Charged Horizons

Exploring the Energy Storage Landscape and Workforce Potential in Ireland

DECEMBER 2023

Green Tech Skillnet

energy storage IRELAND

KPMG

About this report

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Commissioned by

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In collaboration with

energy storage IRELAND

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KPMG

Report context (1/2)

Energy storage is one of the fastest growing segments within the power sector owing to the breadth of high value use cases, the speed of technological innovation and the pace of cost reduction in many technologies. The market has historically relied upon pumped storage however growth is currently dominated by battery energy storage solutions.

28 GW

Total installed global grid-scale battery storage capacity at the end of 2022.

4.45 GW

EirGrid's battery storage capacity projection for 2030*

According to the IEA, global investment in battery energy storage exceeded USD 20 billion in 2022. Grid-scale deployment represented more than 65% of total spending. Battery energy storage investment is expected to exceed USD 35 billion in 2023.

This is driven by the push for renewables investment and growing presence of hybrid renewable energy projects co-located with energy storage. A number of countries are particularly active in the grid modernisation needed to embed storage within energy systems (e.g. Australia, Chile, Germany, Japan, India, Italy, South Korea, the United Kingdom, and the United States). Although new policies and projects in these key markets will accelerate growth, an even faster rise is needed to align with the Net Zero Emissions by 2050 Scenario.

In Ireland, the sector is in a relatively early stage and requires significant uplift to support delivery of the 2030 and 2050 electricity system targets, and to capture the potential of Ireland's renewable energy resources. In the context of the sector's early stage development, there is a need to identify and grow the appropriate new skills and expertise to contribute to the development of a strong supply chain and workforce capable of growing the energy storage sector across the island of Ireland.

Report context (2/2)

Green Tech Skillnet, in collaboration with Energy Storage Ireland (ESI) engaged KPMG to undertake an assessment of the investment and employment potential in the Irish energy storage sector.

Objective

The objective of the study was to explore the investment and employment potential for the energy storage sector in Ireland. In particular the report considers the following topics and questions:

- **To identify the potential for employment opportunities in Ireland, for example across grid, construction, advanced manufacturing, etc;**
- **To identify key supply-side skills development needs such as research, training and development; and**
- **To quantify the overall contribution to, and alignment with, Ireland decarbonisation targets.**

The study considers energy storage in the context of the electric power system, with potential storage technologies examined across four categories, namely electro-chemical, thermal, chemical, and mechanical storage.

Approach

1:

Scenario modelling

Develop scenarios to assess the following:

- Ireland's energy storage needs to 2035
- Ireland's additional storage needs to 2050
- Existing and emerging storage technologies
- Capital and operating expenditure required
- Employment potential in the sector

2:

Supply-side skills development needs

Consider the state of employment and skills in the Irish energy storage sector:

- Assessment of skill and resource needs
- Review of existing capability gaps and barriers
- Recommendations on how to close existing gaps and develop sufficient skills base in Ireland

Sources

A number of primary and secondary research were used, including:

- **A sector survey**: Survey conducted with ESI members, education bodies and other sector stakeholders across the value chain
- **Interviews and consultations:** Insight provided by a series of subject matter expert interviews and workshops with ESI members
- **Third party research and data:** Performed a literature review of reports and sector data from sources including MaREI, ESI, Wind Energy Ireland (WEI), EirGrid, IEA, IRENA and the National Renewable Energy Laboratory (NREL).

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Global context - The importance of energy storage

Energy storage is a key dependency for the transition to a net zero energy system underpinned by intermittent variable sources of renewable generation. The European Commission has advised that "the rapid ongoing deployment of variable renewable energy generation will only reach its full potential with the deployment of additional energy storage"*

While there are many applications around which the business case for energy storage can be build, three primary application areas were considered during this study, namely, dispatch, grid support and customer site applications.

The global energy storage market is one of the fastest growing segments within the power sector. This is due to the breadth and high value of use cases, the pace of cost reduction in many technologies and the speed of technology innovation.

Technology Options

The study examined a wide range of potential technologies and found that battery technologies are expected to dominate the near term growth in energy storage capacity. This is driven by several factors, including the long term trajectory of falling costs of battery technologies along with the increasing need for demand flexibility.

However, a mix of storage technologies is needed to deliver a net zero power system, for example hydrogen is expected to act as a means of seasonal energy storage.

Storage technologies can be grouped into four categories, namely, electro-chemical, thermal, chemical, and mechanical storage.

Based on a set of weighted criteria, considering each technology's techno-economic feasibility for deployment in the Irish energy system, battery technologies ranked the highest, followed by hydrogen storage.

Scenario's for Ireland's energy storage needs

Scenario modelling was used to assess Ireland's energy storage needs to 2035 and 2050:

- Scenario 1: Modest Transition - This scenario examines Ireland making a modest transition to a decarbonised power system over the medium and longer term
- Scenario 2: Greening our economy - This scenario examines Ireland making a concerted effort to decarbonise over the medium term
- Scenario 3: Slow Growth - This scenario examines Ireland decarbonising slowest due to slow economic growth
- Scenario 4: Green Export - This scenario examines Ireland making a concerted effort to decarbonise the economy and avail of renewable energy export opportunities

The scenarios were developed before the publication of EirGrid's Shaping Our Electricity Future v1.1 roadmap and are broadly aligned with EirGrid's projections while also highlighting the key factors which impact the quantum of energy storage capacity needed over the long term.

*Source: Energy Storage - Underpinning a decarbonised and secure EU energy system

Executive Summary

Employment Potential

The development, deployment and operation of energy storage infrastructure will provide an injection of expenditure into the local economy, particularly for inputs that can be sourced from within Ireland. This expenditure will create a multiplier impact via inter-industry linkages in the supply chain. The associated economic impact includes the creation of direct jobs and indirect jobs in the supply chain.

For each scenario, the total storage capacity required, the associated investment, and the potential employment impact was evaluated.

2035: Total value chain employment	~2,270 – 4,980 jobs*
2050: Total value chain employment	~270 – 4,020 jobs*

Recommendations

1. Further analysis and industry engagement is needed to address the limited data and research available on Ireland's future energy system and storage needs beyond 2030.

2. **Policy evolution** is needed to support the development of the energy storage sector throughout the value chain, from R&D and product development through to project delivery and operation. To support this, Ireland needs an end-to-end energy storage strategy that can support the development of the sector. Skills should form a key part of the energy storage strategy, delivering a plan for skills development that integrates with EU level efforts across technology, skills and collaboration

3. **Skills intelligence** needs to be developed by establishing 'real-time' view of skills demand and gaps, supported by collaboration between industry and the education sector to ensure the required skills training is made available

Recommendations (continued)

4. **Career Development:** Based on industry feedback, clearly defined energy storage related career paths need to be developed and promoted to new entrants to the labour market and those seeking new opportunities. This will require greater collaboration between education providers and industry. Concurrently, on the job learning delivered by industry, and industry graduate programmes with corporate and academic collaboration is needed for ongoing development of the necessary skills amongst current employees, new entrants to the labour market, and those seeking new opportunities

5. **Strategy:** Skills intelligence, aligned with the skills aspects of the energy storage strategy, should be used to develop a career and skills roadmap. This should be linked to strategic technology areas to guide efforts to support and meet the energy storage sector's skills needs

Notes: * The employment impact estimates consider the potential capital and operating expenditure required to meet the modelled energy storage needs at a specific point in time - for 2035 and 2050 respectively. These estimates are illustrative and the modelling is based on the current structure of the economy. Given the timeframe to 2050, these figures include a high level of uncertainty.

Executive Summary

Recommended Actions
Actions are considered across three themes:

01 Technology and the future energy system

02 Growing Ireland's energy storage sector

03 Delivering the necessary skills

These three themes are further developed, with actions highlighted across several key areas, including the following: Key technologies, Ireland's energy system needs, mechanisms to inform policy, energy storage strategy, delivering skills, 'real-time' skills intelligence and an energy storage career roadmap.

Notes: *The employment impact estimates consider the potential capital and operating expenditure required to meet the modelled energy storage needs at a specific point in time - for 2035 and 2050 respectively. These estimates are illustrative and the modelling is based on the current structure of the economy. Given the timeframe to 2050, these figures include a high level of uncertainty.

Executive Summary

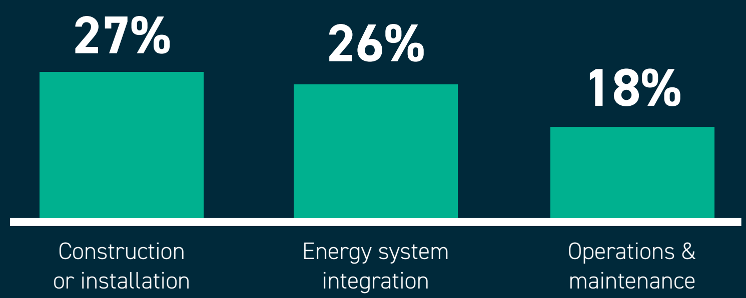
A survey of the sector highlights key technologies, and issues for employment and skills in Irish energy storage.

Top-3 energy storage technologies that will allow Ireland to deliver energy storage needs post 2030

- **Lithium-ion batteries**
- **Hydrogen storage**
- **Flow batteries**

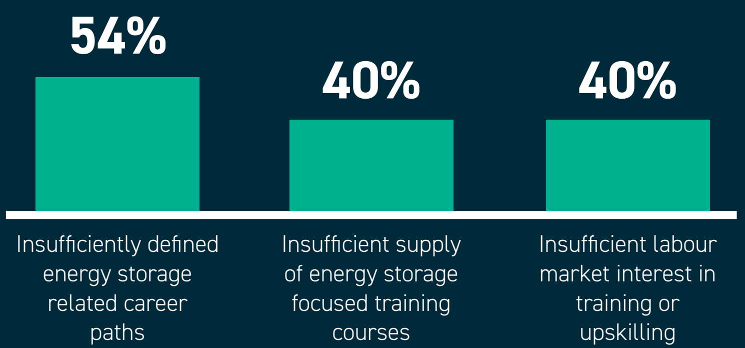
Top-3 energy storage value chain segments that have the greatest opportunities for job creation in Ireland over the next 7 years

Share of respondents



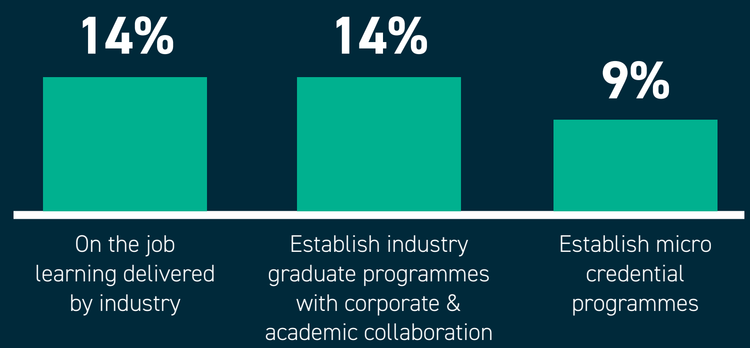
Main challenges to growing the skills needed in Ireland's energy storage sector

Share of respondents

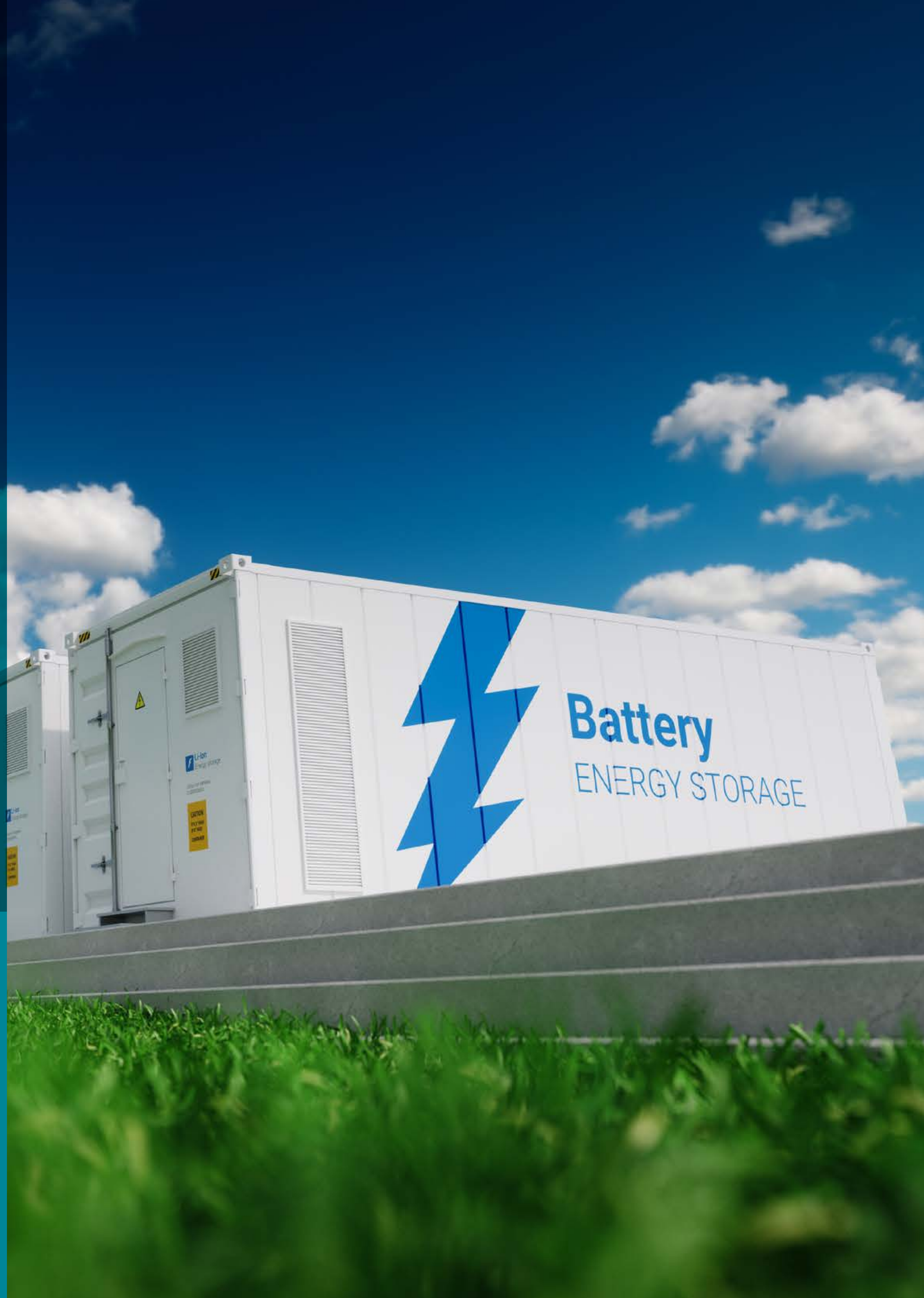


Approach to training needed today to address future skill gaps

Share of respondents



Scenario modelling



Scenario modelling: Overview

Four scenarios for Ireland's energy storage needs were developed looking at 2035 and 2050.

