
    - There are further considerations around import capacity limitations for storage assets, whereby storage assets are paying Use of System charges on the import portion of their connection, and as such are seeking to minimise their exposure to tariffs while aiming to be able to trade in the wholesale market to receive a negative position
    - There is a relative lack of liquidity in the intra-day market in Ireland, which reduces the potential opportunities to trade in this market. Fewer opportunities to trade (due to lower liquidity) mean there are fewer opportunities for BESS assets to secure value from price arbitrage (i.e. importing at low price periods and exporting at high price periods) in turn also reduces a potential source of revenue for storage assets
- The Balancing Market (BM)
    - Participants offer to either increase or decrease their power output or consumption in exchange for a price they submit. The TSO then dispatches assets to manage system requirements, which means participants recognise financial benefits from managing energy imbalances (i.e. supply and demand being unequal) and system constraints (i.e. re-dispatching assets due to physical limitations with the network infrastructure)
    - The BM is one of the ways network congestion is managed, e.g., by turning up a generator on one side of a point of network congestion and turning one down on the other side. This kind of issue is expected to become worse as increased renewable generation connects to the system and storage, in particular LDES, could be well placed to support this kind of network management

    - The market rules around storage assets' participation in the BM causes challenges for them and limits it as a revenue opportunity. For example, participants in the BM are not able to submit negative physical notifications (PNs), which for storage assets makes charging (importing) in the BM a challenge and they are exposed to market penalties. Work is underway to address this as part of the Scheduling and Dispatch Programme of Work (discussed below)
- DS3 System Services
    - Through the DS3 scheme participants are paid for providing a number of different services including frequency response services (i.e. helping manage fluctuations in frequency) and Steady State Reactive Power. These typically require extremely fast response times and are primarily provided by battery storage sites
    - Historically this has been one of the main sources of revenue for battery assets due to the incentives for fast response times and has been a material driver for the storage that has been deployed in Ireland to date. However, market saturation and planned reforms to system services, under the Future Arrangements for System Services (FASS) expected in 2026, mean this revenue opportunity is likely to reduce in the near future
- Capacity Remuneration Mechanism (CRM)
    - The CRM was designed to ensure security of supply by providing participants with payments for being available to generate electricity or reduce consumption when required by System Operators
    - This has also been a key revenue stream for storage, providing long-term bankable revenue certainty. However, significant reductions to de-rating factors (which determine how much an asset will be paid) have reduced the revenue opportunity for short-duration storage assets

The issues identified above make it very challenging, if not impossible, for developers to invest in the current LDES market. The lack of investment signals has been recognised by EirGrid, ESB and Government, and there are many ongoing workstreams seeking to address them.

"The issues identified […] make it very challenging, if not impossible, for developers to invest in the current LDES market. The lack of investment signals has been recognised by EirGrid, ESB and government, and there are many ongoing workstreams seeking to address it."

The Scheduling and Dispatch Programme is being undertaken by EirGrid and SONI with the aim of improving the technology and capability of scheduling and dispatch across the island of Ireland. This is driven by a number of factors, including: market participant needs, the EU Clean Energy Package, and to support the CAP targets. The work under this program will support a range of market participants, but specifically for storage assets it should allow them to better engage with the wholesale markets and the Balancing Market.

The Department of the Environment, Climate and Communications (DECC) is aware of the need to improve the market for storage assets in Ireland and has been developing an Electricity Storage Policy Framework for Ireland. In 2022-23 the department issued a *consultation* on developing the framework, in which it highlighted the need for a "balanced portfolio", which would include long duration storage technologies. It is expected that the framework will be published later in May or June 2024.

In the *Shaping Our Electricity Future Roadmap v1.1*, EirGrid highlighted the revenue challenges for LDES, noting that it assumed that of the 3.8GW of storage capacity it assumed would be on the system in 2030, 2.4GW of it would be long duration (>4hr). Following on from this report EirGrid issued its *Call for Evidence on the Market Procurement Options for Long Duration Energy Storage*, in which it noted that it had received feedback that the existing available revenue streams still result in a 'missing money' problem for LDES developers. Therefore, it noted, there may be a need for an LDES-specific procurement exercise.

In March 2024 EirGrid *published* a summary of the responses it received to the Call for Evidence. This included the following points:

- The majority of respondents agreed that there was a need for LDES and that it could be a major facilitator of reaching decarbonisation goals, although there was not a consensus that the 8+ hour duration definition proposed by EirGrid[3] should be used
- There was support for holding multiple rounds of procurement, including having separate procurement processes for up to 2030 and post-2030. It was also suggested that long-term benefits be considered over short-term and that environmental consideration relating to construction be considered
- Most participants agreed that there was a ‘missing money’ problem for LDES and that building a business case around only arbitrage (trading in the wholesale and balancing markets) would either be impossible or extremely difficult
- Participants’ preferred procurement option was a Storage Support Scheme Auction, similar to the RESS scheme for renewables

ESB Networks are also currently consulting on a new Flexibility Product. This will be a locational service to manage both demand and generation constraints in different locations on the distribution network. Due to the locational nature of the constraints being managed, ESBN has proposed to run locational tenders. It was intended to publish a preliminary shortlist of locations early in 2024, it is provisionally expected in April 2024 now, with a further refined list shared prior to the procurement process. Based on engagement with ESBN we understand that the duration that participants will be required to provide will vary based on the type of constraint being managed. It is expected that demand congestion related constraints will require ~4hr duration support, while generation related constraints may require 6-8hr+ support.

ESBN is proposing to use a ‘floor-and-share’ scheme that provides successful participants with availability payments and penalties for non-delivery. It is believed that this approach will incentivise flexibility by offering revenue certainty through a guaranteed floor (typically covering the cost of financing the asset). Under a typical cap and floor mechanism any revenues above the cap would be returned to consumers, but this may not incentivise efficient operation of assets above the cap. ESBN believe that a sharing mechanism, which would see a fixed portion of revenues earned above the floor returned to consumers. It is also intended that the revenues available under this service would be stackable with other energy market revenues.

There is a requirement for EirGrid and ESBN to work together on the interactions between distribution and transmission system flexibility services and this is underway.

5.6. Summary of Market Landscape

- The recent and forecast growth in intermittent renewable capacity, combined with the closure of existing fossil fuelled thermal capacity, has created a need for more flexible generation to be deployed to help manage the electricity system
- Currently this has been met by short duration BESS assets, but looking ahead it is expected that there will be a need to store energy for prolonged periods of time to shift it from periods of high renewable output to periods of low renewable output
- One of the key limitations of BESS assets is their limited durations, so this expected future system need creates an opportunity for LDES
- Despite this market need, currently there is a lack of investment signals for LDES, which will need to be addressed in order for LDES to be deployed
- There are also barriers to LDES participation in existing market revenue streams that need to be resolved to facilitate successful rollout

[3] *We note that this definition is different to the 4hr+ definition set out in CAP 2024 that is being used in this report*

6. LDES technology analysis

Having identified the need for LDES in Ireland in the previous section, in this section we have analysed and assessed a number of storage technologies. For each technology we have considered a range of metrics and provided an overall view of their suitability as a form of LDES. These findings will be built upon in later sections when we assess the opportunities and challenges for LDES in Ireland.

In their *Shaping our Electricity Future Roadmap*, EirGrid have identified a set of technologies which qualify as LDES amongst established and developing storage technologies. Focusing in this report on LDES technologies capable of storing energy for >4hrs, we have selected seven of these technologies and have assessed them for suitability to provide sustained support over a long period of time and ability to meet definite requirements that are specific to the Irish electricity system. In this section we have assessed the following technologies:

- Battery storage
- Pumped hydro
- Hydrogen storage
- Compressed Air Energy Storage (CAES)
- Liquid Air Energy Storage (LAES)
- Thermal Energy Storage
- Flywheels
- Technology specific learnings
- Summary: LDES technology analysis

6.1. Battery storage

6.1.1. Technology description

The chemical storage of energy from the grid, which can then be released back to the grid when the need arises is referred to as Battery Energy Storage Systems. This encompasses a wide range of different chemistries, with lithium-ion (Li-ion) being most commonly seen in the market.

BESS is an established technology at present and is a financially viable option to manage system needs and allow for higher intermittent renewable energy on the grid, the need for which is driven by a global move towards decarbonisation and governmental net zero goals. For example, energy arbitrage is a strategy that can help to reduce renewable energy curtailment by charging the battery with low-cost energy during periods of excess renewable generation and discharging during periods of high demand.

Unlike a number of other storage technologies, BESS asset lifespans depend on the number of cycles the asset undertakes. The lifespan of a Li-ion battery storage system is estimated *for approximately 10-15 years*, 2-3000 cycles, with replacements typically occurring after ~10 year when usable capacity falls below ~70-60%. Different trading strategies and manufacturing processes can impact this lifespan. Technological advancements however mean this could increase further. Due to various factors discussed below, alternatives to Li-ion are being researched and developed (e.g. lead acid, nickel cadmium, Lithium cobalt, potassium ion, etc)

At present, BESS durations are primarily in the shorter ranges between 0.5-4hrs. Coupled with the impact of battery degradation (the decline over time of a battery's ability to store and deliver energy) means that BESS applications and use cases are restricted to frequency services, short-term arbitrage, as well as behind-the-meter (BtM) demand-side response, peak shaving and load shifting which permits businesses to shift their energy consumption from one time period to another by utilising the battery when energy costs are higher.

6.1.2. Technology specific benefits and risks

The opportunity for BESS assets in Ireland is their ability to be co-located with renewable generation assets. The use case is proven and has ease of implementation, and although most commonly alongside solar, in Ireland it may prove to be beneficial when co-located with onshore wind assets. Typically, a co-located BESS would share the same grid connection as the other asset and operate in a complementary manner by supporting periods of low renewable output. This offers the ability to 'smooth out' fluctuations by storing excess energy produced by renewables, ready for discharge when needed. However, in Ireland at present several barriers exist for this use case and are being reviewed so that they can be removed. There are issues with multiple legal entities sitting behind one connection point which makes partnership very difficult. There are also issues with submetering and hierarchy of dispatch.

There are also considerations for renewable generation assets that are in receipt of a renewable energy subsidy scheme (RESS) contract as there are limitations for battery storage load on the sites.

The significant costs associated with scaling up BESS for long durations means that this technology has mainly been utilised for shorter duration applications. However, with the automotive industry supporting the advancement of li-ion cells in order to lower the cost of batteries for electric vehicles with longer range, this may in turn increase the affordability of utility-scale battery capex in coming years.

"The significant costs associated with scaling up BESS for long durations means that this technology has mainly been utilised for shorter duration applications."

Recent concerns over resource availability, price volatility, safety concerns and geopolitical complications, have prompted battery manufacturers to consider alternative metal-ion technologies such as sodium-ion, or the development of solid state batteries (SSB). The considerations are further compounded with the understanding that the extraction of rare earth elements also represents adverse environmental impacts (e.g. habitat disruption, water pollution, carbon emissions). The use of high-abundance alternative metal-ion batteries (e.g. sodium, potassium, aluminium) have proved successful due to the reduced cost of using sodium electrolytes in sodium-ion batteries instead of the copper used for Li-ion batteries, albeit offering a relatively low energy density relative to battery volume. Benefits are also seen in the use of potassium-ion batteries (high ionic conductivity means high power density), and potassium-ion batteries (cheaper electrolytes materials compared to Li-ion).

Over the course of its lifespan, a BESS asset, regardless of the metal-ion makeup, will also undergo decay and degradation, limiting storage capacity, and in turn leading to a reduction in their ability to store energy effectively. In the case of long-duration batteries, their round-trip efficiency of charging and discharging cycles may not be as high as shorter-duration alternatives, meaning more energy is wasted in the storage process.

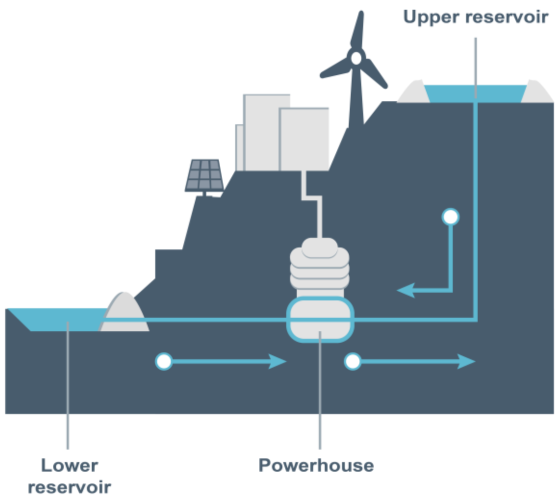
6.1.3. Suitability for LDES

Battery storage tends to be used for short-duration dispatch scenarios, with an average length of dispatch for battery energy storage ranging generally between 30mins to 4hrs. Though BESS has the benefit of offering very fast response times with its high capacity to duration ratio, this does not make it suitable for longer duration LDES technology applications.

6.2. Pumped-Storage Hydroelectric (PSH/PHES)

6.2.1. Technology description

Figure 10: Illustration of a PSH system



Representing *94% of installed global energy storage capacity and ~9,000GWh of electricity worldwide*, PSH is a type of hydroelectric energy storage which consists of two water reservoirs situated at different elevations in order for the water to travel from the upper reservoir to the lower reservoir, therefore generating power by passing through a turbine (discharge). The water is then pumped back to the upper reservoir (charging). The energy storage capacity is dependent on the size of the two reservoirs, while the amount of power generated links to the size of the turbine(s), meaning that geographic factors have a large influence on the options for PSH to deploy.

Two categories of PSH may be used: open-loop and closed-loop. Open-loop projects are continuously connected to a naturally flowing water source (e.g. a river), whereas a closed-loop project ('off-river') is not.

PSH acts in a similar way to a large BESS, as it can store power and then rapidly release it in large quantities when needed. This technology has an efficiency ranging *between 70-85%,* and is highly scalable, with power capacity between *10MW and 4,000MW,* and energy storage capacity of up to 100GWh, with a discharge duration at rated power between 6–24hrs+. The *Energy Storage Association* estimates that, accounting for conversion losses and evaporation losses from exposed water surfaces, energy recovery of >70-80% may be achieved.

6.2.2. Technology specific benefits and risks

PSH is a proven technology globally which may be deployed at scale for multiple decades. Operational projects are capable of both rapid response energy delivery over either short or long periods of discharge, as well as the ability to store large amounts of power. Ireland already has an operational PSH site, Turlough Hill, which has an installed capacity of 292MW and was commissioned in 1974. Currently this is the only form of commercial scale LDES in operation in Ireland. However, a 360 MW PSH plant has been proposed at Silvermines, Tipperary which is expected to become operational in 2028.

Closed-loop projects have the *smallest carbon emissions per unit of storage* of any large-scale energy storage candidates. PSH also enjoys the advantages of a having a long asset life (40 years for the equipment, 100 years for the dam), *low-lifetime cost*, as well as independence from raw materials.

