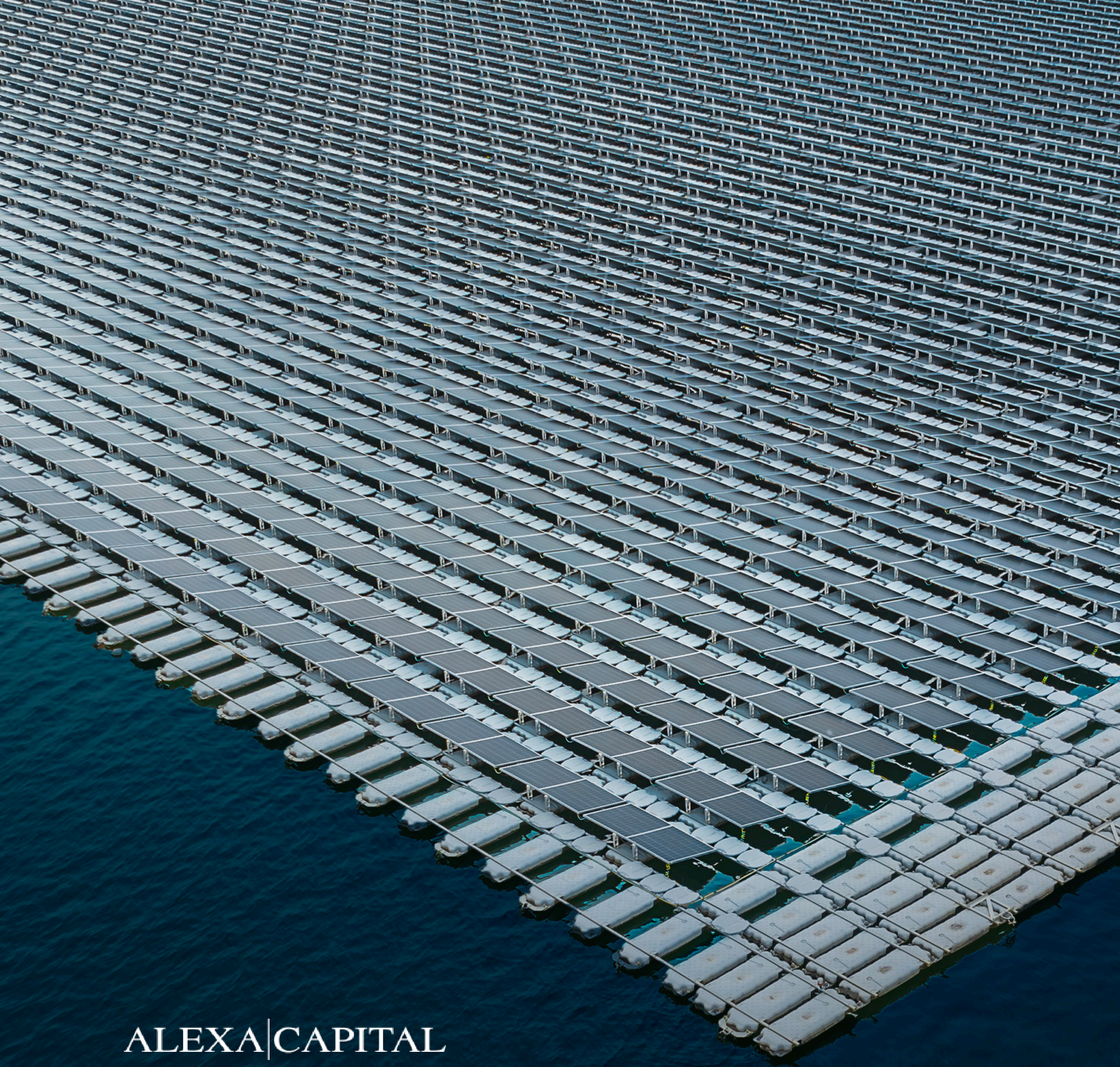

ALEXA|CAPITAL

Investing in the Energy Storage Revolution

May 2024

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Foreword

As the world embarks on a transformative journey towards a new era in energy and mobility, the spotlight increasingly falls on energy storage technology as the key enabler of this revolution. Central to this transformation are lithium-ion (Li-Ion) batteries, which, with their Swiss Army knife-like versatility, offer an array of applications that extend far beyond their current use. Their capacity to store and discharge energy on demand is not just reshaping our energy systems but is also setting the stage for a radical shift in transportation paradigms. In short, batteries are a key building block for our increasingly digital, distributed and decarbonised economy.

Today batteries power a wide spectrum of devices and vehicles and are crucial for integrating renewable energy sources into our power grids, acting as buffers to balance fluctuating supply and demand. Their high energy density, longevity and efficiency underscores their significance as a transformative technology in a sustainable and interconnected energy future.

Batteries are a key building block for our increasingly digital, distributed and decarbonised economy

This pivotal role of energy storage, particularly the range of lithium-ion technologies, underscores a burgeoning investment opportunity impacting the power and transport sectors. Demand for batteries is projected to surge exponentially, driven by forces including the electric vehicle (EV) boom, the growing penetration of renewable energy and rising benefits for power grid and behind-the-meter storage applications.

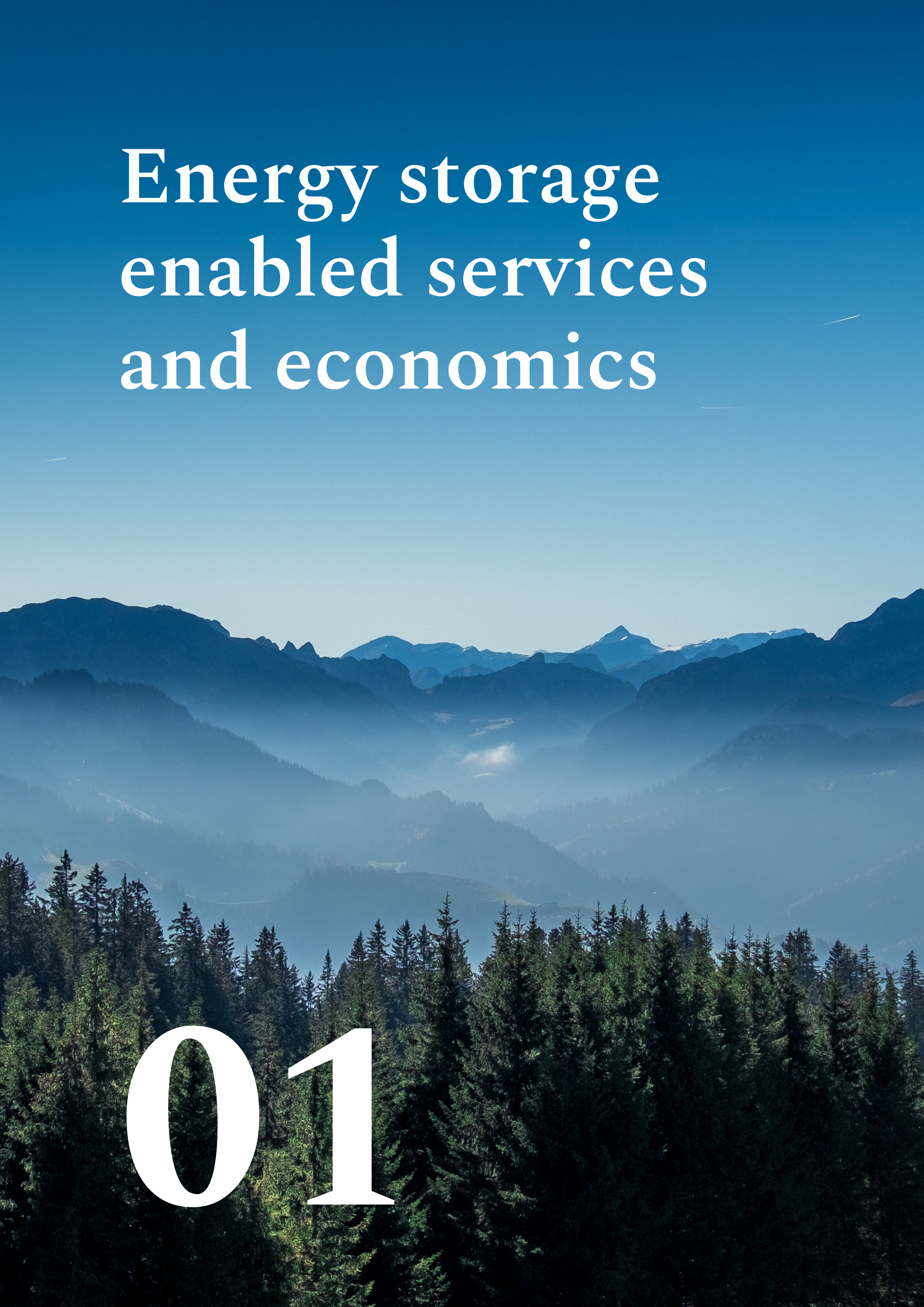
The battery revolution offers fertile ground for investment avenues from raw materials and manufacturing through technology innovation and recycling to enabling digital infrastructure and energy services solutions. The sector promises financial returns and the opportunity to contribute to the broader industrial decarbonisation.

Moreover, as countries amplify efforts to mitigate climate change, policy shifts and regulatory incentives are expected to further boost the energy storage sector. This support, combined with cost reductions and advances in battery technology performance, enhances the investment appeal of the storage sector.

Energy storage is increasingly attracting not just technology and supply chain funding but also infrastructure investment to capture the opportunity around rising power price volatility associated with decarbonising our power systems - which require more intermittent renewable generation (solar, wind, etc). Our power system is also integrating growing demand, and is more exposed to day-to-day, hour-to-hour and minute-to-minute fluctuations associated with changeable weather patterns (impacting solar irradiation, such as cloud formation and wind), unscheduled outages of grid infrastructure and aged conventional power plants, not to mention geopolitical impacts of fossil fuel input prices. Energy storage is emerging as an asset class ‘hedge’ against the volatility resulting from decarbonising our power systems.

However, investors must consider factors such as technological disruption, supply chain constraints and ethical considerations around raw material extraction. These are also balanced by a rapidly developing array of new energy storage-enabled services across global and regional markets.

Our report is designed to facilitate an enhanced understanding of the storage industry, as well as the investment options available to gain market exposure.



Energy storage enabled services and economics

01

What are today's main applications for energy storage?

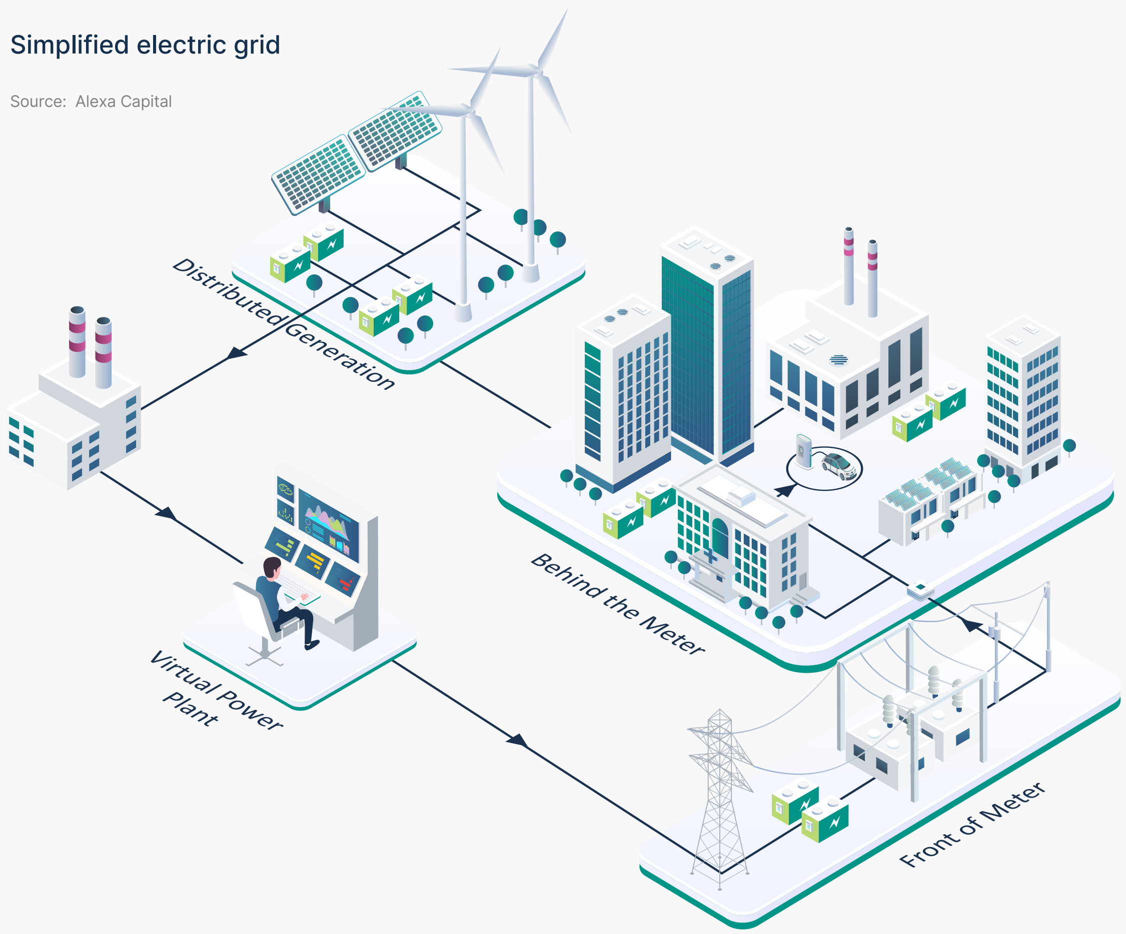
Enabling a new generation of energy services

Storage is revolutionising energy systems, particularly as the adoption of renewable energy accelerates. In regions such as the UK, Portugal, Germany, California, and Texas, where renewable generation rates are high, grid operators face a challenge in managing intermittency. To address this, transmission system operators (TSOs) are encouraging third-party development of storage.

