Revolutionising energy storage

Innovations driving the future

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PERSPECTIVES

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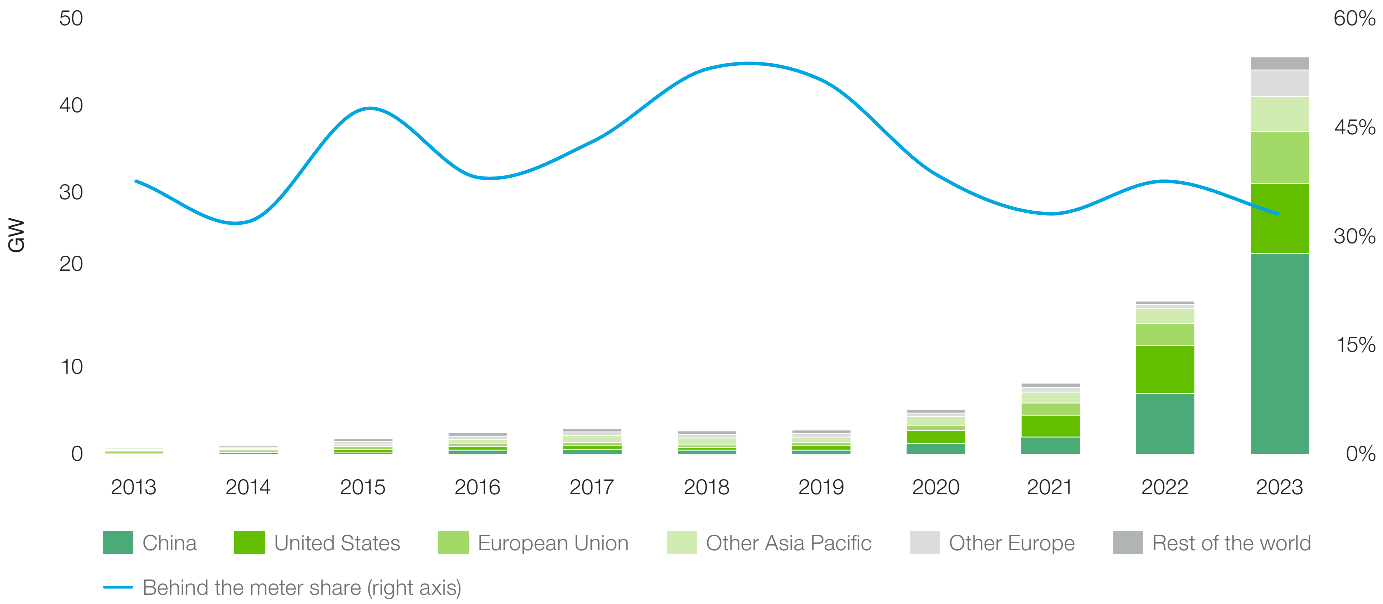
Batteries play a crucial role in today's global energy infrastructure. Moreover, they represent the fastest-growing energy storage technology in the sector. In 2023, deployments more than doubled compared with 2022, making battery storage the leading commercially available energy technology in the power sector. Significant growth has been observed in utility-scale and behind-the-meter (site-specific) batteries, as well as in local grids and residential solar energy systems (which are often paired with residential batteries). All this contributed to a global addition of 42 GW in battery storage capacity in 2023. Battery deployment in electric vehicles (EVs) alone increased by 40% in the same year, thanks to 14 million new electric cars on the road.

According to the International Energy Agency (IEA), a six-fold increase in global battery storage capacity is necessary to meet the ambitious climate targets for 2030 set by COP28. This increase is essential to facilitate tripling the world's renewable energy capacity and phasing out fossil fuels by the end of the decade. Indeed, to stabilise the integration of renewable sources like solar and wind into the energy grid, approximately 1,500 GW of energy storage capacity will be needed by 2030, of which 1,200 GW is expected to be provided by batteries.

Figure 1 **Global battery storage capacity additions 2013–2023**



Source: Solar Power Europe

Battery technologies feature various chemistries, each suited to specific applications. For example, lead-acid batteries are favoured for their cost-effectiveness, while nickel–cadmium batteries are valued for their durability and high discharge rates in industrial settings. Nickel-metal hydride batteries offer high energy density. And emerging alternatives promise greater sustainability and safety than traditional varieties. Lithium-ion batteries are the most prevalent of these emerging battery technologies, occupying more than 50% of the market in 2023 thanks to their superior energy density and efficiency. This makes them indispensable across a wide range of applications, particularly for mobile electronics and EVs.