Despite being considered to be one of the most cost-effective methods for storing large amounts of electricity, the high upfront capital costs and long-term investment, relatively lower energy density alongside the requirement for a specific 'hilly' geography presents barriers to the selection of project sites. Investment incentive for new developments is also being impeded by existing market regulations and policy frameworks, with calls for governments to include PSH technology in their decarbonisation policies.

"PSH is well suited to LDES with its long storage and discharge duration, high-power capacity, quick response time"

6.2.3. Suitability for LDES

PSH is well suited to LDES with its long storage and discharge duration, high-power capacity, quick response time, as well as being a well-established technology. It remains limited however by the requirement for suitable geography with access to water, restricting its ability to provide seasonal storage capabilities.

6.3. Hydrogen storage

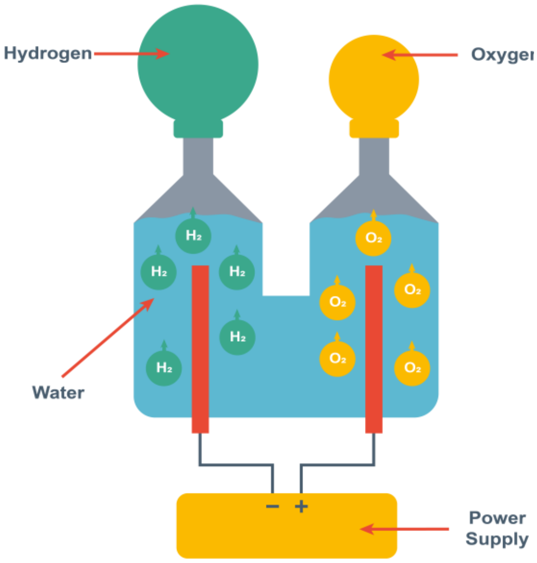
6.3.1. Technology description

Hydrogen can be produced for power storage (and other uses) through the electrolysis of water using electricity. Depending on the source of the electricity used for electrolysis the resultant hydrogen can be known by a number of names (including green hydrogen when produced from renewable electricity or, pink or yellow when nuclear electricity)[4]. The hydrogen can be used to generate electricity via either fuel cells or combustion in a gas turbine. Non-energy related applications include the use of ammonia as a low-carbon fertiliser.

The acquired hydrogen must then be stored, potentially in underground caverns for large-scale energy storage. Steel containers may also be used for smaller scale storage.

Three types of storage are used: High-pressure gas compression, liquefaction (requiring cryogenic temperatures below -252.9°C), and solid-state storage (using metal hydride hydrogen storage or carbon nanotube adsorption).

Figure 11: Illustration of a hydrogen storage system



6.3.2. Technology specific benefits and risks

Hydrogen can provide very long-term, including seasonal, energy storage when combined with large scale storage infrastructure. There is the potential for hydrogen to reuse existing gas sector infrastructure, including transmission and storage infrastructure. This could potentially lower the upfront capex required and lower the risk of stranded assets with the gas sector.

"Hydrogen, and synthetic fuels derived from hydrogen, are capable of bridging long-term (including seasonal) shortfalls in variable energy generation"

While hydrogen production is currently undertaken on a large scale globally, it is predominantly produced via steam reformation. Green hydrogen can be used for a range of use cases beyond energy storage, including green steel production, high quality heat, and transport decarbonisation. Therefore, the infrastructure developed for LDES can be used to support wider decarbonisation and potentially further reduce emissions. As physical storage medium, hydrogen can be transported from production site to use site, both domestically and potentially internationally.

Work has already been undertaken in relation to hydrogen storage in Ireland. The *Hydrogen Salt Storage (HYSS) project* looked to locate and assess the potential for man-made salt caverns to be used for hydrogen storage. Hydrogen also lends itself well to be co-located with offshore wind and there is a CAP 2024 target for 2 GW of hydrogen.

6.3.3. Suitability for LDES

Hydrogen, and synthetic fuels derived from hydrogen, are capable of bridging long-term (including seasonal) shortfalls in variable energy generation caused by issues such as low annual wind speeds or the prolonged loss of large-scale equipment such as interconnectors or electricity generating plants.

[4] N.B. Hydrogen can be produced via other methods including steam reformation of natural gas or geological hydrogen, but these are not considered electricity storage options as they do not convert electricity to hydrogen.

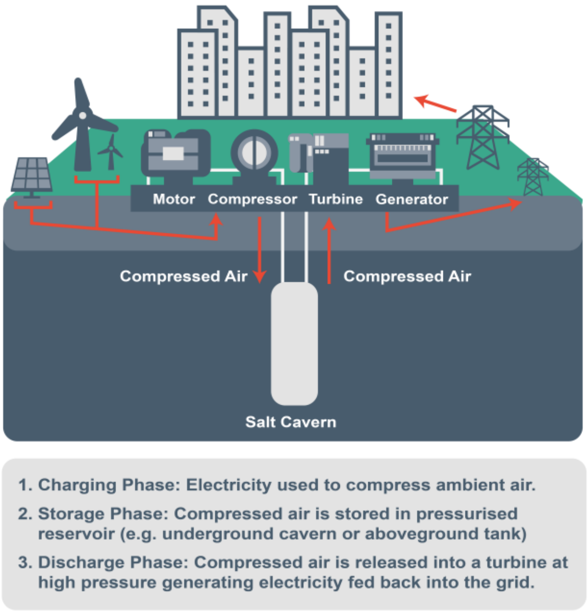
6.4. Compressed Air Energy Storage (CAES)

6.4.1. Technology description

CAES stores energy by compressing air during periods of cheap power prices and then releasing this to drive turbines which then generate electricity from the flow of the high-pressure air. The compressed air can be stored in a range of solutions, including salt caverns or above ground containers.

CAES is a well-established technology, with the first plant becoming operational nearly 50 years ago. It was used primarily as a load balancer for fossil fuel-generated electricity. The limited deployment at scale of CAES plants can be potentially attributed to a general lack of awareness of this technology as an option by planners, especially considering that potential CAES sites are relatively common. However, with the renewed emphasis on low-carbon and renewable generation, applications of CAES at utility-scale have been revisited by the wider industry to support widespread decarbonisation efforts.

Figure 12: Illustration of a CAES system



The process of air compression results in the generation of heat, with various different approaches employed to manage the increase in temperature. If the heat generated during compression can be used during expansion when the air is colder, the storage efficiency may be improved.

6.4.2. Technology specific benefits and risks

CAES can easily be scaled to a site's specifications, with the ability to store energy for long periods of time (>24hrs), as well as a *high response time* (*30 seconds*) due to its multi-stage storage involving several mechanical systems. As salt caverns are relatively common this presents less of a geographic barrier than may be initially assumed when it comes to identifying a suitable site. Furthermore, CAES plants have a lifespan of more than 40 years, making it a viable long-term investment.

"…its low energy and power density requires a larger storage container to ensure a significant amount of energy is stored"

Due to the nature of the process, CAES is considered to have low energy efficiency, with the compression of air resulting in energy loss in the form of unrecoverable generated heat, which reduces overall efficiency. Additionally, the process of compressing air requires a significant amount of electricity, which reduces the net energy generated by the system. CAES also has the drawback of having a *low depth of discharge* (DoD) (i.e. the percentage of capacity that has been discharged relative to overall capacity. A low DoD means that the system is better suited to short discharges, with extended discharges lowering lifespan).

6.4.3. Suitability for LDES

CAES technology is well suited to LDES, particularly in operating as energy-shifting units, with its ability to store large amounts of energy for long durations, discharge from hours to days, as well as having one of the *lowest energy costs* among energy storage systems.

There are currently few operational utility-scale CAES projects, none of which are in Ireland. There is one 320MW project in Germany (Huntorf) and another 110MW project in the USA (McIntosh, AL). As interest in developing traditional and hybrid CAES projects grows (e.g. newly operational *100MW project in China*), *greater evidence will be available* to support its viability as a LDES technology.

However, it should be noted that similarly to PSH, CAES requires a relatively high initial capital cost, as well as its low energy and power density requiring a larger storage container to ensure a significant amount of energy is stored.

6.5. Liquid Air Energy Storage (LAES)

6.5.1. Technology description

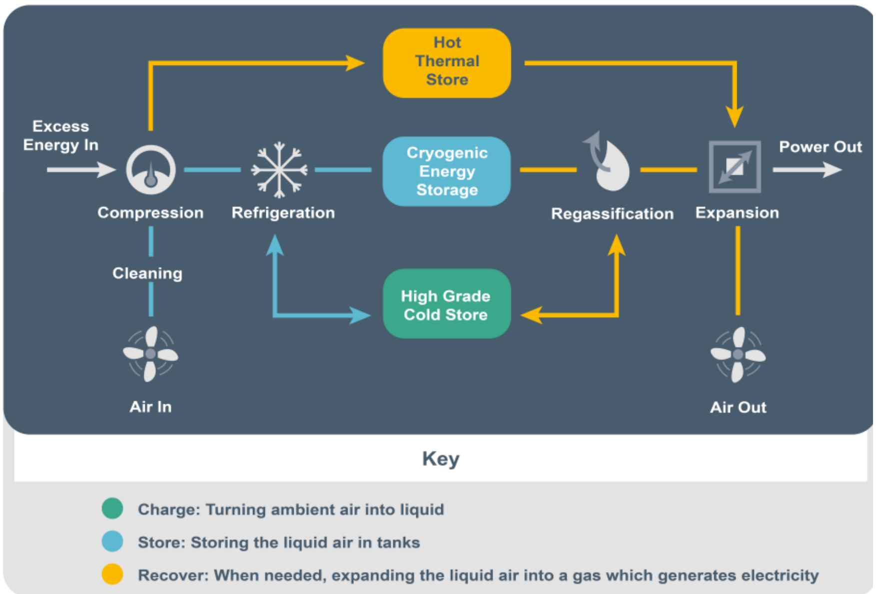
LAES involves the liquefaction of air for storage in insulated tanks which will be discharged during periods of high electrical demand.

> ***"[LAES] has the advantage of being able to operate using readily available, off-the-shelf components commonly deployed in various industrial applications, decreasing capital costs of procuring bespoke equipment."***

The gas liquefaction involves an air liquefier that uses excess electrical energy at off-peak times to draw air from the surroundings. The air is cooled down to −196 °C during this stage in order to liquefy 700L of ambient air into 1L of liquid air. Excess electricity is used to pressurise atmospheric air through the compressor, during which, the storage tank can be used to superheat the air in the discharging process to increase power output. The liquefied air is stored at low pressure in an insulated tank functioning as the energy store. In order to recover the power for discharge, liquid air is pumped into the high-pressure evaporator and heated. The heat storage tank heats the air, which is used to generate electricity through air turbines at high demand.

An additional cycle can be added to improve the system efficiency and reduce the energy demand for producing liquid air, called cold recycle. In this stage, the cold gas is exhausted during the power recovery process and recycled back into the gas liquefaction process.

Figure 13: LAES Main Components and Basic Principles



6.5.2. Technology specific benefits and risks

LAES has the advantage of not being limited by geographical restrictions, as seen with CAES projects which require large underground caves to store high volumes of compressed air, and PSH projects necessitating gravitational potential and large quantities of water storage.

This technology also has the advantage of being able to operate using readily available, off-the-shelf components commonly deployed in various industrial applications, decreasing capital costs of procuring bespoke equipment. Furthermore, with its high volumetric energy density, significantly *less storage space* is required compared to CAES, with a ~700 times reduction. Supplementary pipelines may also be minimised or avoided by placing LAES systems near to other energy conversion processes, ideally at a grid node.

Integration of LAES with other thermal energy systems is also easily achieved across a good range of applications.

A disadvantage of LAES is its low round trip efficiency (<50%) making its viability only practical at larger scales. However, there are *processes* that may be used to increase this efficiency to 50-60%.

6.5.3. Suitability for LDES

LAES is well suited to LDES applications, being scalable from *5MW to 100MW+* of discharge power, storage capacity typically ranging from *200MWh to 2.5GWh*, with no geographical constraints or emissions, a lifetime of 20-40yrs, and the ability to discharge up 10-12hrs+. In addition, the ability to use '*off-the-shelf*' components used in other established industries make LAES a relatively low-risk storage technology.

Challenges to the uptake of LAES projects include a broad range of implementation methods, knowledge, and processes. The absence of full studies due to the lack of actual operating conditions and results from large plants affects in the first instance *techno-economic predictions*. This, coupled with its low efficiency, high payback periods, and profit values, means the commercialisation of LAES is stunted. Considered applications for LAES include energy balancing the day-ahead market, power balancing and reserve provision in the intra-day market, to the smart use of LAES as a multi-faceted provider.

6.6. Thermal Energy Storage (TES)

6.6.1. Technology description

This approach involves the storage of thermal energy ranging from <0°C to 2,400°C for use at a later time. TES can be used to capture and store heat from a range of sources from hours to months. Sources include environmental heat (e.g. during summer daytime), excess industrial heat, or heat specifically created using excess renewable electricity generation. This means that, unlike the other storage technologies considered, TES can provide system benefits through two potential routes depending on its set-up – either by storing excess electricity in the same manner as other technologies for later use, or by lowering electricity demands that would be utilised to meet heat demand by instead offsetting this with heat captured from other sources.

There is a large variety in the approaches to, and use cases for, TES, with storage times ranging from hours to potentially months and seasons.

6.6.2. Technology specific benefits and risks

In a similar vein to LAES, TES can be charged with renewable electricity or waste heat to discharge heat to users such as industrial plants or buildings. With the ability to deliver very high temperatures, TES has applications both domestically and for businesses, as well as in some industrial processes requiring 1000°C+ temperatures. TES also presents the possibility to avoid renewable generation curtailment by providing longer duration energy storage at large-scale.

"TES is suited to LDES applications in the context of meeting heat demand"

One of the main barriers to uptake is the lack of awareness of the capabilities of TES among business leaders, policymakers, and investors. A McKinsey & Company report suggests that business leaders could support awareness by investing in pilots and demonstration plants in order to raise awareness and showcase TES technology. A *2022 report by McKinsey & Company* sees TES as having the potential to boost LDES global capacity to between 2-8TW (against 1-3TW without TES).

6.6.3. Suitability for LDES

TES is suited to LDES applications in the context of meeting heat demand as it is capable of storing thermal energy for prolonged periods in a cost-effective and low-carbon manner.