Scenario modelling was used to assess Ireland's energy storage needs in 2035 and 2050. This was done by considering the global context, demand projections, renewable energy scenarios, established and emerging energy storage technologies, the potential capital and operating expenditure required to meet Ireland's energy storage needs, and the potential for value chain employment resulting from investments in energy storage capacity. Potential storage technologies were considered and assessed within four technology categories: electro-chemical, thermal, chemical, and mechanical storage.

Ireland's energy storage needs was considered in terms of the energy surplus and deficits from dispatch on the transmission grid and the need to deliver 25-30% of flexible demand by 2030 which was assumed to continue post 2030. The scenario analysis was performed before the publication of EirGrid's Shaping Our Electricity Future v1.1 roadmap and are broadly aligned with EirGrid's projection of 4.45 GW of battery energy storage needed by 2030. The scenarios also highlighting the key factors which impact the quantum of energy storage capacity needed over the long term, namely demand flexibility and the level of interconnection capacity.

The analysis did not examine the energy storage assets needed to provide system services as it is assumed that within the timeframe of the scenarios storage assets will be able operate in multiple markets allowing the portfolio to offer system services. Grid constraints and congestion were not modelled, EirGrid and ESB Networks are currently working to quantify the role of energy storage in these areas.

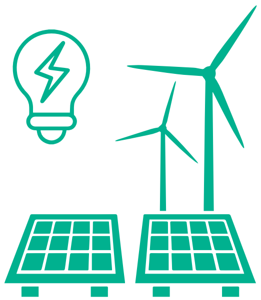
Global view (1/2)

The potential benefits from energy storage are significant and wide ranging, encompassing economic, decarbonisation and energy security benefits. These can be categorised into the three main application areas for global energy storage use presented below.

The technology, regulations and market rules for all these application areas are evolving rapidly.

Primary energy storage application areas

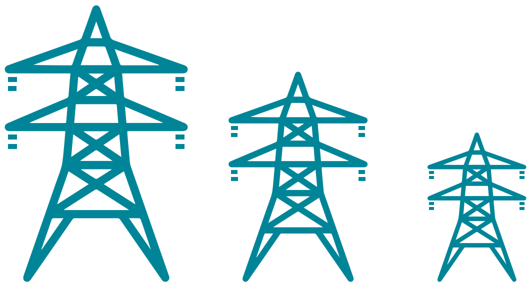
Dispatch



- Shift excess energy to periods of scarcity
- Reduce renewable generation dispatch down
- Capacity firming
- Reserve capacity

The focus of the scenario analysis in this report focuses on grid dispatch

Grid Support



- Frequency regulation
- Voltage regulation
- Fast ramping services
- Congestion relief
- Deferred grid upgrades
- Black start services

Customer Site

- Demand shifting / peak price avoidance
- Procurement optimisation
- Connection firming
- Back-up power supply

Global view (2/2)

The global energy storage market holds vast potential.

The global energy storage market is one of the fastest growing segments within the power sector. This is due to the:

1. Breadth of high value use cases

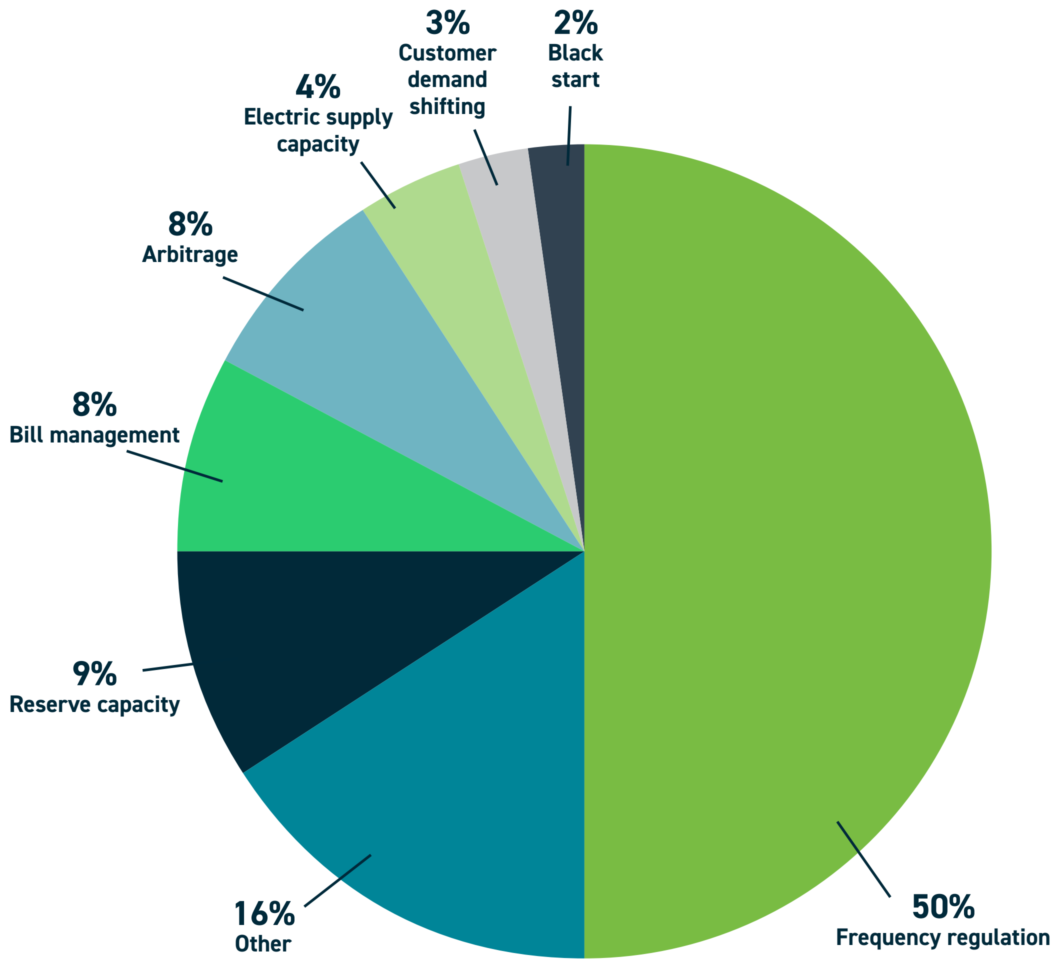
2. Pace of cost reduction in many technologies

3. Speed of technological innovation

Energy storage is a key dependency for the transition to a net zero energy system underpinned by the intermittency of wind and solar generation. Large, long duration energy storage solutions are required to store low cost surplus renewable energy, and make it available when needed. This not only has the benefit of providing energy when it is needed most, but also avoids the loss of renewable energy that is dispatched down when there is insufficient demand for it, or insufficient grid capacity to transport the energy to customers. Energy storage can also provide additional grid capacity without the need for expensive grid investment.

Energy storage systems can provide the ancillary and system services needed to operate power grids which were originally designed to transfer power from GHG emitting fossil fuel generators to large demand centres, and now need to accommodate high levels of renewable generation and generation embedded behind the customer's meter.

Share of energy operational storage capacity by application areas

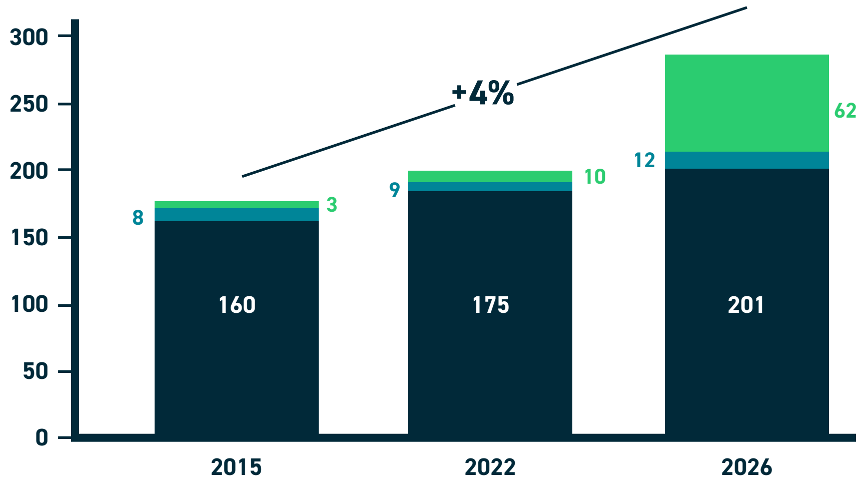


Customers, from residential to commercial energy users, stand to benefit from the flexibility and control energy storage provides when making energy supply decisions.

Global energy storage market size and growth

Batteries prominent in new growth in energy storage.

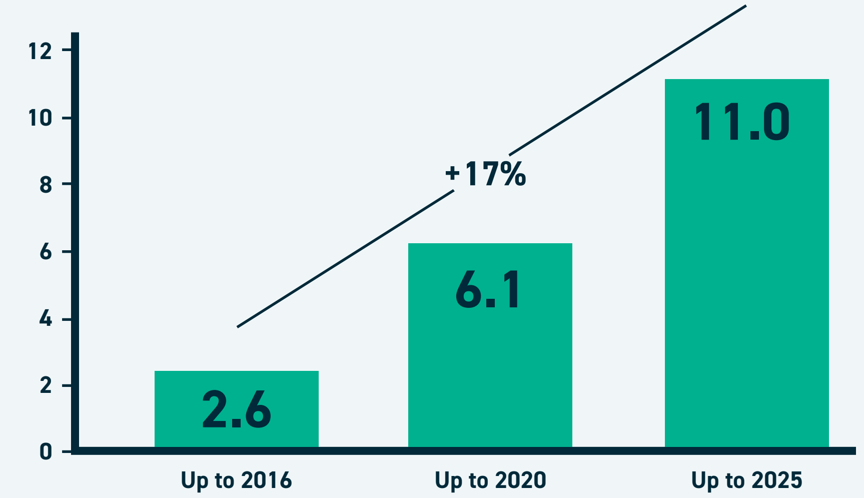
Global Energy Storage Capacity (GW & CAGR)



Energy storage growth

- Since its inception in the early 1900s, pumped hydro has been the dominant technology for grid-scale storage of electrical energy. Reversible turbines (capable of functioning as pumps) store excess electricity by pumping water from a lower to higher-elevation reservoir for dispatch to meet peak electricity demand .
- While pumped hydro is projected to add an additional 40 GW of energy storage capacity by 2026, battery energy storage systems (BESS) is growing much faster.
- From less than 3 GW in 2015, BESS deployment has tripled in the last seven years to around 10 GW in 2022, and is projected to surpass 60 GW by 2026.
- BESS capacity is growing at a Compound Annual Growth Rate (CAGR) of 17% which is far in excess of the 4% CAGR across all storage capacity with significant growth expected until at least the end of the decade.

Global Battery Energy Storage Market Value ($bn & CAGR)



The global battery energy system market

Several factors contribute to high levels of growth within this market segment, including:

- The steep long term decline in battery technology prices
- The decentralisation of national power systems and the flexibility of battery energy storage to address issues this presents; and
- The increasing need for grid stability solutions.

Types of energy storage

Storage technologies can be grouped into four categories,
a brief summary of key technologies is presented below with further detail available in Appendix B

Electro-chemical

Batteries store electricity as electro-chemical energy. When a voltage difference is applied between the cathode and the anode of a battery electricity flows across the electrolyte enabling energy to be stored.

01: Lithium-Ion (Li-ion) Batteries

Currently the most popular grid scale battery technology, the reversible reduction of lithium ions is used to store energy in these batteries.

02: Sodium-Ion (Na-ion) Batteries

Almost identical working principle to Li-ion, but replacing the lithium with sodium.

03: Metal-Air Batteries

Uses anodes from pure metal and air as the cathode with an aqueous electrolyte solution.

04: Redox Flow Batteries

Consists of two looping tanks of liquid connected through a membrane enabling the flow of electrical current.

05: Nickel-Metal Hydride (NiMH) Batteries

A more recent innovation uses one nickelbased and one hydrogen-absorbing electrode.

06: Lead-Acid Batteries

The original rechargeable battery uses lead electrodes in a sulfuric acid electrolyte solution

Thermal

07: Molten Salt

Primarily used in conjunction with concentrated solar power (CSP) plants. Energy is stored as heat attemperatures ranging from 150 to 600 C. This heat is converted to electricity using conventional steam turbines and generators

Chemical

13: Hydrogen

Converting electricity to hydrogen through electrolysis (or other means) for energy storage in chemical bonds.

Mechanical

Mechanical energy storage involves increasing the potential energy of an object or material, either through elevation, pressure, or temperature.

08: Pumped Hydro

Stores energy as the potential energy of a volume of water by pumping it to reservoirs at an increased elevation.

09: Gravity Storage

Similarly to pumped hydro, gravity storage stores energy as potential energy by raising a heavy object to an increased elevation.

10: Liquid Air

Energy is stored by cooling air until it liquifies. Dispatched is performed by returning the expanding gases to ambient temperature through a turbine.

11: Compressed Air

Similar to liquid air storage, energy is stored at high-pressure, which is later dispatched by releasing it through a turbine.

12: CO2 Battery

Like liquid air, CO2 is stored in its liquid form but under pressure at low or ambient temperatures. It can then be dispatchedthrough a turbine. The CO2 is cycled through a closed loop rather than released to the atmosphere like with air-technologies.

Technology ranking – in Ireland

Rank	Tech Type	Score (1-5)
01	Li-Ion Battery	3.8
02	Na-Ion Battery	3.55
03	Redox Flow Battery	3.45
04	Lead-Acid Battery	3.45
05	Hydrogen	3.4
06	Nickel-based Battery	3.35
07	CO2 Battery	3.4
08	Molten Salt	3.2
09	Metal-air Battery	3.2
10	Liquid Air	3.15
11	Pumped Hydro	2.85
12	Compressed Air	2.7
13	Gravity Storage	1.75

Technologies evaluated

Energy storage solutions were ranked using a set of weighted criteria that consider their techno-economic feasibility for large scale deployment on the Irish power system. The results of the ranking analysis is presented in the table to the left.

Electro-chemical solutions generally ranked highest owing to their cost base, favourable round-trip efficiencies, current TRL, and modular nature and despite their lower energy storage potential and supply chain dependencies.

Mechanical technologies generally ranked lower due to a combination of higher fixed costs, lower round trip efficiency, high learning curve and lower modularity, depending on the specific technology choice.