The simplified grid below illustrates the array of connection points for storage, which are discussed in more detail on the following pages.

Simplified electric grid

Source: Alexa Capital



Front-of-meter utility-scale storage applications

As regional energy systems decarbonise through development of renewable energy (especially wind and solar), grid operators are under pressure to manage the intermittency associated with distributed generation. Advanced economies are achieving high rates of renewable generation, especially in Portugal (78%), Germany (57%), Spain (52%), the UK (45%), Ireland (37%), Italy (44%), Australia (32%), California (76%) and Texas (26%) in the US.

Balancing power from intermittent renewable generation when there is excess power, or a shortage of power, creates massive opportunities for large-scale energy storage projects, including when wholesale power prices are negative or when neither wind nor solar irradiation is prevalent. Grid system operators such as ERCOT in Texas, CAISO in California, National Grid in the UK, EirGrid in Ireland, Terna in Italy and TenneT, 50Hertz Transmission, Amprion and TransnetBW in Germany have set ambitious targets for 3rd party development of storage – in recognition of the need for storage to balance the grid.

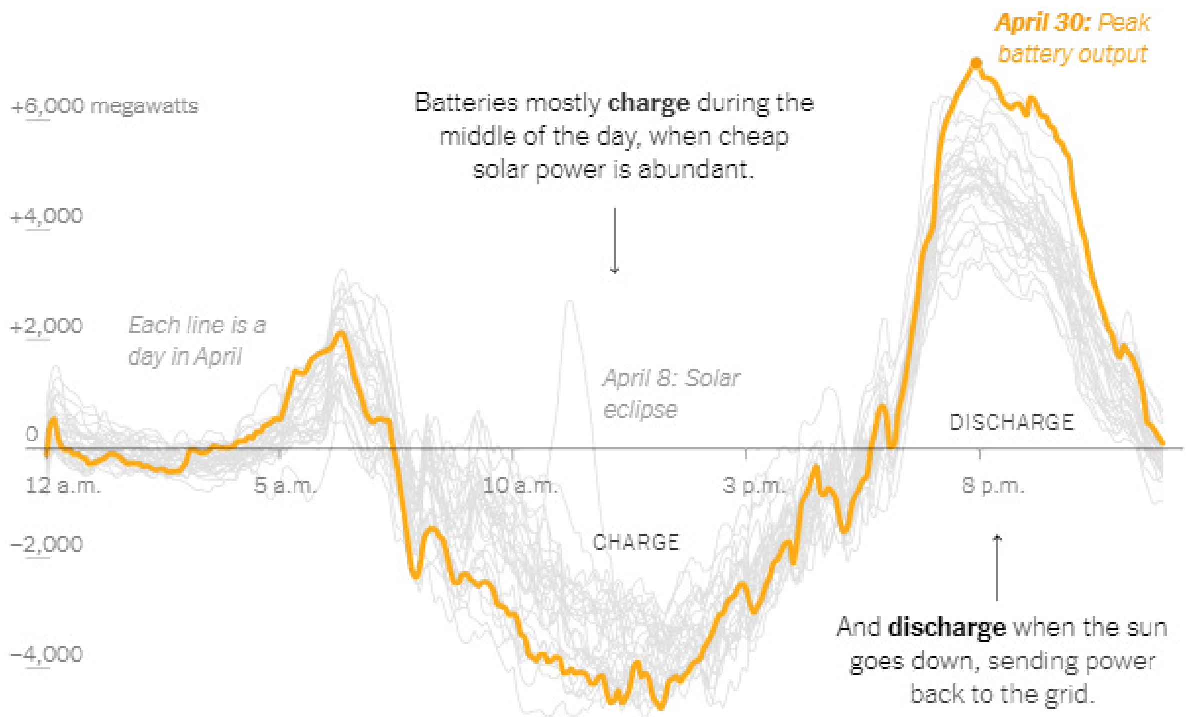
Currently 40 gigawatts (GW) of battery storage capacity is operational for these regions. UK (3.5 GW) and California (11.2 GW) have been early adopter markets, with substantial growth coming through in regions including Texas (4.4 GW), Italy (3.0 GW), Germany (7.1 GW), Iberia (0.4 GW), and Australia (3.1 GW).[1]

Each market has commenced with grid frequency and other ancillary services and moved to providing balancing through arbitrage and peak shifting of renewable generation, leveraging wholesale power markets.

Early mover storage platform groups include:

- **Listed entities** such as Fluence, Gore Street Energy Storage Fund (GSF), Gresham House Energy Storage Fund (GRID), Harmony Energy Investment Trust (HEIT) and Tesla (TSLA).
- **Power utilities** such as Duke Energy (DUK), EDF Energy (EDF), NextEra Energy (NEE) and SSE plc (SSE).
- **Private equity-backed platforms** including Alcemi, Banks Renewables, Cambridge Power, Cypress Creek Renewables, Eel Power, Eku Energy, esVolta, Exagen, LS Power, Penso Power/BW Group, Pulse Clean Energy, Quinbrook, Renewable Power Company and Zenobe.

California Example: How batteries operated on the grid in April 2024



Sources: California Independent System Operator visa Grid Status By The New York Times

Front-of-meter co-located storage applications

Large independent power producers (IPPs) are integrating energy storage into their renewable platforms to reduce curtailment, where the grid operator declines to take power due to grid imbalance issues and/or negative prices. This phenomenon is occurring more frequently in regions such as the north of the UK (around Scottish wind resource), Spain (photovoltaic aka PV solar) and Germany (around solar PV in the south and wind in the north). In a post-subsidy environment, with many government incentives falling away after years of operation, IPPs are increasingly focused on securing better prices for their generated power. Co-location with energy storage enables exports of power into the grid at times when generation achieves higher prices.

Examples of larger co-located installations include Quinbrook's Nevada Gemini project, with 1.4 GWh storage co-located with 690 MW solar and Terra-Gen's 3.3 GWh storage co-located with 875 MW solar in California.

Behind-the-meter residential storage applications

As customers struggle with inflation and high electricity prices, especially in regions such as Continental Europe, Australia, UK and California, there is increased demand for behind-the-meter PV plus energy storage. Power utility and energy services platforms allow customers to reduce their reliance on grid-supplied electricity. Each higher-priced electricity region has seen the emergence of market platforms focused on delivering PV and storage services, often augmented with EV charging.

These companies strive to simplify the sale and installation of rooftop solar, giving customers hardware, installation, maintenance, financing and energy supply. Regional regulatory development is supporting innovative energy service businesses addressing these markets. Tesla's Solar City (TSLA), Sunrun (RUN), Enpal, Octopus Energy and Sonnen are amongst regional leaders in these markets.

Behind-the-meter commercial and industrial storage

Commercial and industrial groups have long sought energy resiliency to support their operations. Power price inflation and volatility has impacted many businesses around the world, especially in regions including Continental Europe, the UK, and Japan. Data centres are concerned about resiliency levels, as many provide disaster backup and recovery support, not to mention the real-time processing needs for trading, e-commerce and artificial intelligence (AI). Corporates focus increasingly on low-carbon resiliency beyond diesel backup generation, with investment into solar PV and battery storage.

The digitalisation of the economy comes with electric costs of $35 billion or more a year [2]. To reduce costs and stress on the grid, some data centres are using microgrids based on batteries and solar to self-generate the electricity they need. Heavy digital consumers such as Microsoft (MSFT), Google (GOOGL), and Amazon (AMZN) employ these strategies for their data centres. Eaton (ETN) and Emerson (EMR) are at the forefront of microgrid engineering, designs, and installations.

The municipal, university, schools and hospitals sector is also an important consumer, served by companies such as Ameresco (AMRC), Engie (ENGI), Resalta and Noresco.

To reduce costs and stress on the grid, many corporates are using microgrids based on batteries and solar to self-generate the electricity they need

Behind-the-meter EV charging storage

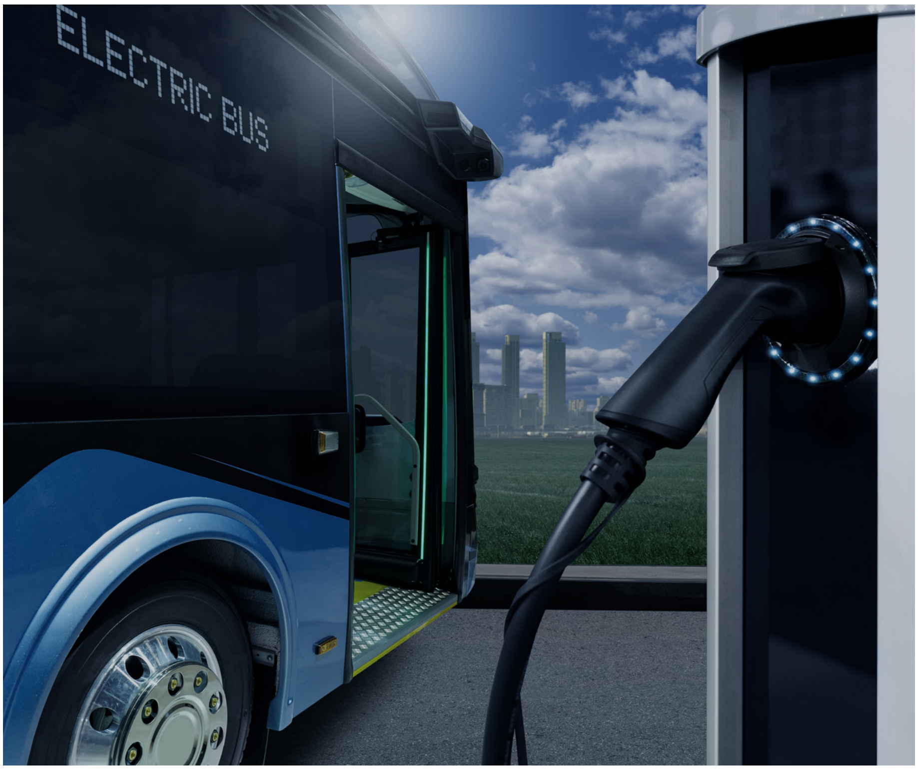
EV sales reached 13.7 million units globally in 2023[3], with global public charging infrastructure reaching an estimated 4 million connectors. Markets such as Norway have reached tipping points where charging infrastructure is beginning to put stress on electricity grids, with additional pressure expected as global EV sales are projected to surpass 30 million units by 2025[4].

To remediate grid weakness and support customer requirements for charging, groups such as Allego (ALLG), Blink Charging (BLNK), Chargepoint (CHPT), EVgo (EVGO), Gridserve and Zenobe are sourcing, installing and financing energy storage alongside EV charging infrastructure.

Behind-the-meter marine and heavy transport storage

The marine and heavy transport industries generate more carbon than any other transport sector. The marine industry is making substantial moves toward decarbonisation, addressing regulatory demands and port requirements to meet carbon reduction targets. Major ports including Rotterdam, Southampton, Hamburg, Antwerp and Gothenburg are putting pressure on shipping to implement last-mile electrification systems. An emerging set of suppliers provides hybrid battery, conventional power and fuel cell systems for this sector.

Groups including Wartsila (WRT1V), Siemens (SIE) and ABB are prime suppliers, with specialist battery solution groups including Leclanche (LECN), Fortescue Future Industries (FMG) and Corvus Energy. Furthermore, there are companies like Ballard Power Systems (TSE: BLDP) and PowerCell Sweden (STO: PCELL) that develop and produce fuel cells stacks for the heavy transport industry. Altogether, these solutions are finding their way into other heavy transport applications, including rail and industrial vehicles.