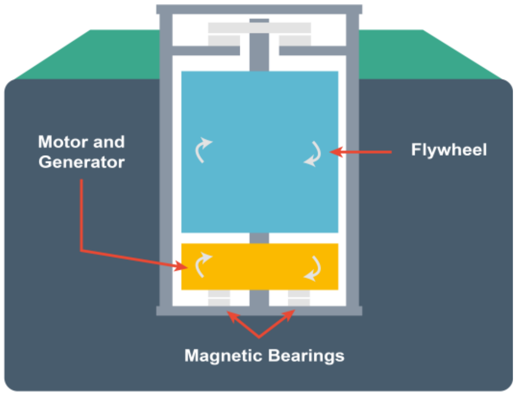
6.7. Flywheel Energy Storage (FES)

6.7.1. Technology description

FES involves the acceleration of a flywheel rotor to very high speeds using electric motors. When energy is required, the flywheel is slowed, and the kinetic energy is converted back to electricity for discharge.

Advanced FES systems are capable of coming up to full speed (20,000-50,000rpm) within minutes, reaching energy capacity much faster than alternative forms of storage.

Figure 14 Illustration of FES



6.7.2. Technology specific benefits and risks

Notable benefits of a FES system include the ability to operate at 100% depth of discharge as well as being able to operate more than 150,000 full discharge cycles while not degrading over time and is durable with a system lifetime expected to exceed 20 years.

To date FES has been deployed at scale for short duration storage requirements, particularly where high capacity, short duration outputs are required.

"[FES is] more suited to intra-day energy shifting and frequency regulation"

6.7.3. Suitability for LDES

FES systems fall outside of LDES suitability range with a duration of dispatch between 0-4hrs, making it more suited to intra-day energy shifting and frequency regulation. Furthermore, the physical characteristics of flywheels, including the loss of stored power over time due to friction limit the appropriateness of this technology for LDES deployment at scale.

6.8. Technology specific learnings

Figure 15 gives a synopsis of the key benefits and challenges of the LDES technologies that have been assessed in the sub-sections above.

Figure 15: Technology specific learnings from LDES technologies

Storage technology	Key benefit	Key risk
Battery storage	• Co-location with renewable generation assets • Very fast response times • High capacity-to-duration ratio	• Significant cost in scaling to LDES capabilities • Low lifespan compared to other considered technologies • Potential resource availability issues causing price volatility
Pumped-Storage Hydroelectric (PSH/PHES)	• Very long lifespan • Fast dispatch and long discharge capabilities • Well established technology providing scalable blueprints for future projects	• Geographic requirements • Large upfront capital cost • Relatively low energy density
Hydrogen storage	• Suited to long-discharge applications • Potential to use preexisting gas	• Technology still in development with few operational examples compared to other LDES technologies

	infrastructure, reducing costs	• Infrastructure still in development to accommodate H_2
Compressed Air Energy Storage (CAES)	• Ability to store large amounts of energy for long periods • Long discharge capabilities • Lowest capital cost range	• Few operational examples to support potential future projects • Large upfront capital cost • Relatively low energy density
Liquid Air Energy Storage (LAES)	• Long lifespan • Long discharge capabilities • Does not require bespoke parts to construct (therefore lower capital cost) • High volumetric energy density which means less storage space is required	• Low roundtrip efficiency • Under-researched
Thermal Energy Storage (TES)	• Free up other technologies for other non-heat related energy needs • Cost-effective and low-carbon storage	• Low awareness which is impeding investment
Flywheel Energy Storage (FES)	• Very fast dispatch response • 100% depth of discharge • Low maintenance	• Further technological developments need to support viability • Short duration of dispatch

6.9. LDES Matrix and technology analysis

For every technology, we have understood and analysed the suitability of using the identified technology to provide LDES support in Ireland by performing a qualitative RAG analysis as per the methodology in Figure 16. Every RAG rating has also been assigned a score to inform a final technology specific overall score. The higher the score the more suitable we consider it for implementation and uptake in Ireland as per our evaluation parameters.

Figure 16: Methodology for analysing suitable LDES technologies for the Irish electricity grid.

Score	High scoring: 3	Medium scoring: 2	Low scoring: 1
Ability to reduce emissions[5]	Technology is proven to be capable of curbing and reducing carbon emissions	The technology goes some way towards reducing carbon emissions but falls short compared to alternative options	The technology does not demonstrate a significant or notable ability to reduce emissions
Geographic requirement	Minor or negligible requirement	Some geographical requirements	Technology has significant geographic requirements which limit its deployment
Lifespan before requiring replacement	30 years+	15-30 years	<15 years
Environmental impact	Little to no environmental impact	Requires or produces moderate environmental impact	The technology requires a significant environmental impact to construct and/or operate
Established technology	There is a wide range of operational examples and studies	Few examples presently in operation	Technology is not widely commercially operational
Timeline to operational	Project operational within <3 years	Project operational within 3-4 years	Project operational post 4 years
Long-term power storage potential	Capable of storing power for days, weeks, months, seasons.	Capable of storing power for days	Capable of storing power for less than a day
Duration of discharge	Capable of continuously discharging power at maximum power output for >24hrs	Capable of continuously discharging power at maximum power output for >8-24hrs	Unable to continuously discharge power at maximum power output for >8hrs
Suitable to LDES	Overall, the technology is well suited to LDES applications with no or negligible drawbacks	The technology has LDES potential but has limitations that may be overcome if the technology improves, or is simply a secondary option to more suitable LDES technologies	Though the technology may score well in parts, it is not considered to be well suited overall to LDES applications

Source: Cornwall Insight analysis

[5] *The technology drives lower carbon levels as compared to the current status in the electricity sector, by virtue of it being a low carbon technology and its ability to provide services that will allow more renewables to be added to the grid.*

In Figure 17 we have provided a scoring matrix for each technology against eight relevant categories using the scoring methodology outlined in Figure 16 and informed by our findings on each technology, we have assigned each technology a score (1, 2, 3) for each criteria. These were then used to inform the score for the technology's LDES suitability. We have then further analysed these technologies in Figure 18 to understand the overall suitability of these technologies for LDES against their timeline to becoming operational. The purpose of this analysis is to understand which technologies will be the most suitable to develop and focus on in Ireland in the near term and in the future.

Figure 17: LDES technology analysis matrix

Storage Technology	Ability to reduce emissions	Geographic requirement	Lifespan	Environmental impact	Established technology	Timeline to operational	Long-term power storage potential	Duration of discharge	Suitable to LDES
Battery storage	3	3	1	2	3	3	2	1	3
Pumped-Storage Hydroelectric (PSH/PHES)	3	1	3	1	3	1	3	2	3
Hydrogen storage	3	2	2	3	1	2	3	3	3
Compressed Air Energy Storage (CAES)	3	2	2	3	2	2	3	2	3
Liquid Air Energy Storage (LAES)	3	3	2	3	1	2	3	2	3
Thermal Energy Storage (TES)	3	3	2	3	2	2	3	2	3
Flywheel Energy Storage (FES)	1	3	2	3	1	3	1	1	1

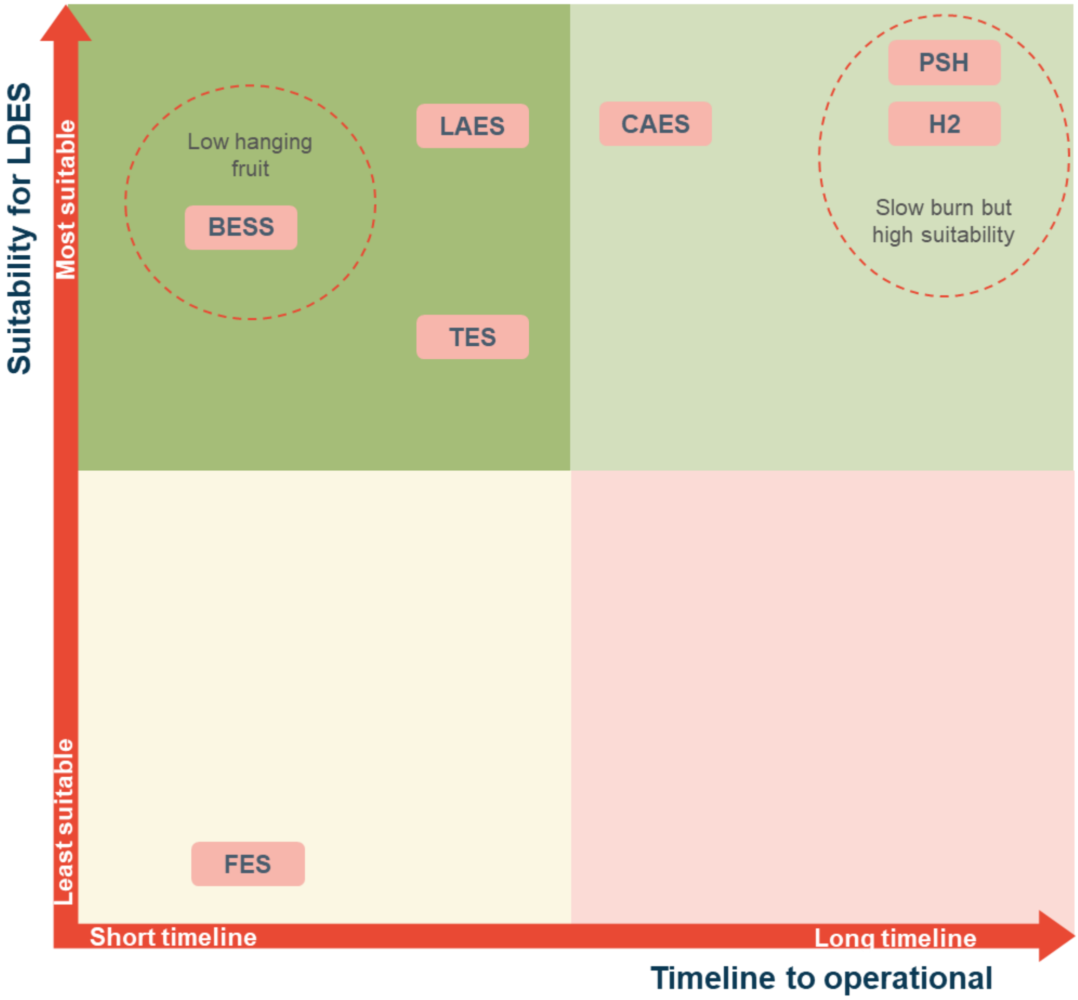
Source: Cornwall Insight analysis

Further to the matrix above, in order to enable us to narrow down the key technologies for Ireland we have analysed technologies against the following factors using a 2X2 model:

- Timeline to becoming operational
- Suitability for LDES

Figure 18 helps us understand the technologies which are suitable to develop immediately versus those where the suitability of the technology may be high, but they will take a longer time to develop, at times because of longer lead times and otherwise technology advancement. From this analysis battery storage, hydrogen and pumped storage emerge as the three key technologies for LDES in Ireland.

Figure 18: Analysing key technologies for LDES



Source: Cornwall Insight analysis

6.10. Summary: LDES technology analysis

- BESS assets present a quick win as they offer an ease of co-location with renewable assets, are modular and can be developed with a short lead time. However, it is generally only effective at durations up to six hours and typically for ~2 hours to, up to ~4 hours at present.
- Pumped hydroelectric storage presents a strong option for the Irish energy market with its high energy storage potential, long duration of discharge, and lengthy lifespan. However there is a geographical requirement with PSH. Ireland already has an operational facility (Turlough Hill), thus the blueprint for future Irish-based projects is readily available. This can be seen by the development of the 360MW *Silvermines PSP* project in Tipperary which is expected to become operational in 2028.
- Hydrogen storage offers the potential to bridge possible long-term shortfalls in variable energy production, even on a seasonal timeline. Though green hydrogen production remains in its nascency, as this becomes more of an established and viable LDES option, salt caverns may instead be utilised for hydrogen storage.
- Compressed Air Energy Storage (CAES) also offers a good option for LDES applications in Ireland. However, it presents a geographical requirement where suitable salt caverns have to be identified. Similarly, to PSH, these are well established technologies with operational applications providing case studies of potential pitfalls and optimisation techniques.
- Liquid Air Energy Storage (LAES) has similar benefits to CAES with the added benefit of not requiring plants to be located at salt cavern sites. This technology remains under-studied and may have low round trip efficiency comparatively to the other technologies discussed.
- Thermal Energy Storage (TES) also presents strong applications for LDES scenarios relating to heat demand, especially in its ability to curb the need for energy generated from renewable sources being spent on heating purposes, freeing them up for other applications in the grid. Low awareness and investment appear to be one of the main barriers to more widespread TES projects.

7. International case studies

While there is a need for LDES in Ireland, currently the market signals are not available to incentivise its deployment. In this section we have provided a number of international case studies to identify any learnings that Ireland could benefit from. These learnings are used in later sections to inform our overall recommendations.

7.1. Overview

The case studies set out in this section seek to provide a representation of the variety of LDES technologies being considered or deployed across Europe, including the EU recommendations for energy storage driving some of this uptake. This includes examining how the countries have supported, or are seeking to support, LDES through a range of policy initiatives and financial mechanisms. These include government funding for testing emerging technologies to providing tax credits, and state aid to support more developed technologies. The case studies will also provide an overview of the country's respective broader market landscapes to provide context and outline more specific investments into various LDES projects. The goal of using these case studies was to identify lessons that could be applied to an Irish context. The countries and specific projects assessed are:

- GB: Multiple pumped storage plants, Carrington LAES plant
- Norway: Dammed hydro
- France: Hypster hydrogen storage project
- Germany: Huntorf CAES plant
- Spain: Molten salt thermal storage

7.2. The EU Commission's recommendations for energy storage

In March 2023 the EU Commission published Recommendation: *Energy Storage – Underpinning a decarbonised and secure EU energy system*. The document was created by the Commission to ensure a greater rollout of energy storage, alongside publishing an outlook of the EU's current regulatory and financing framework for storage. The recommendations set out the support the EU should provide, in tandem with the steps EU countries should take when making decisions surrounding investing in, choosing locations for, and evaluating new energy-storage facilities. This includes assessing capacity and potential financing gaps, removing barriers to deploying demand response and behind the-meter storage, establishing cost-effective processes such as capacity mechanisms and competitive bidding systems details and supporting research and innovation- especially in long-term energy storage. Providing tangible recommendations such as considering avoiding double taxation, alongside suggesting increasing long-term visibility and predictability of revenues like allowing storage operators to receive remuneration for certain services currently provided. As energy systems like Ireland and the international examples detailed below undergo profound changes on the way to climate neutrality, the requirement for greater flexibility, stability and security of supply will be increasingly at the forefront and the EU Commission's recommendations highlights this shared need for LDES.