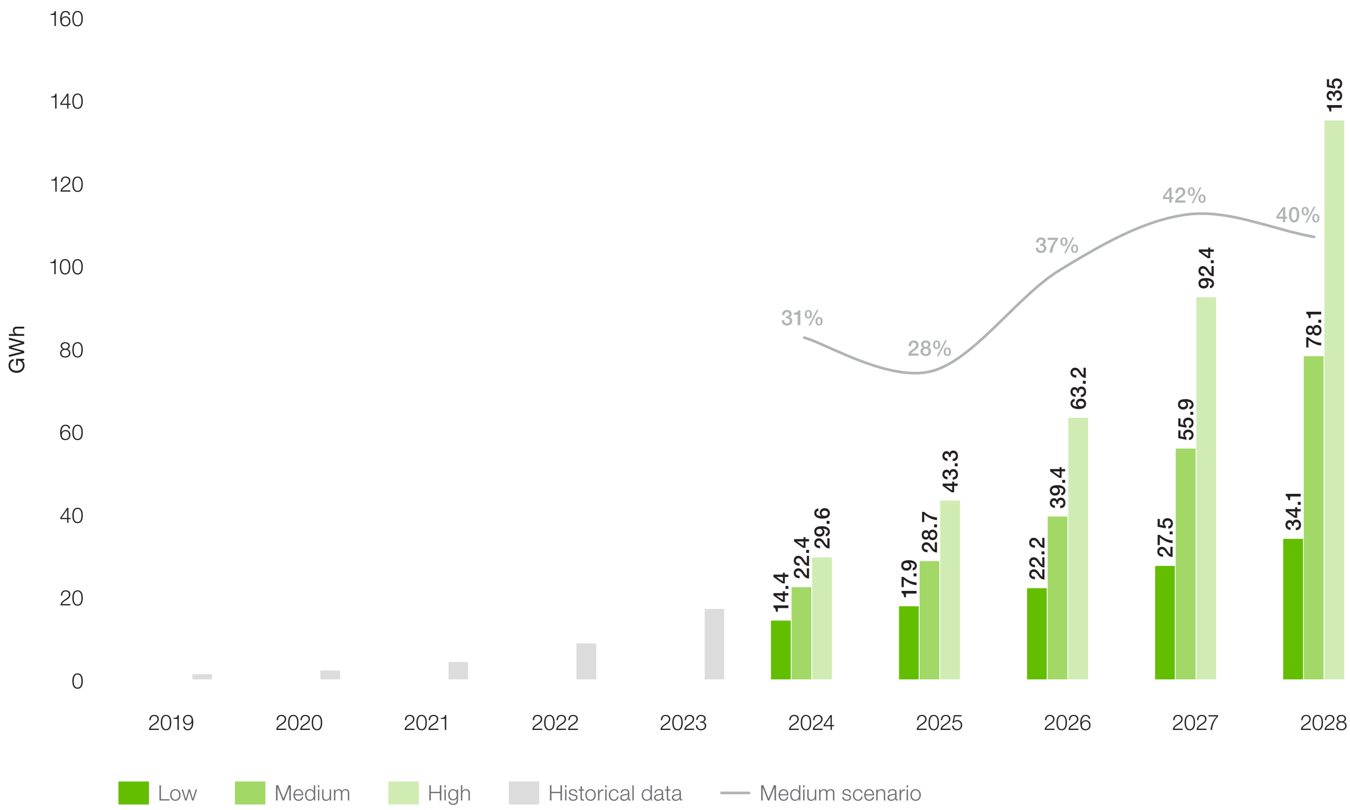
While lithium-ion batteries continue to power billions of personal devices worldwide, demand from the energy sector already makes up over 90% of their annual production, a significant increase from 50% in 2016, when the market was just one tenth its current size. With decreasing costs and enhanced performance, these batteries have become a cornerstone of modern economies, not only driving the continued offset of the environmental impact of personal electronic devices, but also boosting growth in the energy sector. To give some idea of the size of the market, nearly 45 million EVs—comprising cars, buses and trucks—were on the road in 2023, and over 85 GW of battery storage was operational in the global power sector.

This article aims to provide an overview of the latest advances in energy storage technologies, highlighting their rapid growth and increasing significance in the global power sector. It also explores how these developments are shaping the future of energy systems, particularly through the adoption of battery storage in various applications.

2 Rapid growth in battery storage: leading European markets and outlook

The year 2023 marked a significant breakthrough for battery storage systems in Europe, as their vital role in ensuring a secure and cost-effective clean energy transition was recognised. Batteries have now entered a new phase of their development, with the exponential growth curve beginning to steepen. During 2023, 17.2 GWh of storage capacity was installed, nearly doubling the market size (+94%) compared with 2022 and surpassing the 10 GWh mark for the first time. This was the third consecutive year that the European market doubled in size, following record growth in 2021 and 2022 of 94% and 102% respectively. The market size in 2023 was 115 times larger than a decade ago when only 150 MWh was installed.