Virtual power plants

Located in front or behind the meter, virtual power plants (VPPs) use software to aggregate distributed energy resources (DER) such as stationary storage, EV batteries, rooftop solar, and heat pumps into a single system. These aggregated portfolios then participate in power markets that were traditionally accessible only by front-of-meter participants. VPPs also enhance grid reliability and remunerate customers.

During the California 2022 heat wave, VPPs were called on to supply a peak in demand over a nine-day period. US-based OhmConnect's VPP generated $2.7 million for its customers and generally saves them between $250 and $300 per year.[5] New York has a Connected Solutions programme that compensates customers for registering their smart devices.[6] UK-based Flexitricity aggregates nearly 1 GW per annum of commercial and industrial flexible demand, including behind-the-meter batteries, into ancillary services markets. Irish-based GridBeyond is aggregating flexibility for commercial and industrial customers in Ireland, the UK, Japan, the US, and Australia, including c.500MW battery storage. In addition, Volue (OSL:VOLUE) and Origami are building services and ecosystem of partnerships that integrate resources within energy system at scale.

The integration of distributed resources enables granular understanding of demand to better forecast generation and consumption.

Understanding storage services by customer segment

Rocky Mountain Institute (RMI) has identified 13 battery services (defined in Appendix III) which can be grouped into system operator services to balance the grid, utility services to defer infrastructure investments, or customer services to reduce the cost of electricity.

System operator services

Batteries on the grid enhance performance flexibility to better meet fluctuations in demand. They can participate in capacity, wholesale and ancillary services markets. The technology has a competitive edge due to quick response times, which often leads to a range of revenue opportunities around ancillary and balancing mechanism services.

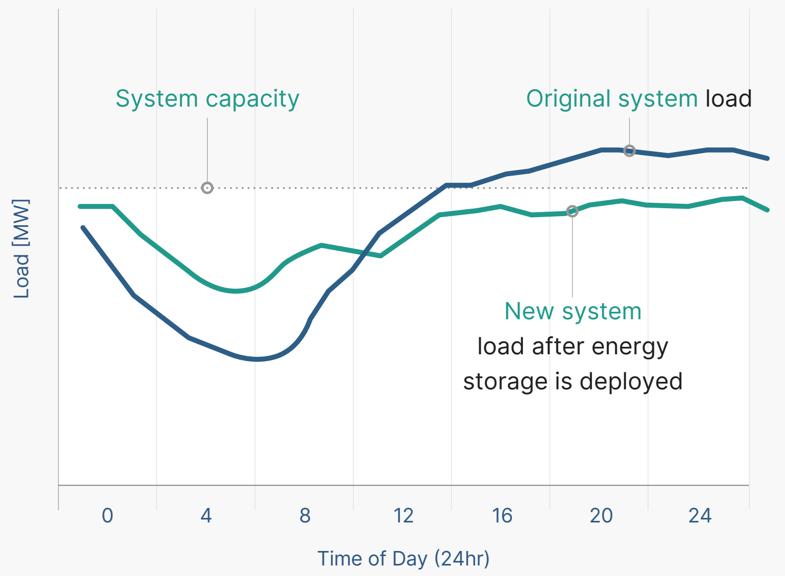
Utility services

Batteries can defer the need for grid infrastructure investment by storing excess generated energy near points of consumption to meet spikes in demand. This avoids oversizing the system to meet outlier periods in electric demand and optimising use of existing grid transmission and distribution infrastructure.

Customer services

Residential storage reduces reliance on the grid by storing solar electricity during the day to be used in the evening when solar generation is no longer possible. Distributed energy resources such as rooftop solar can be aggregated into virtual power plants to participate in power markets and support broader system resiliency.

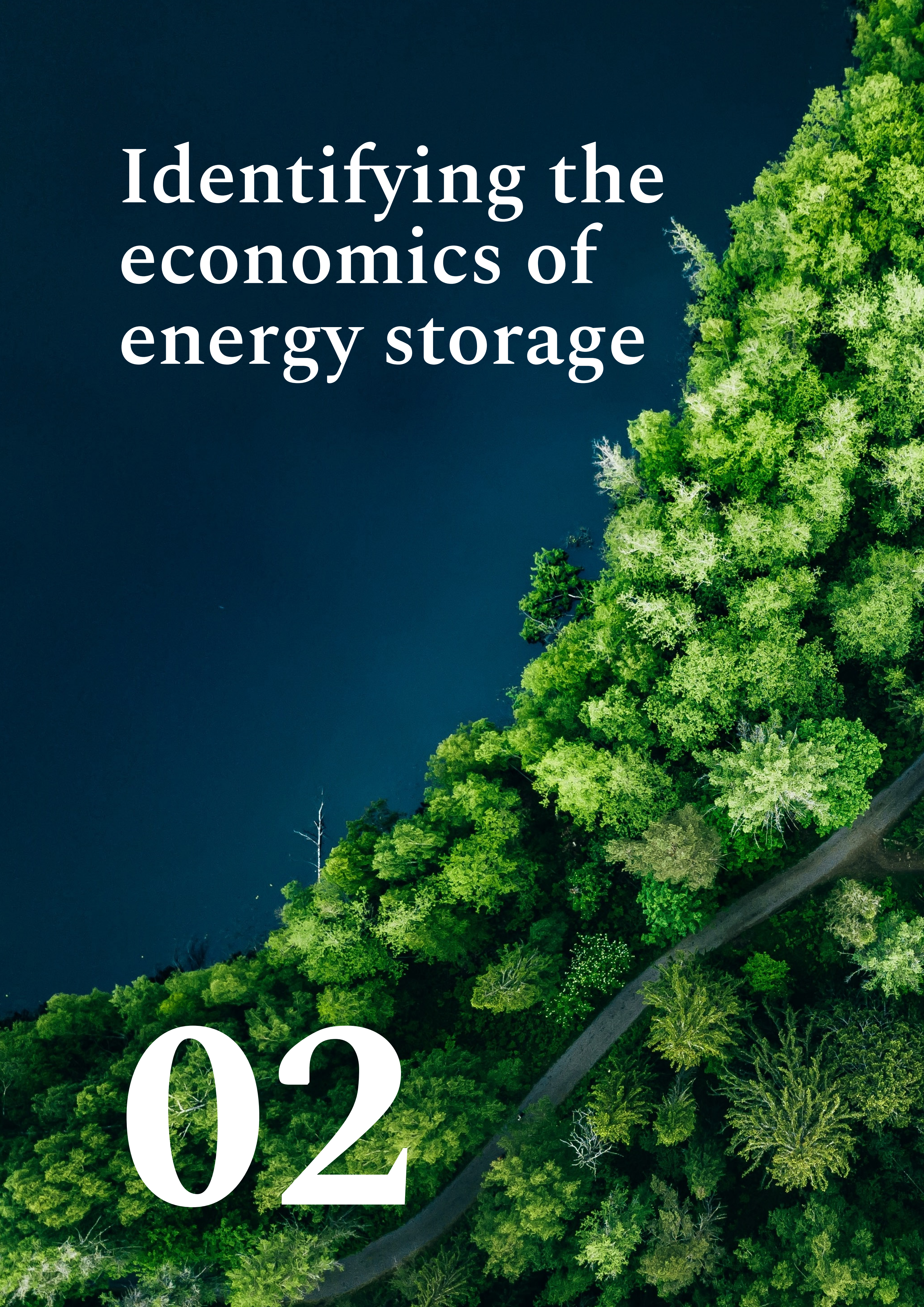
System upgrade deferral



Grid system upgrade deferral

Source: Advancing Contracting in Energy Storage and Alexa Capital

Identifying the economics of energy storage



02

Front-of-the-meter: market overview

This section delves into the evolving landscape of front-of-the-meter (FTM) storage and its impact on power markets.

Our analysis begins with an overview of the revenue opportunities inherent in front-of-meter storage systems, highlighting the dependency on market access and regulatory frameworks. We delve into specific market dynamics, examining liberalised markets versus vertically integrated ones and the revenue potential associated with capacity markets, wholesale markets, and ancillary services.

Additionally, we explore the role of renewable energy integration as a key driver of front-of-meter storage revenues, shedding light on evolving market landscapes in regions such as the United Kingdom and the USA.

Throughout the following pages, we review:

- Revenue Opportunities: An analysis of the multiple revenue streams available for FTM storage and their dependence on market access and regulatory frameworks.
- Market Access and Integration: Insights into the challenges and opportunities associated with integrating FTM storage into different power markets, including examples from advanced markets like the UK, California, and Texas.
- Value Stacking: Examination of value stacking strategies for FTM storage, including the combination of ancillary services, capacity market payments, and power market arbitrage.
- Case Studies: Case studies from the UK and Texas, highlighting the revenue breakdown and market dynamics shaping FTM storage in these regions.

Revenue opportunities for front-of-meter storage are multiple, including wholesale trading (intraday, day ahead etc), ancillary markets and capacity payments, to name a few

Front-of-meter: revenue value-stacking

The revenue opportunities for front-of-meter storage are multiple, with monetisation dependent on market access. Governments and system operators are busy tackling these challenges, which include but are not limited to grid connections and fee structures, formalisation of new markets and participation in existing ones that preclude storage participation.

In liberalised markets, batteries can be monetised via capacity, wholesale, intraday, or ancillary markets, if regulation allows. Furthermore, power arbitrage opportunities exist where battery storage can capture the daily spread in power prices by opportunistically charging and discharging. In markets operated by a vertically integrated entity, storage can engage in bilateral contracts with the utility or directly with consumers. An overview of European and United States power markets is available in Appendix I.

Power markets are in various stages of development, with some more open to battery storage than others. Advanced markets include the UK, California, Texas and Australia. Renewable integration is a key driver, with more and more regional power markets embracing energy storage integration.

The UK is a prime example of the system operator reforming markets for storage, formalising existing opportunities while establishing new ones. For example, the ancillary services Enduring Auction Capability launched in November 2023 depressed prices by 44% in a month due to greater price transparency and competition.[7] The outsized returns from ancillary services were partially compensated by capacity market contracts; 94% of UK battery plants had a capacity contract in 2023.[8]

Batteries can generate multiple revenue streams, yet most systems are dispatched to provide one primary service, leaving the battery unused between 50% to 95% of its useful life.[9] Increasing battery utilisation creates new revenues, impacting project profitability. At the same time, it is critical to match increased revenue generation against damage to the lifetime of a battery.

Optimisation of the revenue value stack is highly reliant on experienced traders and algorithmic software optimisation to capture power market peaks and troughs and monetise the spread. Limitations to value stacking services can include:

- Geographic rules that preclude battery participation in some power markets.
- Contractual limitations precluding other services during a system's idle time.
- Technical limitations that impact the ability to provide a service; this will also change over time as the battery degrades with use.
- Operational limits since a battery can only discharge for one application at a time. It can also not simultaneously charge and discharge.

Value stacking often combines ancillary services, capacity market payments and power market arbitrage revenues. For example, batteries can discharge on one day when prices are high, buy a future to charge the unit at a lower price on the next day and still meet a capacity market contractual dispatch.

Batteries can generate multiple revenue streams, yet most are dispatched for one service at a time, leaving 50-95% unused capacity, which creates opportunities for future revenues and profitability

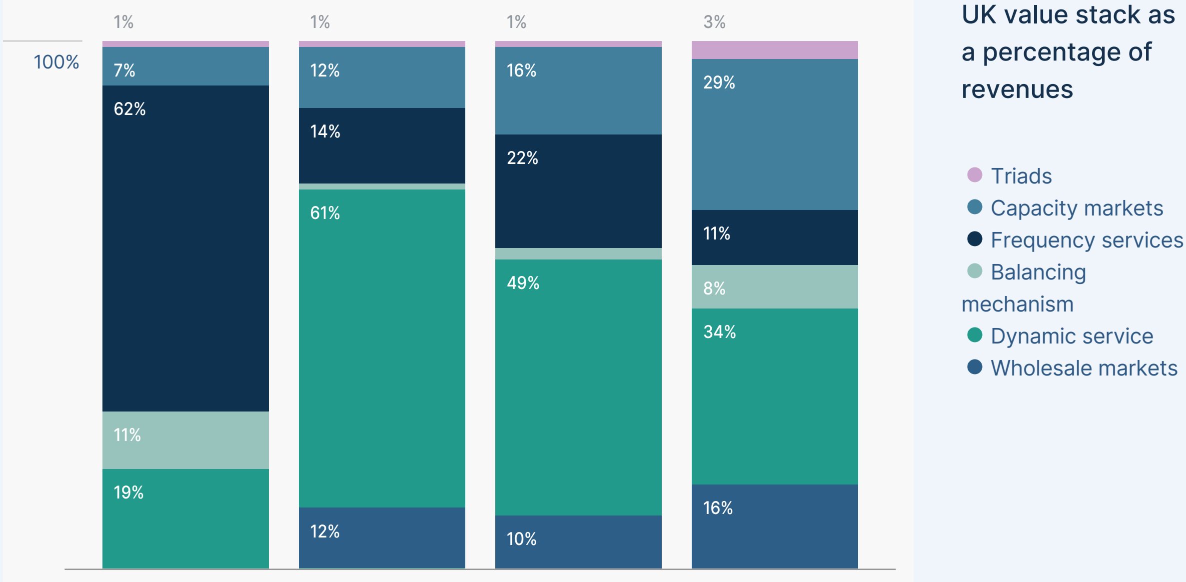
Case study

United Kingdom

A revenue breakdown from Modo Energy's registered assets in the British power market illustrates the revenue stacks that can be used to optimise performance with changes in market conditions.

