European Commission

Clean energy for EU islands: Battery Energy Storage Overview

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Battery Energy Storage Overview

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List of Abbreviations

AC	Alternating Current
BES	Battery Energy Storage
BMS	Battery Management System
CAPEX	Capital Expenditure
DC	Direct Current
EMS	Energy Management System
HVAC	Heating Ventilation and Air-Conditioning
PCS	Power Conversion System
LCOE	Levelized Cost of Electricity
LCOS	Levelized Cost of Storage
OPEX	Operational Expenditure

Executive Summary

Battery Energy Storage (BES) systems are a critical enabling technology for the transition to a low-carbon energy sector. As renewable energy penetration grows, driven by carbon-neutrality targets such as the EU 2050 objective, the need to store intermittent energy from solar and wind sources becomes increasingly important. BES provides a practical solution by capturing surplus electricity and releasing it when generation is insufficient, reducing reliance on fossil-fuel plants and enhancing grid stability.

A typical BES consists of several integrated components, including the battery modules, battery management system (BMS), power conversion system (PCS), controller, heating ventilation and air-conditioning (HVAC), fire suppression system, and energy management system (EMS). Together, these subsystems ensure safe operation, optimal performance, and efficient integration with the grid.

Cost analysis using the Levelized Cost of Storage (LCOS) shows that lithium-ion technology is expected to remain the most competitive option for most short-duration and high-cycling applications through 2050, with steady declines in cost driven by improved efficiency and scale. Lithium-ion batteries dominate nearly all evaluated use cases except seasonal storage, where hydrogen solutions outperform due to superior long-duration capability. Real-world deployment, such as the 200 MWh BES facility in Dahlem, Germany, demonstrates the scale and investment levels involved, with the battery equipment itself accounting for the largest portion of overall cost.

BES systems offer major advantages, including enhanced grid reliability, effective renewable integration, peak-shaving capabilities, and high round-trip efficiency, but challenges persist. Environmental impacts from battery production and end-of-life handling, degradation risks from improper operation, regulatory inconsistencies, and fire-safety concerns remain significant barriers to widespread adoption. Continued technological, regulatory, and sustainability improvements will be essential to unlocking the full potential of BES in modern energy systems.

1. Introduction

Battery Energy Storage (BES) systems are a critical enabling technology for the transition to a low-carbon energy sector. As renewable energy penetration grows, driven by carbon-neutrality targets such as the EU 2050 objective, the need to store intermittent energy from solar and wind sources becomes increasingly important. BES provides a practical solution by capturing surplus electricity and releasing it when generation is insufficient, reducing reliance on fossil-fuel plants and enhancing grid stability.

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This report provides an overview of BES technologies, their components, and associated costs. The main advantages and disadvantages of the technology are also presented, together with some useful real-world application examples.

2. Energy Storage

2.1. What is an Energy Storage System?

An energy storage system captures energy made by renewables or another energy source, and stores this energy for discharge when it is required. There are multiple kinds of energy storage systems, such as mechanical storage (pumped hydro), electrochemical (battery), electrical (capacitors), thermal (heat storage), chemical (hydrogen) or thermomechanical (solar fuels). In this review, an insight is given into battery energy storage (BES).

3. Battery Energy Storage

Battery energy storage relies on electrochemical systems to store energy. These systems generate electricity through chemical reactions. One of the most common examples is lithium-ion batteries. Lithium-ion batteries are widely used in smartphones, electric vehicles, and other personal electronic devices. However, around 90% of the annual demand for lithium-ion batteries now comes from the energy sector[1].