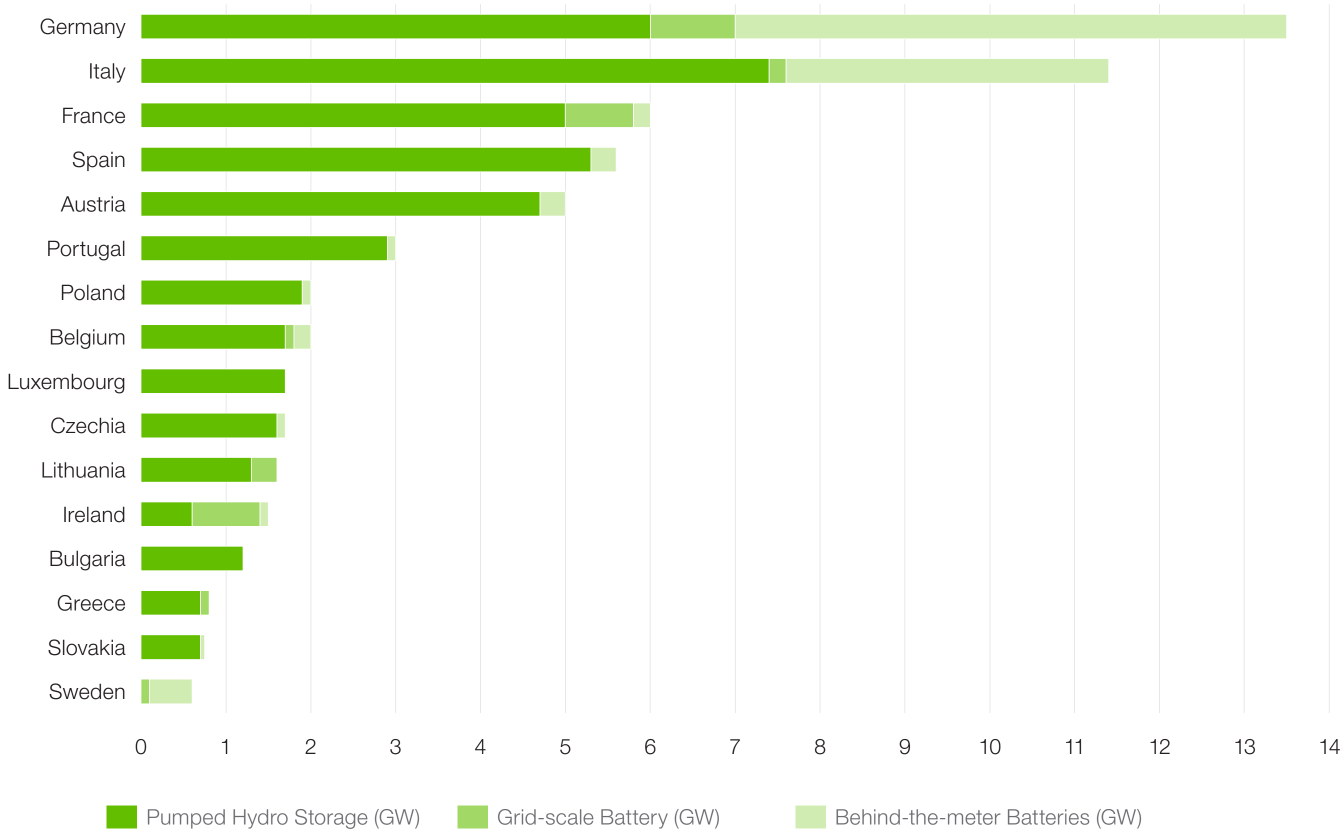
Figure 2 **Projected annual battery storage installations in Europe 2024–2028**



Source: IEA

In terms of new capacity, three countries emerged in 2023 as the most successful markets in the EU (see Fig. 3). Germany led the way by deploying a further 5.9 GWh (+152% versus 2022), followed by Italy, which connected a record 3.7 GWh to the grid (+86%) and Austria, which continued its strong growth trajectory adding over 1 GWh of battery storage capacity (+95%). Czechia is also worth noting for its remarkable surge: it tripled its annual market with over 900 MWh installed in 2023, driven by its robust residential sector. Elsewhere in Europe, we see the United Kingdom, which added 2.7 GWh to its network (+91% versus 2022).