The impact of regulation is most evident in frequency response (an ancillary service), which historically has been the quickest route to market for utility-scale battery storage. The market for frequency services has increased by an average 32% a year since 2020, despite cannibalisation of firm frequency by dynamic services, also ancillary. Similarly, the November 2023 launch of the Enduring Auction Capability created a more efficient way for participants to supply services, increasing competition and driving down the price (and revenues). In response, battery operators diversified the revenue stack with greater exposure to balancing mechanism and capacity market revenues. In 2024, National Grid relaunched bulk dispatch to aggregate multiple storage assets for use in the balancing mechanism, where the grid is balanced in real time. Dispatch volumes increased 47% in the eight weeks since the relaunch.[10]

Depending on the operating environment, optimisation will result in different revenue stacks. For example, wholesale market power arbitrage has taken advantage of distortions caused by market shocks such as the pandemic in 2021, the Russia–Ukraine War in 2022 and an increase in renewable generation creating negative pricing days in 2023.



UK value stack as a percentage of revenues

Source: Modo Energy and Alexa Capital

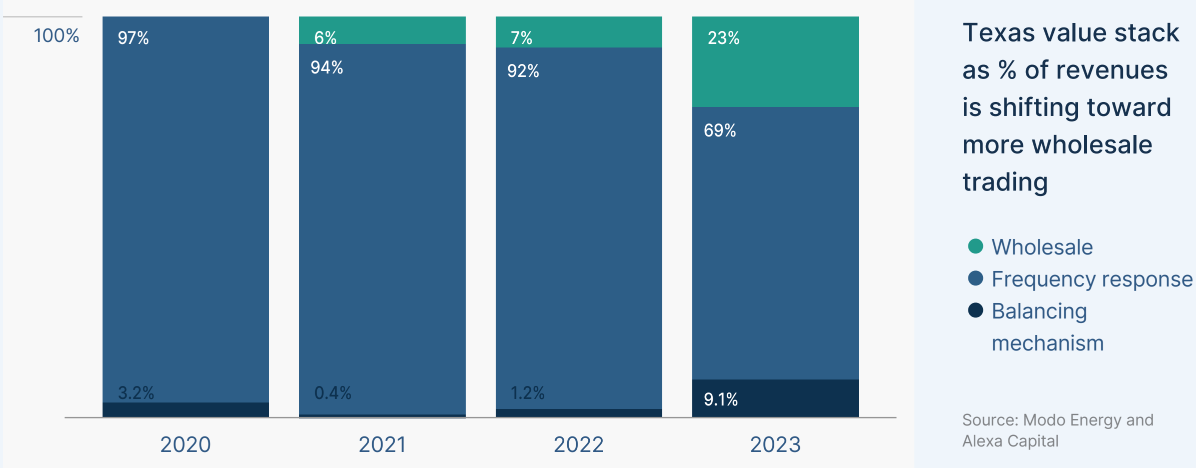
Case study

Texas, US

Texas is second only to California in terms of installed storage capacity in the USA, at 3.7 GW and 7.3 GW, respectively.[11] The state is also one of the fastest growing battery markets globally, accounting for 50% (1.5 GW) of planned US capacity additions. Market reforms drafted in response to a 2021 grid collapse[12] resulted in a competitive market for capacity (called the Operating Reserve Demand Curve) and ancillary services (ERCOT Contingency Reserve Services) to improve grid reliability amid a notable increase in renewable generation. Thanks to these developments, Texas's renewable generation now outdoes California's by two to one.[13]

Like the UK, storage revenues on the Texas grid, ERCOT, were first driven by frequency response service requirements. The segment's profitability attracted competition as well as regulatory oversight, creating a competitive market for ancillary services with the launch of the Contingency Reserve Service in June 2023. Increased competition from planned capacity additions is likely to saturate the frequency market, requiring stacking of alternative revenue streams for battery operators to remain profitable.

Differences in the value stack are reflective of these changes, with frequency response profits diminishing 86% year-on-year in 2023 and being progressively offset by arbitrage revenues (with a compound annual growth rate or CAGR of 53% from 2021) in the wholesale market. High market volatility has more than compensated for revenue shortfalls elsewhere, with prices reaching $1,000 per megawatt-hour (MWh) in March 2024 as generators went offline in a planned outage. The summer months are often more lucrative, as electricity demand is higher due to hot weather. Last year, 51% of battery revenues from January 2023 to August 2023 (inclusive) were earned in just 10 days, with nine of those happening in August.[12]



Texas value stack as % of revenues is shifting toward more wholesale trading

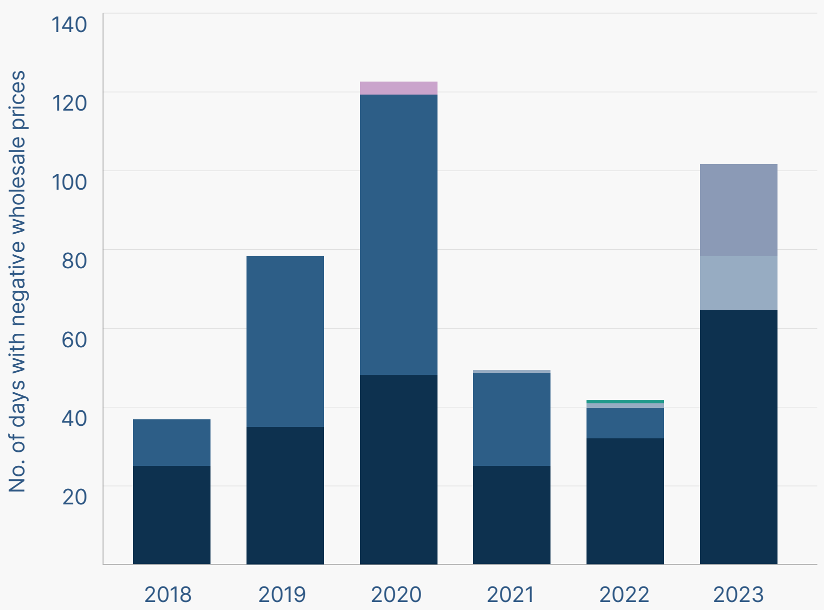
Source: Modo Energy and Alexa Capital

Front-of-meter: power arbitrage

The price of electricity in competitive power markets fluctuates in line with supply and demand. Batteries can capture the spread to generate revenues, discharging when prices are high and charging when prices are low. Power arbitrage is most profitable when volatility is high, as in 2022 when the start of the war in Ukraine caused volatility in Europe to increase fourfold.[14]

A much-debated topic is the influence of renewables on market volatility; what is undeniable is the effect of renewable generation on the level of prices. A 2022 study by the International Monetary Fund (IMF) estimated variable renewables lowered prices 0.6% on average for every 1% increase in renewable generation.[15] This has been evidenced in markets with high levels of renewable penetration.

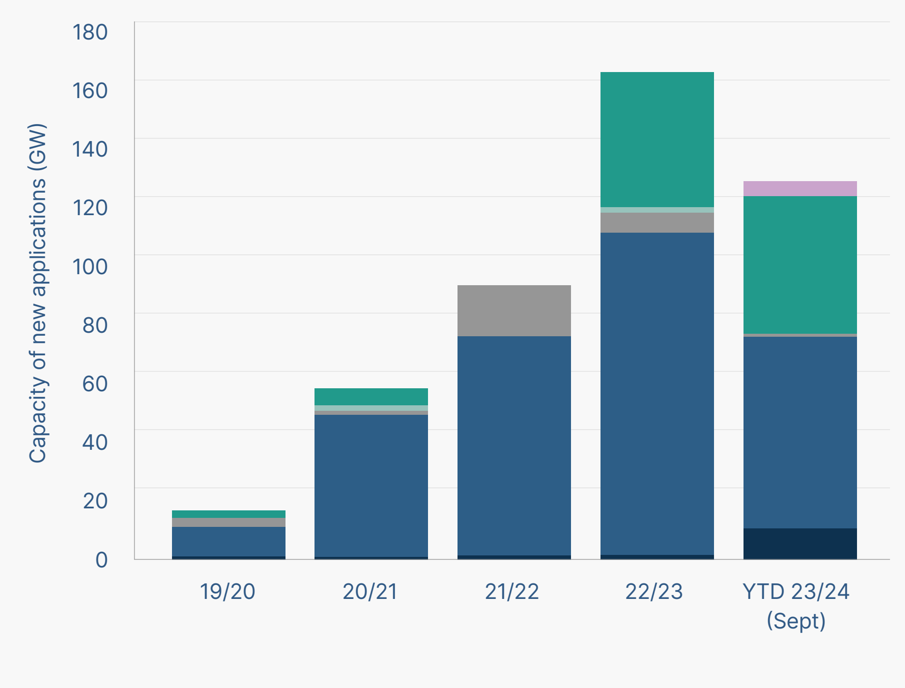
For example, Germany experienced 65 days with negative wholesale power pricing in 2023. In the UK, December 2023 average maximum prices fell by 25% month on month due to negative wholesale power pricing on windy days.[16] Markets such as Spain don't compensate generators for the cost of reducing generation with negative pricing; instead, they set the price of producing electricity at zero, resulting in economic curtailment from losses due to producing free electricity. Nevertheless, even Spain has increased the number of days of economic curtailment to balance the grid, from one day in 2022 to 24 in 2023. Curtailment costs in real terms have increased 58% in the UK, 3.5 times in Spain and 2.25 times in Germany from 2020 to 2023[17], enhancing the investment case.



Negative wholesale power prices are on the rise across Europe

Source Ember Climate and Alexa Capital

With more renewable generation queued to connect to the grid, we should expect more days of negative electricity pricing on windy or sunny days. Negative pricing translates into revenues for energy storage, which can consume electricity when prices are negative and discharge when prices are high. Grid connection reforms could accelerate this trend. For example, in November 2023 UK energy regulator Ofgem announced reforms to the grid connection application process which could add more than 300 GW of solar, wind and storage capacity,[18] representing a more than three times increase on the UK's installed renewable capacity of 56.3 GW[19] in 2023.



Transmission applications in the UK show increasing renewable integration impacts

Source: Ofgem and Alexa Capital Markets

Front-of-meter arbitrage: how much market volatility do you need?

As renewable generation in the power mix increases, near-term market distortions are likely from pricing impacts caused by additional generation and changes in the profile of electric demand. Short-term market dislocations are opportunities for battery storage operators to enhance operating revenue, stacking power arbitrage amongst other services.

A simplified payback model highlights the revenue enhancement opportunity of power arbitrage as well as the importance of value stacking to optimise a battery's revenue potential. A battery system's main operating costs include charging and an operating margin to cover operations and maintenance, asset management charges, land lease, insurance and warranties, most of which currently limit a battery to two cycles per day.