The thermal solution of molten salt scored well on deployment constraints and modularity, and less favourably on round trip efficiency and learning curve.
Finally, hydrogen storage ranked in the top half owing to the potential for modularity and scalability. Improvements in round-trip efficiency and fixed cost are needed to rank among the top technologies.

The sector survey found that sector stakeholders consider the following technologies as highly important:

- Lithium-ion batteries
- Hydrogen
- Flow batteries
- Pumped hydro

Note that respondents also cited thermal storage as important. However, this falls outside the focus on electricity storage.

Ireland’s energy policies and targets

80% RES-E and an ambitious carbon budget for the electricity sector are key parts of Ireland’s Climate Action Plan (CAP 23).

Urgent priority to deliver framework and market for System Services Future Arrangements.

Renewable gases will play a significant role with 5.7 TWh biomethane and 2 GW green hydrogen targeted by 2030.

Dispatch down targeted at below 7% both in 2025 and 2030.

25-30% of demand to be flexible by 2030.

The National Network, Local Connections Programme (NNLC) will make the distribution network more flexible and interactive by encouraging demand participation.

Significant grid upgrades required to ensure adequacy detailed in EirGrid’s Shaping our Electricity Future v1.1

Ireland’s hydrogen strategy envisages hydrogen will be generated from excess renewable electricity in the short term.

Onshore wind generation capacity to double to 9 GW by 2030.

Ireland’s Hydrogen Strategy identifies geological storage of hydrogen from 2033 as a major source of energy storage.

At least 5 GW of offshore wind generation to be delivered by 2030.

8 GW of solar PV capacity targeted by 2030.

Scenarios: Ireland’s energy storage needs

Scenarios for 2035 and 2050

Scenario 1: Modest Transition

- This scenario examines Ireland making a modest transition to a decarbonised system over the medium and longer term. Key characteristics of the scenario include base case all island electricity demand growth to c.60 TWh by 2035 and 100 TWh by 2050 including over c. 7 TWh of electrification of heat and transport demand in 2035, rising to 12 TWh in 2050.
- The 2030 demand is served by onshore renewable generation capacity aligned to the CAP targets and a modest deployment of 7.5 GW of offshore wind by 2035, modest island interconnection capacity of 2.5 GW and a need to must run 3 fossil fuel units at all times to maintain system security.
- The 2050 demand is served by onshore renewable generation capacity aligned to the CAP targets while offshore wind capacity doubles to 13 GW. All island interconnection capacity increases to 5.2 GW to enable greater export and import of renewables.

Scenario 2: Greening our economy

- This scenario examines Ireland making a concerted effort to decarbonise over the medium and longer term. Key characteristics of the scenario include base case all island electricity demand growth to c.60 TWh by 2035 and 77 TWh by 2050 including over c. 7 TWh of electrification of heat and transport demand in 2035, rising to 12 TWh in 2050. The lower overall 2050 demand is a result of higher energy efficiency.
- The 2030 demand is served by onshore renewable generation capacity aligned to the CAP targets and a deployment of 13.5 GW of offshore wind by 2035 as a linear progression to 20 GW by 2040. All island interconnection capacity of 5.2 GW exports surplus renewables while the need for must run fossil fuel units has been addressed.
- The 2050 demand is served by onshore renewable generation capacity aligned to the CAP targets while offshore wind capacity grows to 30 GW. All island interconnection capacity increases to 8 GW to enable greater export and import of renewables.

Scenario 3: Slow Growth

- This scenario examines Ireland decarbonising slowest due to slow growth. All island electricity demand grows c.55 TWh by 2035 and 77 TWh by 2050 including over c. 7 TWh of electrification of heat and transport demand in 2035, rising to 12 TWh in 2050. The electronification of heat and transport is viewed as a mandatory fuel switch while the demand for traditional electricity use grows more slowly.
- The 2030 demand is served by onshore renewable generation capacity aligned to the CAP targets and a modest deployment of 7.5 GW of offshore wind by 2035, modest island interconnection capacity of 2.5 GW and a need to must run 3 fossil fuel units at all times to maintain system security.
- The 2050 demand is served by onshore renewable generation capacity aligned to the CAP targets while offshore wind capacity grows to 15 GW while all island interconnection capacity increases to 5 GW aligned to slow growth.

Scenario 4: Green Export

- This scenario examines Ireland making a concerted effort to decarbonise the economy and avail of green energy export opportunities. Key characteristics of the scenario include base case all island electricity demand growth to c.60 TWh by 2035 and 100 TWh by 2050 including over c. 7 TWh of electrification of heat and transport demand in 2035, rising to 12 TWh in 2050.
- The 2030 demand is served by onshore renewable generation capacity aligned to the CAP targets and a deployment of 13.5 GW of offshore wind by 2035 as a linear progression to 20 GW by 2040. All island interconnection capacity of 7 GW exports surplus renewables while the need for must run fossil fuel units has been addressed.
- The 2050 demand is served by onshore renewable generation capacity aligned to the CAP targets while all island offshore wind capacity grows to 38 GW which is aligned to Ireland’. All island interconnection capacity increases to 9 GW to enable greater export and import of renewables.

Ireland’s energy storage needs to 2035 and 2050

Key Findings: As the Irish power system transitions to a ultra-high RES system and periods of oversupply prevail on the grid energy storage is needed to balance daily and seasonal supply. The volume and form of storage needed is set by our decarbonisation ambition and sensitive to the availability and operation of interconnection.

Scenario	2035 Storage capacity required	2050 Storage capacity required	Findings
Scenario 1: Modest Transition	c.5.4 GW	c.9.4 GW	• This scenario has the least amount of surplus renewable electricity and the highest annual electricity supply deficit to be met by storage and imports. • The need for storage is widespread, with intra-day to long term storage operating throughout the year. • Large volumes of storage capacity is required to enable flexible demand support renewable penetration and compensate for a modest increase in interconnection capacity.
Scenario 2: Greening our economy	c.4.2 GW	c.3.4 GW	• This scenario has the highest amount of surplus renewable electricity in 2035 and the second highest in 2050. Storage competes with interconnection to address electricity supply surplus and deficits • The need for, and the utilisation of storage is highly sensitive to interconnector availability. Medium duration energy storage is required in the summer months while the oversupply of wind generation in the winter months can meet demand on the transmission grid if interconnection is available.
Scenario 3: Slow Growth	c.4.3 GW	c.5.5 GW	• Similar to the Modest Transition scenario, the need for energy storage in 2035 is widespread, with intra-day to long term storage throughout the year despite the unconstrained annual electricity surplus exceeding the Modest Transition scenario by c.25%. • Despite annual surplus electricity more than doubling compared to Modest Transition in 2050, along with exports increasing by c25%, there is a need to dispatch storage in most months even when interconnection is available.
Scenario 4: Green Export	c.3.0 GW	c.5.6 GW	• The Green Export scenario has the highest level of interconnection capacity, however this is offset by a large demand for electricity on the island, leading to a need for energy storage in 2035 and 2050 to maintain system security despite very high levels of renewable deployment. • A reduction in interconnection import capacity drives greater need for energy storage dispatch outside of winter months while the oversupply of wind generation in the winter months can meet demand on the transmission grid.

1 Modest Transition 2 Greening Our Economy 3 Slow Growth 4 Green Export

Employment potential: Approach

Value chain employment impacts are considered for each of the four scenarios in 2035 and 2050.

The energy storage scenarios for 2035 and 2050 are considered by assuming an equal contribution (1/3) of different energy storage technologies will be used to meet Ireland's energy storage needs.

Based on our sector survey, stakeholders identified five technologies as highly important. These include lithium-ion batteries, hydrogen storage, thermal storage, flow batteries and pumped hydro storage. However, thermal storage fell outside of the focus on electricity storage and the potential for additional pumped hydro storage in Ireland is considered to be fairly limited and so neither were modelled in detail.

The following technologies were chosen to form the technology mix for the economic modelling exercise:

1. **Lithium-ion batteries**
2. **Hydrogen storage**
3. **Flow batteries**

Lithium-ion batteries were assumed to be a key technology option for meeting Ireland's energy storage needs towards 2035, with a wider mix of technologies being deployed to achieve 2050's net zero targets.

The development and operation of energy storage infrastructure will provide an injection of expenditure into the local economy, particularly for inputs that can be sourced from within Ireland. This expenditure will create a multiplier impact via inter-industry linkages in the supply chain. The associated economic impact includes the creation of direct jobs and indirect jobs in the supply chain.

For each scenario, the total storage capacity required and the associated investment is evaluated by considering the €/GW cost for each technology. Technology costs were considered in terms of key cost components, for example, controls and communication, engineering procurement and construction, and system integration. The potential employment impact was estimated by applying employment multipliers* to the expenditure for cost components that are possible to be sourced from within Ireland. This is considered for both the operational (OPEX) and capital (CAPEX) expenditure required to meet the storage needs modelled in the four scenarios.

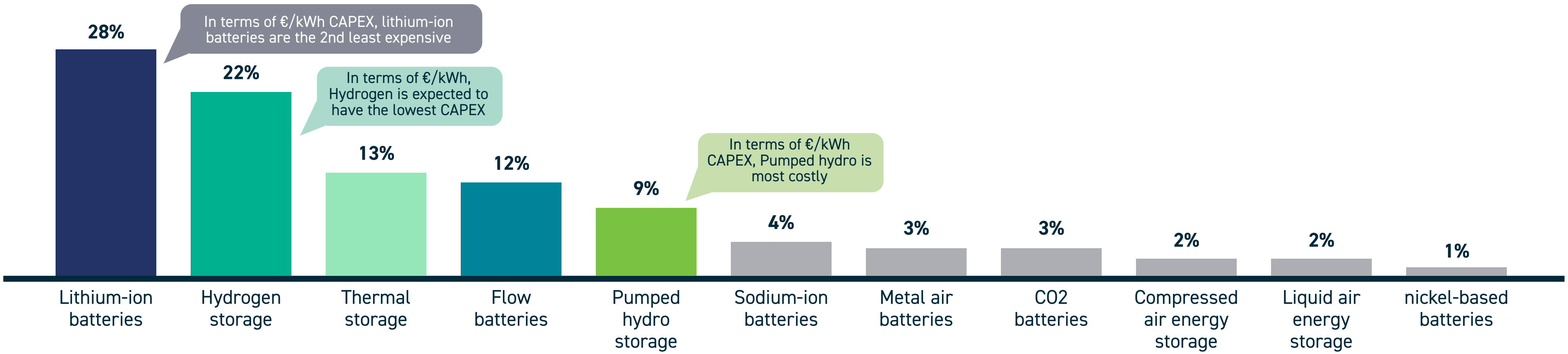
Notes: *Based on CSO data and KPMG's economic impact model

Employment potential: OPEX & CAPEX

Industry stakeholders view lithium-ion batteries and hydrogen storage as highly important.*

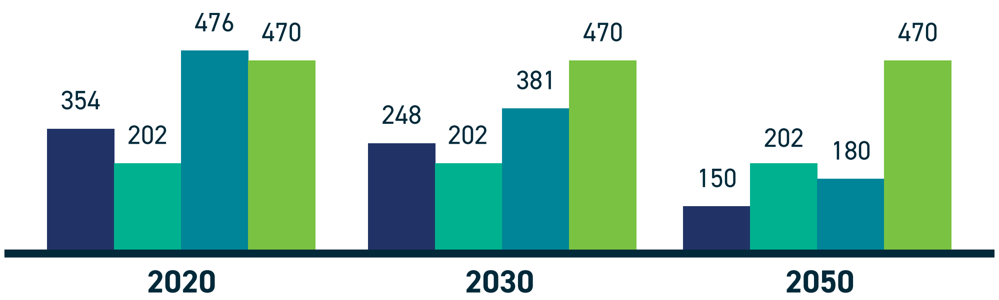
Most important energy storage technologies that will allow Ireland to fulfil energy storage needs post 2030

Share of survey respondents



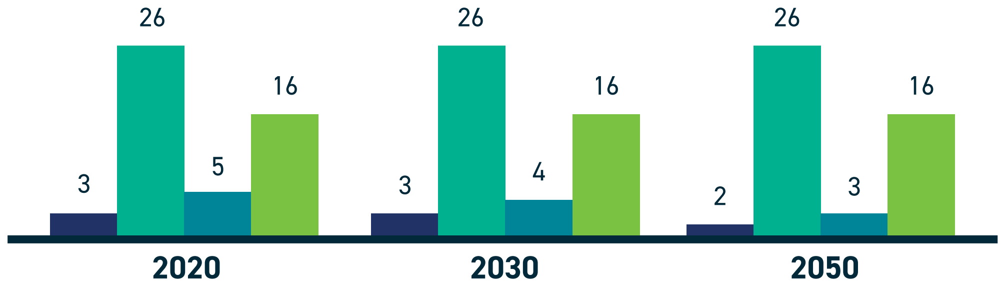
CAPEX for selected energy storage technologies

€/kWh



OPEX for selected energy storage technologies

Annual fixed, €/kw*y



Lithium-ion batteries (4h - 100mw)
Hydrogen - salt Cavern Storage (100mw - 10hr)
Flow batteries (4h - 100mw)
Pumped Hydro Storage (4h - 100mw)

Sources: Sector survey and various sector reports

Notes: *Based on responses to sector survey. CAPEX for selected technologies are based on specific storage capacities.

Employment potential: value chain (1/2)

The sector's employment potential is influenced by the main components of project development, and the level of capital and operating expenditure directed to the domestic value chain.

1 Technology
Some technologies will have more local employment potential

Opportunities for local research and development

- Local solution research, design and development capabilities

2 Manufacture
Opportunities for Ireland to manufacture and create jobs

Opportunities for manufacturing

- Technologies that can realistically be produced in Ireland

3 Project development & delivery
Opportunities for employment during installation

Opportunities for project development and delivery

- Employment opportunities during the project life cycle

4 Operation
Opportunities for employment across asset lifetime

Opportunities from operation

- Employment opportunities from operations and maintenance

CAPEX **OPEX** → **Linkages to local supply chain** → **Supply chain expenditure** → **Employment multipliers** → **Employment impact**

LOCAL CAPEX

Engineering Procurement and Construction

Project Development	Ancillaries
Controls & Communication	Cavern Storage
System Integration	Grid Integration

Supply chain expenditure

LOCAL OPEX

Headoffice Activities
Labour
LTSA (Long-Term Service Agreements)
Consumables
Management Consultancy Activities

Employment potential: value chain (2/2)

A

For the modelling exercise the following technologies were selected to form the technology mix: lithium-ion batteries, hydrogen, and flow batteries. The composition of inputs for CAPEX are considered in terms of the components being fully or partially available within the local supply chain or whether the components are imported. Similarly, the inputs for OPEX are considered in terms of local availability.