3.1.1. Why is there a need for BES?

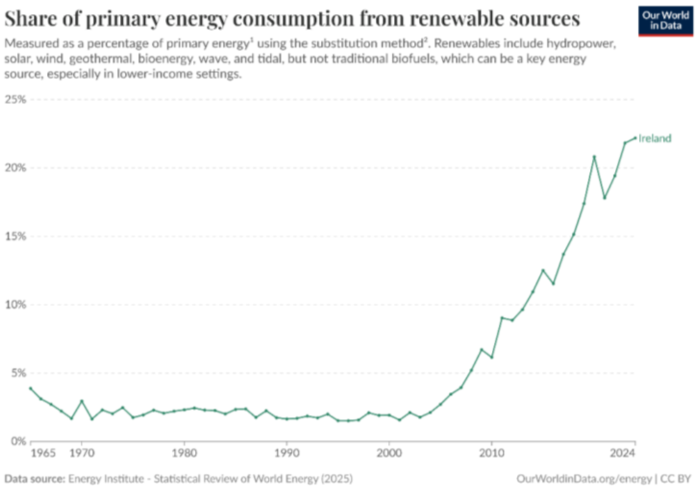
The European Union aims to become climate-neutral by 2050.[2] This means achieving an economy with net-zero greenhouse gas emissions. To reach this goal, several industries must change their habits and transition to more sustainable practices. One of the most significant sectors in this transition is the energy industry, which is undergoing major changes in how energy is produced. For

[1] IEA (2024), Batteries and Secure Energy Transitions, IEA, Paris https://www.iea.org/reports/batteries-and-secure-energy-transitions, Licence: CC BY 4.0

[2] European Commission. (n.d.). 2050 long-term strategy. Retrieved October 14, 2025, from https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en

example, Ireland’s share of renewable energy consumption was below 2% in 2000 but has now risen to just over 20%. Although considerable progress has been made, there is still a long way to go.[3]

Figure 1: Ireland's share of primary energy consumption from renewable sources.



To achieve an energy mix that relies entirely on renewable sources, we need to change the way we manage energy. Renewable energy sources are not always available. For example, solar and wind power are abundant, but during the night or when wind speeds are low, they may not meet the energy demand. That is why effective energy storage systems are essential.

The principle of BES is simple, yet effective; the storage of excess electricity generated when supply exceeds demand, i.e. when there is a surplus of energy production from renewables. This energy can be stored in batteries and supplied when the demand is higher than the production at that time. These storage techniques reduce the need for traditional fossil fuel plants.

3.1.2. Components of BES

3.1.2.1. Battery

The battery is, of course, a crucial component of the BES. It stores energy and releases it when discharge is required. A battery consists of multiple cells connected in series and parallel to form a module. Several modules together make up a rack, and multiple racks can again be connected in series or parallel to achieve the desired voltage and current for the BES.[4] This modular design allows the system to be easily scaled and adapted to different requirements.

3.1.2.2. Battery management system

Every BES needs a battery management system or BMS. BMS can be regarded as the brain of the system. Its primary function is to protect the battery and maintain operation within safe limits. For example, it cannot be charged above its maximum voltage.

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[3] Hannah Ritchie, Max Roser, and Pablo Rosado (2020) - “Renewable Energy” Published online at OurWorldinData.org. Retrieved from: 'https://ourworldindata.org/renewable-energy' [Online Resource]

[4] Power-Sonic. (n.d.). Battery energy storage system components. Retrieved October 14, 2025, from https://www.power-sonic.com/battery-energy-storage-system-components/

3.1.2.3. Power conversion system

The battery in a BES stores electricity as direct current (DC); however, most electrical systems operate on alternating current (AC). To bridge this difference, a Power Conversion System (PCS) is used. These devices can convert power in both directions, DC to AC for supplying the grid or electrical loads, and AC to DC for charging the battery, enabling the BES to efficiently both charge and discharge energy.[5]

3.1.2.4. Controller

The controller acts as the brain of the entire system, overseeing and protecting all key subsystems. It monitors operations, communicates with internal components as well as external devices like electricity meters and transformers, and ensures the system operates efficiently.