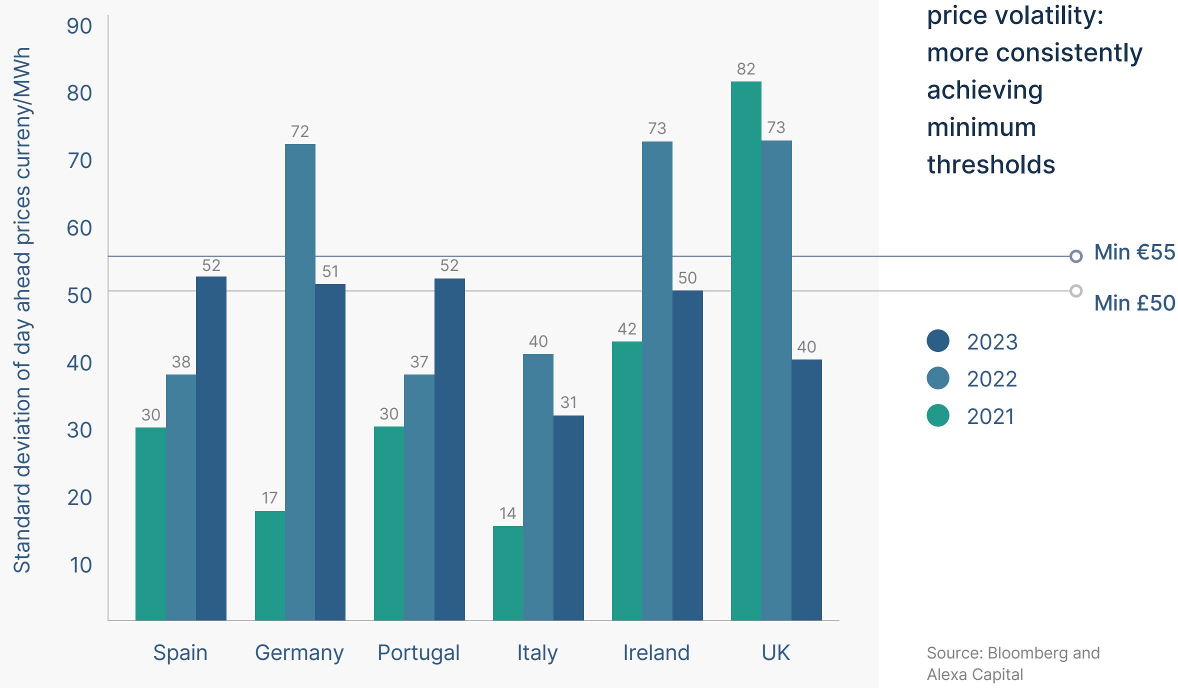
Firstly, it is important to note that today's investors in large-scale battery storage are assessing returns based on a diversified value-stack of revenues, across energy arbitrage, grid and utility services (frequency regulation, congestion relief, other ancillary support) and, in some markets, long-term contracted capacity payments. Also, major power traders are beginning to offer some storage developers multi-year tolling agreements to 'rent' access to battery infrastructure, which equate to fixed price contracts for the use of storage, within certain operating constraints to maintain the system's warranty.

That said, over time we expect a greater percentage of revenues to be derived from energy arbitrage. Accordingly, we have assessed the decline needed for large scale battery storage system prices to provide for investor returns from arbitrage (only).

The operating margin on a 100 MWh (one-hour duration) battery averages about £15,000 (€17,250) per MW. Spreads in power markets must be at least £50 (€55/$60) to cover the costs of turning the battery on, without factoring the charging costs which would widen the needed spread. A simple standard deviation of the hourly prices for the day-ahead market illustrates that with only power arbitrage there is insufficient volatility in most markets to consistently capture arbitrage revenues. However, short-term dislocations due to market shocks provide opportunities to enhance the fixed revenues from capacity payments and help compensate for shrinking margins in ancillary services while also reducing the battery's idle time. For example, there were 73 days during 2023 in Spain, one of the least volatile markets, where the intraday spread was greater than €100 — insufficient for a grid-scale battery investment strategy, but a significant boost over standing idle between deployments.

Our battery payback model highlights the revenue opportunity of power arbitrage together with the importance of value stacking

European power price volatility: more consistently achieving minimum thresholds

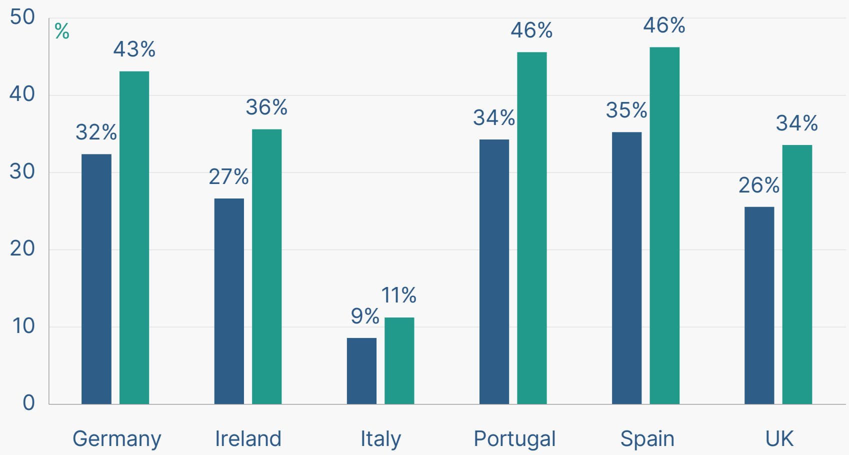


Source: Bloomberg and Alexa Capital

In our front-of-meter storage model, we can estimate the price of storage needed to "break even" under current market conditions with only power arbitrage, excluding other elements of the grid-scale storage revenue stack. The analysis does not factor operating margins and uses the average price of electricity to estimate charging costs.

Battery prices are falling rapidly (but not linearly). At the beginning of 2024, one-hour duration battery costs in the range of £450,000 taking into account the batteries, engineering and construction, grid connection and development costs, noting these costs are currently estimated to be below £375,000 per MW for new build. It is a notable reference that price does not increase linearly with duration, so a two-hour duration grid-scale battery costs in the range of £700,000 per MW (c.€800,000 per MW) in early 2024, noting this level is now falling to around £500,000 per MW (c.€580,000 per MW) for prospective new build. These references do vary by geography, level of grid connectivity and installation sizing, with the battery cost component expected to reduce over time.

To achieve a 10-year payback based on power arbitrage alone, battery prices would need to fall further, such that, a 100 MWh (1 hour duration) battery with two cycles per day would need to cost between €170,000 and €185,000 per MW in Germany, Spain and Portugal to recover capital. Thus arbitrage (only) would have supported c.34% of system costs earlier this year, but on current prices covers c.36% of costs. In comparison, arbitrage (only) in those same regions for a 2 hour system would have supported c.45% of the cost for a 2 hour duration battery earlier this year, but now covers c.51%. Unsurprisingly, markets are now rapidly trending toward longer duration systems.



European power arbitrage revenues as a % of battery capex

Source: Alexa Capital

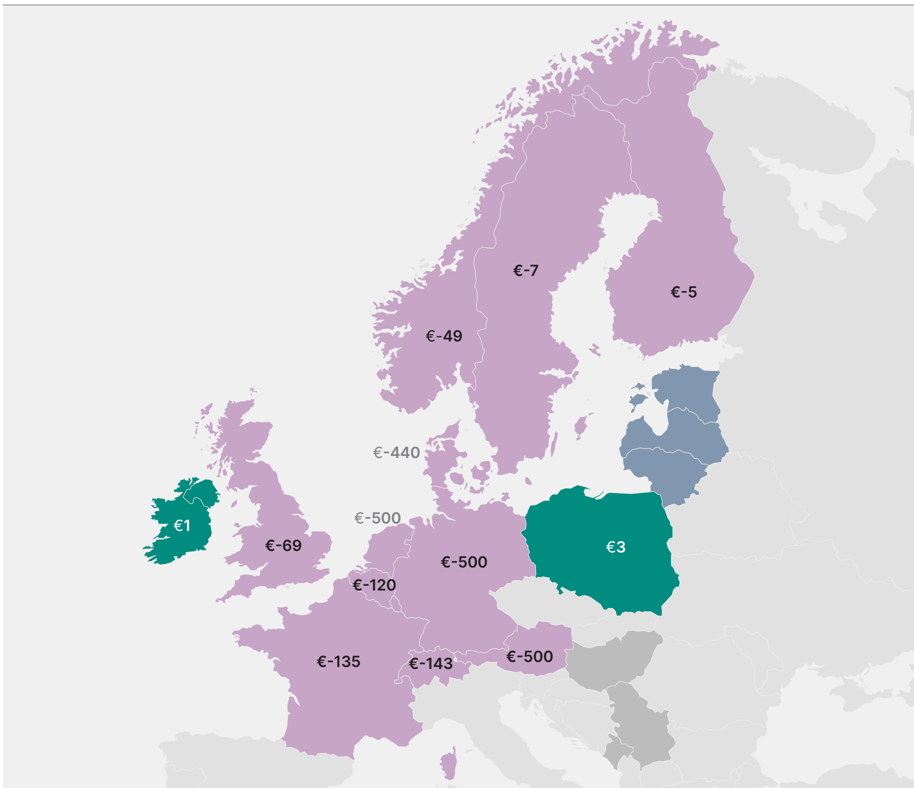
Although these arbitrage-only covered values are materially below current battery costs, these costs are expected to fall further by 2025. These estimates assume a battery pays to charge. If charging is free due to co-location or negative pricing, the payback period for batteries improves significantly, converting charging cost into potential revenues and improving the economics of higher-priced storage. Not surprisingly, with expectations of future ‘tightness’ in the power markets based on demand growth (driven by data centres, AI, etc), weather and climate volatility impacts, unscheduled grid and older conventional generation outages, geopolitical shocks impacting marginal wholesale power pricing, plus the benefit of additional revenues sources in the value stack, investors continue to fund large scale battery infrastructure as a hedge on market uncertainty.

Front-of-meter markets in Europe

As economies transition away from fossil fuels, more renewable energy will be added to the system, lowering the cost of electricity as well as increasing the probability and frequency of negative pricing or curtailment in wholesale markets. This was particularly pronounced in July 2023, when negative prices reached new records across Europe as wind and solar generation coincided with low demand.[20]

Competitive wholesale power markets set the price of electricity by the most expensive marginal producer, with lower-cost producers capturing additional premia from the higher price. As more renewable generation is connected to the grid, the top end of prices can be expected to remain a reflection of ongoing fossil fuel generation during the transition (typically gas-fired generation). But the low end of prices will fall in proportion to the amount of renewable energy added to the system, with the IMF estimating a 1% increase in renewable energy will lead to a 0.6% decrease in electricity prices.

Since 45% of UK generation is from renewable resources, a 1% increase to 46% should theoretically lower the floor in the wholesale market by 0.6% to £77/MWh. Extending this calculation to the UK renewable generation target of 60% would imply a wholesale market price drop of 9%.

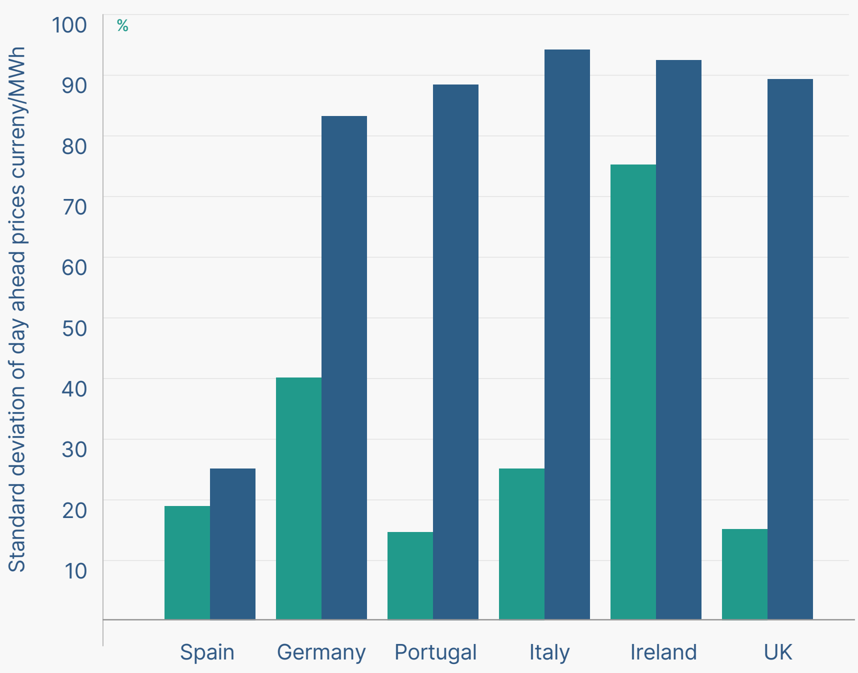


European power markets: mostly negative day-ahead prices on 2nd July 2023

Geography	Day-Ahead Prices €
UK	-69.30
Ireland	1.00
Germany	-500.00
Belgium	-120.00
Netherlands	-500.00
Poland	2.74
Denmark	-440.10
Austria	-500.00
Switzerland	-142.88
Finland	-5.03
Norway	-49.20
Sweden	-6.62
France	-134.94

Negative
Positive

By applying this decrease to the lowest intraday price and recalculating the spread, we can identify markets where power arbitrage opportunities are more likely to arise from increased renewable generation connections. From the analysis, Ireland and Germany will continue to dominate, with spreads above €100 on more than half the days in the year. Spain, a non-volatile market, may experience the greatest increase in the number of profitable days as it shortens the 29-percentage point gap to its renewables target. Although generators in Spain are not compensated for curtailment directly by the grid operator, they are incentivised to reduce generation when the market price falls below running costs. Thus, storage could improve profits by generating revenues and deferring the costs of curtailing generation.