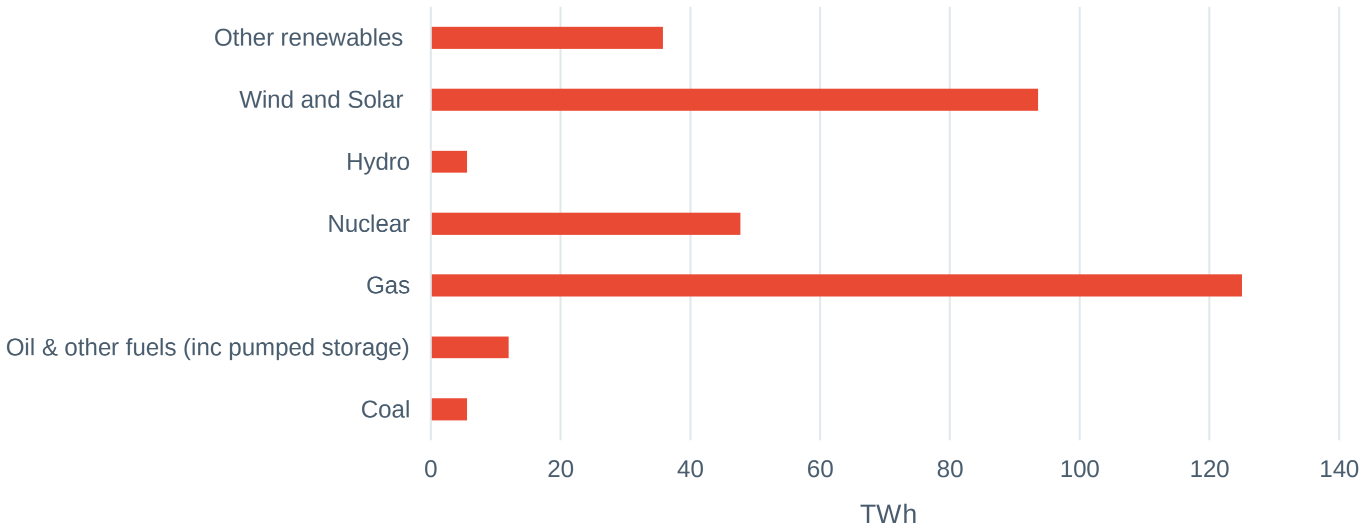
7.3. GB

7.3.1. Market overview for LDES

In 2023, GB continued to grow its sources of zero-carbon electricity, with renewables outperforming traditional fossil fuel generation by providing *51% of the electricity used last year*. Wind is the largest source of renewable electricity but remains second to gas generation overall. The increase in intermittent renewable generation has led to an increased need for storage technologies as part of the electricity system. This has been recognised by industry and is evidenced by the energy storage pipeline growing by two thirds in the last year. In GB there is currently *3GW* of LDES capacity, all of which is pumped hydro that was developed before the privatisation of the electricity system. The largest of these pumped hydro storage assets is Dinorwig Power Station in north Wales, with a capacity of 1.7GW. The government has recognised that increasing the amount of LDES within the electricity system could be vital, predicting that at least 30GW of low carbon flexible assets may be needed by 2030 to maintain energy security. There are currently numerous pumped hydro projects that are undergoing development in GB, the majority of which are in *Scotland*. The government is clear in its support for developing new projects and technologies, and have committed to implementing a policy on LDES in 2024, as stated in its *response to a call for evidence* published in August 2022. Following this, on 9 January 2024, the government published a *consultation* seeking views on an LDES policy framework to unlock investment in LDES to attempt to alleviate some of the barriers discussed in the consultation above. It is proposing to implement a cap and floor mechanism, similar to those available for interconnectors, to provide guaranteed revenue if returns from assets drop below the floor level. If revenues go above the level of the cap, then developers pay back any excess. The government hopes this framework could overcome current challenges to investment in LDES because of its potential to reduce Weighted Average Cost of Capital (WACC) for projects.

Figure 19: GB electricity generation mix by fuel type (2022) (TWh)

Total: 325.3TWh



Source: DESNZ

7.3.2. Financial enablers for LDES or storage

As a result of recognising the potential for LDES in a system with significant levels of intermittent renewable capacity, in 2021 the government launched the *Longer Duration Energy Storage Demonstration (LODES) competition* as part of the *Net Zero Innovation Portfolio (NZIP)*. The competition aims to “accelerate commercialisation of innovative longer duration energy storage projects”, to help manage of the system with increased renewable penetration. Projects were only eligible to apply for this funding if the technology type was not already widely deployed in GB, meaning that lithium-ion batteries, pumped hydro and large water tanks were all ineligible. The available technologies were split into two categories based on their Technology Readiness Level (TRL). Stream 1 offered £37mn for first-of-a-kind technologies at the ‘actual demonstration’ phase. Up to £1mn in funding was available for the planning stage of each project, with up to £11mn for building and commissioning. Stream 2 offered a total of £30mn for projects that may be able to perform a prototype demonstration, with up to £150,000 available for a feasibility study, and a further £9.45mn per project to build and commission.

In terms of revenue streams, for LDES plants in GB there are *5 key revenue streams:*

- **Wholesale market:** Price arbitrage opportunities within the day-ahead and intraday market means LDES is charging during lower price periods, often during times of excess renewables, and discharging at times of high prices, e.g. during periods of low renewable output and high demand.
- **Balancing Mechanism:** Price arbitrage opportunities occur when generation does not match demand, e.g. when wind or solar output is inaccurately forecast. This allows LDES to have a role in wider system balancing, alongside supporting demand management and wind curtailment.
- **Locational Constraints**: LDES can act during times of locational imbalance, helping in managing network constraints.
- **System Services**: Revenues are achievable through ancillary markets by providing services such as, reserve, system inertia, reactive power, and black start service

- **Capacity Market:** LDES can bid into Capacity Market auctions, with revenues being impacted by the de-rating factors applied to all forms of storage.

Figure 20: LODES allocations to date, stream 2, phase 2

Technology	Capacity	Total funding
Thermal energy storage: Extend	No MWh capacity stated, will be developed in 100 trial homes	£9.2mn
Thermal energy storage: ADSorB	No MWh capacity stated, being trialled in two homes in University of Nottingham's living test-site for energy research	£2.6mn
Power-to-X energy storage: HyDUS	Scheduled for completion by 2024, world's first pilot scale demonstrator of bulk hydrogen storage using depleted uranium	£7.7mn
Sustainable Single Liquid Flow Battery: StorTera	At end of phase two, eight modular units will be combined to build a 1.6MWh demonstrator SLIQ	£5mn
High Density Hydro Energy Storage: RheEnergise	1MWh	£8.2mn
Pumped Thermal Energy Storage: SynchroStar	1MW	£9.43mn
CAES and thermal: FlexiTanker	Microgrid development will be co-located with up to 8MW of solar	£9.4mn

Source: DESNZ

7.3.3. Overview of relevant projects

7.3.3.1. Carrington LAES plant

Highview Power and MAN Energy Solutions have partnered to deliver a world first Liquid Air Energy Storage Facility (LAES) facility in Carrington, Greater Manchester, with an expected capacity of 50MW. The technology uses liquified air as a medium for storing energy, which is then evaporated when power is required. Highview state that the technology is modular and therefore scalable, unrestricted geographically, and able to store energy from *6 hours to several weeks*. According to a *Financial Times article* published in 2022, Highview Power planned to raise £400mn in order to develop the project, none of which has come from the LODES competition. It is estimated that *£250mn* of the £400mn will be used to construct the Carrington site, with a further £150mn being used to develop four further sites. The project is part of the wider Trafford Battery Energy Storage System, which will be operated by Carlton Power. According to the Carlton Power website, a grid connection for the site was expected by mid-2023. The Energy System Operator (ESO) *Transmission Entry Capacity (TEC) Register* states that the connection to the LAES Carrington site is expected to be producing power from October 2024. Initial reports suggested the project would become operational by *2022*, but it is unclear as to why this timeline has not been met.

7.3.3.2. Multiple pumped storage plants

Ffestiniog Power Station, commissioned in 1963, was GB's first major pumped storage facility and its four generating units are still able to deliver a combined output of 360MW of electricity. This is enough to supply the *entire power needs of north Wales for several hours*.

Dinorwig Power Station in north Wales is currently the largest pumped hydro storage facility in GB. The *1.7GW* capacity facility can deliver maximum generation within 16 seconds and can generate for *5 hours*. The Dinorwig site is a registered balancing mechanism unit (BMU), this is notable as it provides additional revenue opportunities for the site operator, alongside enabling the site to provide a source of grid stability through assisting in balancing supply and demand. As well as receiving funding as a part of the Capacity Market. There are currently six pumped hydro storage projects under development in Scotland. If all were to go ahead, the total installed capacity of pumped hydro storage would almost triple, almost *15,000* jobs could be created, and by 2035, £5.8bn would be generated for GB economy. Coire Glas, located in the Scottish Highlands, is one of the proposed projects. It would be the first large scale pumped hydro system to be developed in GB in 40 years, with a potential capacity of 1.5GW. SSE, who have proposed the project, have so far invested £100mn into the development of Coire Glas, with the final investment decision (FID) scheduled for *2024*. The FID may be heavily linked with Government policy, with SSE's Finance Director, Gregor Alexander *stating* "*it is critically important GB Government urgently confirms its intention on exactly how they will help facilitate the deployment of such projects* ", whilst noting that the project "doesn't need subsidy". If the project does go ahead, SSE expect go-live in *2031* with around *£1.5 bn* to be invested.

7.3.4. Lessons for Ireland

GB is one of the only examples of a country making an explicit commitment to LDES separate from short term energy storage, recognising its significance specifically in meeting its net zero goals. It has meant GB's policy agenda is at the forefront of deploying dynamic innovative government funding schemes to test and trial a range of LDES technology types. Figure 20 outlining winners of the LODES funding competition highlights the depth and breadth of technology types being tested. The competition aspect is an interesting mechanism which Ireland could consider as a method of trialling new types of LDES before providing longer term incentives in order to figure out what LDES types will be most effective and economically viable in Ireland.

GB is also committed to overcoming legal and regulatory barriers for LDES operators, as well as supporting investment in LDES going forwards. This is evidenced through the government proposing and consulting on the implementation of a cap and floor mechanism to guarantee revenue. These initiatives that seek to improve the business case and provide more certainty to investors will be pivotal for Ireland to unlock its LDES potential and overcome current challenges in investment due to high upfront costs and a lack of long-term

"Initiatives that seek to improve the business case and provide more certainty to investors will be pivotal for Ireland to unlock its LDES potential."

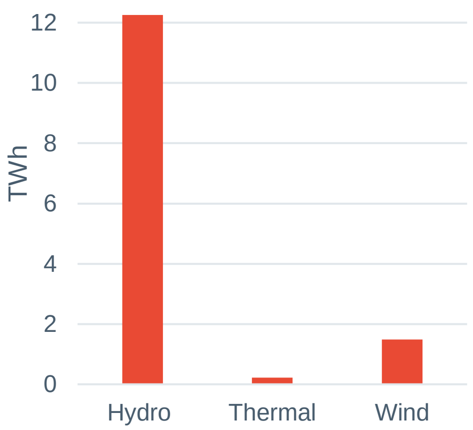
forecastable revenue streams. By de-risking development of LDES in Ireland through some kind of mechanism similar to a modified cap and floor regime, this could provide an element of stability and security to incentivise investment in LDES.

7.4. Norway

7.4.1. Market overview for LDES

Figure 21: Proportion of total power production in Norway in December 2023, by generation type (TWh)

Total: 13.9TWH



Source: Statistics Norway

The Norwegian electricity generation system is dominated by hydroelectric power, accounting for around 90% of the country's electricity generation. This is largely due to the geography of Norway. The myriad of natural lakes and waterways, as well as extensive mountain ranges, mean that hydropower is feasible without much disruption to the land or people. The hydropower system in Norway accounts for *half of Europe's reservoir storage capacity* and is equivalent to *70% of annual electricity consumption in Norway*. The majority (75%) of Norwegian electricity production capacity is flexible, including a total of 87TWh total storage capacity from over 1,240 hydropower storage reservoirs. As a result of the high levels of hydro storage, there is very limited investment and implementation of other LDES technologies. Norway has a long history with pumped hydro storage facilities, with the first coming into operation in 1955. There are 10 pumped hydro plants in Norway with a total capacity of *1.4GW*, all of which are located in West and Central Norway. The largest pumped hydro asset is the 640MW Saurdal power plant, which is part of the larger Ulla-Førre hydroelectric scheme. Since the Norwegian power market underwent deregulation in 1991, *only two pumped storage plants have been built*, indicating a lack of investment signals for LDES, potentially showing saturation in the market.

7.4.2. Financial enablers for LDES or storage

While there are no specific financial mechanisms in place to support LDES storage in Norway, this provides evidence that the LDES market is well developed, and the lack of state level interventions suggests the market is able to operate without additional support. Based on our research, in Norway *the below market based revenue streams* are enough to make an investment without government intervention:

- **Wholesale market:** Norway is part of the Nordpool electricity market. The country is split into six bidding zones and operates as an 'energy only' market. The majority of power trades are made using the Nord Pool platform, which offers a spot market for trading electricity at the day ahead stage. Nord Pool is also a market for trading electricity intra-day.
- **Reserve Market:** Norway is part of an integrated Nordic balancing energy market for manual frequency restoration reserves (mFRR) known as the regulating power market. Statnett buys flexibility through procuring different products in the reserve markets so that consumption and production can be regulated up or down, depending on the imbalance.

7.4.3. Overview of relevant projects

7.4.3.1. Dammed hydro

Dammed hydropower in Norway plays a major role in the energy system. As previously mentioned, there are *1,240* hydropower storage reservoirs in Norway, with a total capacity of 87TWh, half of which is provided by the 30 largest reservoirs. The storage capacity of these reservoirs varies significantly, with flexibility timescales ranging from hourly to yearly, depending on the size of the reservoir. The largest of the reservoir, Blåsjø, would take between *7-8 months* to empty from full capacity, offering long term, seasonal flexibility. This capacity is located in mountainous regions, with the majority in the southern half of the country.

Statkraft are undergoing works to increase the total installed capacity in some of their hydropower stations, however, the majority of all hydropower stations in Norway were built before 1991, with the construction of new hydroelectric assets appearing limited.

7.4.4. Lessons for Ireland

Norway has ultimately made the most out of its natural resources to secure low carbon-based forms of electricity in the form of LDES, and Ireland should seek to replicate this based on what resources are available. LDES forms an integral part as to why Norway's electricity system is set up so well, the country generally has lower wholesale power prices than the rest of Europe, with storage providing a source of stability and flexibility as well as capacity.

LDES works well in Norway because Norway holds 50% of the Europe's reservoir capacity and is therefore uniquely positioned to have high levels of dammed hydropower due to its natural geography. While this is not directly repeatable in Ireland due to differing geography, there are some lessons that could be learned, such as the importance of having a market fit for a range of LDES technologies, as Norway finds itself in a market dominated by a singular LDES technology type. Norwegian electricity demand is projected to rise from 133TWh per year to 220TWh by 2050, requiring additional generation capacity, and the potential for more hydropower is constrained as most viable locations have been developed or are restricted by environmental protections, leaving the country having to consider other options such as expanding its offshore wind capacity.