3.1.2.5. HVAC (Heating, ventilation, and air conditioning)

The HVAC system in a BES regulates temperature and airflow, helping maintain optimal battery conditions. Proper thermal management prevents overheating, reduces degradation, and extends battery life, ensuring better system performance.[6]

3.1.2.6. Fire suppression

The fire suppression system in a BES provides an essential backup to the BMS, activating in cases of thermal runaway. It detects heat, gas, or smoke and releases an agent to suppress fire, cool the system, and protect the batteries.

3.1.2.7. Energy management system

The energy management system (EMS) controls and schedules BESS operations, communicating with the BMS and PCS while considering external data. It optimises performance, manages power discharge based on application needs, balances battery life and return on investment (ROI), and collects data for reporting and forecasting.[7]

3.1.3. Cost of BES

The Levelized Cost of Storage (LCOS) represents the discounted cost per unit of electricity discharged for a specific storage technology and application. It accounts for all factors contributing to the total lifetime cost of the storage system, including investment, operation and maintenance, charging, and end-of-life costs, divided by the total electricity discharged over the system's lifetime.[8]

When evaluating the cost of energy storage, several factors must be considered. The LCOS is a useful metric for comparing technologies, but it does not provide the full picture. It is equally important to consider the context in which a technology is applied, as operating conditions can significantly influence the LCOS and overall performance. For instance, lithium-ion batteries are highly effective in applications that require frequent charge and discharge cycles due to their high round-trip efficiency. In contrast, hydrogen or pumped-hydro storage performs less efficiently in such short-

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[5] Power-Sonic. (n.d.). Battery energy storage system components. Retrieved October 14, 2025, from https://www.power-sonic.com/battery-energy-storage-system-components/

[6] Power-Sonic. (n.d.). Battery energy storage system components. Retrieved October 14, 2025, from https://www.power-sonic.com/battery-energy-storage-system-components/

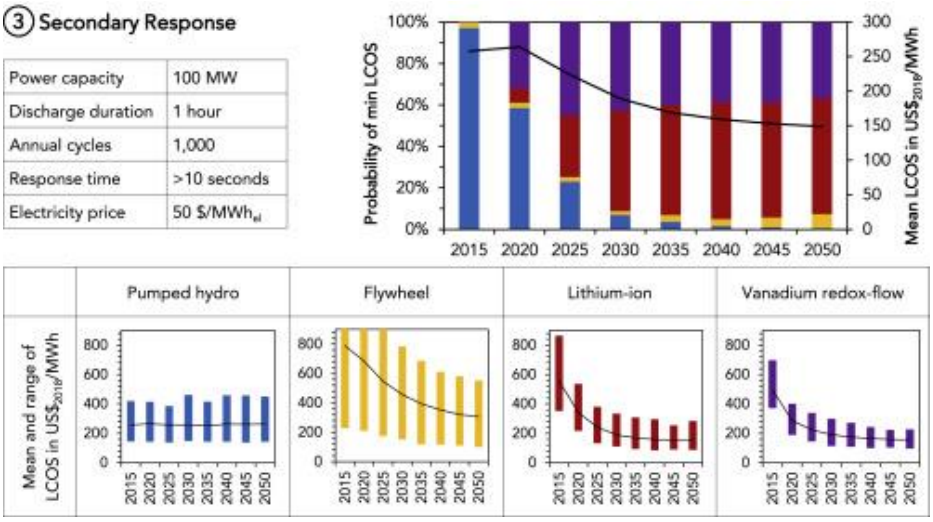
[7] Power-Sonic. (n.d.). Battery energy storage system components. Retrieved October 14, 2025, from https://www.power-sonic.com/battery-energy-storage-system-components/

[8] Clark, E. (2023, November 17). What is Levelized Cost of Storage (LCOS)? Energy Theory. https://energytheory.com/what-is-levelized-cost-of-storage-lcos/

term applications. However, for long-discharge applications, they perform better than lithium-ion.[9] The study, Projecting the Future Levelized Cost of Electricity Storage Technologies, examined nine different storage technologies from 2015 to 2050. The findings showed that lithium-ion batteries are expected to be the most competitive option for most applications from 2030 onward.[10] An example of one such application is shown in the figure below. The top left section displays the system requirements, while the top right shows the probability of each storage technology achieving the lowest LCOS. The bottom section illustrates the four most competitive technologies for this specific scenario, with their LCOS trends from 2015 to 2050, including uncertainty ranges.