B

1 Lithium-ion batteries Components	Local or imported component	2 Hydrogen storage Components	Local or imported component	3 Flow batteries Components	Local or imported component
Storage Block	Imported	Electrolyser Capital Cost	Imported	Storage block	Imported
Storage Balance of system	Imported	Rectifier	Imported	Storage balance of system	Imported
Power equipment	Imported	Compressor	20% Local	Power Equipment	Imported
Controls & Communication	50% Local	Cavern Storage	50% Local	Controls & Communication	50% Local
System integration	Local	Stationary Fuel Cell Capital Cost	Imported	System Integration	Local
Engineering procurement & Construction (EPC)	Local	Inverter	Imported	Engineering procurement & construction (EPC)	Local
Project Development	Local	Controls & Communication	50% Local	Project Development	Local
Grid Integration	Local	Grid Integration	Local	Grid Integration	Local
OPEX	75% Local	OPEX	75% Local	OPEX	75% Local

C

For each scenario, the total storage capacity required is considered in terms of the three energy storage technologies, the CAPAX components required for each technology, the cost of these components, OPEX across the three technologies, and the local availability of inputs for CAPEX and OPEX to estimate the level of domestic expenditure, from where the employment multiplier impact is calculated.

Energy storage was found to have significant value chain employment potential in Ireland

Near term investment in energy storage provides upfront benefits and eases the transition to net zero.

Scenario	2035 – Potential Employment Impact			2050 Potential Employment Impact		
	Direct employment	Indirect employment	Total value chain employment	Direct employment	Indirect employment	Total value chain employment
1. Modest Transition	2,980 +	2,000 =	4,980	2,440 +	1,580 =	4,020
2. Greening Our Economy	2,170 +	1,460 =	3,630	170 +	100 =	270
3. Slow Growth	2,230 +	1,500 =	3,730	1,110 +	710 =	1,820
4. Green Export	1,360 +	910 =	2,270	1,730 +	1,130 =	2,860

How we approach the energy transition will have an impact on energy storage employment potential.

Note: The above employment impact estimates consider the potential capital and operating expenditure required to meet the modelled energy storage needs at a specific point in time - for 2035 and 2050. These estimates are illustrative and the modelling is based on the current structure of the economy. Given the timeframe to 2035 and 2050, these figures include a high level of uncertainty.

Skills development needs

Skills development needs: Overview

The demand for STEM and clean energy related skills is growing and presents an significant opportunity for job creation. Ireland has access to a range of skills development initiative which can support the growth of the energy storage sector and help maximise the potential for local job creation.

A sector survey and stakeholder consultations were conducted to assess the state of employment and skills in the Irish energy storage sector. This considered development programmes and courses offered in Ireland, an assessment of skills and resources needs, a review of existing capability gaps and barriers, and recommendations to close existing gaps and develop a sufficient skills base in Ireland.

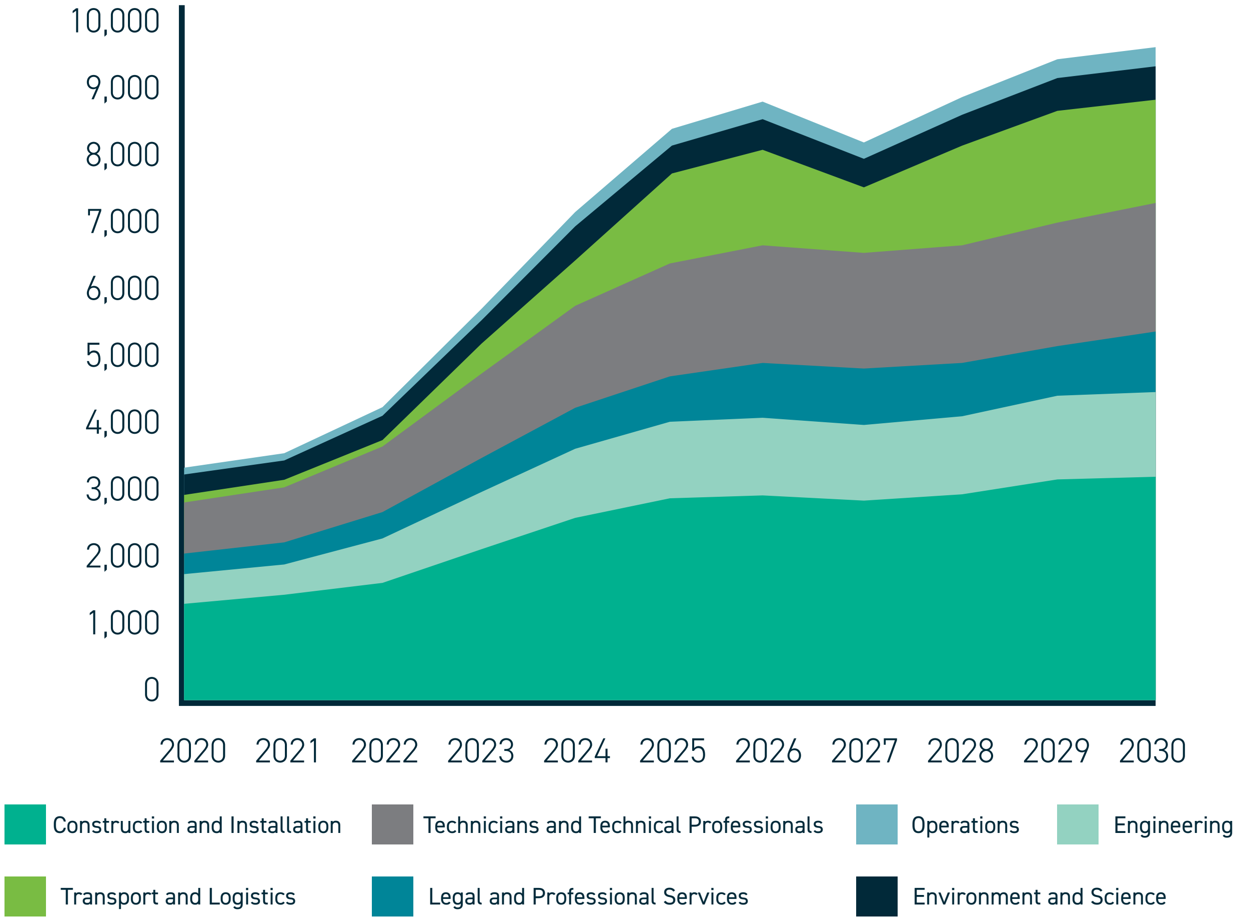
A range of careers need to be supported across the domestic energy storage value chain. A non-exhaustive list of careers is provided as a starting point to a career roadmap for the sector.

Similarly, a range of commercial, technical and regulatory skills are needed to enable the fulfilment of career opportunities in the energy storage sector. A non-exhaustive list of courses to facilitate this is provided.

Renewable energy: Ireland's employment landscape

The demand for labour in Ireland's renewable energy industry is set to grow significantly towards 2030.

Modelled labour demand from renewable energy by broad occupational group, 2021-2030 (Full-time equivalent: FTE)



Source: National Skills Council

Energy transition employment trends and data

- The renewable energy sector's demand for labour is expected to increase across most of the occupational groups considered towards 2030.
- In particular, demand for candidates in construction and installation, and technicians and technical professionals are expected to increase.
- In terms of employment in Ireland's energy storage sector, there are no specific statistics available.
- The Irish government has launched several initiatives to support the development of skills in the energy storage sector. For example, the government's Skills to Advance initiative provides funding to support upskilling and reskilling of workers in areas such as energy storage.

International skills and training trends (1/2)

The global renewable energy sector is expected to undergo exponential growth, with a coinciding need for STEM skills, as well as reskilling and upskilling.

Context

The global renewable energy sector is expected to undergo exponential growth. For example, the IEA estimates that global renewable capacity additions are set to soar by 107 gigawatts (GW), the largest absolute increase ever, to more than 440 GW in 2023.

Key drivers of this include expanding policy support, growing energy security concerns and improving competitiveness againstfossil fuel alternatives.

Energy storage is a key dependency for the transition to a net zero energy system underpinned by intermittent variable sources of renewable generation.

Implications

The growth in renewables creates an environment with strong competition between employment in the renewable energy and the energy storage sector, coinciding with insufficient new entrants and skills coming through the education system. Given the sector's dependency on energy storage, these dynamics are equally applicable to the energy storage sector.

These challenges are relevant across the value chain and solving this requires a focus beyond specific technologies, considering the full project lifecycle in the deployment of renewable energy and storage technologies.

EU Pact for Skills

- The European Commission's REPowerEU Plan aims to reduce energy import dependency by accelerating the deployment of renewables and considers the skilled workforce necessary for such an acceleration.
- As part of the Green Deal Industrial Plan, a 'Pact for Skills' seeks to create large-scale European public-private multi-stakeholder partnerships to provide up-/re-skilling opportunities for employees in the whole industrial ecosystem.
- Achieving the REPowerEU targets will require the creation of over 3.5 million jobs by 2030 – specific skills will be needed, particularly in technical and STEM (Science, Technology, Engineering and Mathematics) fields.

STEM skills needed

- Approximately 1.3 million people where employed (directly and indirectly) in the EU renewable energy sector in 2020.
- Between 2019 and 2020, there was a gross increase of 65,000 jobs (+5.2%).
- A general shortage of professionals with STEM backgrounds creates a potential bottleneck to achieving the envisaged growth in the renewable energy sector.

Up and re-skilling

- Up-skilling and re-skilling will support the vision of meeting the EU's climate and energy targets.
- The European Commission estimates that investments of around €12 billion (between 2015 and 2030) will be needed for retraining that includes reskilling and upskilling.

Source: The European Commission

International skills and training trends (2/2)

The European Skills Agenda is a five-year plan to support skills development which provides a framework for delivering energy storage skills in Ireland.

European skills agenda

The European Skills Agenda is a five-year plan supporting individuals and businesses in developing more and better skills. The agenda:

- Calls for collaboration between business, social partners and stakeholders.
- Identifies the funding to support investment in skill.s
- Provides a strategy to translate skills into jobs.
- Supports individuals to build their skills throughout life – lifelong learning.
- Sets objectives for up- and reskilling over a five year period.

Indicators (in %)	Objectives for 2025	Current level (latest available year)	Increase (in %)
Participation of adults aged 25-64 in learning during the last 12 months	50%	38% (2016)	+32%
Participation of low-qualified adults 25-64 in learning during the last 12 months	30%	18% (2016)	+67%
Share of unemployed adults aged 25-64 with a recent learning experience	20%	11% (2019)	+82%
Share of adults aged 16-74 having at least basic digital skills	70%	56% (2019)	+25%

Source: The European Commission

The European Skills Agenda includes a dozen key actions

- **Pact for Skills:** seeks to create large-scale European public-private multistakeholder partnerships to provide up-/re-skilling opportunities for employees in the whole industrial ecosystem.
- **Strengthening skills intelligence:** online 'real-time' information on skills demand is needed, using big data analysis of job vacancies and making it widely available.
- **EU support for strategic national upskilling action:** work with Member States on national skills strategies and collaborate with national public employment agencies to realise them.
- **Future-proof vocational education and training (VET):** make vocational education and training more modern, attractive for all learners, flexible and fit for the digital age and green transition.
- **Rolling out the European Universities initiative and upskilling scientists:** Build long-term transnational alliances between higher education institutions.
- **Skills to support the green and digital transitions:** Develop green skills, statistical monitoring of the greening of our workplaces, boosting digital skills through a Digital Education Action Plan and ICT jump-start training courses.
- **Increasing STEM graduates, fostering entrepreneurial and transversal skills:** Encourage young people, especially women, into Science, Technology, Engineering and Maths.
- **Skills for life:** support adult learning for everyone, on issues such as media literacy, civic competences, and financial, environmental and health literacy.
- **Initiative on individual learning accounts:** Explore if and how portable and quality checked training entitlements could help stimulate lifelong learning for all.
- **A European approach to micro-credentials:** Create European standards that should help recognise the results of such training.
- **New Europass platform:** Revamped the Europass platform - it offers online tools and guidance on CV-writing, suggests tailored jobs and learning opportunities, provides information for job seekers.
- **Improving the enabling framework to unlock investment:** boosted EU budget to catalyse Member States and private actors to invest in skills.

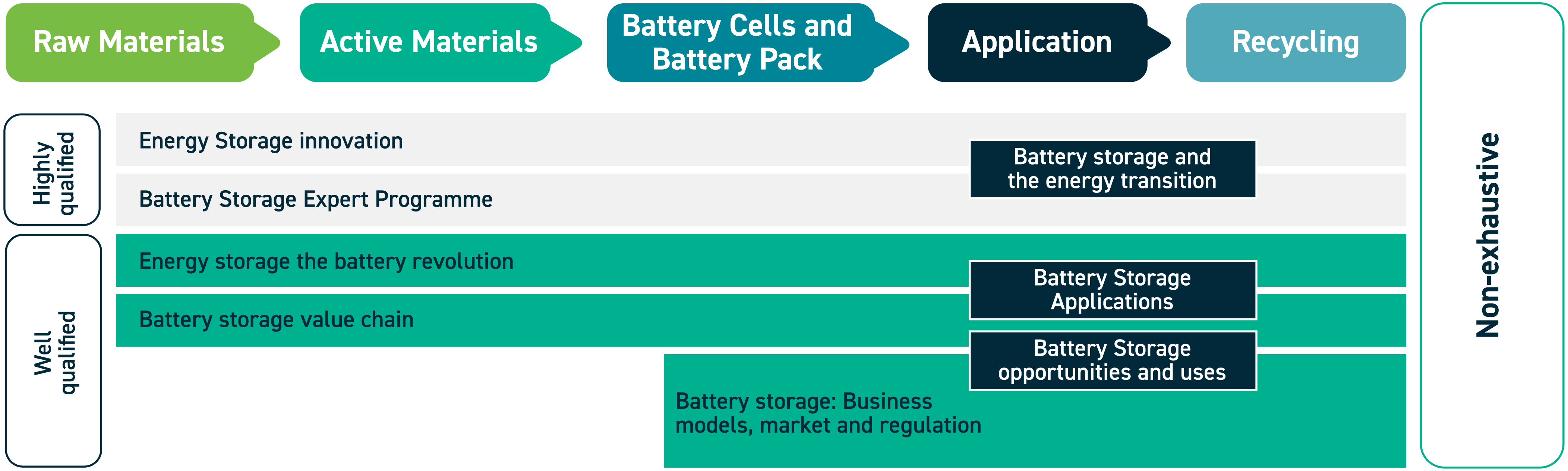
Spotlight on the European Battery Alliance

The European Battery Academy (EBA) offers training to support a sustainable battery value chain in the EU and demonstrates how to deliver an end to end approach to skills development.