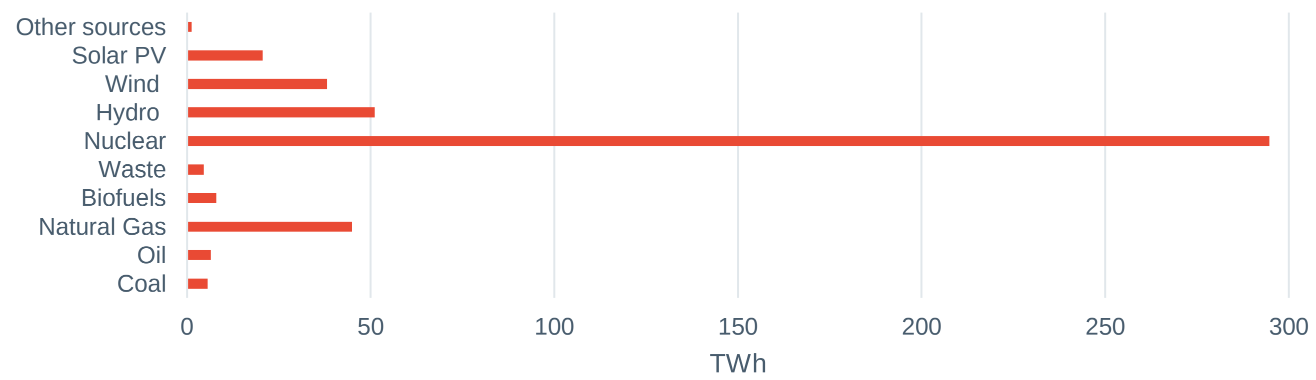
Norway has a closely integrated power system with other Nordic systems (physically and via market integration) and the rest of Europe through cross-border interconnectors, which means exporting is commonplace and may pose the question as to why LDES is still so prominent in the country. However, this should reinforce for Ireland that it is economically viable to have both LDES and greater levels of interconnection. While interconnection in Ireland is currently low it is expected to grow over the coming years, and Norway shows that this does not have to limit the opportunities for LDES.

7.5. France

7.5.1. Market overview for LDES

Figure 22: France's electricity generation by source, 2022 (TWh)

Total: 475.3TWh



Source: International Energy Agency

France possesses a very low carbon electricity system due to its large nuclear fleet, with the 56 reactors producing 62% of the country's electricity generation. However, as the country recognises the challenges of nuclear power and seeks to diversify its generation portfolio, there is a need for policy makers and regulators to act on technological changes, as the need for flexibility in power systems will increase with more intermittent generation sources coming into the country's generation mix. In terms of LDES, France currently has 5.05GW of pumped hydrogen storage capacity, forming part of this is Europe's largest pumped storage plant Grand'Maison, with 1.8GW of capacity. The French Government has repeatedly recognised the potential of pumped hydrogen, and more specifically hydrogen's ability to unlock longer-term storage opportunities, subsequently, as part of its France 30 policy, it has committed €7bn over 10 years to support low-carbon hydrogen. The French Government has emphasised its support for provisions of energy storage in Article L.352-1- 1 in The Climate and Resilience Act, allowing the energy minister to resort to a tender process if storage capacities fail to meet the objectives of the multiannual energy program or if forecasted balancing shows a need for greater flexibility.

7.5.2. Financial enablers for LDES or storage

On 8 January 2024, the European Commission announced that it has approved a €2.9bn French State aid scheme for supporting investment in green industries. Under this Framework, the aid will take the form of a tax credit, open to companies which are planning to invest in the production of batteries and other renewable sources of electricity.

7.5.3. Overview of relevant projects

7.5.3.1. Hypster hydrogen storage project

Hypster hydrogen storage project was inaugurated on 15 September 2023 and is the first renewable hydrogen storage demonstrator in a salt cavern. Based at the Storenergy storage site in Etrez, near Bourg-en-Bresse, France, with a budget of €13mn, the aim of the project initially is to test the production and storage of renewable hydrogen in a salt cavern on an industrial scale, to ensure the quality of the gas in the cavern. At the site, renewable hydrogen will be produced from renewable sources and a 1MW electrolyser. At its peak, the installation will produce 400kg of hydrogen per day and by 2026, hydrogen production and storage will slowly ramp up, until the salt caverns full capacity of around 50 tonnes is used up. Hypster will become the largest French site for salt cavern gas storage, suppling the area's industrial players and hydrogen filling stations. The project will participate in the French regional hydrogen strategy with other noteworthy projects such as the construction of hydrogen production units in Bourgogne-Franche-Comté, to develop a local hydrogen hub to enable a transition towards hydrogen mobility.

7.5.4. Lessons for Ireland

One lesson Ireland can take from France is the country's innovation and exploration into hydrogen for LDES. The Hypster project is a model example for Ireland of the importance of initially testing and experimenting with LDES technologies. It also highlights how it could work practically and in a broader regional hydrogen strategy that focusses on delivering hydrogen as a transport fuel. This is significant, as Ireland is going in a similar direction in utilising hydrogen as a long duration energy store and in the transport sector, as outlined in its draft ORE Future Framework and the National Hydrogen strategy.

Another important consideration for Ireland is ongoing initiatives related to hydrogen infrastructure and storage in other European countries and how it can benefit from these. France is focussed on how it can leverage its strategic geographic location and Ireland should also examine how it could benefit from a pan-European interconnected hydrogen network. This would allow it to make the most of potentially utilising hydrogen as an LDES solution. Ireland would need to recognise its role in this network, and its strategic advantages due to its abundance of significant natural wind resources, which should be rigorously assessed through undertaking strategic planning when assessing location sites, sizes, and types of hydrogen storage.

> ***"The Hypster project is a model example for Ireland of the importance of initially testing and experimenting with LDES technologies."***

As Ireland seeks to expand its offshore wind capacity, hydrogen will play a pivotal role in enabling this intermittent capacity to connect in a way that does not risk system security. In relation to this, Ireland has already acknowledged that some of its offshore wind capacity will need to be specifically developed for hydrogen production. France is a useful example of how that can work in practice, through its additional investment in infrastructure related to hydrogen.

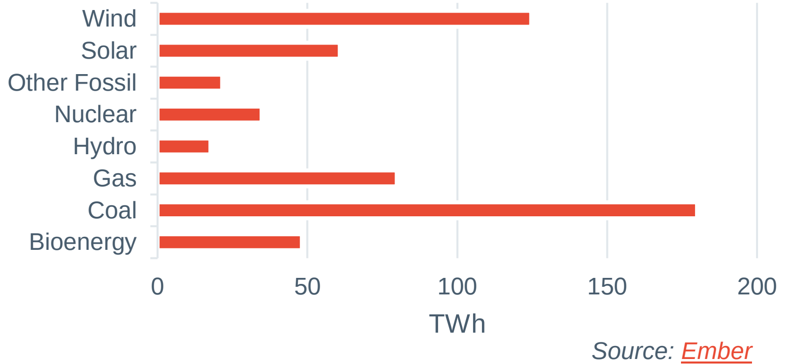
Both France and Ireland share a commitment to flexible solutions and while France is currently exploring LDES, specifically within those industrial clusters, it does still have barriers to deployment. Regulatory barriers and a lack of appropriate legal framework in France for energy storage specifically means the market has struggled to establish itself. Ireland can learn from this and ensure these barriers are resolved in a timely fashion. This could be done through ensuring the relevant bodies are resourced sufficiently to allow for the development of the power system, for example EirGrid and CRU amongst others. By establishing a Regulatory Framework for Storage, further development of LDES can become a viable option in Ireland.

7.6. Germany

7.6.1. Market overview for LDES

Figure 23: Germany's electricity generation by source, 2022 (TWh)

Total: 567TWH



Source: Ember

Until the end of 2022, Germany remained heavily reliant on fossil fuels for its domestic power production, the combined share of renewables stood at approximately 44% in 2022, with wind representing the most significant proportion of this. However, the country witnessed a shift in 2023, as reports recently emerged that a record *56% of German electricity was produced from clean sources in 2023*, with output from fossil fuel sources declining by 20%. This shake up in Germany's clean power share will have implications for the growing necessity of Long Duration Energy Storage, as the expansion of intermittent technologies is likely to continue into 2024. This is noteworthy for Germany, as the country has *shut down its last remaining nuclear reactors*, which previously provided a reliable source of low carbon generation, alongside the fact that grid expansion in Germany is currently behind schedule, and these decentralised energy generation methods require enabling *improved grid stability and flexibility*. While there are no available statistics on Germany's LDES capacity, the country has over 8GWh of battery storage capacity operational, holding around 36% of the total European battery storage market. While large pumped hydro storage facilities provide much of Germany's LDES capacity, Compressed Air Energy Storage Systems (CAES) is a key technology being explored within the German LDES market, noteworthy projects include Kraftwerk Huntorf at 321MW and ADELE at 200MW. The German government's bi-annual *Innovation Auction* promotes energy storage, installation and the inclusion of P2G hydrogen energy storage through incentivising deployments of renewable energy projects.

7.6.2. Financial enablers for LDES or storage

One financial enabler for German energy storage is provided through the *German Renewable Energy Sources Act (EEG)* 2023. The policy enables the German Federal Government to provide funding for innovative concepts, that combine renewable energy sources with local hydrogen-based electricity storage, helping to compensate for the volatility of electricity production that uses renewable sources.

7.6.3. Overview of relevant projects

7.6.3.1. Huntorf CAES plant

The Kraftwerk Huntorf is a 321MW Compressed Air Energy Storage System (CAES) located in Grose Hellmer IE, Germany. The project was *commissioned in 1978* and is owned by Uniper, the electro-mechanical energy storage project works by using compressed air storage as its storage technology, Huntorf uses a 310,000m³ cavern at a depth of 600m with a pressure tolerance between 50 - 70 bar. The plant runs on a daily charging cycle of 8 hours, providing a peak output of 290MW for 2 hours. Due to the centralised nature of the facility, the design allows CAES units to swing quickly from generation to compression modes. This makes the plant *well suited to ancillary services,* providing frequency regulation because of its ability to operate on the daily cycle, beneficial for load-following/ peak shaving.

7.6.4. Lessons for Ireland

Germany recently published their energy storage strategy on 19 December 2023, providing Ireland lessons in the importance of specificity in setting targets for the future and addressing storage types individually, as the negative commentary surrounding the document viewed it as "*lacking both targets and a concrete strategy* on how to make these technologies and their development", LDES targets are well-established in global markets and improve attractiveness for investors.

One thing the strategy does well which Ireland could seek to emulate, is to provide an analysis of the obstacles (listing 17) such as grid connection issues. As well as highlighting the positive steps Germany has taken in easing regulatory barriers like making the *network fee exemption for storage* currently in effect until 2029, permanent. This is critical as both Germany and Ireland phase out fossil fuelled generation, requiring increased levels of flexible generation. By alleviating some of these regulatory costs for operators, this incentivises investors to develop LDES.

> ***"Ireland can learn from Germany the importance of seeing LDES as an independent pillar of the energy system."***

Despite this, the strategy published lacks a clear legislative timetable, Germany is not a pioneer in LDES and Ireland can learn consequently the importance of seeing LDES as an independent pillar of the energy system and a need for the country to consider how storage will be used to *lessen the curtailment of renewable generation and save costs for congestion management*.

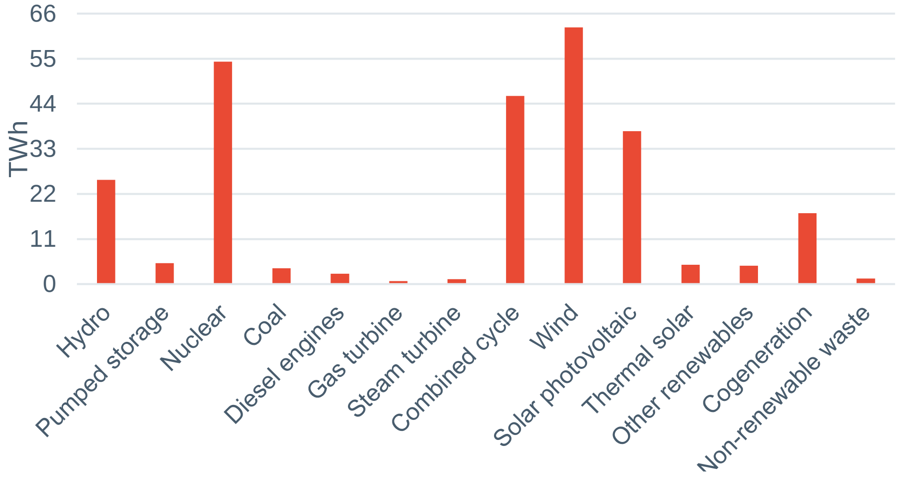
The booming energy storage market in Germany is primarily being driven by wider market interest and less so a result of government involvement. Energy storage projects in Germany face *several legal and commercial challenges* as storage facilities are treated as consumers when drawing electricity and as generators when providing electricity. This means that these facilities face a double charge due to several taxes, levies and charges being imposed on the consumer end. While residential battery systems are extremely popular in Germany, larger scale LDES battery systems are significantly less common, Ireland should learn from Germany and try and support flexibility at scale from the outset of its initial interest, especially when it comes to designing grid tariffs and adopting regulatory and legal frameworks for these technologies.

7.7. Spain

7.7.1. Market overview for LDES

Figure 24: Spain's electricity generation structure by technology, 2023 (TWh)

Total: 266.9TWh



Source: *Red*

Spain has centred itself on having a major rollout of renewables in recent years, in an effort to progress to its 2030 target of an 80% share of renewables in the power mix. In 2023, *50.4% of annual electricity production came from renewable sources*, setting both a record for the share of renewables in the energy mix and total output (135 TWh). This change up in the power mix is likely to continue on this trajectory and subsequently requires careful considerations to enable a smooth transition, especially considering the country's plan to *phase-out both coal and nuclear power generation* (nuclear in 2023 represented 20% of the power mix). These targets and goals that require intermittent generation have led the country to consider expanding energy storage to assure reliable supply. In June 2023, the Spanish government published a draft of its revised National Energy and Climate Plan (NECP), envisioning *22GW of power storage capacity by 2030*. Spain currently has 3.3GW of installed capacity of pumping storage and 6.8GW of storage operative capacity in molten salts in CSP plants, this thermal form of energy storage is key for Spain's LDES systems. In the pipeline is Malta Iberia's *Sun2Store Project*, the largest LDES project that promotes the storage of electrical energy through *heat pumps in molten salt tanks*, with a rated storage capacity at 100MW.