This scenario represents a secondary response application, characterised by short discharge durations and frequent cycling. For lithium-ion batteries, costs ranged from over 800 USD/MWh to about 400 USD/MWh in 2015. These costs are projected to decline rapidly, reaching 350–150 USD/MWh by 2030 and stabilising at an average of around 150 USD/MWh by 2050.

Figure 2: LCOS projections for secondary response[11]



When taking a broader look across multiple applications, it becomes clear that lithium-ion technology consistently stands out as the leading candidate with the highest likelihood of achieving the lowest LCOS in a wide range of use cases. Figure 3 below illustrates 12 different applications, each showing the probability over several years of which storage technology is expected to have the lowest LCOS. In most applications, lithium-ion emerges as a strong contender, once again highlighting the importance of BES.[12]

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[9] Oliver Schmidt, Sylvain Melchior, Adam Hawkes, Iain Staffell, Projecting the Future Levelized Cost of Electricity Storage Technologies, Joule, Volume 3, Issue 1, 2019, Pages 81-100, ISSN 2542-4351, https://doi.org/10.1016/j.joule.2018.12.008. (https://www.sciencedirect.com/science/article/pii/S254243511830583X)

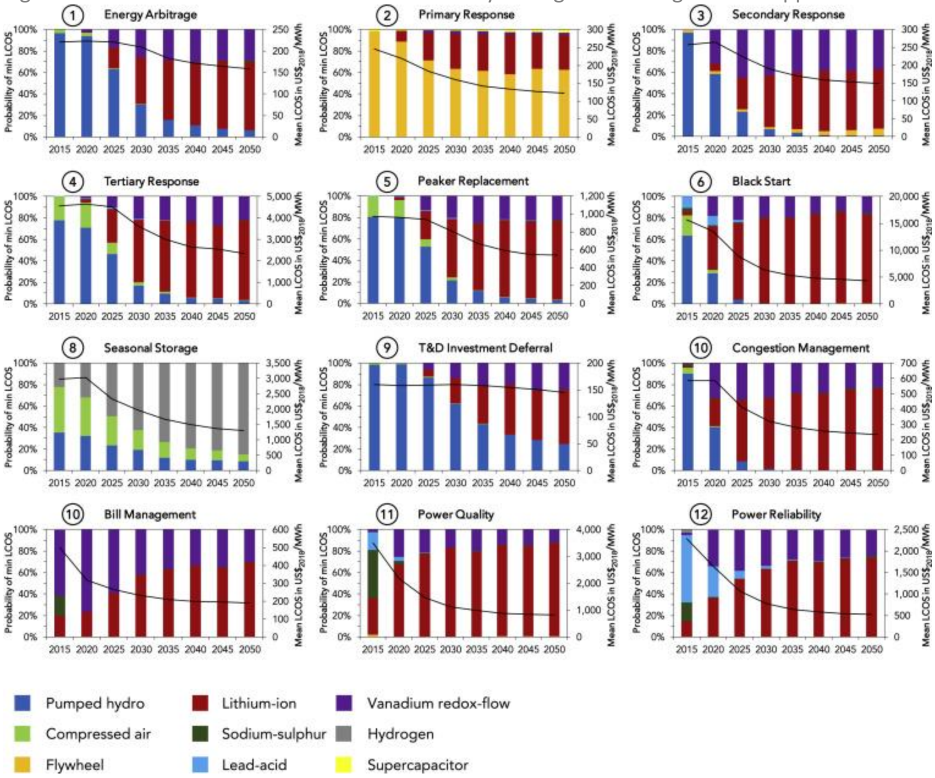
[10] Oliver Schmidt, Sylvain Melchior, Adam Hawkes, Iain Staffell, Projecting the Future Levelized Cost of Electricity Storage Technologies, Joule, Volume 3, Issue 1, 2019, Pages 81-100, ISSN 2542-4351, https://doi.org/10.1016/j.joule.2018.12.008. (https://www.sciencedirect.com/science/article/pii/S254243511830583X).