European Battery Alliance

The European Battery Alliance was launched by the European Commission in 2017 to create a complete, globally competitive and sustainable battery value chain in the EU:

- The European Battery Academy (EBA) was launched in 2022, with the aim of coordinating re-skilling and up-skilling efforts at European level and to provide for the immediate roll out of high-quality training across Member States.
- This forms part of the EU's Skills Agenda, the Pact for Skills and the EU's contribution towards meeting the demand of 800,000 workers that will need to be re-skilled or up-skilled in the battery industry by 2025.
- The EBA offers on-demand training covering introductory, intermediate, and advanced knowledge of battery technology, applications, and energy systems. This includes different training formats: online certification, blended certification, learning game. An illustrative example is provided below.



Source: The European Commission, InnoEnergy Skills Institute

Renewable energy: Irelands' education landscape

Ireland offers several training and higher education programmes related to the energy transition and energy storage, which can help to create a pool of highly qualified specialists.

Examples of programmes*

Core energy storage higher education providers

Island of Ireland

- **Trinity College Dublin**
- **University of Ulster**
- **Queen's University Belfast**
- **UCD**
- **UCC**
- **Waterford Institute of Technology**
- **TUS**
- **DCU**

- MSc, Energy Systems, UCD
- PhD, Optimal operation of domestic battery energy storage, QUB
- BE Energy Engineering, UCC
- Postdoc, Advanced Thermal Energy Storage Systems, DCU
- MSc, Energy Storage, Ulster University
- MSc / P.Grad.Dip, Energy Science, TCD
- BEng, Sustainable Energy Engineering, WIT
- BE, Mechanical Engineering with Energy, TUS

*** All courses have an element of energy storage in curriculum.**

Vocational training programmes available in Ireland

Energy Storage

Wind Energy Ireland & Green Tech Skillnet	Wind Energy Ireland & Green Tech Skillnet provide several specific battery courses as well as general training for the renewable sector.
Sustainable Energy Authority of Ireland (SEAI)	SEAI offers various training programmes focused on sustainable energy, including energy storage. They provide courses on energy management, renewable technologies, and energy storage systems. These programmes are designed for professionals working in the energy sector or those interested in developing skills in energy storage.
Engineers Ireland	Engineers Ireland, a professional body for engineers, offers continuing professional development (CPD) courses and seminars on various engineering topics, including energy storage. These programmes are designed for engineers and cover areas such as energy storage technologies, system design, and integration.
Irish Solar Energy Association (ISEA)	ISEA provides training programs focused on solar energy and related technologies, including energy storage. Their courses cover topics such as battery storage systems, grid integration, and system design. These programmes are suitable for professionals in the solar energy sector or those interested in expanding their knowledge in energy storage.

Source: Education and training programme providers' websites

The emergence of micro-credentials

Micro-credentials support the shift to lifelong reskilling and upskilling in the modern economy. UCD's development of a specialised Electricity Grid Operation micro-credential demonstrates how this approach can deliver highly specialised skills quickly.

UCD Electricity Grid Operation Micro-credential

Subject Area
Electrical Engineering

Mode of delivery
Hybrid - Online lectures and tutorials and 2 days on campus for demonstration labs.

Duration
8 Weeks

Overview
Addresses the key specifics of electrical power system operation, control, and energy economics

Micro-credentials are a key component of re-skilling and upskilling efforts at European level

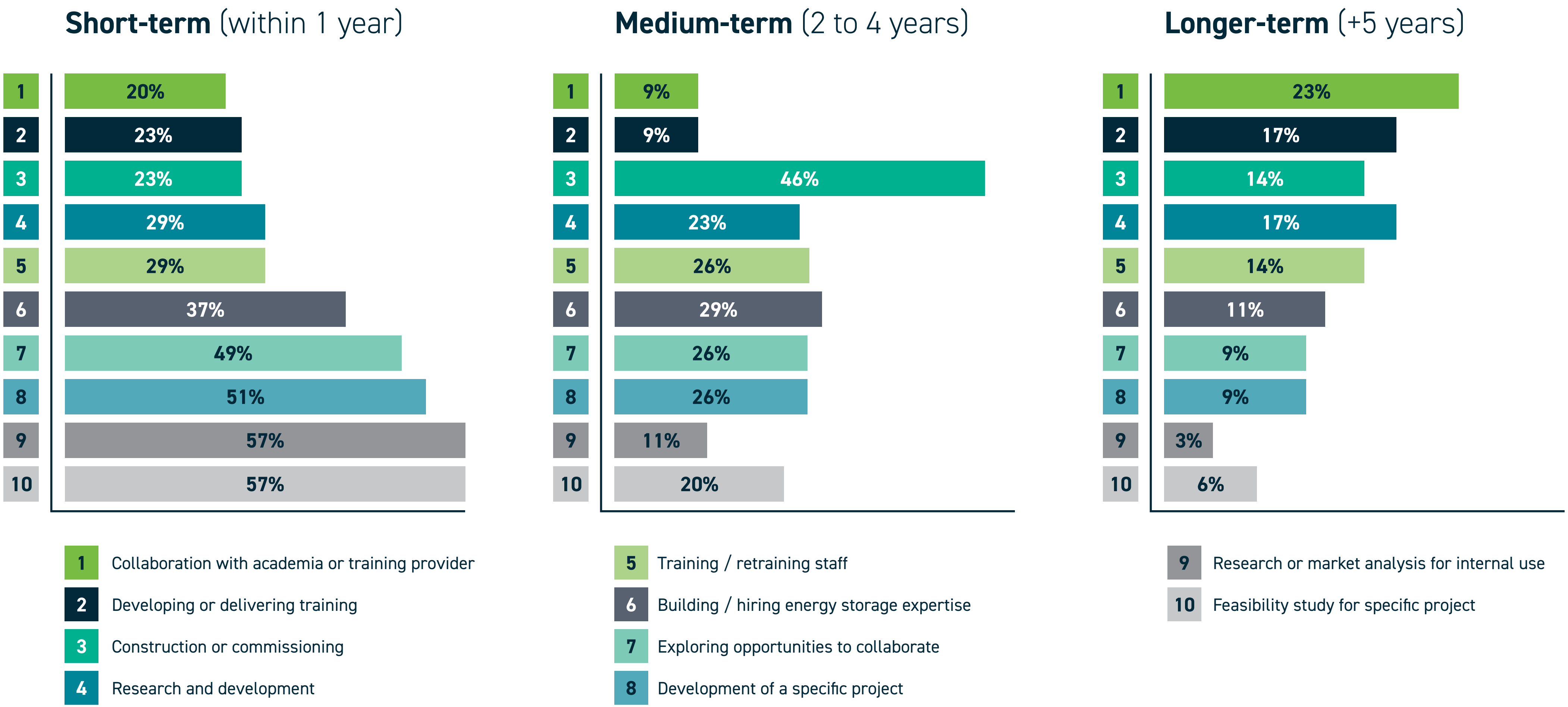
Source: UCD

Industry stakeholder survey results (1/7)

Respondents' energy storage activities shift over time horizons, with a focus on feasibility and research in the short-term and, collaboration and training in the longer-term.

Breakdown of energy storage activities by the horizon of planning

Share of respondents

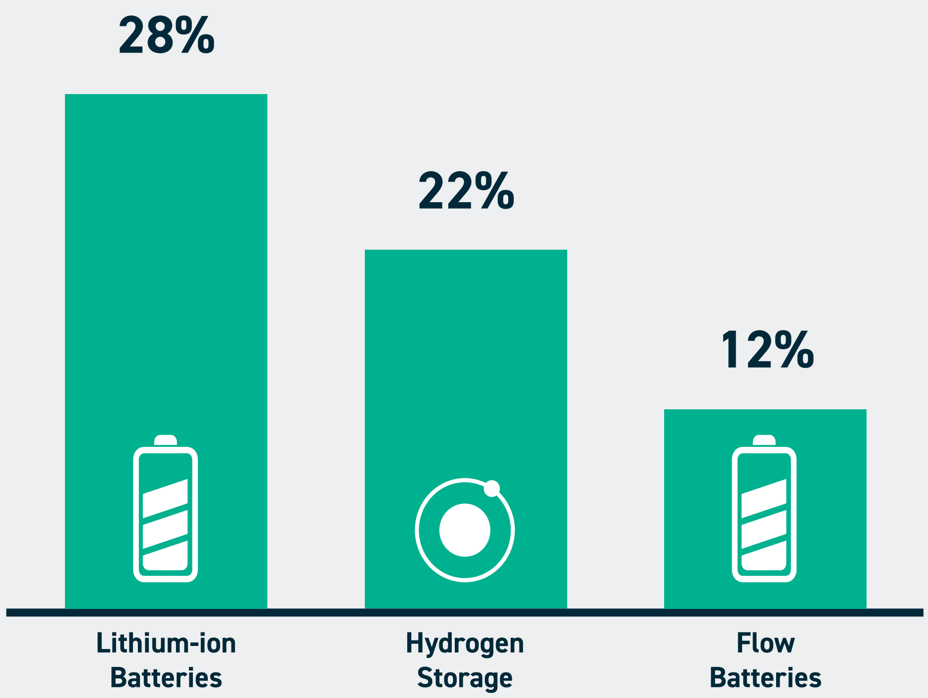


An industry survey respondent profile is included in Appendix A

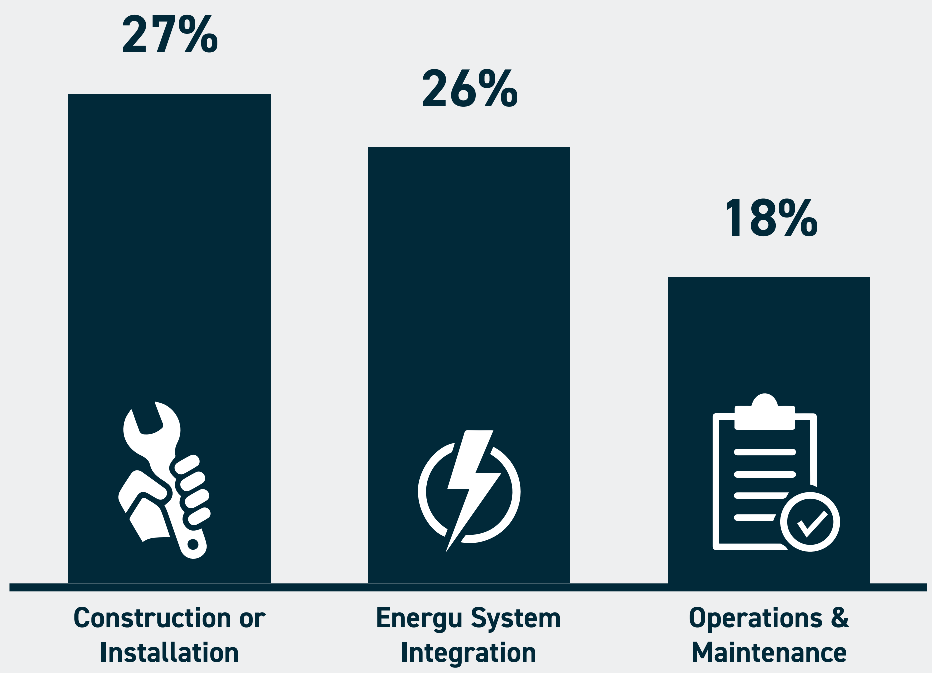
Industry stakeholder survey results (2/7)

Lithium-ion batteries and hydrogen are seen as the top technologies, with construction/installation, and operations and maintenance as key segments for job creation.

Top-3 energy storage technologies that will allow Ireland to deliver energy storage needs post 2030
Share of respondents



Top-3 energy storage value chain segments that have the greatest opportunities for job creation in Ireland over the next 7 years
Share of respondents



Note that respondents also cited thermal storage as important. However, this falls outside the focus on electricity storage.

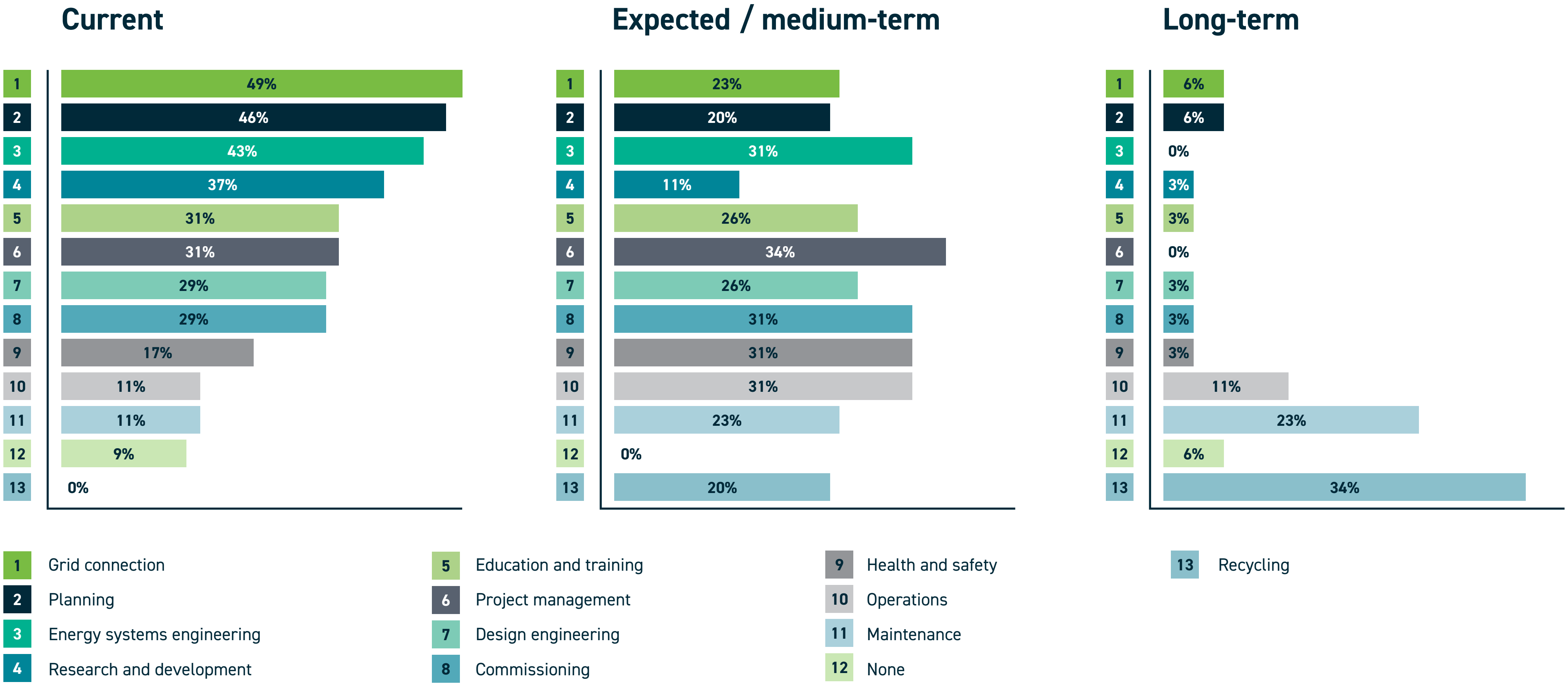
An industry survey respondent profile is included in Appendix A

Industry stakeholder survey results (3/7)

Construction and installation jobs present difficulties to resource in the short-term, with resourcing of recycling and maintenance jobs becoming a concern in the long-term.