Increased renewable generation is widening wholesale pricing spreads across Europe

● 2030 E
● 2023

Source: Bloomberg and Alexa Capital

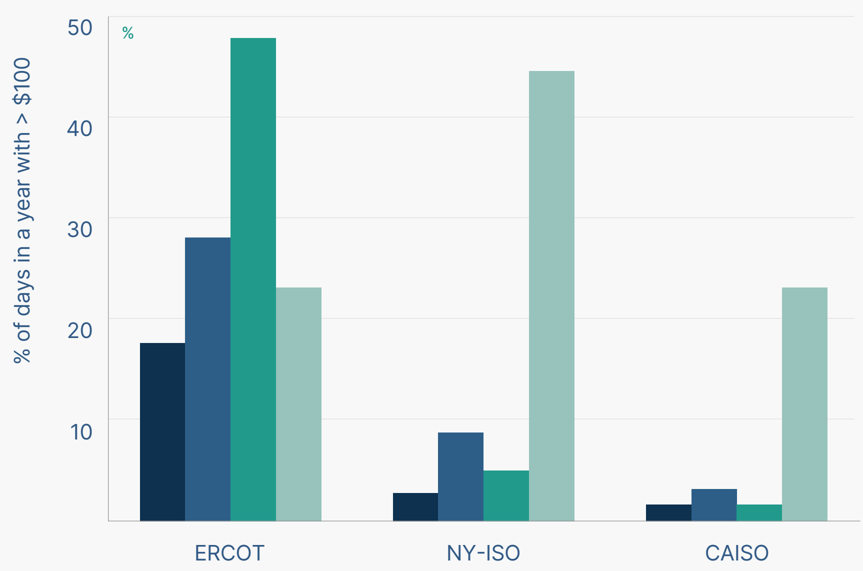
Footnote: The increase in renewable generation input into the IMF formula is the difference between the current generation from renewable sources and the 2030 national target in "Percentage of power generation from renewables".

Front-of-meter markets in the United States

Our analysis of US markets follows a similar approach to the EU one, where days with an on-peak versus off-peak spread greater than $100 per MWh are counted. The $100 threshold was determined in line with prior analysis, keeping in mind that a $60 spread minimum is needed to cover the current operating costs of a gird-scale battery.

The ERCOT market in Texas is the most compatible with power arbitrage revenues, as indicated by the increasing number of days with spreads of $100 or more. Texas has few interconnections to surrounding regional power grids, meaning shocks have a greater impact because there are fewer options to compensate for imbalances with imports. During the 2023 heat waves, volatility remained high as air conditioners were turned on. Regions with the highest volatility include Austin, San Antonio, Houston and the Lower Colorado River Authority, which covers the area between Texas' biggest cities.

Significant price volatility, as well as concerns over grid reliability, spurred 2023 storage capacity in Texas to increase from 1.96 GW to 3.2 GW[21]. It is expected to double again in 2024. Spikes in wholesale electricity prices, recently reaching $1,000 per MWh, are supporting market growth by boosting battery storage revenues that nearly doubled from $187 million in 2022 to $532 million in 2023.[22] Meanwhile, the gap towards New York's renewable target is likely to increase the number of profitable arbitrage days as well as any curtailment revenues from negative pricing, despite low volatility.



Increased renewable generation is also widening wholesale pricing spreads in the US

- 2021
- 2022
- 2023
- VRE target gap

Source: Bloomberg and Alexa Capital

Footnote: The increase in renewable generation input into the IMF formula is the difference between the current generation from renewable sources and the 2030 national target in "Percentage of power generation from renewables"

Front-of-meter storage affordability depends on cost

The cost of utility scale battery storage is primarily down to equipment, project development, operations and maintenance, and end-of-life recycling costs. As the industry matures, we expect prices to reduce with further innovation and competition, as evidenced by the historical cost of lithium battery packs.

Equipment costs:

Battery modules and battery packs, inverters, battery management systems, power conversion systems

£160,000–£255,000 per MW
(€184,000–€300,000/
$198,000–$320,000 per MW)

Battery systems include:

- A battery module of linked lithium packs serving as the system's energy reservoir.
- A battery management system (BMS) that controls the battery's charge and discharge and is equipped to ensure safety and prevent overheating.
- A power conversion system (PCS) facilitating the battery's grid connection and dual functionality as an electricity generator and off taker.

Project costs:

Engineering, procurement and construction

£160,000–£255,000 per MW
(€184,000–€300,000/
$198,000–$320,000 per MW)

Developers often contract engineering, procurement and construction (EPC) firms to design, construct and manage battery operations. The EPC oversees the project scoping, real estate and original equipment manufacturer (OEM) selection, site permitting and regulatory compliance. They also contribute to project profitability by advising on bilateral agreements with customers, tax considerations and local incentives. EPC firm pricing varies wildly due to the fragmented nature of the industry, as well as project size, location and complexity.

Operations and maintenance (O&M) costs:

Upfront costs, lifetime costs
End of battery life costs
Dismantling, Transporting, repurposing, and recycling

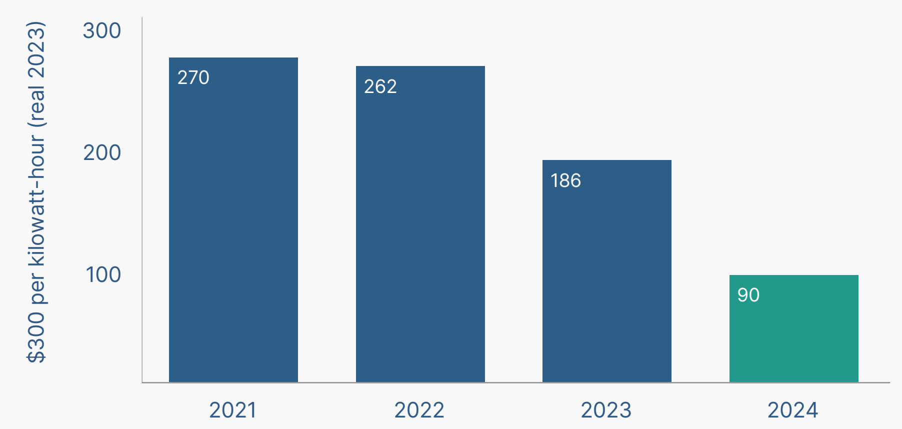
£10,000-£15,000 per MW
(€11,500-€17,000/
$12,400-$18,600 per MW)

O&M is crucial to ensure storage can dispatch safely and reliably to meet contractual obligations as well as capture power arbitrage revenues.

Batteries degrade. To maintain the performance capacity of a unit, the system can be oversized at construction or battery modules replaced to improve performance. Given the lack of standardised performance metrics, experience with monitoring and maintaining systems is paramount to ensure alignment of performance with the business plan.

System costs decreasing

Battery cell and module costs are falling significantly, and reductions are not necessarily linear, but rather relate to supply-demand balances and Chinese/Asian production capacities. A recent chart from BNEF shows the recent trend.



Chinese battery storage system prices are dropping non-linearly

Quoted China energy storage system prices more than halve in 2024

- Yearly delivery prices
- 2024 April quote

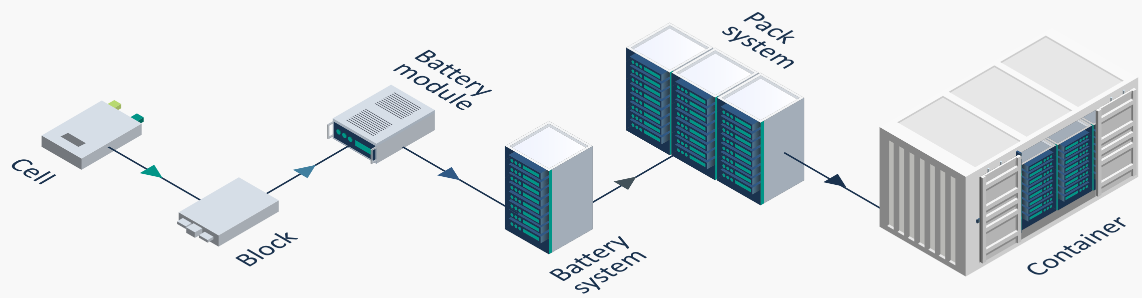
Source: BloombergNEF, participants at the 12th Energy Storage International Conference and Expo (ESIE).

End of life

These costs refer to dismantling, transporting and repurposing or recycling the system or its parts. The addressable market is limited, but with exponential growth expected as scrap from retired EVs and other storage products accumulates. As competition for raw materials intensifies, recycled scrap from retired products will be pivotal to manage costs during the lifetime of the product as well as from the recovery value of the asset at project end. The significance of this industry has caught regulatory attention, with the EU aiming to double recycling capacity from 200,000 metric tons by 2025.[23] Recycling capacity in the US is like that of Europe.

Component parts of a battery storage system

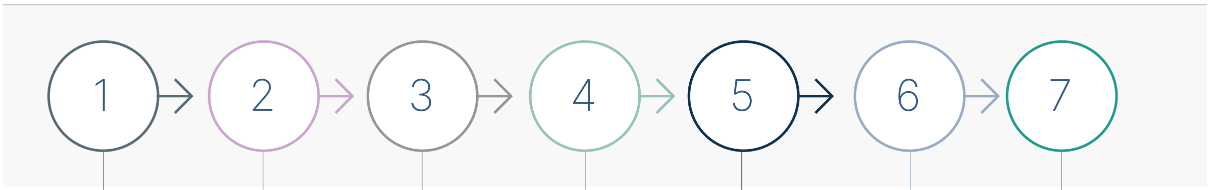
Source: Alexa Capital



Front-of-meter landgrab for top locations

Renewable energy development is localised, akin to real estate development, with a sales process that is consultative with various stages and milestones. Local developers, well-versed in navigating local politics, are often preferred due to their familiarity with laws governing renewables and technical aspects of grid connection. International developers frequently collaborate with local firms, leading to a fragmented market with significant variations in pricing and quality from region to region. Location matters – as those closer to large demand centres and constrained distribution grids are typically more valuable, supporting higher power price volatility and electron flows.

Developers excel in selecting optimal solutions tailored to project and customer needs. However, the barriers to entry are relatively low, primarily revolving around local knowledge, supplier relationships, and ability to secure favourable (unconstrained) grid connections. Consequently, developers have been acquiring land suitable for hosting renewable projects, with sufficient grid connection capacity and available land. This is a clever defensive approach considering growing infrastructure investments in EV charging.



Conceptualisation and research
Identify market needs and research renewable energy technologies.

Feasibility, engineering, and design
Assess resource availability, conduct feasibility studies, and develop detailed engineering and design. plans.

Development, procurement, and construction
Develop the project, procure necessary equipment and materials, and construct the renewable energy infrastructure.

Testing 7 commissioning
Conduct testing to ensure the system operates as intended and commission the project for operation.

Operations and maintenance
Manage ongoing operations, conduct regular maintenance, and monitor system performance.

Performance optimisation
Analyse data and optimise system performance over time through adjustments and improvements.

End-of-life support plan
Develop strategies for decommissioning, repurposing, or disposing of renewable energy assets responsibly at the end of their lifecycle.

Source: Alexa Capital

As EV charging penetration rates surge, particularly in regions like Norway, the strain on electricity grids becomes evident. To address grid weaknesses and meet customer demands for convenience, developers are incorporating energy storage alongside EV charging infrastructure. Notable examples include Chargepoint, Connected Energy and Zenobe.

Front-of-meter storage in a renewable-centric energy landscape

Front-of-the-meter energy storage represents a crucial component in the transition towards a more renewable-centric energy landscape.

Renewable integration remains a key driver, prompting power markets to increasingly embrace energy storage integration. In the UK and Texas, where frequency response services have historically dominated, diversification of revenue streams has become imperative due to increasing competition and regulatory changes. Fortunately, the rise of renewable generation has led to more frequent negative pricing days, creating opportunities for energy storage to capture additional revenues from power arbitrage. Additionally, concerns over grid reliability and significant price volatility in Texas are driving substantial growth in storage capacity.

As the industry matures, we anticipate reductions in acquisition costs, primarily driven by manufacturing improvements and increased competition. The cost-effectiveness of, and investment case for, energy storage is expected to improve further, particularly with the development of charging infrastructure for fleets and resultant integrated energy services. Overall, early movers in the development of grid-scale energy storage solutions stand to benefit from enhanced revenue streams and play a significant role in the transition towards decarbonised energy systems.

Falling battery costs are a massive catalyst for a new generation of behind-the-meter energy services

Front-of-the-meter: summary

Our exploration of front-of-meter storage in this section reveals that FTM is getting more in-the-money – even considering power arbitrage alone – as costs continue to come down.

In this section we explored the markets where power arbitrage opportunities are more likely to arise from increased renewable generation connections. Across Europe, Ireland and Germany will continue to dominate in terms of power arbitrage opportunities, with spreads above €100 on more than half the days in the year. Across the USA, the Texas ERCOT market is the most compatible with power arbitrage revenues, mostly since it bears few interconnections to surrounding regional power grids.