[11] Oliver Schmidt, Sylvain Melchior, Adam Hawkes, Iain Staffell, Projecting the Future Levelized Cost of Electricity Storage Technologies, Joule, Volume 3, Issue 1, 2019, Pages 81-100, ISSN 2542-4351, https://doi.org/10.1016/j.joule.2018.12.008. (https://www.sciencedirect.com/science/article/pii/S254243511830583X).

[12] Oliver Schmidt, Sylvain Melchior, Adam Hawkes, Iain Staffell, Projecting the Future Levelized Cost of Electricity Storage Technologies, Joule, Volume 3, Issue 1, 2019, Pages 81-100, ISSN 2542-4351, https://doi.org/10.1016/j.joule.2018.12.008. (https://www.sciencedirect.com/science/article/pii/S254243511830583X)

The only application where lithium-ion performs less effectively is seasonal storage, which involves storing energy for extended periods and longer discharge times, such as capturing excess solar energy in the summer for use during the winter when solar generation is lower. In this case, hydrogen storage is the clear frontrunner, offering the lowest LCOS for long-duration energy storage.[13]

Figure 3: Lowest LCOS Probabilities for 9 Electricity Storage Technologies in 12 Applications from 2015 to 2050[14]



A real-world example of a BES project can be found in Dahlem, Germany, where TotalEnergies invested over €75 million to deploy a large-scale battery storage system. The system has a total capacity of 200 MWh and a power output of 100 MW.[15]. For comparison, the average household in Ireland used around 4.5 MWh of electricity in 2022.[16] This means the battery could theoretically supply enough electricity to power just over 44 households for an entire year.

The total cost of a BES system can be divided into several main categories: hardware and equipment, installation and integration, and operation and maintenance. The largest share of the total investment comes from the batteries themselves, which account for 30–40% of total costs. Power conversion systems—such as inverters and transformers—contribute an additional 15–20%.

[13] Oliver Schmidt, Sylvain Melchior, Adam Hawkes, Iain Staffell, Projecting the Future Levelized Cost of Electricity Storage Technologies, Joule, Volume 3, Issue 1, 2019, Pages 81-100, ISSN 2542-4351, https://doi.org/10.1016/j.joule.2018.12.008. (https://www.sciencedirect.com/science/article/pii/S254243511830583X)

[14] Oliver Schmidt, Sylvain Melchior, Adam Hawkes, Iain Staffell, Projecting the Future Levelized Cost of Electricity Storage Technologies, Joule, Volume 3, Issue 1, 2019, Pages 81-100, ISSN 2542-4351, https://doi.org/10.1016/j.joule.2018.12.008. (https://www.sciencedirect.com/science/article/pii/S254243511830583X)

[15] TotalEnergies. (2024, July 24). Integrated power in Germany: TotalEnergies launches new 100 MW / 200 MWh battery storage development. Retrieved October 15, 2025, from https://totalenergies.com/news/press-releases/integrated-power-germany-totalenergies-launches-new-100-mw-200-mwh-battery

[16] Sustainable Energy Authority of Ireland. (n.d.). Residential [Energy statistics]. Retrieved October 15, 2025, from https://www.seai.ie/data-and-insights/seai-statistics/residential

Supporting infrastructure, including grid connections, monitoring systems, and safety features, also adds significantly, representing about 20–25% of the total cost.

For a typical 100 MW / 400 MWh utility-scale installation in Europe, hardware and equipment costs alone can reach up to €60 million. However, these costs are expected to decline by 8–10% per year as manufacturing efficiency improves and supply chains mature. Overall, hardware and equipment make up approximately 80% of the total investment, while installation and integration account for 15–25%, and operation and maintenance account for 2–4%.[17]

This breakdown highlights that the initial investment in a BES is substantial, but variable costs, such as operation and maintenance, remain low over the system's lifetime.