Job areas that are expected to present difficulties to resource, by the horizon of planning

Share of respondents



An industry survey respondent profile is included in Appendix A

Industry stakeholder survey results (4/7)

A range of skill gaps are inhibiting Irish organisations from delivering on their energy storage ambition.

Skill gaps that are inhibiting Irish organisations from delivering on their energy storage ambition

Quotes from survey respondents

Hiring qualified researchers is extremely difficult at present. Public sector pay constraints, onerous HR requirements in universities, accommodation shortage, and delays in processing work visas really impede our ability to get skilled staff.

Strategy/Asset valuation - uncertain investment climate.

Very limited pool of available people that understand the technoeconomic characteristics of various existing and emerging LDES technologies and how they can cost effectively support deep decarbonisation.

Lack of experienced power system engineers, experienced renewable design engineers, large scale manufacturers.

Project management and engineering.

Future integrated energy storage solutions are poorly understood due to the lack of demonstration units and training possibilities within Ireland.

Skill gaps in the commercial team in modelling and building a business case for a battery storage project.

We do not have any internal battery expertise in our organisation. We are also struggling with understanding the route to market / financial modelling of battery projects.

Due to the rapid expansion in Renewables in all parts of the Europe and Far east, we are competing for a very small qualified and experienced workforce. We are therefore, in the process of setting up our own internal training organization to assist the expansion going forward.

Lack of genuinely qualified market and engineering consultants.

For an energy trader, the biggest skill gap is around the in-depth market knowledge required to maximise the revenue stack for energy storage units. The evolving regulatory and operational changes surrounding energy storage require significant industry knowledge to maximise their full potential.

Basic knowledge of the dimensioning, operation and life cycle of a battery, as well ascalculation of the LCOS and viability of the project.

The knowledge base (and associated availability of training on same) on the currently available technology remains scarce. This places the OEM in an almost unchallengeable position of power.

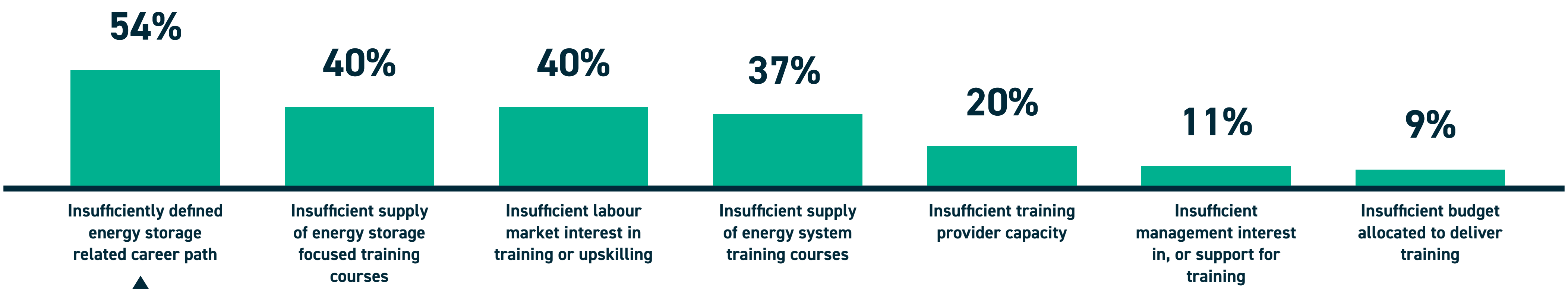
An industry survey respondent profile is included in Appendix A

Industry stakeholder survey results (5/7)

Insufficient knowledge about the role of energy storage in the energy transition has resulted in limited visibility of skill needs, available career paths and interest in training or upskilling.

Main challenges to growing the skills needed in Ireland's energy storage sector

Share of respondents



The majority (54%) of respondents regard "insufficiently defined energy storage related career paths" as the main challenge. This highlights the need for relevant stakeholders to clarify and define career paths in the energy storage sector

Increased awareness of the industry though educational programs.

Employee release to attend training courses. There is sufficient training provision available but not enough support from Companies to release staff to attend.

Energy storage needs to be included in curriculum for engineers and made current.

A coordinated skills development and training plan overseen by the Minister's Department.

Clarify Government policies and set up clear targets for storage and delivery programme.

Development of long duration storage systems to enhance efficient operation of the power system.

Provide a clear, fairly-paid, secure pathway for early career researchers (PhD students, postdocs) to progress to academic/ research positions.

An industry survey respondent profile is included in Appendix A

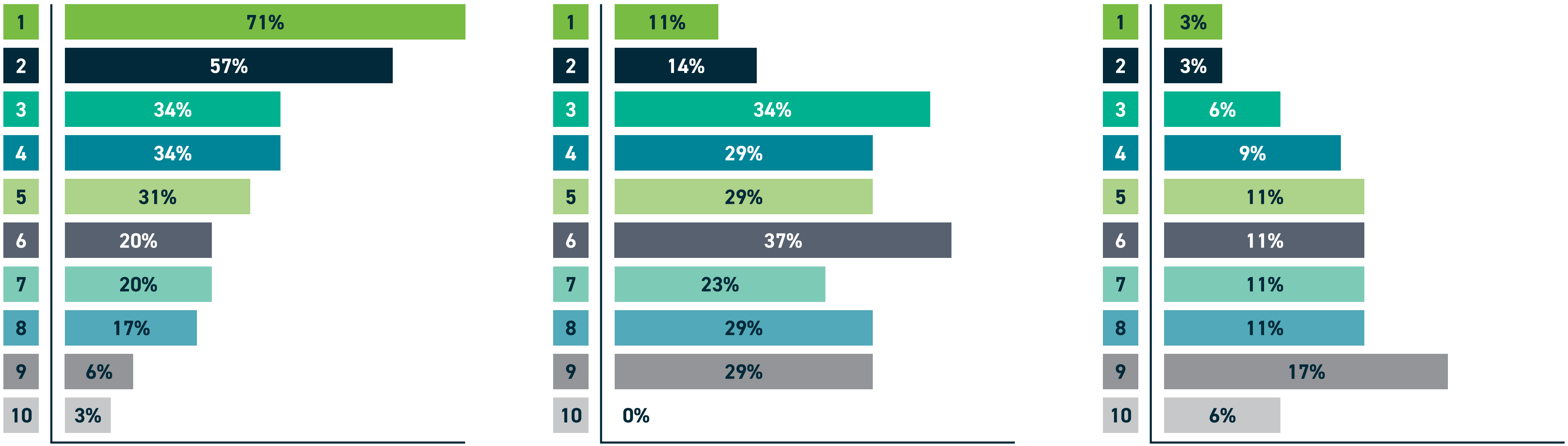
Industry stakeholder survey results (6/7)

Energy system modelling is the most in demand skill in the short-term. Skills demand is expected to change significantly in 3-5 years as more companies deploy and operate assets.

Breakdown of skill needs by urgency

Share of respondents

Short-term (within 1 year) **Medium-term** (2 to 4 years) **Longer-term** (+5 years)



1 Energy system planning
2 Energy storage system design
3 Construction or installation
4 Research and development
5 Project management
6 Operation and Maintenance
7 Digital product and services development
8 Asset Management
9 Manufacturing and assembly
10 None

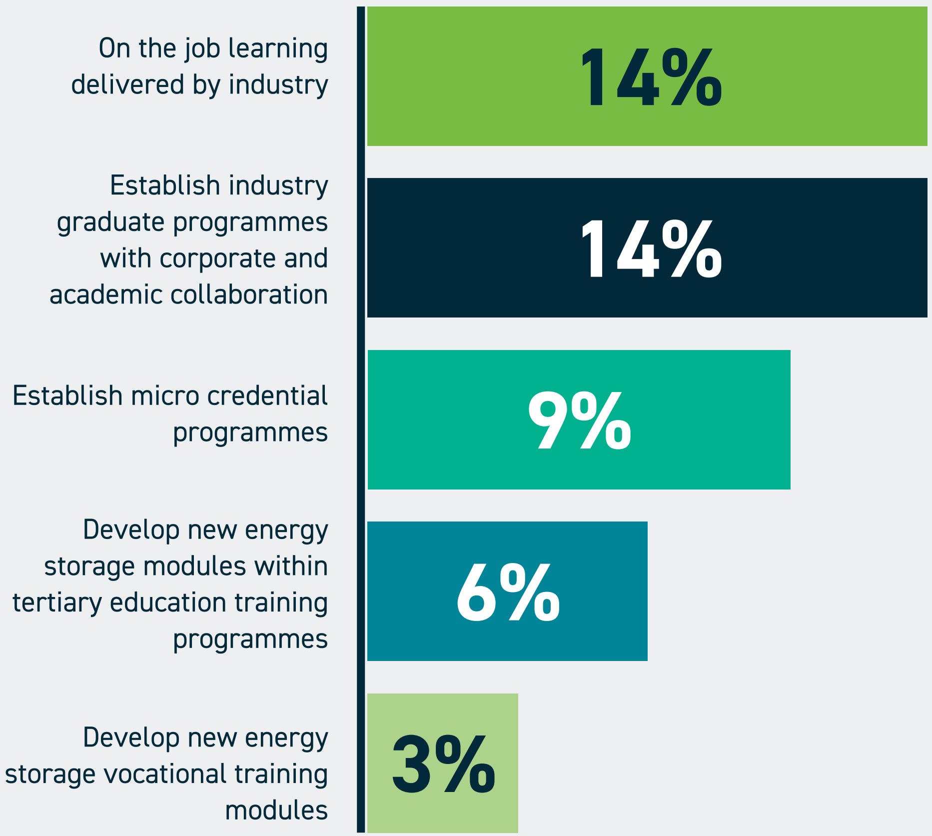
An industry survey respondent profile is included in Appendix A

Industry stakeholder survey results (7/7)

According to survey respondents, the best training approach to address future skill gaps is to encourage on the job learning and to encourage early participation.

Approach to training needed today to address future skill gaps

Share of respondents



Skill gaps that are expected to persist beyond 2030 and inhibit the growth of Ireland's energy storage sector

Training and Education tend to focus on Grade / Apprenticeship level and not enough on the more aged workforce in this area.

O&M and Construction/installation.

Project origination and permitting.

We have a shortage of highvoltage electrical engineers and project managers currently, and due to an aging workforce, we see that this problem is likely to persist beyond 2030.

An industry survey respondent profile is included in Appendix A

There is a wide range of career opportunities spanning the value chain

A range of careers need to be supported across the domestic value chain.
A non-exhaustive list, based on research, is provided below.

Value chain:

1 Technology
Design and development of new technology solutions and products

2 Manufacture
Production or assembly of energy storage system components

3 Project development & delivery
Opportunity identification, technology selection, permitting, financial investment decisions, engineer, procurement and construction

4 Operation
Monitoring and maintaining asset health, performance and environment impacts over the lifetime of the asset. Decommissioning and recycling at end of life

Job roles:

1 Technology

- Material scientists and engineers
- Electrochemical engineers
- Electrical engineers
- Product Engineers
- Control systems specialists
- Simulation and modelling specialists
- Manufacturing design specialists
- Circular economy specialists
- Power electronics specialists
- Funding & investor relations specialists
- IP & patenting specialists
- Hydrogen regulatory experts

2 Manufacture

- Quality control specialists
- Supply chain specialists
- System testing specialists
- Application / product integration support specialists
- Circular economy specialists
- Certification specialists
- Hydrogen logistics specialists
- Hydrogen regulatory experts

3 Project development & delivery

- Geologists
- Advanced power system modelling specialists
- Energy and system services markets specialists
- BESS EPC specialists
- Electrolyser EPC specialists
- Fuel cell EPC specialists
- Hydrogen logistics specialists
- COMAH specialists
- Power electronics specialists
- Funding & investor relations specialists
- Battery commissioning engineers
- Energy storage contract managers
- Electrolyser & fuel cell commissioning engineers
- Hydrogen regulatory experts

4 Operation

- Recycling specialists
- Digital twin specialists
- Environmental Health & Safety Specialists
- RPA / AI / Autonomous Control specialists
- Asset condition and performance monitoring specialists
- Asset refurbishment specialists
- COMAH specialists
- Hydrogen logistics specialists
- Power electronics specialists
- Energy storage contract managers
- Hydrogen regulatory experts

Acronyms: EPC: Engineering, Procurement, and Construction, COMAH: Control of Major Accident Hazards, RPA: Robotic Process Automation, AI: Artificial Intelligence

New skills are needed to develop new career paths

A range of commercial, technical and regulatory skills are needed to enable the fulfilment of career opportunities in the energy storage sector. A non-exhaustive list, based on research, is provided below.

Value chain:

1 Technology
Design and development of new technology solutions and products

2 Manufacture
Production or assembly of energy storage system components

3 Project development & delivery
Opportunity identification, technology selection, permitting, financial investment decisions, engineer, procurement and construction

4 Operation
Monitoring and maintaining asset health, performance and environment impacts over the lifetime of the asset. Decommissioning and recycling at end of life

Courses needed:

1 Technology

- Physical world modelling
- Fundamentals of battery technologies
- Fundamentals of electrolyser technologies
- Hydrogen compression, storage, liquefaction and monitoring technologies
- HV systems design
- Introduction to power electronics
- Fundamentals of RPA / AI / Autonomous Control Systems
- Fluid mechanics
- Electrochemistry fundamentals
- Introduction to material science
- Data handing and security
- Introduction to ultra high RES grid management systems and needs
- Hydrogen regulation

2 Manufacture

- Fundamentals of automated manufacture
- Lean 6 Sigma
- Handling of hazardous materials
- Circular economy design principles
- Environmental impact regulations and best practices
- Battery storage supply chain
- Hydrogen production supply chain
- Hydrogen logistics supply chain
- Hydrogen applications supply chain
- Hydrogen regulation

3 Project development & delivery

- Introduction to energy storage applications and uses
- Energy storage markets and economics
- Future Energy System Technologies
- Introduction to energy system integration
- Battery energy storage value chain
- Hydrogen energy storage value chain
- Introduction to power electronics
- Introduction to geological science
- Introduction to emerging environmental and safety regulations
- Energy storage contract management
- Hydrogen regulation

4 Operation

- Introduction to digital twins
- Introduction to power electronics
- Managing energy data
- Circular economy best practices and value chains
- Fundamentals of energy storage system performance monitoring and management
- Introduction to emerging environmental and safety regulations
- Hydrogen regulation

Acronyms: RES: Renewable Electricity Supply, RPA: Robotic Process Automation, AI: Artificial Intelligence

Conclusion and Recommendations

Conclusion: snapshot of energy storage in Ireland

Energy storage sector

In Ireland, the energy storage sector comprises mainly of an operational pumped hydro generation facility and c.700MW of short duration batteries providing system services, this will need to grow to c.4.5 GW by the mid 2030s.