Figure 3 **Storage is concentrated in a few EU countries 2023**



Source: Ember

3 The importance of energy storage

Energy storage boils down to the capture of energy produced for subsequent use, playing a vital role in maintaining a reliable and stable power supply. This is especially important to balance the intermittent nature of renewable energy sources like solar and wind, which only generate power when the sun shines or the wind blows. Indeed, energy storage systems are indispensable when managing supply and demand; they optimise the use of renewable energy and enhance grid stability.

Among the various storage technologies available, batteries have grown in importance due to their flexibility and reliability. By quickly addressing grid imbalances and providing essential ancillary services like frequency regulation and voltage support, batteries are key to advancing a more efficient and sustainable energy future.

Figure 4 **Battery location in the power system**

	Generation		Network		Consumption	
	Front-of-the-meter				Behind-the-meter	Mini-grids & off-grid systems
	Dispatchable	**Variable**	**Transmission**	**Distribution**	**Residential and C&I** [1]	**Access**
Ancillary services *(essential grid services)*	Black start	Renewables smoothing to correct forecast inaccuracy	Frequency regulation Inertia services Contigency reserve Ramping reserve Grid forming	Voltage support	Power quality Power recovery following outage Backup power	Grid support
Short-term flexibility & optimising use of existing assets	Wholesale arbitrage	Renewables integration via energy	Congestion relief		Increased self-consumption Fixed charge reduction Variable charge reduction	Enable first-time electricity access
System adequacy	Peak capacity	Renewables firming				
Infrastructure planning			Transmission upgrade deferral	Distribution upgrade deferral		