7.7.2. Financial enablers for LDES or storage

In December 2023, the Spanish ministry for ecological transition announced that it has *granted €150mn in state aid* coming from NextGenEu funds to support 36 energy storage projects co-located with renewable energy sites across Spain. These funds, distributed following a competitive bidding setup, will subsidise the installation of 904MW of electrochemical energy storage systems, mainly situated at solar and wind farms. The government department had previously in July 2023 opened two funding programmes with a combined fund of *€280mn in state aid to progress energy storage projects*, with €150mn to support standalone storage projects, thermal storage additionally receiving a €30mn funding boost. Pumped storage hydro projects were targeted in the second programme, making up the remaining €100mn in funding. Another similar mechanism was announced in June 2023 by the ministry. This provided €160mn in grants to support developers by covering *40-65% of the project cost*, depending on the size of company applying. Similar to the UK also putting the focus on innovative technologies.

7.7.3. Overview of relevant projects

7.7.3.1. Molten salt thermal storage

Spain has multiple molten salt thermal storage projects and is a leader in this form of LDES, with a capacity of approximately 6.8GW. The Sun2Store project, set to be commissioned in 2024 will provide 100MW of thermal energy storage at a 10-hour duration. The project will be the *first of its kind in Europe*, combining pumped heat technology with molten salt to provide efficient, reliable and dispatchable renewable energy. An example of an operational thermal storage project is Gemasolar Concentrated Solar Power in Seville, the *first solar plant in the world to use molten heat storage technology*, with an installed capacity of 19.9MW. The molten-salt heat storage system incorporates cold and hot storage salt tanks which can store salts for 15 hours, the tanks avoid wastage of any excess heat generated during the process by storing the heat. The plant's annual production of 110GWh is transferred to the Villanueva Del Ray substation, then is transferred onto the national grid.

7.7.4. Lessons for Ireland

While Ireland may lack the optimal climate and resources that Spain possesses to have molten salt thermal storage, it can take lessons from the country using this technology type and co-locating it with solar, enabling storage to act as a *strategic reserve* to assist in fluctuations in solar. More generally, co-location of renewables and storage is something Ireland will likely have to explore as it seeks to expand wind and solar sources of generation, using batteries to supplement the intermittent nature of these renewable sources.

Spain's Ministry of Ecological Transition's announcement of multiple rounds of state aid for energy storage, incorporating both thermal and pumped hydro emphasises the country's commitment to overcoming barriers to increasing large-scale, long-duration energy storage and is part of Spain's attempt to *increase the installed capacity of storage to 22GW by 2030*. This has been done through helping to finance projects deemed to be most suitable based on criteria including economic viability, ability to help integrate renewable energy into the grid, and ability to bring wider economic opportunities. Direct subsidies such as those implemented by the Spanish government increase revenue certainty and support the financing of projects.

"Direct subsidies such as those implemented by the Spanish government increase revenue certainty and support the financing of projects."

One lesson Ireland should takeaway is how to continue to provide support mechanisms like these and it should consider the factors most integral to making an LDES project financeable like Spain has done. By providing a rigorous assessment pre-subsidy, this ensures that LDES projects are more likely to be successful in eventually becoming operational. This example strengthens the notion of Ireland utilising subsidies to incentivise new and emerging LDES technologies as there is currently an appetite across Europe to encourage the development and testing of a range of LDES solutions.

7.8. Summary: International case studies

- Norway and Spain have maximised the potential of their natural resources and accelerated their LDES uptake as a result (dammed hydropower and molten salt thermal storage respectively). Ireland should seek to replicate this by developing LDES solutions that make best use of the country's natural resources.
- Trialling pilot technologies is prevalent across GB, Germany, and Spain. The diverse nature of the technologies in these trials and financing schemes should be an important consideration for Ireland in terms of establishing what works, as opposed to solely focusing on a singular technology type.
- Spain and the UK also demonstrate the value of LDES being explored as its own specific mechanism, as opposed to grouping it with other forms of energy storage, which means LDES can be prioritised, and specific policy and financial mechanisms can be put in place for it.
- Germany shows the importance of having LDES targets and initiatives with clear timelines applied given that they have not included this in their recent Storage Strategy and industry have pushed back significantly with negative commentary.

8. Review of Opportunities and Challenges for LDES in Ireland

In the previous sections we have discussed the need for LDES in Ireland, the characteristics of various LDES technologies and how different countries have looked to support their deployment. In this section we have combined that information to assess the current opportunities and challenges that LDES face in Ireland. In section 9 we will set out areas for consideration and further evaluation for realising these opportunities or addressing these challenges. In the following sub-sections we will look at:

- A framework for assessing opportunities and challenges
- Analysis of opportunities and challenges
- A summary of key opportunities and challenges

8.1. Framework for assessing opportunities and challenges

In our analysis of opportunities and barriers/challenges we assessed the following (Figure 25):

Figure 25: Framework for assessing opportunities and challenges

Scale of impact:

On a 1-3 scale we have analysed and scored the scale of the impact for each opportunity and challenge. The scoring system used was as follows:

1. Limited impact on the deployment of LDES	2. Noticeable but not significant impact on the deployment of LDES	3. Significant impact on the deployment of LDES

Timeline of impact:

On a 1-3 scale we have analysed and scored the timeline of impact for each opportunity and challenge. The scoring system used will be as follows:

1. Long time for impact to be felt (2030 and beyond)	2. Medium time for impact to felt (2-5 years)	3. Short time for impact to be felt (<2 years)

Materiality of impact:

Calculated by multiplying the scale and timeline scores together to get an overall score for the impact.

Stakeholder:

Who has a role to play: We have identified the stakeholders who have a role to play in ensuring the opportunity remains and the challenge is addressed.

Types of impact:		
We have assessed the impact the occurrence of the opportunity or challenge would have on the following categories:		
Economic: Opportunity or challenge (erosion of possible benefit) arising from opportunity or challenge identified in terms of costs avoided or lowered, money saved, increase in investment, etc	**Policy and regulatory:** Need for policy and regulatory change to encourage and ensure the occurrence of the opportunity and the removal of the challenge.	**System**: Need for the opportunity to be realised and the challenge to be addressed to ensure that the Irish electricity system is secure and stable
Market: Need for market signals to be present for the opportunity to be realised and the challenge to be addressed	**Environmental**: Impact on the environment in the form of achieving and not achieving climate goals	**Political**: Impact of policy on the investment outlook for Ireland's electricity sector, especially LDES investments as a result of decisions made around the opportunities and challenges which exist

Our assessment:
Our analysis of the opportunity or challenge, with any possible way forward to encourage LDES uptake in Ireland.

8.2. Analysis of opportunities and challenges

We have analysed the opportunities and challenges for LDES in Ireland. We have provided a summary table of opportunities and challenges in Figure 27 and Figure 30 respectively. Under each table we then provide a more comprehensive assessment of each opportunity and challenge including proposed next steps required for each.

In relation to opportunities, we have used the following colour coding system.

Figure 26: Key for RAG analysis

Key:	**Green**	High impact (3) Short timeline (3) High materiality (7-9)	**Amber**	Medium impact (2) Medum timeline (2) Medium materiality (4-6)	**Red**	Low impact (1) Long timeline (1) Low materiality (1-3)

Source: Cornwall Insight analysis

8.2.1. Identification and Assessment of Opportunities

Figure 27: Identification of Opportunities for LDES in Ireland

Identification of Opportunity	Scale	Timeline	Materiality	Type(s) of impact	Stakeholder
Evolving generation mix The make-up of the current and future electricity generation portfolio on the system will require flexible generation like storage, and in particular LDES, to support the operation of the power system.	3	3	9	Economic Policy and regulatory System Market Environmental Political	CRU DECC EirGrid SEMC
Low carbon system In line with the National Energy Security Framework published by DECC in April 2022, there is a requirement to provide system security from low or zero carbon sources. This aligns with the Irish CAP, which requires the decarbonisation of the overall electricity sector, with specific renewable targets also included.	3	3	9	Policy and regulatory Environmental System	DECC CRU
Storing offshore wind output LDES is a potential offtake route for offshore wind power and has been referenced in the consultation for offshore wind post 2030 in Ireland.	2	3	6	Economic Policy and regulatory Environmental Political	DECC EirGrid MARA
Interconnection Currently there are low levels of interconnection in Ireland, especially to mainland Europe. This requires the Irish power system to be self-sufficient to a much larger extent to keep prices less volatile, in comparison to mainland Europe's interconnected markets	2	2	4	Policy and regulatory Political System	ESBN EirGrid CRU DECC SEMC
Co-location of renewable and storage assets Excess renewable generation that cannot be absorbed by the grid is dispatched-down resulting in hampering the business case for renewables. Co-locating LDES with renewable assets assist in absorbing the excess generation and lowering the impact of dispatch down of these assets.	3	3	9	Economic Policy and regulatory Environmental Political	EirGrid ESBN CRU DECC

Identification of Opportunity	Scale	Timeline	Materiality	Type(s) of impact	Stakeholder
Congestion management services There are two new services being designed by ESBN with the intention to incentivise LDES	3	3	9	Economic Policy and regulatory Environmental	ESBN CRU

8.2.2. Assessment of the Opportunities

In the following section each of the identified opportunities above are set out in greater detail and the next steps required are discussed.

Evolving generation mix

The make-up of the current and future electricity generation portfolio on the system requires flexible generation like storage, in particular LDES, to support the operation of the power system. In 2022, *~39% of electricity generated in Ireland was from renewable sources*. This share has to increase significantly to reach the target set for the electricity sector under CAP 2021 and reiterated in the 2023 and *2024* CAPs of, 80% of electricity to be generated from renewable sources in Ireland. Thus, going into 2030 and beyond where Ireland targets to be net zero by 2050, with carbon targets and technology/sector specific targets and actions set to achieve these milestones, the system will have significantly more intermittent generation, primarily wind and solar, than today. Alongside this, traditional thermal baseload generation will be continually phased out. This will necessitate technologies that can not only ramp quickly to meet system needs during short periods of time to stabilise the frequency/voltage of the system, but also provide sustained generation over a longer period of time. Several LDES technologies are ideally placed to fill this gap.

Next steps: Given the need for LDES within the Irish electricity market today, it is crucial that it is appropriately incentivised to ensure it is developed. This comes from signals at policy level through targets and through the development of appropriate routes to market for LDES.

Co-location of renewable and storage assets

Excess renewable generation which cannot be absorbed onto the grid due to either, system curtailment, oversupply or congestion on the system leads to dispatch down of the renewable generator. Co-locating LDES with these renewable assets can help absorb renewable generation during times of high generation or system requirements, when they would have otherwise been dispatched down, and then dispatch this stored excess generation at the time that there is a system need. This allows for optimisation of the renewable asset and increased export of renewable generation onto the grid.

However, there are barriers to co-location of two assets at one site. For example, having more than one legal entity behind the meter for an LDES provider that wants to partner with an existing developer, or the metering and dispatch requirements of both generators.

Next steps: The CRU, EirGrid and SEMO are already working through some of the barriers to this type of connection i.e. co-location of two assets behind a single metered point. The decision currently lies with the CRU who is looking into having more than one legal entity behind the meter for an LDES provider that wants to partner with an existing developer, and metering, dispatch priority aspects. Considering there are targets which need to be met by 2030 it is important that the CRU comes to a decision regarding this issue with firm decisions being published as an immediate next step.

Congestion management service

There are additional mechanisms being developed so that LDES can support local constraints without co-locating with renewable assets. ESB Networks have recently consulted on a *flexibility product* that would require longer duration storage of at least 4 hours each day to provide congestion management services. EirGrid also published a call for evidence on LDES procurement strategies and have published a summary of these responses for a design consultation for the LDES service; they are due to publish a consultation on the procurement methodology.

Next steps: It is crucial that both services are fit for purpose for a range of LDES technologies and that the nuances of operating different types have been considered. Furthermore, the interaction between TSO and DSO will become even more important as both operators will be procuring services that could potentially be offered to either or both operators depending on technical need and capability.

Low carbon system

In line with the National Energy Security Framework published by DECC in April 2022, there is a requirement to provide system security from low or zero carbon sources. This aligns with CAP, which requires a decarbonisation of the electricity sector, with specific renewable targets included.

While renewable capacity will help meet electricity demand through low carbon sources, additional system stability and security requirements will need to be procured from low or zero carbon sources and several LDES technologies are ideally placed to provide this support as assessed in section 6 of this report.

Next steps: A full assessment of the LDES technologies and what services they can provide is essential to develop a robust incentive for LDES and ensure there are market signals to support their deployment.

Storing offshore wind output

LDES is a potential offtake route for offshore wind and has been referenced in the January 2024 consultation by DECC on their Draft Offshore Renewable Energy Future Framework Policy Statement, where they discussed the future of a plan led offshore wind system beyond 2030. There is also a planned requirement for ORESS 2.2 to include hydrogen production, which is one of the LDES technologies we have included in this analysis.

The 2030 target of at least 5 GW of offshore wind and 2GW of hydrogen production, alongside the Offshore Future Framework, is starting to signal appropriately to LDES developers that Ireland is a good location for development. However, the policies to date are light touch and the actual implementation of hydrogen production, including the incentives for hydrogen storage, are not clear.

Next step: Policy makers need to develop the market landscape for hydrogen alongside offshore wind and discuss how this can be physically implemented.

Interconnection

Relative lack of interconnection, especially to mainland Europe, requires the Irish generation mix to be self-sufficient to a larger extent compared to mainland Europe’s interconnected markets. Currently the island of Ireland is directly connected to GB through an interconnector to Scotland (Moyle interconnector, 500MW) and another to Wales (EWIC, 500 MW), and through them indirectly to mainland Europe. Once the Celtic interconnector is commissioned, currently planned for 2027, Ireland will have a 700 MW connection to France. Whilst becoming more connected to mainland Europe will help with security of supply in Ireland, there is still a significant advantage for Ireland to have high resilience within its own electricity system; firstly to ensure system security and protection from volatility of external markets for electricity supply and secondly so that it can realise the full potential of its renewable resource, especially wind.

To facilitate a system with high levels of renewables, with targets of at least 5 GW of offshore wind, 8 GW of solar and 9 GW of onshore wind, there are requirements for flexible generation and other stability services, which LDES can provide. It should be noted that there are ambitious targets for additional interconnectors to GB and mainland Europe (Figure 28), but there are equally ambitious targets for offshore wind. Therefore, the requirement for LDES is not expected to reduce as more interconnectors come online.

Figure 28: Planned interconnector capacity

Interconnector	Capacity (MW)
Greenlink	500
Celtic	700
MaresConnect	750
LirIC	700

Next steps: An assessment of LDES capacity is needed, in MW terms, accounting for the additional interconnector capacity expected in order to ensure system security, identifying services which can help create a business case for this additional capacity and then develop a robust framework or incentive mechanism to ensure that the capacity has the incentives and route to market to get built.