3.1.4. Advantages & disadvantages

3.1.4.1. Advantages

- BES provides backup power during disruptions, stabilises voltage and frequency, and supports grid resilience.[18]
- BES helps integrate intermittent renewable energy by storing excess power and supplying it when needed.
- By enabling peak shaving and load shifting, BES helps lower electricity bills and reduce demand charges.[19]
- BES provides an efficient way of storing energy by having a high round-trip efficiency.

3.1.4.2. Disadvantages/challenges

- Battery production, use, and disposal involve toxic materials, intensive mining, and poor recycling, making sustainable practices and regulatory compliance essential to reduce environmental impact.
- Proper system control is needed to prevent accelerated lithium-ion degradation from improper charging, discharging, or temperature, ensuring long-term performance.
- BES deployment and operation face unclear and inconsistent regulations, creating uncertainty for investors and hindering grid service provision and capital investment.
- BES carry fire risks from thermal runaway or external hazards, requiring early warning systems, rapid-response protocols, and advanced suppression measures to protect people and equipment.

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[17] euro-inox. (2025, February 4). Real cost behind grid-scale battery storage: 2024 European market analysis**.** Retrieved October 15, 2025, from https://www.euro-inox.org/real-cost-behind-grid-scale-battery-storage-2024-european-market-analysis/

[18] ACP. (2024, September 13). Benefits of energy storage | ACP. ACP. https://cleanpower.org/facts/clean-energy-storage/benefits-of-energy-storage/

[19] JMS Energy. (2024, April 13). 5 Key Advantages of BESS Battery Energy Storage Systems for Modern Energy Solutions - JMS Energy. Retrieved October 15, 2025, from JMS Energy website: https://www.jmsenergy.net/5-key-advantages-of-bess-battery-energy-storage-systems-for-modern-energy-solutions/

4. Real-world cases

4.1. Batteries and Secure Energy Transitions

A report about battery energy storage and how it plays a crucial role in the energy transition. Made by the International Energy Agency (IEA).[20]

4.2. Review of Battery Energy Storage Systems: Challenges, Strategies and Applications

A paper that reviews battery energy storage systems. It explains the technology and dives deeper into its challenges and strategies, as the name suggests.[21]

4.3. ESB officially launches major battery project at Poolbeg Energy Hub as part of €300m investment

Press release about a BES investment in Dublin, Ireland.[22]

4.4. A comprehensive review of electricity storage applications in island systems

A paper that focuses on the implementation of energy storage technologies on island systems.[23]

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[20] International Energy Agency. (2024). Batteries and secure energy transitions (World Energy Outlook Special Report). International Energy Agency. https://www.iea.org/reports/batteries-and-secure-energy-transitions

[21] Zhenyong, Y., Hongwei, Z., Sathya Prakash, S., Yangyi, L., Xianping, W., & Zili, D. (2025). Review of battery energy storage systems: Challenges, strategies and applications. International Journal of Engineering and Technology, 17(1), 81–89. https://www.ijetch.org/2025/IJET-V17N1-1306.pdf

[22] ESB. (2024, February 7). ESB officially launches major battery project at Poolbeg Energy Hub as part of €300m investment. ESB. https://esb.ie/news---insights/press-releases/article/2024/02/07/esb-officially-launches-major-battery-project-at-poolbeg-energy-hub-as-part-of-300m-investment

[23] Georgios N. Psarros, Pantelis A. Dratsas, Stavros A. Papathanassiou, A comprehensive review of electricity storage applications in island systems, Journal of Energy Storage, Volume 83, 2024, 110658, ISSN 2352-152X, https://doi.org/10.1016/j.est.2024.110658. (https://www.sciencedirect.com/science/article/pii/S2352152X24002421)