Source: Accuracy

Note

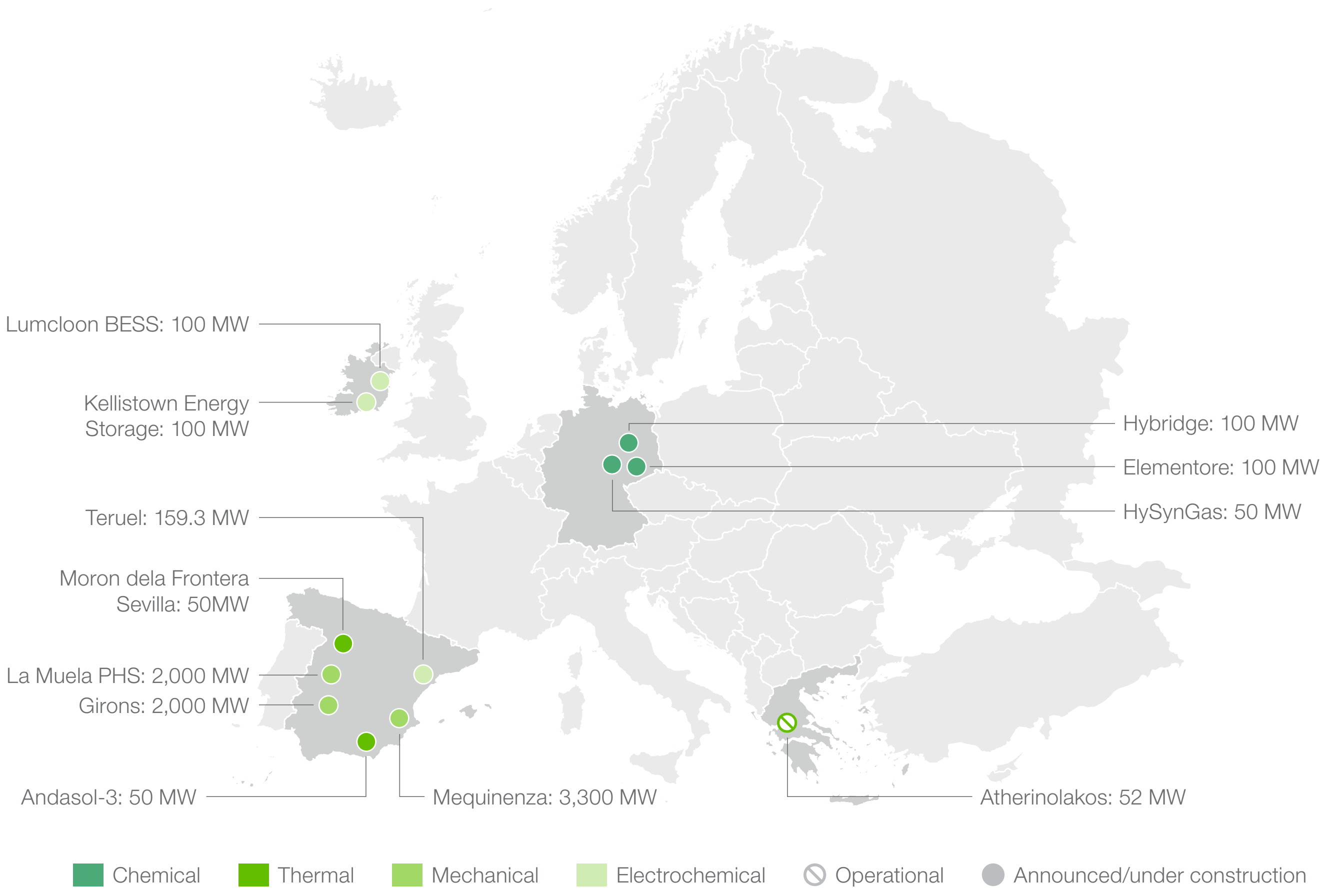
1) Commercial & Industrial users

Although the sector has grown significantly and seen much progress, innovation in energy storage remains essential to meet future energy demand and achieve sustainability goals. As the world transitions towards a low-carbon economy, reliance on renewable energy sources will continue to grow, making the need for efficient and cost-effective energy storage solutions more pressing than ever. Without innovation in energy storage, the potential for renewable energy to replace fossil fuels could be severely limited.

New solutions are required to address the current challenges in energy storage. Developing new battery chemistries that offer longer lifespans, higher energy densities and lower environmental impacts could revolutionise the industry. Additionally, breakthroughs in materials science, manufacturing processes and recycling techniques could help reduce costs and improve sustainability.

Alternative storage technologies are needed too. Solid-state batteries, flow batteries and hydrogen storage are all expected to offer better performance and fewer environmental concerns than current options. Innovation in energy storage is not just about improving existing technologies but also about finding entirely new ways to store and manage energy.

Figure 5 **Europe – The largest projects by technology type**



Source: ENTEC

5 Current challenges

Energy storage, particularly in the form of batteries, has become a critical component of modern energy systems, especially as renewable energy sources like solar and wind represent ever greater proportions of total energy generation. However, despite its importance, energy storage still faces various challenges that hinder its widespread adoption.

- *Energy density*
  Achieving high energy density is essential for storing large amounts of energy in a small space. Notwithstanding, this characteristic in current battery technologies is limited when compared with the energy required for applications like EVs and grid storage. This results in a situation where batteries must be larger and heavier—and charged more frequently—leading to lower efficiency and higher cost.

- *Cost*
  The cost of lithium-ion battery production is relatively high at €126 per kWh, particularly for the advanced technologies necessary for long-duration storage and high-capacity applications. High costs make energy storage less economically viable, a problem that is exacerbated in large-scale grid applications. By comparison, in some of the most efficient markets, the levelised cost of energy for solar power and offshore wind can be as low as €0.05 and €0.08 per kWh respectively.

- *Resource availability*
  Batteries rely on critical raw materials like lithium, cobalt and nickel. However, these elements are rare, and they are often sourced from geopolitically sensitive regions. Supply chain constraints and environmental concerns could thus limit the scalability and sustainability of current battery technologies.

- *Cycle life and degradation*
  Batteries degrade over time. This natural process reduces their capacity and efficiency, resulting in shorter battery lifespans, as well as greater waste and higher replacement costs. This is a limiting factor in the overall sustainability of battery systems.

- *Safety*
  Despite their use in everyday items, lithium-ion batteries can pose safety risks due to overheating. Safety concerns can limit the deployment of batteries for certain applications, particularly in densely populated or high-risk areas.

- *Environmental impact*
  The lifecycle of batteries, from mining to disposal, raises considerable environmental challenges, including a significant level of carbon emissions and toxic waste. Without improved recycling methods and the use of more sustainable materials, batteries could be considered more a hindrance than a help for environmental concerns.

- *Scalability for grid storage*
  Grid-scale energy storage requires batteries that can store and discharge large amounts of energy over long periods. Yet, current technologies struggle with the cost, scale and duration needed for such use. Inadequate grid storage can lead to inefficiencies in the system and limit the integration of renewable energy sources upstream.