8.2.3. Identification and Assessment of Challenges

In relation to challenges we have used the following colour coding system.

Figure 29: Key for RAG analysis

Key:	**Green**	Low impact (1) Long timeline (1) Low materiality (1-3)	**Amber**	Medium impact (2) Medum timeline (2) Medium materiality (4-6)	**Red**	High impact (3) Short timeline (3) High materiality (7-9)

Source: Cornwall Insight analysis

Figure 30: Identification of Challenges for LDES in Ireland

Identification of challenges	Scale	Timeline	Materiality	Type(s) of impact	Stakeholder
Financial incentives There are currently no specific financial incentive/investment signals for LDES in Ireland making the business case very difficult to create.	3	3	9	Economic Policy and regulatory Market	SEMC CRU
Clear policy and targets for LDES There are no tangible targets and a lack of clear policy for LDES in Ireland, the lack of which can and is leading to a lack of development of LDES projects.	3	3	9	Economic Policy and regulatory Political	DECC CRU EirGrid
Planning permission and grid connection delays There are significant delays in the planning permission and grid development processes in Ireland. This is significantly impacting the deliverability of projects as they get ‘stuck’ in processes.	2	3	6	Economic Policy and regulatory Political	EirGrid An Bord Pleanála DECC CRU Loal planning authorities
System Services market changes Currently storage assets in Ireland earn on average 80% of their revenues from the System Services market. This market is currently undergoing a move from a regulated tariff-based approach to a competitive procurement process. During this transition there are many uncertainties leading to low investor certainty.	2	3	6	Economic Policy and regulatory Market	EirGrid CRU SEMC
Technical viability	2	2	4	Policy and regulatory	DECC

Identification of challenges	Scale	Timeline	Materiality	Type(s) of impact	Stakeholder
The technical viability of some LDES technologies still needs to be demonstrated to provide more certainty of the impact they can play in the power system of the future. In the absence of this it can prove harder for policy makers to develop policies and targets.				System Environmental	
Behavioural aspects There are various entities involved in actually commissioning a LDES asset, including particularly sensitive aspects such as public opinion and community buy-in. These need to be understood, accounted and planned for before LDES technology growth can be implemented.	2	2	4	Policy and regulatory Economic	DECC Planning authorities Industry bodies Developers/ investors Customers
Development buildout timelines In general, there are longer build out lead times for LDES projects compared to shorter duration battery storage. This reduces the suitability of some existing revenue streams and can impact the business case for LDES projects.	2	1	2	System Market	EirGrid SEMC
Geographical considerations Certain LDES technologies require specific geographical terrains in which to be developed. For example, a PHES requires an upper and lower reservoir with a significant 'drop' between both to allow for the generation of the electricity. This can impact the business case for those projects as congestion management may not be a viable revenue opportunity depending on the location of the project.	2	2	4	Economic Policy and regulatory Market System	DECC CRU
Capacity Market The Capacity Market currently has significant de-rating factors applied to storage assets which reduces the revenue that can be earned by storage assets. This revenue stream is traditionally a base guaranteed revenue for generation assets in Ireland and these de-rating factors mean this is unlikely to be the case for LDES assets.	2	2	4	Economic Policy and regulatory Market	SEMC CRU

Source: Cornwall Insight Analysis

8.2.4. Assessment of the challenges

Given the quantity of LDES required to allow high volumes of intermittent renewable electricity to be dispatched to meet climate targets, it is important to overcome the challenges to deployment. These include financial, policy, market, technology and planning challenges. In the following section each of the identified challenges above are set out in greater detail and the next steps required are discussed.

Financial Incentives

There are currently no specific financial incentives/investment signals for LDES in Ireland, making the business case very difficult to create. Furthermore, no other financial enablers, such as subsidies, tax breaks, lowering of use of system tariffs, have been put in place to incentivise development.

In addition to the elements discussed above, there are barriers to storage fully participating in the wholesale and balancing markets. Most of these barriers are there because storage assets import as well as export from the grid and to be able to participate fully in the markets need to be able to take up negative as well as positive positions in the market.

- Wholesale market: At present storage assts in the wholesale markets cannot achieve a negative position and they have certain import limitations as well. A negative position in the market would essentially give them a traded position while they are charging or importing from the grid, which the current market rules do not allow
- Balancing market: Similar to the wholesale market currently the scheduling and dispatch rules around charging and discharging prevent battery asset participants in the balancing market to fully realise their potential, as they cannot hold a negative position

EirGrid and SEMO are working on these issues through the scheduling and dispatch programme of work, although progress has not been as quick as market participants would have liked. There is also a concern that the changes are geared towards shorter duration batteries and not LDES.

Next steps: Whilst market signals are a must to ensure growth of the sector, in order to ensure accelerated growth and adequate incentivisation other methods could be assessed and implemented. Ireland could emulate Germany which provides an exemption on network charges for storage assets. It is also crucial that the market system changes that are being proposed at the moment look at LDES storage as well as shorter duration storage. The entities who are responsible for removing these market barriers are, CRU, SEMO and EirGrid.

Clear policy and targets for LDES

There are no tangible targets for LDES in Ireland in the CAPs up to 2024, the draft Energy Storage Policy Framework that was consulted on in November 2022 or any other related government policy or plan, the lack of which can and is leading to a lack of development of LDES projects. Ireland needs to be wary that even when political will and robust policy framework exists, when no tangible targets are set, it can lead to stagnation of actual action-based development, as seen in Germany. There is also limited policy direction from DECC to date, however, there is a Storage Policy Framework due in Q2 2024.

Within the ongoing SOEF Roadmap, EirGrid detailed how much LDES volume they would like to see installed for system operation reasons i.e. an additional 2.4 GW. Previously in an emissions analysis carried out for CAP 2023, EirGrid’s central scenario estimated that ~1.7GW of storage with over 4 hours duration would be required by 2030. Following on from this they published a Call for Evidence for LDES procurement which could well contain the appropriate push that the sector needs to gain traction.

Further to this it is important that the Storage Policy Framework delves into the intricacies of LDES; which technology types are required or at least what specific capabilities are required. The market signals will then need to incentivise the right type of LDES. Without tangible targets there is technically no mandate for the CRU, SEM Committee or EirGrid to develop procurement mechanisms.

Next steps: There remains uncertainty around inclusions in the DECC Storage Policy Framework or how EirGrid’s procurement design will look for LDES. It will be important that there are clear steps included within the Storage Policy Framework to steer the direction of travel for LDES as well as other types of storage and that the design of the EirGrid and ESBN LDES procurement mechanisms provide enough clarity and the correct signals to incentivise participation by LDES developers.

Planning permission and grid connection delays

There are significant delays in the planning permission and grid development processes in Ireland. This is significantly impacting the deliverability of projects as they face unprecedented timelines to complete processes.

Next steps: LDES alongside other technologies, will struggle to be developed in Ireland if the planning permission and grid connection delays that are currently being experienced continue. Whilst there are some LDES technologies that do not require significant land usage such as battery assets, others do. If acceleration of LDES technologies is needed in line with targets set, a Single Window of Clearance (SWC) for these projects may need to be considered, where a single entity is responsible for assessing and permitting grid and planning requirements for supported LDES technologies, in the way the Maritime Area Regulatory Authority (MARA) is responsible for offshore wind development in Ireland. In addition, the larger need for planning and grid connection reforms will continue to need to be addressed, including the key need for simplified planning processes, incorporation of a single window of clearance, pressure on planning bodies to reduce timelines, rules around judicial reviews, etc.

System Services market changes

Currently storage assets in Ireland earn on average 80% of their revenues from the System Services market and there is very little opportunity for diversification of revenue streams. This is a challenge, especially as the regulated arrangements under the current regime, DS3, which provides revenue certainty, will cease to exist post April 2026, and storage assets will move away from regulated tariffs into competitive procurement under FASS.

Further there is lack of certainty around FASS arrangements and the details of the procurement methodology under it, including the daily auctions. The interim period between DS3 regulated arrangements ending (April 2026) and the go live of the FASS daily auctions (December 2026), does not have a clear procurement path for System Services. This coupled with a lack of certainty of the design of the daily auctions and whether fixed contracts will complement this or not, is leading to a lower investor appetite to develop LDES in Ireland.

Further to this it is important to note that LDES technologies are likely to be seeking energisation post 2026, when the FASS arrangements are in place. The potential revenues that can be earned in System Services is likely to reduce as the market becomes saturated, therefore trading in the wholesale market becomes more important.

Next steps: Further details on the FASS program, are due to be published throughout 2024 and beyond, by EirGrid, CRU and the SEM Committee. It needs to be understood whether the investment signal for LDES technologies that will be needed for the future system in Ireland exists within the daily auction framework, or whether there is need for addition incentivisation. The responsibility currently lies with primarily EirGrid and then CRU and SEMO to support EirGrid, in providing more information around FASS.

Technical viability

The technical viability of some LDES technologies still needs to be demonstrated to provide more certainty of the impact they can have on the power system of the future. In the absence of demonstration projects or studies it can prove harder for policy makers to develop policies and targets. Several LDES technologies, especially some which are more established or advanced, have requirements around resource requirement, environmental impact and are climate dependant. Additionally, their viability needs to be tested before financing and policy targets are channelled towards them.

Next steps: A study looking at the technical viability of different LDES technologies specifically in Ireland may be required, including some demonstration or pilot projects. This analysis should include what the technical requirements from EirGrid and ESBN are, how LDES can support them specifically and what can be conceivably developed in Ireland in a timely fashion.

Behavioural aspects

Ensuring that an asset moves through the development pipeline from interest to investment to commissioning has multiple stakeholders involved. Insuring that an asset reaches commissioning requires buy-ins from all stakeholders involved. Gaps in the chain of stakeholders whether it is related to understanding of the technology and the impact it could have on them or their role in ensuring that the technology is implemented is key in implementation of LDES technologies. This is especially true as a significant number of these technologies are new to Ireland and have not had any precedent.

Next steps: A key part of understanding the behavioural aspect is carrying out stakeholder interaction across various stakeholder groups such as government entities, industry bodies, developers, investors and consumers. A detailed stakeholder interaction could be carried out as a next step to understand where concerns lie and what is needed to achieve buy-in from all stakeholders.

Development buildout timelines

There are longer build out lead times for LDES projects compared to shorter duration batteries. This reduces the suitability of some existing revenue streams and can impact the business case for LDES projects. Currently the two key storage technologies in Ireland are short duration battery storage and pumped storage hydro. Both are established technologies and batteries especially are modular and have short build times. However, the future system may need additional storage technologies to encourage an optimal generation mix. These technologies, such as hydrogen storage, have longer lead times to build out and are not modular, thus not lending itself to short term solutions.

Next steps: The methodology put in place to encourage LDES investment needs to be mindful that LDES technologies that are best placed to deliver the System requirements, may not have an ease of implementation and short lead times similar to batteries. For example, batteries are modular have a short lead time and are less capital intensive than technologies such as hydrogen storage. However, batteries do not lend themselves adequately to longer duration storage such as 6 hours and above, which can only be provided by more capital intensive and non-modular technologies with longer lead times, such as pumped storage and hydrogen storage.

Geographical considerations

Certain LDES technologies require specific geographical terrains in which to develop their projects. For example, a PHES requires an upper and lower reservoir with a significant ‘drop’ between both to allow for the generation of electricity. This can impact the business case for those projects as congestion management may not be a viable revenue opportunity depending on the location of the project. It should be noted that other LDES technologies are not dependant on location and are ideally placed to ease issues such as locational constraints.

Next steps: The solution may lie with technologies which are at a more nascent stage, but these would need to be identified with an understanding of investment appetite, economic viability and the enablers needed i.e., they may need additional subsidies/investment initiative. Thus, the next step would be to understand these technologies, their viability and use cases.

Capacity Market

In its current form the design of the CRM means there are issues that are effectively disincentivising LDES to participate, such as derating factors for these technologies. The CRM is used to incentivise new generators to develop. However, it does not currently send adequate investment signals for storage technologies as there are significant de-rating factors applied to these assets, which reduces the revenue that can be earned in the CRM. For example, recent auctions had a derating factor of ~ 38% for a 6-hour storage asset. This revenue stream is traditionally a base guaranteed revenue for generation assets in Ireland and these de-rating factors mean this is unlikely to be the case for LDES assets unless it changes.

Next steps: There are two potential areas. Firstly, EirGrid and SEMO could re-assess the de-rating factors that apply for LDES and set them at a more economically viable level. The second route is to replicate the Renewable Energy Support Schemes, which are essentially a contract for difference for development of renewable capacity and introduce a subsidy support scheme specifically for LDES. The responsibility lies with SEMO, CRU and EirGrid to ensure the capacity market or alternate support mechanism provides a viable investment signal to LDES technologies.

8.3. Summary: Key opportunities and barriers

- There is a system wide need for technologies which can provide flexible, fast acting and sustained power to the grid. LDES is well placed to meet this need.
- This is already being recognised with a Storage Policy Framework due to be published by DECC and procurement methodologies for LDES being evaluated by EirGrid.
- However, there are barriers which exist within the current market mechanisms which are being evaluated for change to allow participation from storage assets.
- Different LDES technologies have different applicability and are at different stages of development. In order to encourage the optimal technologies for Ireland’s energy future these will need to be assessed and identified and investment signals put in place in the form of financial enablers at best and market signals at the least.

9. Areas for consideration and further evaluation

Previous sections of this report have highlighted the growing need for LDES in Ireland which EirGrid in its SOEF roadmap has identified as ~2.4 GW of additional capacity as well as the wider opportunities that we have identified for LDES in Ireland in *section 7.2.1*. This section sets out how the challenges identified in section *7.2.3* can be addressed and the opportunities identified in section *7.2.1* can be aided in crystallising.

This section covers our assessment of the key areas of focus that can enable the growth of the LDES sector in Ireland including areas for consideration and further evaluation (considerations). This section contains:

- Methodology for assessment of the key areas of focus and considerations
- Assessment of the key areas of focus
- Considerations and underlying actions

9.1. Methodology for selecting areas for consideration and further evaluations

We have determined the key areas of focus and the associated considerations we have identified that we feel can enable the growth of the LDES sector in Ireland. This was based on: our subject matter expertise on LDES including our ongoing association with stakeholders in the storage industry; our analysis of the market landscape in Ireland; comparisons of relevant international case studies of LDES markets; and our assessment of the opportunities and challenges for LDES in Ireland.