As costs continue to decline and market landscapes and regulations evolve, the investment case for front-of-meter storage strengthens, offering substantial returns and contributing to the realization of decarbonized energy systems.

Behind-the-meter: market overview

This section explores the transformative impact of behind-the-meter (BTM) storage on power markets. It delves into how the adoption of BTM storage solutions, alongside factors like heat pumps and electric vehicles, is reshaping the dynamics of electric supply.

We analyse the fundamental changes in power market dynamics propelled by the decentralization of electric supply, focusing on the affordability and accessibility of BTM storage solutions and their implications for market growth.

BTM storage is lower complexity and cheaper to produce than utility applications, with expectations of an accelerated growth phase

Throughout the following pages, we review:

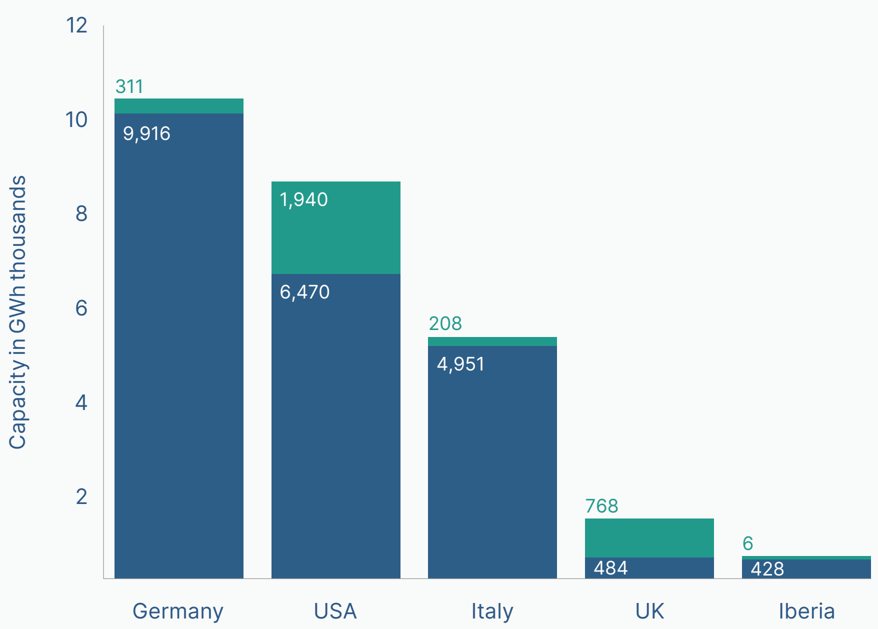
- Market Dynamics: An examination of how BTM storage is fundamentally changing power market dynamics.
- Residential Storage Growth: We delve into the global landscape of residential storage, shedding light on key markets and regulatory incentives driving adoption.
- Economic Viability: Analysis of the economic viability of BTM storage solutions, including payback periods and regulatory incentives.
- Global Market Landscape: An overview of the global market landscape for BTM storage, including key regions and market drivers.

Through our proprietary analysis and real-world case studies, we illuminate the economic viability and accessibility of BTM storage, highlighting the industry's growth potential and market drivers.

Behind-the-meter: a revolution in power markets

Power market dynamics will fundamentally change with accelerated adoption of BTM commercial and residential storage, as well as the impact of heat pumps and electric vehicles. Electric supply will no longer be centralised at power plants, but also delivered on the distribution grid near consumers who can manage their consumption. A Deloitte study estimated that 70% of the 510 GW of renewable capacity additions from 2017 to 2030 will be connected to the distribution grid, of which 40 GW will be self-consumption additions behind the meter.[24]

BTM storage is lower in complexity than utility scale applications, and therefore cheaper to produce. This, in combination with mass-market sales volumes, is likely to trigger the industry's accelerated growth phase. Manufacturers such as Tesla, BYD, CATL and Sonnen are increasingly launching residential battery storage products and partnering with local installers.[25] BNEF estimates residential storage had a 51% CAGR from 2020 to 2023, reaching 33.4 gigawatt-hours (GWh) of installed capacity. Global capacity is expected to reach 195.7 GWh by 2030.[26] That amounts to an estimated 30 million batteries at 6.5 kWh per battery.



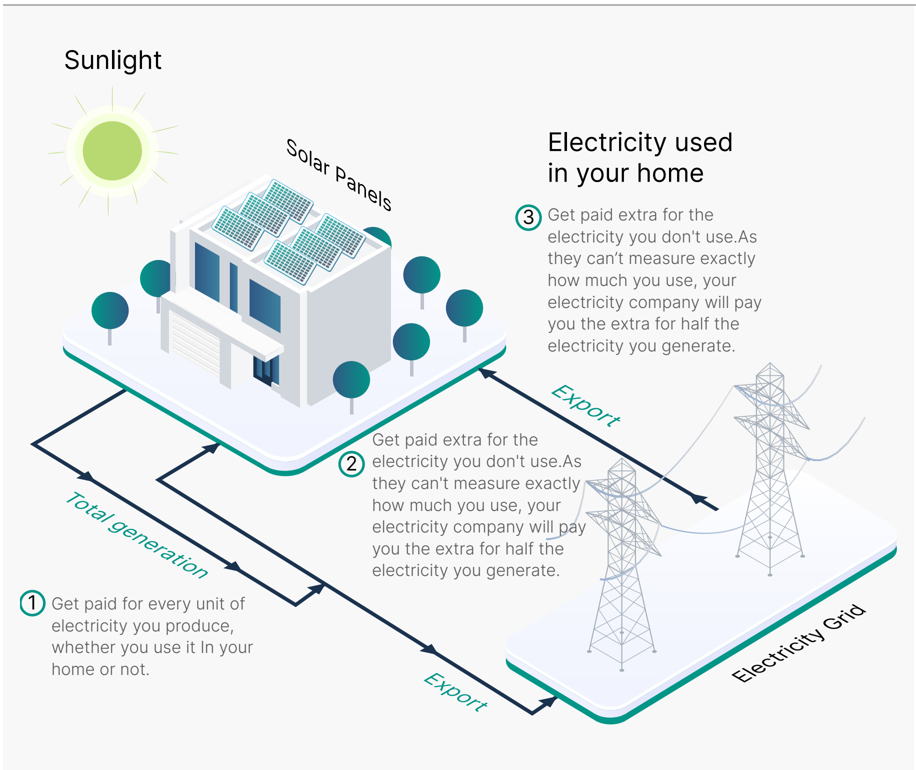
Battery integration varies widely by geography, highest proportions of BTM storage in Germany and Italy

Source: BNEF and Alexa Capital

Customers are motivated by bill savings from solar self-supply and back-up power in areas with unreliable electricity access. Bill savings from solar self-supply are often a result of reducing electricity sourced from the grid with self-generation. Additional savings can be earned from feed-in tariffs that compensate consumers for electricity injected to the grid, thereby reducing payback periods on investment.

BTM storage customers rely on installers to navigate the technological, regulatory and construction aspects of installation, often alongside solar in residences, or microgrids. Installers prioritise safety and brand reputation to mitigate unforeseen risks as they rely on referrals for their customer pipeline. Nearly nine out of 10 residential installers offer only one or two inverter brands, reflecting a high level of brand loyalty. This is an understandable development considering product quality issues from mass manufacturing as the industry develops to scale.

Germany, USA and Italy are the largest residential storage markets, in part driven by incentive programs that reduce the cost of installing batteries. In Italy, a tax incentive covering 50% capex costs has unsurprisingly resulted in more than 77% of new home solar installations including batteries.[27] Similarly, the 2023 California Self-Generation Incentive program reduces the cost of battery installation with a rebate from between $150 and $1,000 per kWh.[28] Many of these incentives are now winding down as the industry matures and the costs of residential storage fall.



Feed-in tariffs explained: 3 ways for residential homeowners to get paid

Source: Scottish Energy Saving and Alexa Capital

Residential storage economics and payback periods

The cost of rooftop solar varies according to the generating capacity of the system, measured in kWp (kilowatt peak), with additional costs for battery storage that depend on capacity, measured in kWh (kilowatt hours). Our proprietary model shows single digit investment paybacks for many countries and regions.

Our model looks at the cost of a home system including inverters, cables, solar panels and labour, which equates to €1,200 to €1,900 per kWp in the EU, £2,000 in the UK and $3,000 in the US. A basic system of 2 kWp (five solar panels of 400 Watts each) can cost $6,000 in San Francisco and $6,725 in New York. Cost varies in part due to labour, but also the regulatory compliance burden of the region. Other inputs to which the payback period on investment is sensitive include levels of consumption, system size, geography, the retail price of electricity and maintenance capex, among others. The model assumes maintenance capex of 50% the original value of storage every 10 years, reflecting accelerating manufacturing efficiencies, fewer parts, and lower labour costs, as well as 25 years of system life.

Our residential payback model considers the variations in solar and storage pricing across a range of geographies

Estimated price of solar and storage by geography

	Retail Price (Currency/kWh)	Price of Solar (Currency/kWp)	Price of Storage (Currency/kWh)
Dublin Ireland	€ 0.2332	€ 1,895	€ 800
Rome, Italy	€ 0.2687	€ 1,647	€ 732
Lisbon, Portugal	€ 0.2277	€ 1,201	€ 732
Berlin, Germany	€ 0.3183	€ 1,556	€ 900
Madrid, Spain	€ 0.1766	€ 1,622	€ 774
London, UK	£0.2450	£1,928	£696
San Francisco, CA USA	$0.2911	$2,977	$1,220
New York City, NY USA	$0.2252	$3,362	$1,220
Houston, TX USA	$0.1458	$2,800	$1,220
Sydney, Australia	$0.2651	$1,463	$1,415
Brisbane, Australia	$0.2703	$1,435	$1,415

Source: Alexa Capital

The sensitivity to these elements is evident in the payback period across different countries. Our model adjusts for irradiation capacity, how much electricity is used by month and hour, and retail price. Looking just at Europe, storage can increase the payback period with additional cost of €3,000 to €4,500 (£2,750 to £3,500). Nevertheless, the accelerated savings in London more than compensated for the additional cost of storage, reducing the payback period by eight months in a two-bedroom house scenario. A combination of low retail prices and high consumption, as in a two-bedroom house in Spain, does not favour storage at current costs.

Repeating the same analysis for the US emphasises the benefit of storage for higher levels of power consumption and shows regions with a higher average $ per kWh have lower payback periods. The payback period for a single family detached house with storage in Texas is equivalent to San Francisco, driven by differences in the price of electricity. Installation costs in New York are significantly higher, resulting in a payback period of 12.6 years for a detached house with 5 kWh storage versus 4 kWh. We model the residential storage payback period for a range of consumption levels and installation sizes in Appendix VI.

Not all regions show shortening PV+S payback periods, despite enhanced resiliency; however, improving regulation suggests upside optionality

Most European payback periods are single digit years

	2 bedroom house (3,000 kWh per year)		3 bedroom house (4,000 kWh per year)	
	Solar (2 kWp) Only	Solar + 4kWh Storage	Solar (4 kWp) Only	Solar + 5kWh Storage
Dublin Ireland	10.4	9.2	11.0	9.9
Rome, Italy	5.5	6.9	8.2	9.0
Lisbon, Portugal	4.8	6.6	7.2	8.2
Berlin, Germany	5.1	6.8	6.5	7.4
London, UK	8.6	7.9	11.3	9.3
Madrid, Spain	9.4	13.7	14.2	17.3

Source: ENTSO-E and Alexa Capital

USA (selected states) payback period in years

	Single Family Attached (6,650 kWh)		Single Family Detached (9,250 kWh)	
	Solar (2 kWp) Only	Solar + 4kWh Storage	Solar (4 kWp) Only	Solar + 5kWh Storage
San Francisco, CA USA	5.2	7.2	7.1	8.5
	Single Family Attached (7,983 kWh)		Single Family Detached (10,035 kWh)	
	Solar (2 kWp) Only	Solar + 4kWh Storage	Solar (4 kWp) Only	Solar + 5kWh Storage
New York City, NY USA	6.5	8.7	9.4	12.6
	Single Family Attached (12,929 kWh)		Single Family Detached (17,924 kWh)	
	Solar (2 kWp) Only	Solar + 4kWh Storage	Solar (4 kWp) Only	Solar + 5kWh Storage
Houston,. TX USA	6.3	9.6	6.2	8.5

Source: US Energy Administration, Open Energy Data Initiative and Alexa Capital

Australia is the largest market globally in rooftop solar, with 3.7 million[29] households self-generating their electric need. Rooftop solar represents 3.1 GW of renewable capacity, up from 2.7 GW in 2022, and is responsible for 28.5% of renewable generation in 2023 as well as 11.2% of total generation.[30] Adoption has been driven in part by the Small Scale Renewable Energy Scheme, reducing upfront costs, but even without the subsidy it is clear the economics of rooftop solar are underpinning ongoing adoption. The region has higher consumption than in Europe and retail electricity prices on the higher end of the range for previously mentioned comparable regions.