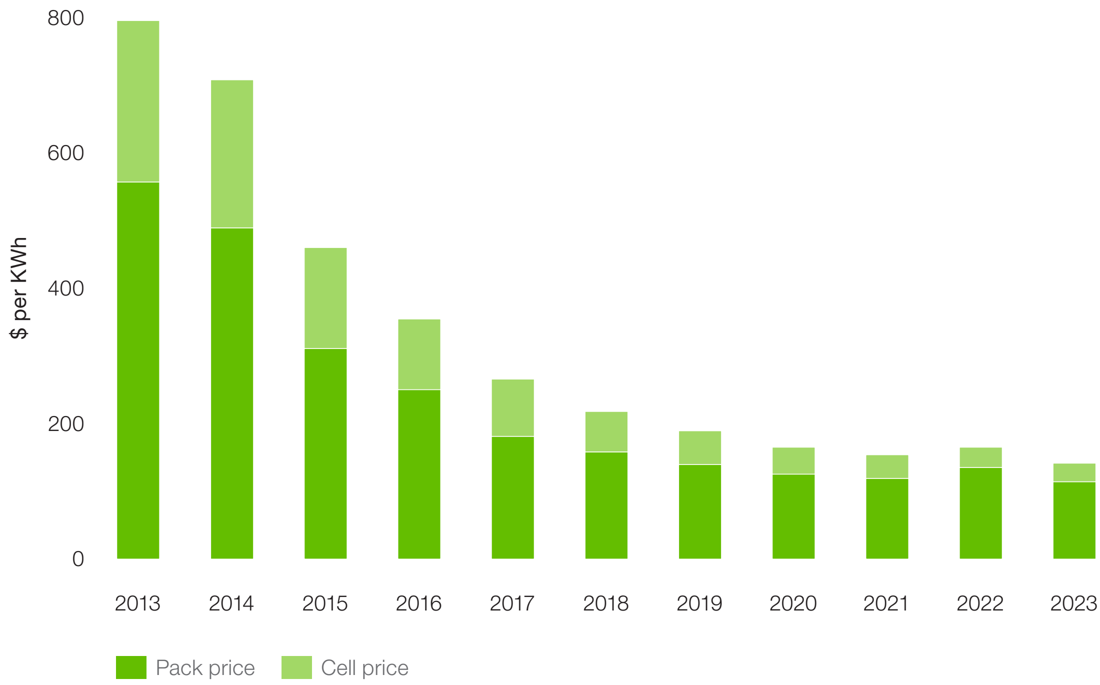
- *Technology diversification*
  There is a risk of relying too heavily on a single battery technology, like lithium-ion. Diversifying storage technologies to include solid-state batteries, flow batteries or alternative chemistries is important to avoid supply chain disruptions or technological limitations.

Energy storage technologies are rapidly advancing on several fronts. Lithium-ion batteries continue to improve in capacity, charging speed and longevity, while solid-state batteries promise significant safety and energy density improvements. Below is an overview of the latest advances and key developments in various energy storage technologies:

Lithium-ion batteries

- Researchers are developing new electrode materials, such as silicon anodes and high-nickel cathodes, that significantly increase energy density. Silicon anodes, for example, can hold up to 10 times more charge than traditional graphite anodes.
- Advances in electrolyte formulations and battery management systems have enabled faster charging speeds without compromising battery life. Some new designs allow for charging to 80% capacity in under 10 minutes.
- New additives in electrolytes, together with improvements in cell design, are reducing battery degradation and extending the cycle life. Technologies like “anode-free” designs are also being explored to increase lifespan.

Figure 6 **Lithium-Ion battery pack and cell prices 2013–2023**



Source: IEA

Solid-state batteries

- Solid-state batteries replace the flammable liquid electrolyte found in lithium-ion batteries with a solid electrolyte, significantly reducing the risk of fires and thermal runaway.
- The solid electrolyte allows for the use of lithium metal anodes, which have a much higher energy density compared with traditional anodes.
- Companies like QuantumScape and Toyota are making significant strides in this area, with prototypes that show promising energy density and cycle life. However, challenges remain in scalability and cost, as well as in addressing issues like dendrite formation, which can short-circuit the battery.

Cutting-edge technologies […]