Based on this analysis we have identified three key areas of focus in section 9.2 where we have detailed why they are important. Building on this, our considerations in section 9.3 are provided through the lens of these key focus areas and detail the following points:

- A list of actions that are needed to grow the LDES sector
- Recommended timelines to complete each action, whether it is to be completed in the short term (1-2 years), medium term (before 2030) or long term (2030 and beyond)
- Ease of implementation of actions on a scale of 1 to 3, with one signifying relative ease
- Entities who will need to be involved

9.2. Key areas of focus

This section looks at the key areas of focus which we believe will enable the growth of the LDES sector in Ireland. These areas have been determined primarily based on three elements:

- Our understanding of the status quo in Ireland as detailed in section 5;
- The lessons learned from our international case studies assessments in section 7
- Our detailed descriptors of the opportunities and challenges that currently exist for LDES in Ireland as discussed in section 8.

The LDES technology analysis in section 6 highlights the range of LDES technologies available, and how important it will be to understand their capabilities, operational profiles, and business case requirements.

Based on the above, we have identified three key areas of focus which will then be discussed in more detail:

- Strategy and Policy Landscape
- Understanding the capabilities of different LDES technologies
- Incentivising development of LDES

9.2.1. Strategy and Policy Landscape

As detailed in *section 7.2.3*, there is currently a lack of policy for LDES in Ireland. Whilst there are targets for renewables and requirement volumes for LDES in EirGrid's SOEF, there are no specific targets for LDES set at government level. A Storage Policy Framework is due from the Government in Q2 2024, which may set out targets for storage alongside initiatives for incentivising development. However, the precise content of this document or whether it will go far enough to identify the pathway for LDES sector is uncertain.

Our international case study assessment in section 7 highlights some lessons that can be learned for Ireland in this regard, showing the need for clear targets and policy that facilitates development. There are lessons for Ireland in other countries, such as Germany and France, whereby the strategy and policy landscape and pathway to achieve them will need to be clear, tangible, and timely but equally there needs to be sufficient buy-in from other relevant organisations alongside appropriate resource levels to realise the strategy.

Germany published their energy storage strategy in December 2023 and the strategy received significant negative commentary around its lack of targets and concrete actions for delivery. Further to this, it also lacked clear timelines for implementation. In France however, whilst there is a robust policy framework for LDES, especially hydrogen LDES, and the political will, there are regulatory barriers that are stymying the development of LDES.

9.2.2. Understanding the capabilities of different LDES technologies

Section 6 carries out analysis on the different LDES technologies. Throughout this section we highlight the different types of benefits and risks to each technology type under a number of headings; is it a nascent or advanced technology, how long does it take to be operational, the storage duration potential, duration of discharge, and suitability as an LDES type service provider. Different technologies rank differently under these headings, however as a whole we find that technologies such as battery storage, hydrogen, and pumped storage hydro will find applicability in Ireland. However, it is clear that there are different considerations depending on the technology type. From our understanding of the market landscape, we believe the technical characteristics of these technologies are not widely understood by some stakeholders in Ireland past the obvious of they can store electricity longer. The intricacies of these technologies in terms of other types of services they can provide to the grid, such as resilience, security of supply, frequency response, congestion management etc, need to be understood by all key stakeholders. This will ensure that at all stages of the process of developing the LDES sector, be that strategy development, market design, incentive design, operational considerations etc., the nuances of LDES technologies can be considered. As identified in Section 8 under the challenges to LDES in Ireland, there is a concern that significant market changes that are being proposed to facilitate shorter duration storage assets may not be considering LDES technologies and their requirements in the market systems.

Ireland needs to apply the lessons from other jurisdictions on this. In GB, government funded schemes to test and trial a range of LDES technology types through the Longer Duration Energy Storage Demonstration (LODES) programme are being deployed. France have also been trialling technologies around hydrogen LDES and have committed funding to the development of this industry. Another lesson that Ireland can learn is from Norway, where they have a significant existing LDES portfolio, which is almost exclusively pumped hydro LDES. This means that their market design, regulations, and operational rules are all geared towards this type of LDES, and the market is not as open to other forms. Now that they have exhausted the majority of available space for this type of LDES in terms of the location requirements, they are looking to open the sector for other types of LDES. Ireland needs to understand the nuances of each type of LDES and design the relevant aspects appropriately.

9.2.3. Incentivising development of LDES

In section 5 on the existing market landscape in Ireland we have highlighted the lack of market signals to encourage LDES developers to participate in the Irish electricity markets. Without the correct incentives and market signals, developers will find it difficult to design a business case around these types of projects. In section 8 we have highlighted some of the challenges around the full participation of LDES in existing market revenue streams, including trading in the wholesale market, Balancing Market, System Services and

Capacity Market. We have also highlighted that with high capital costs to develop LDES, albeit to varying degrees depending on technology type, the certainty of cost recovery is vitally important.

The System Services market where LDES is likely to participate is undergoing significant change as it moves to a competitive arrangement. This, combined with the increased connection of more service providers, means this market is likely to saturate and the wholesale market will become more important to LDES players. However, there is no certainty of revenue in the wholesale market. The Capacity Market, where traditionally generators have enjoyed a certainty of revenue is also not incentivising LDES given the significant de-rating factors that apply to the revenue potential in that market, such as 38% for six-hour duration storage assets in recent auctions.

Storage assets in general are not considered appropriately in terms of Use of System tariffs, where they now must pay demand Use of System tariffs even through their demand is so that they can later export power. The key decision makers need to look at LDES as dual focussed assets that can assist with delivering or absorbing power depending on market signals and system operator needs.

As per our international case studies in Section 7, lessons could be learned from a number of EU countries in this regard. In Germany they have recently made permanent a decision to exempt storage assets from network tariffs. The EU have recently approved a State Aid Scheme in France to apply a tax credit to companies who are developing storage assets. Whilst in Spain, there are direct subsidies for LDES but there is a robust pre-award assessment to ensure viability of projects given the sometimes-lengthy time to operation. Ireland should also look to their existing subsidy schemes for lessons for storage. As laid out in Section 5 on the existing market landscape, renewable support schemes for onshore and offshore wind, RESS and ORESS respectively, support the development of renewable generation in Ireland through the Public Services Obligation. It is important that policy makers look to LDES as a way to support the transition to climate neutrality and consider it as important as the renewable generation that is also supporting the transition.

9.3. Areas for consideration and further evaluation

Based on our assessment of the three key areas of focus in section 9.2., in this sub-section we provide our suggestions for consideration that we feel can enable the growth of the LDES sector in Ireland.

Each consideration is linked to one of the three key areas of focus and Figure 31 details the following points:

- Key area of focus: Which key area of focus the consideration addresses
- Consideration: details of the consideration
- Timeline: Indicative timelines to deliver reforms related to each consideration, whether it is to be delivered in the short term (1-2 years), medium term (before 2030) or long term (2030 and beyond)
- Ease of implementation: Ease of implementation of actions on a scale of 1 to 3, with three signifying relative ease
- Current status: Current status looks at whether there is an ongoing initiative or area of work that is being considered already where LDES specific action needs to be taken, or ensured or whether a new initiative needs to be started

Figure 31: Key considerations

Key Area of Focus	Considerations	Timeline	Ease of implementation	Entities with responsibility/ roles	Current status
Strategy and Policy Landscape	Inclusion of LDES with LDES specific targets and initiatives (including timeline to deliver and to mandate key stakeholders to develop appropriate mechanisms to facilitate LDES) in the planned Storage Policy Framework.	Short term	3	DECC	Ongoing
Strategy and Policy Landscape	Develop an LDES specific strategy with targets and initiatives including timeline to deliver if the planned Storage Policy Framework does not include these.	Short term	2	DECC	New
Strategy and Policy Landscape	Develop a strategy for approaching resourcing out to 2030 within key stakeholder organisations.	Short term	3	CRU DECC EirGrid ESBN An Bord Pleanála Industry bodies	New
Understanding the capabilities of different LDES technologies	Develop a mechanism, either auction or tariff based, with subsidy design dependent on whether state or private investment is being tapped into, to trial new to Ireland LDES technologies to ensure all stakeholders can understand the capabilities of LDES and the nuances to its incorporation into the power system.	Short – medium term	1	DECC EirGrid ESBN	New
Understanding the capabilities of different LDES technologies	Consider conducting analysis to understand capabilities of different LDES technologies, review limitations such as geographical requirements, financial requirements, behavioural risks and review the existing market and operational arrangements and systems to ensure they are fit for purpose for LDES. Following this, develop a list of actions, including timeline for implementation, which are required to allow full participation of LDES in Ireland.	Short term Review needed	2	EirGrid SEMO ESBN	Ongoing
Understanding the capabilities of different LDES technologies	TSO's current review of System Service requirements and volumes for the Future Arrangements of System Services should consider LDES capabilities and ensure that the System Services market is defining the services with a	Short – medium term	2	EirGrid	Ongoing

Key Area of Focus	Considerations	Timeline	Ease of implementation	Entities with responsibility/ roles	Current status
	consideration of the capabilities of LDES that might differ from other technology types.				
Incentivising development of LDES	Develop a consultation to implement a change as needed in the application of demand network tariffs to storage assets.	Short term Review needed	2	CRU EirGrid	Ongoing
Incentivising development of LDES	Develop a design for a LDES support scheme in Ireland defining how that support scheme could work for LDES in Ireland, how would this scheme be paid for, behavioural aspects that would need to be accounted for, and the design of the procurement mechanism.	Medium term	2	DECC	New
Incentivising development of LDES	Attempt to finalise design of the LDES procurement strategy along with specific timelines for procurement and delivery.	Short term	3	EirGrid	New
Incentivising development of LDES	Consider conducting a new review into storage asset derating factors in the Capacity Market with a specific focus on LDES assets.	Short term	3	EirGrid SEMO CRU	New

10. Appendix 1: Acronyms and definitions

BESS: Battery Energy Storage System
BM: Balancing Mechanism
BMU: Balancing Mechanism Unit
BtM: Behind-the-Meter
CAES: Compressed Air Energy Storage
CAPEX: Capital Expenditure
CCGT: Combined Cycle Gas Turbine
CCS: Carbon Capture and Storage
CNG: Compressed Natural Gas
CRM: Capacity Remuneration Mechanism
CSO: Central Statistics Office
CSP: Concentrated Solar Plant
DoD: Depth of Discharge
DSR: Demand Side Response
DS3: Delivering a Secure, Sustainable Power System
EEG: Energy Sources Act
ES: Energy System Operator
ESB: Electricity Supply Board
EV: Electric Vehicle
FES: Flywheel Energy Storage
FID: Financial Investment Decision
HGV: Heavy Goods Vehicle
H_2: Hydrogen
LAES: Liquid Air Energy Storage
LDES: Lond-Duration Energy Storage
LODES: Longer Duration Energy Storage Demonstration
Li-ion: Lithium-Ion (batteries)
MARA: Maritime Area Regulatory Authority
mFRR: manual Frequency Restoration Reserves
NECP: National Energy and Climate Plan
NZIP: Net Zero Innovation Portfolio
OCGT: Open Cycle Gas Turbine
ORE: Offshore Renewable Energy
PSH/PHES: Pumped-Storage Hydroelectric Storage
P2G: Power-to-Grid
RES: Renewable Energy Storage
RESS: Renewable Electricity Support Scheme
ROI: Return on Investment
RPM: Revolutions Per Minute
Solar PV: Solar Photovoltaic
TEC: Transmission Entry Capacity
TES: Thermal Energy Storage
TRL: Technology Readiness Level
V2G: Vehicle-to-Grid
WACC: Weighted Average Cost of Capital

11. Appendix 2: List of tables and figures

12. Appendix 3: Cornwall Insight SEM Benchmark Power Curve modelling methodology

The scope of Cornwall Insight's power model covers the power system of the SEM (from resources to final demand) to the period 2050. The Forward Curves are based on the modelling of detailed fundamental drivers that affect the market now and in the future.

Aggregation decisions are taken at all stages of the model (i.e., demand, transmission, generators, and resources) to optimise the model up to a point where key insights are not compromised. In that context, to achieve our commitment to detail, we have undertaken extensive surveys of current and prospective generation assets. Any aggregation of assets was carried out in such a way as to preserve as much of the individual characteristics of each asset as possible.

The first component of the model structure is the 'input models' and assumptions. These are the exogenous inputs into the power models in that they determine the system's initial state. Given this separation it is important to acknowledge the important feedback loop ensuring that the power model results are logically consistent with the original inputs.

To address the inherent uncertainty in long-term modelling, the following input parameters create a self-consistent and credible scenario:

- Load factors for new and repowered wind turbines
- Cross border flows
- Electricity demand
- Fuel and emissions prices
- Technology deployment costs
- Emissions targets
- Electric vehicle deployment

The second component is the Long-term (LT) Planning Model. The main outputs from this model are the capacity build and retirement decisions for each of the generating units modelled. The model takes each of the initial system states and makes decisions on which capacity to deploy and retire to meet the system needs. This approach includes meeting demand, complying with the annual electricity system emissions limits, and meeting security of supply standards. When deploying capacity there are also restrictions on how much capacity can be deployed in a single year.

For the long-term planning model to achieve credible build and retirement decisions, the optimiser needs to have visibility of the full horizon (rather than making decisions in groupings of years – this allows the model to optimise the electricity price while solving for capacity). It is important to note that due to the complexity of this problem, various rationalisation techniques are used to ensure it is computationally feasible, therefore all results are subsequently validated by the detailed dispatch model.

The final component is the 'detailed dispatch model', which uses the capacity build and retirement decisions from the LT Planning Model and dispatches assets according to the full range of dynamic constraints (i.e., higher time resolution and chronology and physical constraints on the assets). This produces solutions at an hourly basis, solved in weekly steps.

At the heart of our analysis are scenarios developed to highlight uncertainties around the future evolution of the market. Because these are scenario frameworks, there can be periods when, for example, prices in the central scenario could be lower than the low scenario or higher than the high scenario.

Cornwall Insight has developed three scenarios to frame our views of the future of the electricity market.

- The Central scenario is our expected view of commodity prices and the capital cost of different technologies.

- The High scenario provides a view of high commodity prices and low costs for variable renewables technologies.
- The Low scenario provides a view of low commodity costs and lower costs for firm low-carbon capacity such as BECCS and CCUS

All of our scenarios are informed by EirGrid and SONI's forecasts of capacity build out, but these are built upon and expanded to produce our forecasts.

Table 1: Cornwall Insight modelling scenarios

	Central	High	Low
Commodity prices	Based on Cornwall Insight's internal commodity price modelling	Increased process assumed in comparison to central scenario	Decreased prices assumed in comparison to central scenario
Technology costs	Based on Cornwall Insight's internal research and assumptions	Renewable costs are lower – thermal plant costs are higher	Renewable costs are higher – thermal plant costs are lower
Demand	Based on Cornwall Insight's internal demand model	Tapered uplift compared to central scenario – rising to 20% increase over 2050 level	No change to central scenario
RES targets	80% renewable target in 2030. Offshore wind targets for 2050 based on government ambitions		
CO2 targets	Net Zero economy target by 2050 in line with government ambitions	Net Zero reached by 2045	Net Zero reached by 2055

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