Energy storage solutions

Energy storage solutions will play a crucial role to enable the energy transition, provide system security and reduce the cost to consumers. Some solutions are more suitable than others to Ireland's needs and strengths.

Skills and expertise

In the context of the sector's recent rapid innovation and growth, there is a need to prioritise and develop appropriate new skills to enable the full potential of energy storage solutions as a decarbonisation and high value job creation mechanism in Ireland.

Capability and capacity uplift

The sector's capability and capacity requires a significant and near term uplift in order to meet the medium to long term energy storage needs necessary to decarbonise our energy system and maintain system adequacy.

Competition for Skills

The growth in renewables creates an environment with strong competition between employment in the renewable energy and the energy storage sector, coinciding with insufficient new entrants and skills coming through the education system. Given the sector's dependency on energy storage, these dynamics are equally applicable to the energy storage sector.

Feedback from industry concluded that "insufficiently defined energy storage related career paths" is the main challenges to growing the skills needed in Ireland's energy storage sector. If this is addressed on the job learning delivered by industry and industry graduate programmes with corporate and academic collaboration is viewed as the best means to develop the necessary skills.

Conclusion: The future is bright but uncertain

Batteries
Batteries are set to dominate near term growth in energy storage capacity. This is driven by several factors, including technology maturity, improving economics and the highly modular nature of battery technologies which can be deployed to solve grid scale to domestic challenges.

Technology mix
However, a mix of potential storage technologies is needed with hydrogen expected to serve as the enabler of seasonal storage solutions. A multitude of alternative technologies based on electro-chemical, thermal, chemical, or mechanical energy storage also have potential to meet particular applications, however their adoption is unlikely to be as widespread.

Energy Storage Pathways
As illustrated by the scenario modelling, Ireland's energy storage needs will be influenced by longer-term developments in the composition of the energy mix, zero emission generation capacity, the balance of electricity supply and flexible demand enabled though the deployment of energy storage, and the operation of interconnection capacity. The Irish energy storage sector should consider these evolving needs in line with developments in energy storage technologies and the benefits of reducing our dependency on imported energy.

Employment Potential
In addition to energy storage capacity supporting the energy transition, the potential for research and development, project development, asset management and supply chain job creation highlights the importance and value of the Irish energy storage sector for the Irish economy.

Recommendation areas

Data

With limited data on Ireland's future energy system and storage needs beyond 2030, further analysis and industry engagement is needed.

Skills intelligence

Skills intelligence needs to be developed by establishing online 'realtime' information on skills demand and gaps, supported by collaboration between industry and the education sector to ensure the required skills training is made available.

Career development

Based on industry feedback, clearly defined energy storage related career paths need to be developed and promoted to new entrants to the labour market and those seeking new opportunities. This will require greater collaboration between education providers and industry. Concurrently, on the job learning delivered by industry, and industry graduate programmes with corporate and academic collaboration is needed for ongoing development of the necessary skills amongst current employees, new entrants to the labour market, and those seeking new opportunities.

Policy evolution

Policy evolution is needed to support the development of the energy storage sector throughout the value chain, from product development (R&D) through to project delivery and operation. To support this, Ireland needs an end-to-end energy storage strategy that can support the development of the sector. Skills shouldform a key part of the energy storage strategy, formulating a plan for skills development thatintegrates with EU level efforts across technology, skills and collaboration.

Strategy

Skills intelligence, tied with the skills focused energy storage strategy, should be used to develop a career and skills roadmap linked to strategic technology areas to guide efforts to support and meet the energy storage sector's skills needs.

Recommended Actions (1/3)

Energy storage ‘technology toolbox’

Establish an energy storage ‘technology toolbox’ to track the technology readiness level (TRL) of key solutions along with an understanding of the technical, regulatory and commercial barriers to their adoption.

Ireland’s energy system needs

Establish modelling and analysis of Ireland’s energy system needs for the period post 2030. This is needed to examine the role of energy storage, flexibility, interconnection along with the role of other key topics.

Future energy system scenarios

Develop a set of future energy system scenarios that reflect current policy arrangements, policy gaps and expected technology improvements to explore how Ireland’s energy storage needs can be addressed and supported.

Pace of the energy transition

Such is the pace of the energy transition, updates to the technology toolbox, scenarios, evidence base and models should be performed annually.

Recommended Actions (2/3)

Growing Ireland's energy storage sector

Mechanisms to inform policy

Establish mechanisms to ensure policy and decision makers are kept informed of the technological innovation, costs and domestic supply chain opportunities in a rapidly evolving sector.

Industry collaboration

Work with industry to identify and support the energy storage applications needed for Ireland to deliver our decarbonisation and energy security.

Energy storage strategy

Develop an energy storage strategy that complements the demand flexibility strategy, the interconnection policy framework and Ireland's security of supply review to deliver the energy transition.

- Examine the potential for local supply chain opportunities and integration with international supply chains
- Examine what initiatives and supports are available to develop energy storage supply chains and assets locally

Key technologies

As part of the energy storage strategy, identify the key technologies Ireland should focus on over the medium to long term and the skills required to deliver this.

Competitive advanced capabilities

As part of the energy storage strategy, identify Ireland's competitive advanced capabilities such as our renewable and digital technologies sector and how these can be leveraged to create additional adjacent job opportunities.

International collaboration

Promote public and private sector participation in EU and international research and skills development programmes.

Recommended Actions (3/3)

Delivering the necessary skills

Delivering skills

- Perform a comprehensive assessment of the currently available means to deliver energy storage skills
- Perform a capability and capacity assessment to assess the ability of Ireland's training and education providers to provide relevant upskilling
- This should be done on an ongoing basis to ensure the necessary skills are developed and that the existing renewable energy skills pool is not cannibalised

This report provides a foundation for these assessments to build on, considering the industry survey, stakeholder workshops and consultations that informed the report.

Real-time' skills intelligence

- Develop a data driven solution to track jobs and skills demand and gaps in the energy storage sector
- Monitor Ireland and competing jurisdictions to target the development or acquisition of skills

Public-private partnerships (PPPs)

Form public-private partnerships (PPPs) – domestic and international, to develop STEM skills for the energy storage sector and enhance STEM skills from vocational training to post doctorate research.

Energy storage career roadmap

Support the development of an energy storage industry career roadmap through collaboration with professional bodies, industry and education providers.

Regularly refresh and update

Regularly refresh the skills and career roadmaps to reflect the evolution in the energy storage sector and Ireland's position in the supply chain.

Appendix A

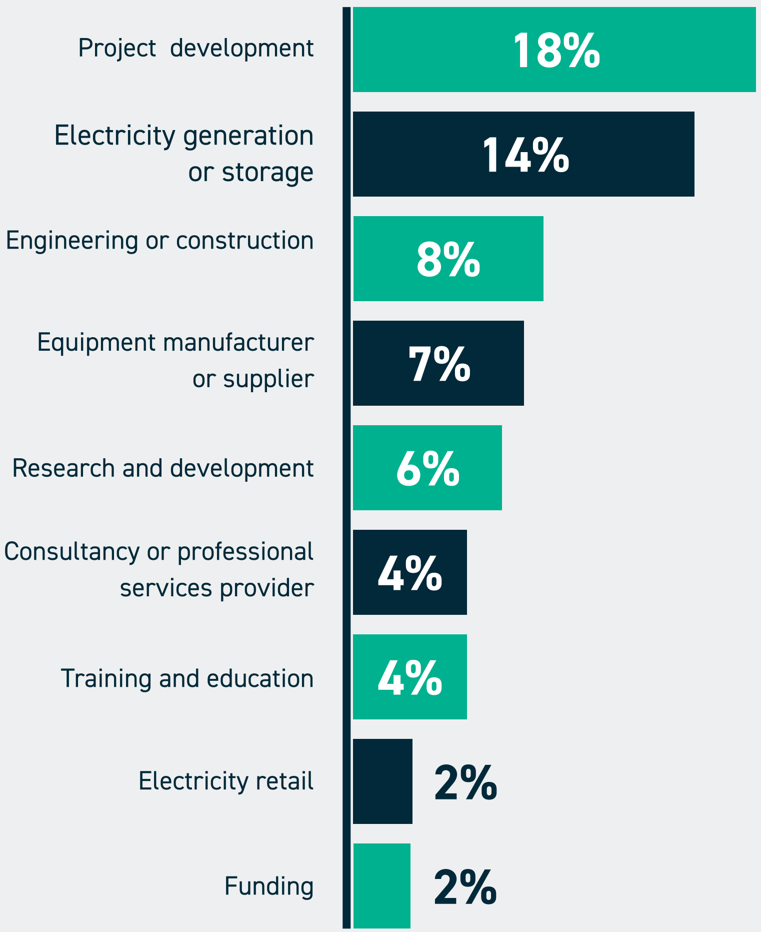
Industry survey respondent profile

Industry survey respondent profile

Respondents: 35

Principal Activity

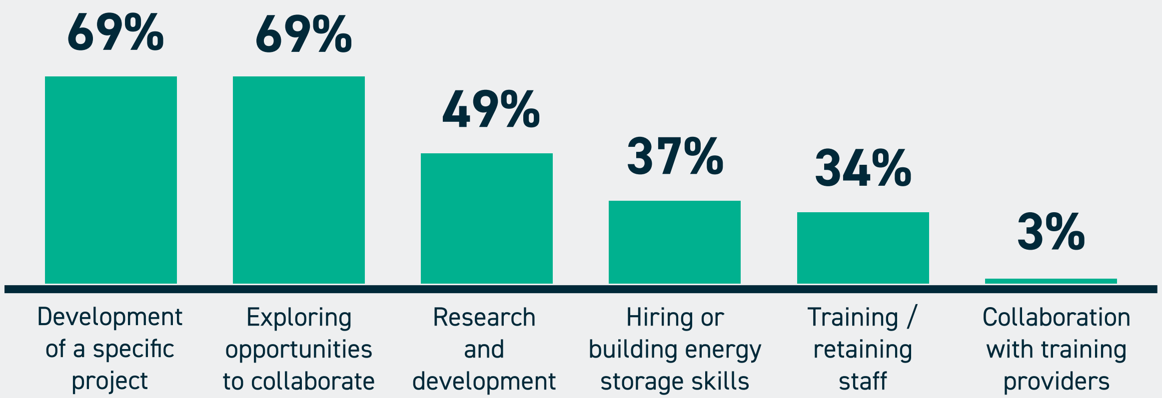
Principal activity of respondent's organisation, %



Majority of respondents work in project development

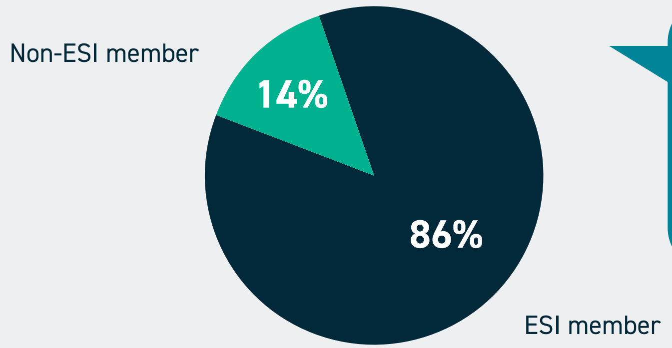
Focus Areas

Breakdown of which energy storage areas the respondent's organisation are currently engaged in, %



Energy Storage Ireland (ESI) members

Percentage of respondents that are ESI members



Of the 35 surveyed respondents, 30 (86%) are ESI members

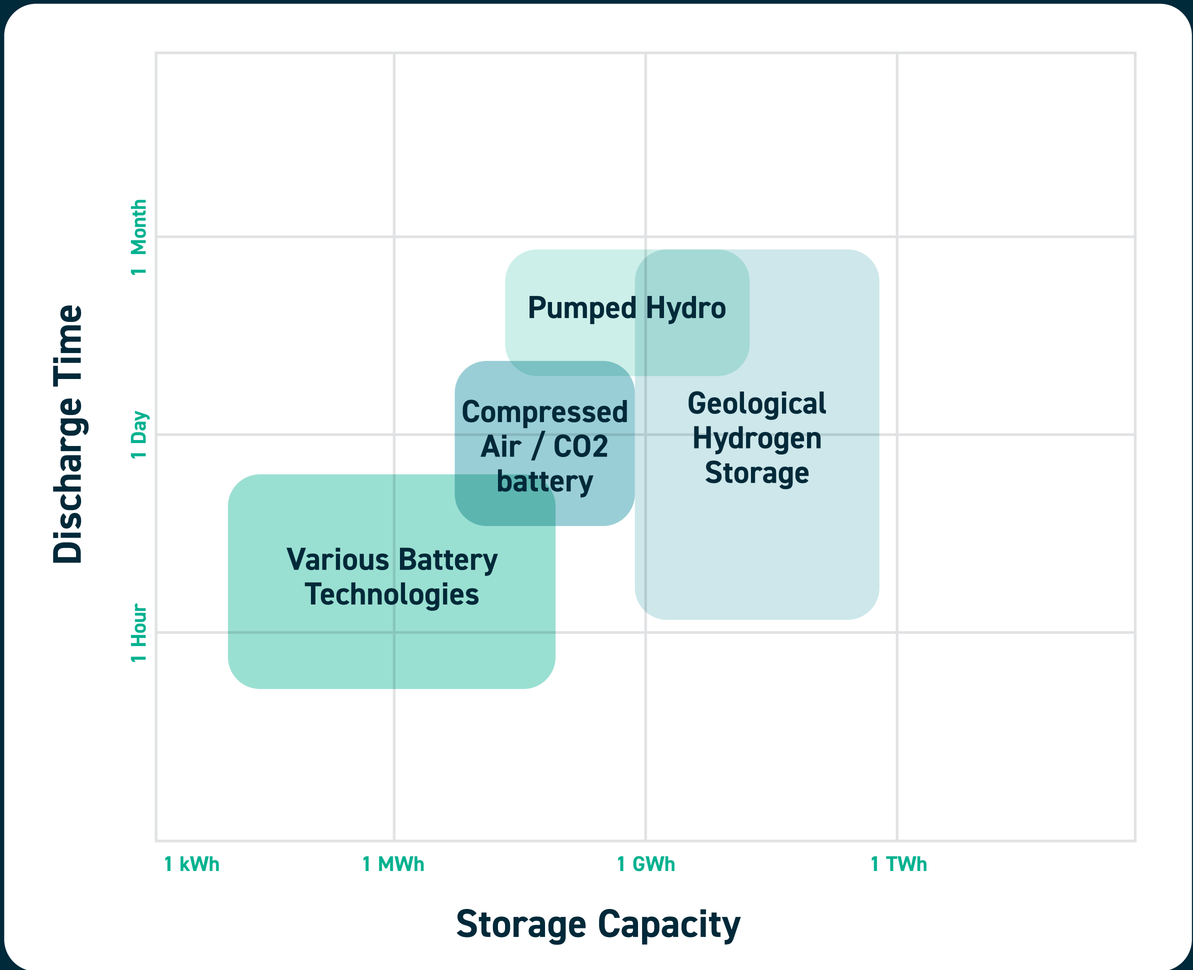
Appendix B

Energy storage technologies evaluation

Storage technologies vary by system configurations and design parameters

Storage technologies can vary across system configurations and design parameters.