Flow batteries

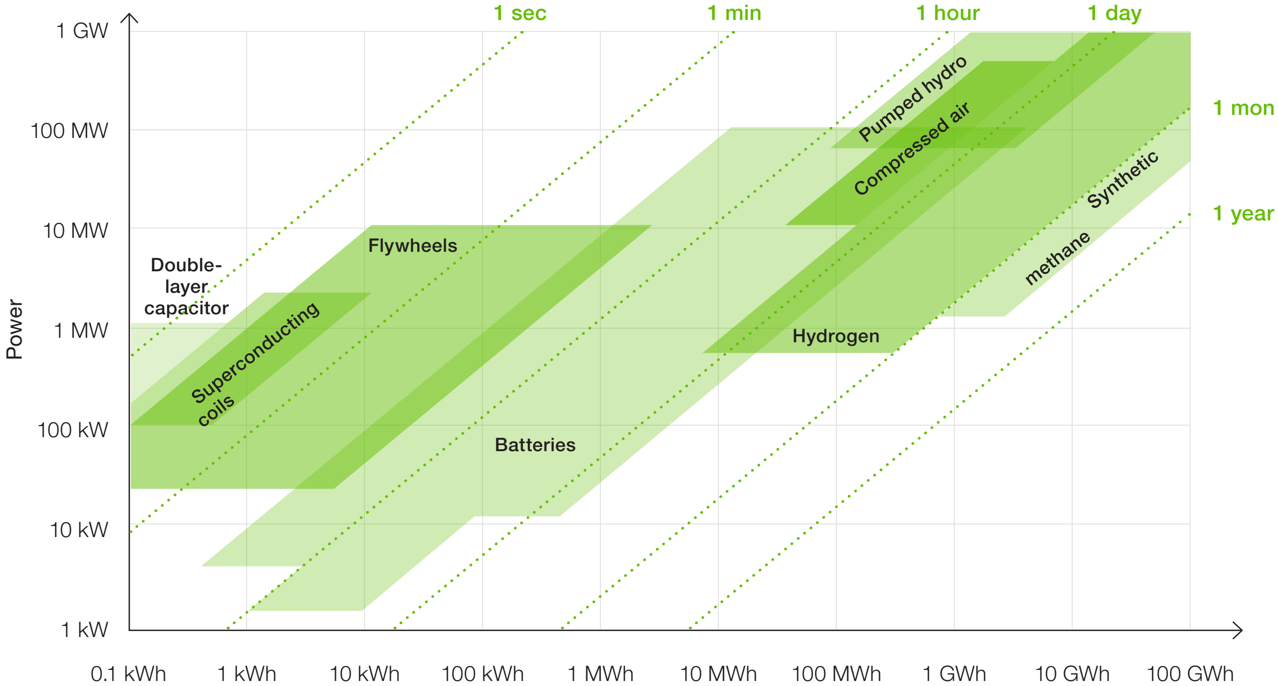
- Flow batteries store energy in liquid electrolytes contained in external tanks. During charging and discharging, the electrolytes are pumped through a cell stack where the chemical reactions occur.
- The capacity of flow batteries can be easily scaled by increasing the size of the tanks, making them ideal for large-scale grid storage. Flow batteries have a long cycle life, often exceeding 10,000 cycles, with minimal degradation. They are particularly suitable for applications that require long-duration energy storage, for example, stabilising renewable energy sources.
- Vanadium flow batteries are the most mature, but research into alternative chemistries like zinc-bromine and iron-chromium is ongoing to reduce costs and improve performance.

Supercapacitors

- Supercapacitors can charge and discharge much faster than batteries due to their physical storage mechanism, making them ideal for applications requiring quick bursts of energy.
- They can deliver high power over short periods, which is particularly useful for applications like regenerative braking in EVs and quick response power grids. Supercapacitors are being used in combination with batteries to provide hybrid systems that benefit from both the high energy density of batteries and the high power density of supercapacitors.
- Advances in materials, like graphene and carbon nanotubes, are increasing the energy density of supercapacitors, narrowing the gap with batteries.

Different energy storage technologies offer varying power and energy ranges to meet diverse needs across the energy sector. For instance, pumped hydro storage, one of the most established methods to date, typically provides high energy capacity with power outputs ranging from megawatts to gigawatts. This makes it suitable for large-scale, long-duration storage. By contrast, lithium-ion batteries, known for their fast response times and high energy density, generally offer power outputs from a few kilowatts to megawatts, with energy capacities suitable for both grid applications and EVs. Flywheels deliver high power with short-duration energy storage, making them ideal for applications requiring rapid energy release and quick frequency regulation. Supercapacitors, with their ability to deliver bursts of power over short periods, are well-suited for applications needing rapid charge and discharge cycles. Each technology's power and energy capabilities align with specific operational requirements, making it essential to choose the right solution based on the application's duration, response time and scale.

Figure 7 **Power and energy ranges of different storage technologies**



Source: Accuracy

Recent developments in The Netherlands

The Netherlands is steadily incorporating more renewable energy sources into its grid. The Dutch government's *Hoofdlijnenakkoord* underlines the critical role of battery storage in the national energy transition, highlighting its importance to achieve energy independence and enhance grid stability. This comes as, in its latest plans unveiled on 13 September, the Dutch government announced it will continue to invest in and stimulate the development of battery energy storage solutions, albeit reducing the overall size of its investment.

Many initiatives are being put in place to boost the development of energy storage technologies in the country. Initiatives like the time-limited contracts introduced by TenneT, the national grid operator, effectively manage grid congestion, an increasingly important factor as the country moves towards a more sustainable energy model. Additionally, projects like GIGA Leopard and Mufasa highlight the practical steps being taken to enhance energy storage capabilities. These efforts are part of a broader strategy to improve energy efficiency and stability without drastically overhauling existing systems, reflecting a pragmatic approach to energy innovation.

GIGA STORAGE

GIGA Storage and TenneT have signed the Netherlands' first time-limited contract, marking a significant milestone in the more efficient use of the existing electricity grid. This groundbreaking agreement allows GIGA Storage to draw electricity from the grid or feed it back for at least 85% of the time.

This new type of contract, created under the National Action Programme for Grid Congestion, enables GIGA Storage to connect its battery project, GIGA Leopard—with a capacity of 300 MW and a storage capacity of up to 1,200 MWh—to the electricity grid. It will be the first time that energy storage will be realised at an industrial scale in the country. This innovative contract promotes more efficient use of the limited grid space, a need that is growing due to congestion that prevents connections with full and fixed transmission rights. Moreover, it offers customers a discount of up to 65% on transmission tariffs.

To supplement the existing firm transmission law, the Netherlands Authority for Consumers and Markets approved time-based and time-block contracts in July 2024. Time-based contracts allow large consumers to connect to the electricity grid with guaranteed availability for at least 85% of the time. These contracts apply exclusively to TenneT's large business customers, which benefit from reduced transmission tariffs, and potentially free up capacity for others on the waiting list. These new contract types are especially appealing to companies without round-the-clock operations and are offered by grid operators as an alternative to fixed transmission rights.

RWE

The German energy company RWE is launching its first battery storage project in the Netherlands. The company will invest €25 million in a 35 MW / 41 MWh battery energy storage system (BESS) at its Eemshaven biomass plant. Construction is set to begin by the end of the year, with commissioning expected in early 2025.

RWE stated that the BESS is one of several "innovative demand assets" aimed at integrating the OranjeWind offshore wind farm's intermittent power into the Dutch energy grid. The company also plans to incorporate green hydrogen production as part of this effort.

LION STORAGE

The Dutch developer Lion Storage has secured a building permit for a battery energy storage project located in the Vlissingen port, in the southwestern Netherlands. After introducing the project earlier this year, Lion Storage announced in June that its flagship BESS project, Mufasa, had reached the significant milestone, with its building permit now granted irrevocably.

With a power output of 364 MW and a capacity of 1,457 MWh, Mufasa is set to become the largest utility-scale BESS in the Netherlands. Strategically located on the North Sea at one of the country's emerging energy hubs, the project will have direct access to TenneT's high-voltage grid and proximity to several large-scale hydrogen electrolysis and offshore wind projects currently under development. Commercial operations are expected to begin in 2026.

8 Policy and incentives

European and Dutch policies and incentives are vital to support the development and adoption of innovative energy storage solutions. The EU's comprehensive approach includes regulatory support, funding and strategic initiatives like the Green Deal and Horizon Europe. The Green Deal aims to make Europe the first climate-neutral continent by 2050, driving substantial investment in clean technologies, renewable energy and large-scale infrastructure projects. The Horizon Europe programme supports this vision by funding research and innovation to develop advanced energy storage solutions, facilitating a sustainable transition and reinforcing Europe's technological leadership in new and emerging technologies.

The Netherlands is advancing towards a sustainable energy model through targeted actions (e.g. subsidies, research initiatives and regulatory reforms). These measures are key to managing the integration of variable renewable energy sources like solar and wind, which can strain the grid without effective energy storage solutions. Financial and regulatory incentives aim to boost private investment in energy storage, which will be essential to meet climate goals and ensure a reliable energy system, in line with EU strategies for energy independence and sustainability.

However, the country faces significant challenges in scaling up energy storage. Current capacity is just 150–200 MW, far short of the estimated 9 GW needed by 2030, according to TenneT. Barriers include high initial costs, complex project evaluations and a lack of supportive financing and regulatory frameworks. Dutch battery operators also face high grid transportation costs, which can account for over 80% of operating expenses, making subsidies or cost reductions vital to competitiveness.

Further, standards and regulations on safety, recycling and cybersecurity for battery systems must be updated. Robust standards will improve the efficiency and safety of storage solutions, boosting public and investor confidence in the sector's sustainability.

9 Conclusion

The Netherlands faces significant challenges in scaling up energy storage, including high initial costs, complex regulatory frameworks and insufficient financial support, and these all hinder its rapid development. Current storage capacity falls far short of the projected need for 2030, underlining the urgency for action. The specifics of the government's "Schoof 1" plans, expected to be released in the coming weeks, will be instrumental in addressing these barriers and shaping the future of energy storage in the country.

Looking ahead, the future of battery storage appears promising as its expansion accelerates, fuelled by the ongoing energy transition: the continuous rise of renewables is closely connected with the deployment of clean flexible sources like batteries, and the electrification of the transportation network and heating, together with grid modernisation, will also depend on battery storage. Technological advances are expected, with significant cost reductions likely to boost the deployment of battery energy storage systems. In this context, policy and regulatory efforts should focus on establishing a robust and stable framework for batteries.

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