Storage capacity and discharge times of selected energy storage technologies.



Differences in energy storage technologies

Energy storage technologies differ in terms of system configurations and design parameters. Key characteristics in which energy storage technologies are differentiated include:

- **Technology maturity**
- **Storage capacity i.e. energy and power density**
- **Storage discharge time i.e. duration**
- **Conversion efficiency**
- **Energy losses - over time and round trip losses**
- **Standby time**
- **Response time**
- **Number of economic cycles over asset life**
- **Environmental impacts**
- **Safety aspects**

The graph on the left shows how different technologies compare in terms of two of the most important differentiators

*Source: A Critical Study of Stationary Energy Storage Polices in Australia in an International Context: The Role of Hydrogen and Battery Technologies

Comparing Storage technologies: Evaluation criteria

Energy storage solutions were considered across mechanical, electrical and chemical based technologies.

Comparing the range of energy storage technologies

To consistently evaluate the range of available storage technologies, a number of weighted criteria were applied to capture their technoeconomic feasibility for implementation in the Irish energy system.

Criterion	Description
1: Energy storage potential	The volume of energy it is possible to store using a standard installation unit of the technology
2: Solution modularity	The potential to combine modular units to deploy a larger energy storage system with ease
3: Deployment constraints	Deployment constraints that present barriers to widespread deployment of the technology, for example dependency on supply chain bottlenecks, raw material concerns, or geological constraints
4: Fixed cost	Level of capital investment needed and / or fixed operating costs
5: Round trip efficiency	A representation of the amount of energy lost between import and export cycles
6: Current TRL	Technology Readiness Level – the status of development of the technology today
7: Learning curve	The potential improvement in technology performance and / or cost realisable over the short to long term

Existing and emerging storage technologies

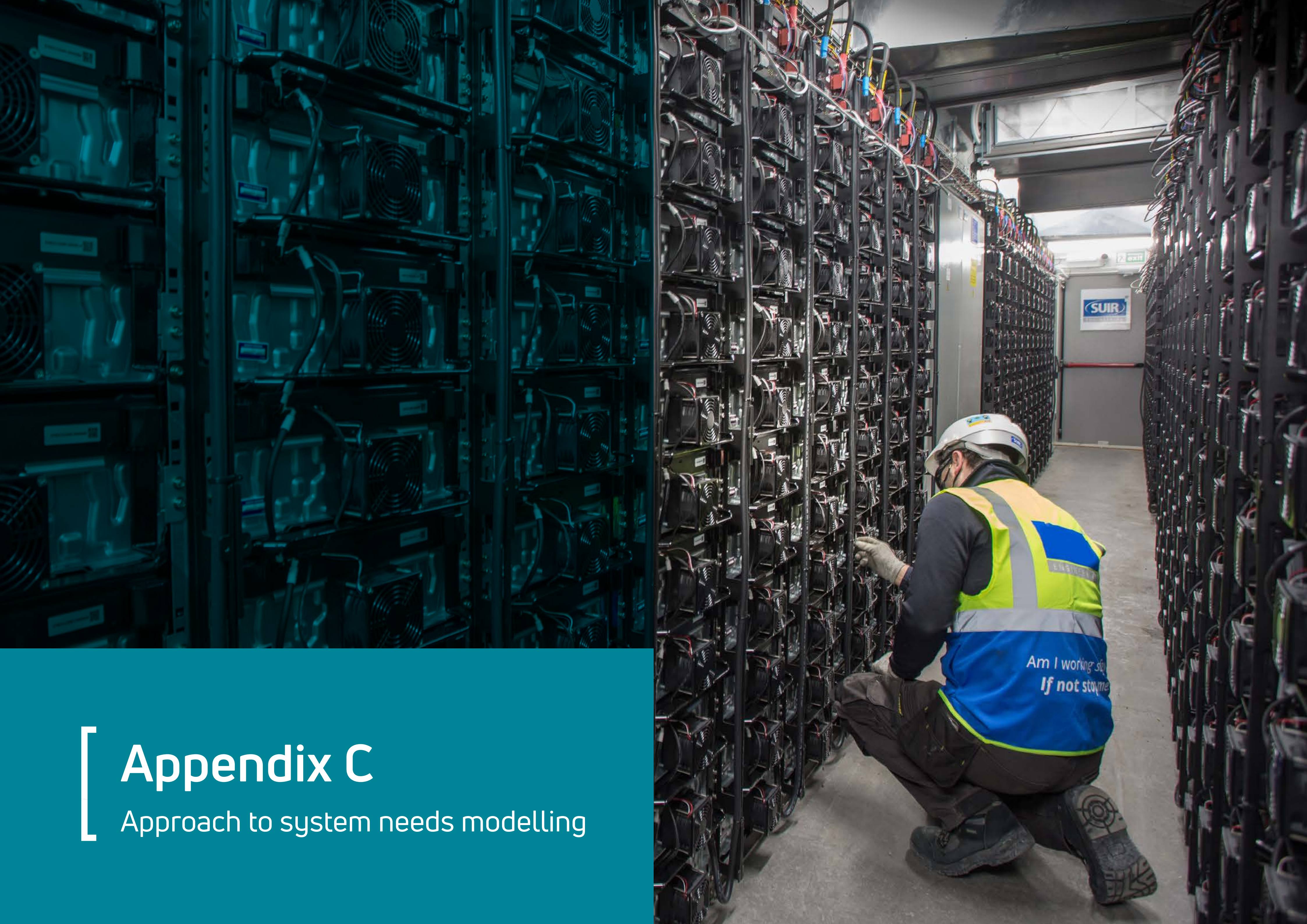
Tech Type	Pros	Cons	CAPEX	OPEX	Score (1-5)
01 Li-ion	• Highly modular • Very fast response technology • Costs falling rapidly • Significant global investments • Can be deployed anywhere	• Considered a short duration solution • Costs scale linearly with energy storage capacity • Demand for Lithium considered somewhat problematic due to potential scarcity and environmental impacts	L	M	3.8
02 Na-ion	• Sodium is an abundant raw material • Highly modular • Costs falling • Can be deployed anywhere	• Low energy density • Units are larger and heavier than Li-ion • Not yet commercially significant with investment needed in the supply chain	L-M	M	3.45
03 Metal Air	• Long storage durations • Abundant low cost raw materials. • Potentially can store more energy per kg than Li-ion,	• Not demonstrated at scale • Low round-trip efficiency • Prone to corrosion and film development which decreases efficiency and voltage	L-M	M	3.2
04 Redox flow	• Less volatile materials • Easily scalable by increasing fluid tank volume as energy conversion and storage are decoupled	• Higher cost than Li-ion • Lower round-trip efficiency than Li-ion • Requires Vanadium rare earth metal • Not widely deployed commercial • Low round-trip efficiency	L-M	M	3.45
05 NiMH	• High power density • Not dependant on rare earth metals • Profitable to recycle	• Generates heat during fast charge and discharge • Low round-trip efficiency • High self-discharge.	L-M	M	3.35
06 Lead Acid	• Highly mature technology • Low cost • Stable battery cycles • Simple manufacturing process	• Lead is a toxic material • Lower efficiency than alternatives • Low energy density • Little opportunity for innovation	L	M-H	3.45

Sources: Kit Fitton (2022)

Existing and emerging storage technologies

Tech Type	Pros	Cons	CAPEX	OPEX	Score (1-5)
07 Molten Salt	• Supports electrification of heat without requiring significant grid upgrades • Mature in conjunction with concentrated solar power (CSP)	• Not strictly an electricity storage technology • Low efficiency on electricity conversion	L	M	3.2
08 Pumped Hydro	• Mature technology • Long technical and economic life • Low lifetime cost • Low supply chain dependency	• Limited to areas with specific geographical / topographical features • Long delivery timeframes • Little opportunity for innovation	H	L-M	2.85
09 Gravity Storage	• Generally simple technology • Can theoretically be deployed anywhere • Low supply chain dependency • Multiple competing technologies	• Limited by low energy density • Not suitable to large scale energy storage • Generally at early stage development	M	L-M	1.75
10 Liquid Air	• Low capital cost • Allows decoupling of conversion and storage - modular design possible • Low supply chain dependency	• Low efficiency in electricity conversion • Significant heat loss from compression • At early stage in development • Energy needed to maintain liquid state	L-M	M-H	3.15
11 Compressed Air	• Low capital cost • Allows decoupling of conversion and storage - modular design possible • Low supply chain dependency	• Limited by geology - requires salt caverns for large scale storage • Generally at early stage development	L-M	M	2.7
12 CO2 Battery	• Low capital cost • Allows decoupling of conversion and storage - modular design possible • Low supply chain dependency • Higher efficiency than compressed air.	• Complex engineering projects • Not yet demonstrated at meaningful scale • Lower round trip efficiency than chemical batteries	M	M-H	3.3
13 Hydrogen	• Multiple storge options including long (intersessional) storage durations • Decoupling of conversion and storage • Potential for significant innovation and cost reduction	• Currently high capital costs • Very low round trip efficiency • Gas infrastructure required • Large scale storage limited to suitable geology e.g. salt caverns	H	H	3.4

Sources: Kit Fitton (2022)



Appendix C

Approach to system needs modelling

Ireland's energy storage needs to 2035 and 2050

Approach to scenarios: high level quantification of wholesale energy storage needs

Scenario Sensitivity Analysis

MaREI Annual Demand + **CRU Demand & Renewable Profile Shape** + **Renewable Capacity, Constrained Dispatch & Interconnector Assumptions** = **Energy Surplus & Deficit**

MaREI Annual Demand

- Scenarios for long terms demand growth
- Includes electrification of heat and transport assumptions
- Excludes energy storage demand / hydrogen production

CRU Demand & Renewable Profile Shape

- Hour granularity shape applied to MaREI forecast for both BAU and electrification of heat and transport demand
- CRU Plexos hourly renewable profile applied to renewable capacity

Renewable Capacity, Constrained Dispatch & Interconnector Assumptions

- Developed renewable transition scenarios with varied assumptions to assess impact on energy storage needs
- Assessed storage needs sensitivity to key assumptions

Energy Surplus & Deficit

- Examined daily, weekly and monthly energy (MW & MWh) surplus and deficit as a proxy for energy needs

Ireland's energy storage needs to 2035

Scenarios for 2035

Scenario	Demand	Peak Demand	Unconstrained renewable generation	Dispatch Constraints	Interconnection capacity
1	60 TWh	9.2 GW	67 TWh	3 x 150 MW	2.5 GW
2	60 TWh	9.2 GW	95 TWh	None	5.2 GW
3	55 TWh	8.3 GW	67 TWh	3 x 150 MW	2.5 GW
4	60 TWh	9.2 GW	95 TWh	None	7 GW

1 Modest Transition
2 Greening Our Economy
3 Slow Growth
4 Green Export

Ireland's energy storage needs to 2050

Scenarios for 2050

Scenario	Demand	Peak Demand	Unconstrained renewable generation	Dispatch Constraints	Interconnection capacity
1	100 TWh	15.5 GW	126 TWh	None	5.2 GW
2	77 TWh	11.3 GW	203 TWh	None	8 GW
3	77 TWh	11.3 GW	131 TWh	None	5 GW
4	100 TWh	15.5 GW	236 TWh	None	9 GW

1 Modest Transition   2 Greening Our Economy   3 Slow Growth   4 Green Export

Scenarios Sensitivity

The scenario modelling exercise highlighted the lack of analysis examining Ireland's power system in the years post 2030, the impact of interconnection on energy storage needs and the impact of flexible demand targets on energy storage needs. Further work is needed on each of these fronts to provide greater clarity on how energy storage can support the decarbonisation of Ireland's power system and maintaining future system security.

	Scenario 1: Modest Transition	**Scenario 2:** Greening our economy	**Scenario 3:** Slow Growth	**Scenario 4:** Green Export
2035	• In the absence of interconnection up to 7 GW of energy storage is required by the all island power system. • Alternatively c.5.7 GW of interconnection capacity is needed if Ireland's battery energy storage capacity is maintained at the current operational level of c.800 MW.	• In the absence of interconnection up to 7.5 GW of energy storage is required by the all island power system. • Alternatively c.6.2 GW of interconnection capacity is needed if Ireland's battery energy storage capacity is maintained at the current operational level of c.800 MW.	• In the absence of interconnection up to 5.7 GW of energy storage is required by the all island power system. • Alternatively c.4.6 GW of interconnection capacity is needed if Ireland's battery energy storage capacity is maintained at the current operational level of c.800 MW.	• In the absence of interconnection up to 7.5 GW of energy storage is required by the all island power system. • Alternatively c.6.1 GW of interconnection capacity is needed if Ireland's battery energy storage capacity is maintained at the current operational level of c.800 MW.
2050	• With peak demand of 15.5 GW the 5.2 GW of interconnection capacity and 9.2 GW of energy storage comes close to covering a Dunkelflaute event however additional GWs of seasonal storage is required to ensure system security.	• With peak demand of 11.3 GW the 8 GW of interconnection capacity and 3.4 GW of energy storage should cover a Dunkelflaute event provided sufficient energy storage capacity is long duration and all interconnector capacity is available for import.	• With peak demand of 11.3 GW the 5 GW of interconnection capacity and 5.5 GW of energy storage should cover a Dunkelflaute event provided sufficient energy storage capacity is long duration and all interconnector capacity is available for import.	• With peak demand of 15.5 GW the 9 GW of interconnection capacity and 5.6 GW of energy storage should cover a Dunkelflaute event provided sufficient energy storage capacity is long duration and all interconnector capacity is available for import.

Analysis of Ireland's energy system examining the period post 2030 is needed to ascertain the potential for energy storage to maintain system security in a ultra-high renewables grid.

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