Australia (Selected States) payback period in years

	2 person Household (5,236 kWh)		4 person Household (7,312 kWh)	
	Solar (2 kWp) Only	Solar + 4kWh Storage	Solar (4 kWp) Only	Solar + 5kWh Storage
Sydney, Australia	3.1	7.0	4.5	7.8
	2 person Household (5,128 kWh)		4 person Household (7,684 kWh)	
	Solar (2 kWp) Only	Solar + 4kWh Storage	Solar (4 kWp) Only	Solar + 5kWh Storage
Brisbane, Australia	3.2	7.1	4.3	7.4

Source: CSIRO and Alexa Capital

Behind-the-meter: a catalyst for a new generation of energy services

The rise of behind-the-meter storage heralds a significant transformation in power markets, altering the traditional dynamics of electric supply. With the proliferation of electric vehicles, commercial and residential storage, and heat pumps, the landscape of electric generation is shifting towards decentralised energy resources located on the grid near the consumer.

The increasing accessibility and affordability of behind-the-meter storage, exemplified by the growth in residential storage installations and EV sales, is expected to catalyse the industry's high-growth phase. Incentive programs in various countries further reduce the installation costs, bolstering the economic case for storage. However, even without subsidies the payback period analysis highlights the economic case for rooftop solar and storage for those with higher levels of consumption or in regions with high electricity prices.

While regulatory compliance and product quality issues persist, the trajectory of behind-the-meter storage points towards a future where consumers play a more active role in managing their energy consumption and contributing to grid stability. As technology advances and markets mature, behind-the-meter storage is poised to emerge as a cornerstone of the energy transition, reshaping power markets and enabling a new generation of energy services driven by technology.

Behind-the-meter: summary

Overall, our behind-the-meter storage analysis reveals that payback periods are single-digits years in many geographies. As costs continue to come down, payback periods will shorten dramatically, especially as new sets of services come into the market.

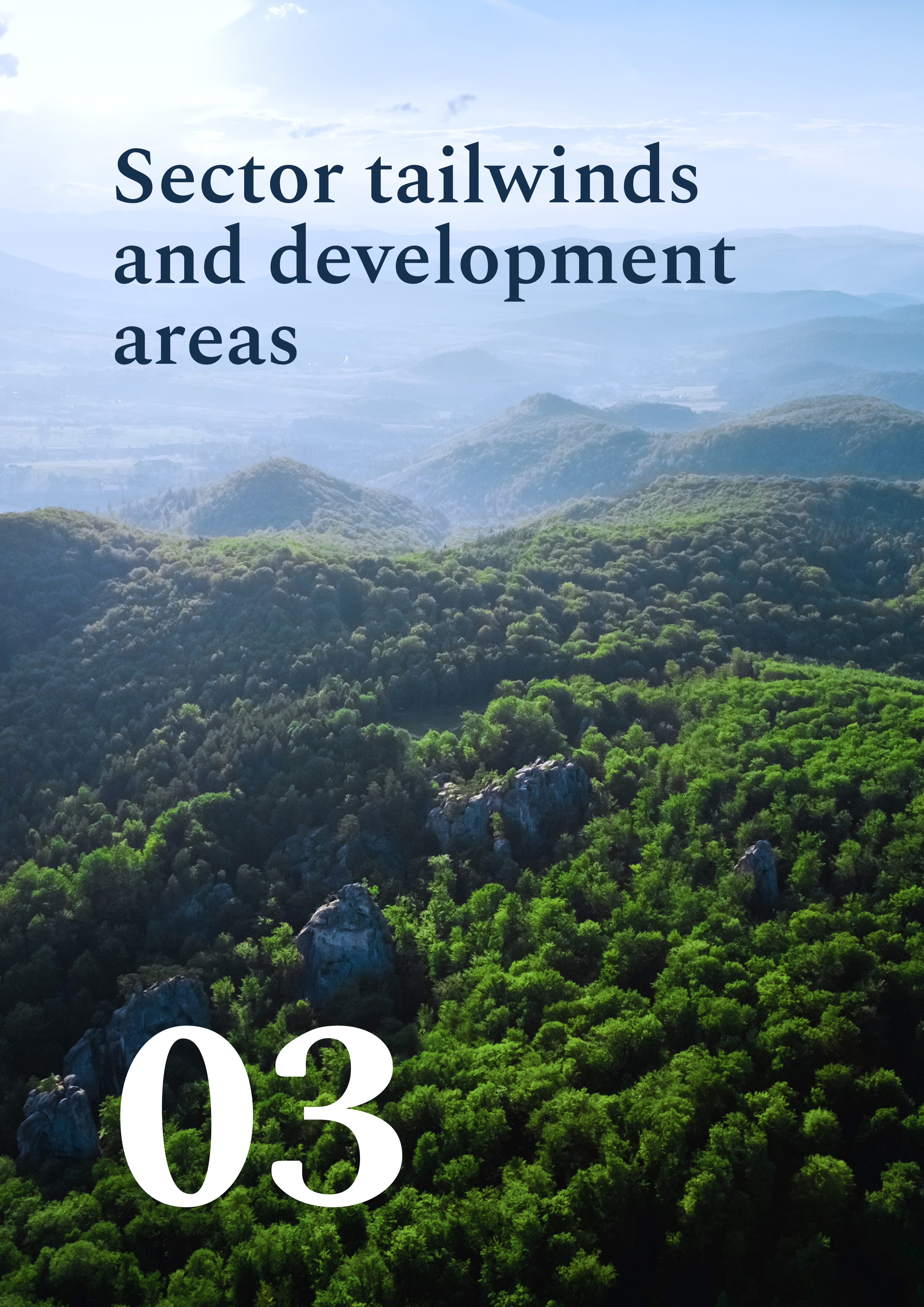
Despite regulatory challenges, the economic viability of BTM storage remains undeniably compelling. Our analysis demonstrates that the payback period for rooftop solar and storage installations are becoming more and more attractive, particularly for consumers with higher levels of energy consumption or those residing in regions with elevated electricity prices.

The rise of BTM storage offers consumers newfound control over their energy consumption, which is leading to a significant transformation in power markets. Data from our research indicates that residential storage installations have experienced a remarkable 51% compound annual growth rate (CAGR) from 2020 to 2023.

Looking ahead, as this growth continues to proliferate, and as accessibility increases and economics grow more favourable, BTM storage will serves as a catalyst for grid stability and resilience, reshaping the energy landscape and enabling a new generation of energy services.

The rise of BTM storage offers consumers newfound control over energy consumption, which will lead to a significant transformation in power markets

Sector tailwinds and development areas

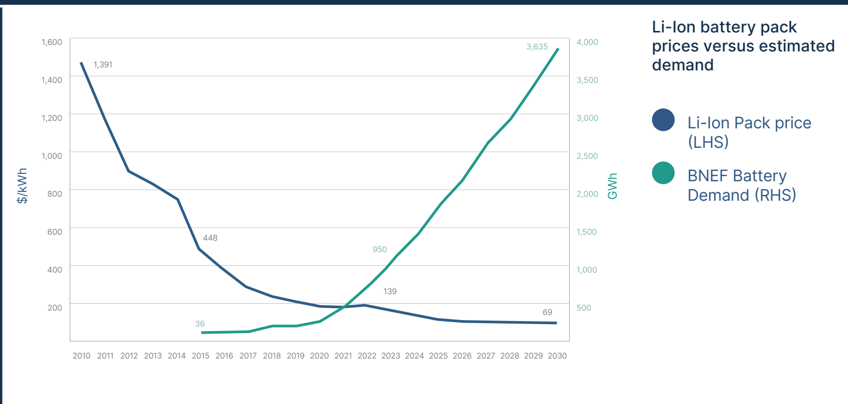


03

An investment thesis in four charts

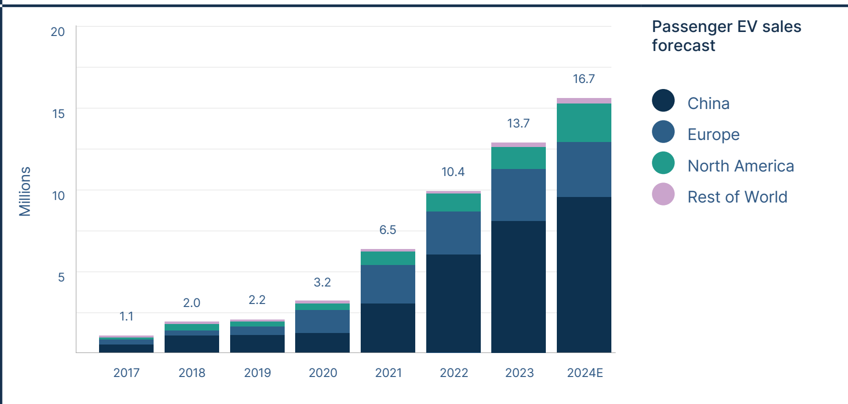
Performance and manufacturing improvements from innovation have reduced the cost of storage battery...

Source: Goldman Sachs, BNEF and Alexa Capital



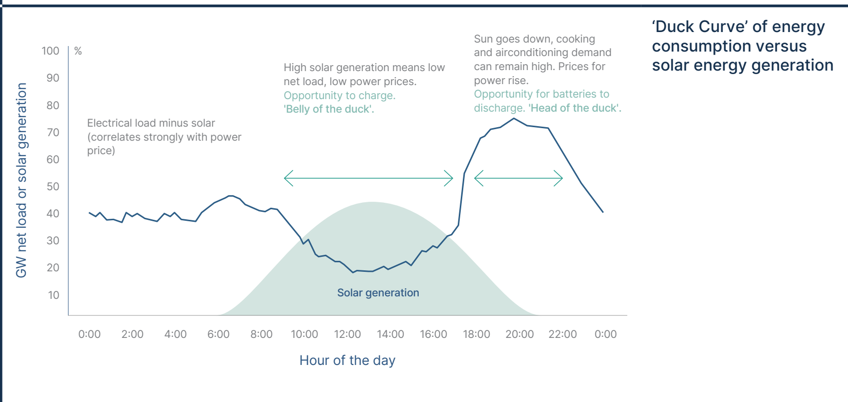
...resulting in increased manufacturing capacities to meet EV (and other) battery storage demand...

Source: BNEF and Alexa Capital



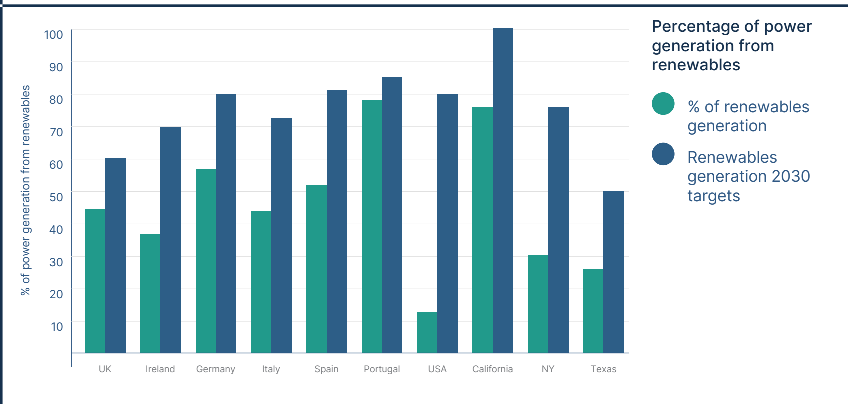
...creating more opportunities to integrate storage for fast-responding grid flexibility to integrate renewable generation...

Source: BNEF and Alexa Capital



...that will increasingly be the source of electric generation on the grid as 2030 renewable targets are achieved

Source: IEA, UK gov and Alexa Capital



Tailwinds driving storage growth

Performance improvements and cost reductions from innovation

In the rapidly evolving world of energy storage, the trajectory of battery technology has been profoundly influenced by a consistent theme: innovation driving performance improvements and cost reductions. This narrative is not just a reflection of technological advancements but a testament to the transformative power of innovation in shaping the future of batteries. From the early days of lead-acid batteries to the current era dominated by lithium-ion technology, each leap forward has been underpinned by a relentless pursuit of efficiency, affordability and adaptability.

A key factor in the cost reduction of battery technology has been the scale of production. As more industries adopt battery solutions—from power electronics to automotive and renewable energy storage—the scale of battery manufacturing has expanded dramatically. This expansion, coupled with improvements in manufacturing processes and material sourcing, has contributed to a significant decrease in battery costs over the past decade. Economies of scale have made once-expensive technologies like Li-Ion batteries increasingly cost-competitive, opening new markets and applications.

The price of a Li-Ion battery pack decreased 50% from 2016 to 2022, with an additional decrease of 40% expected by 2025

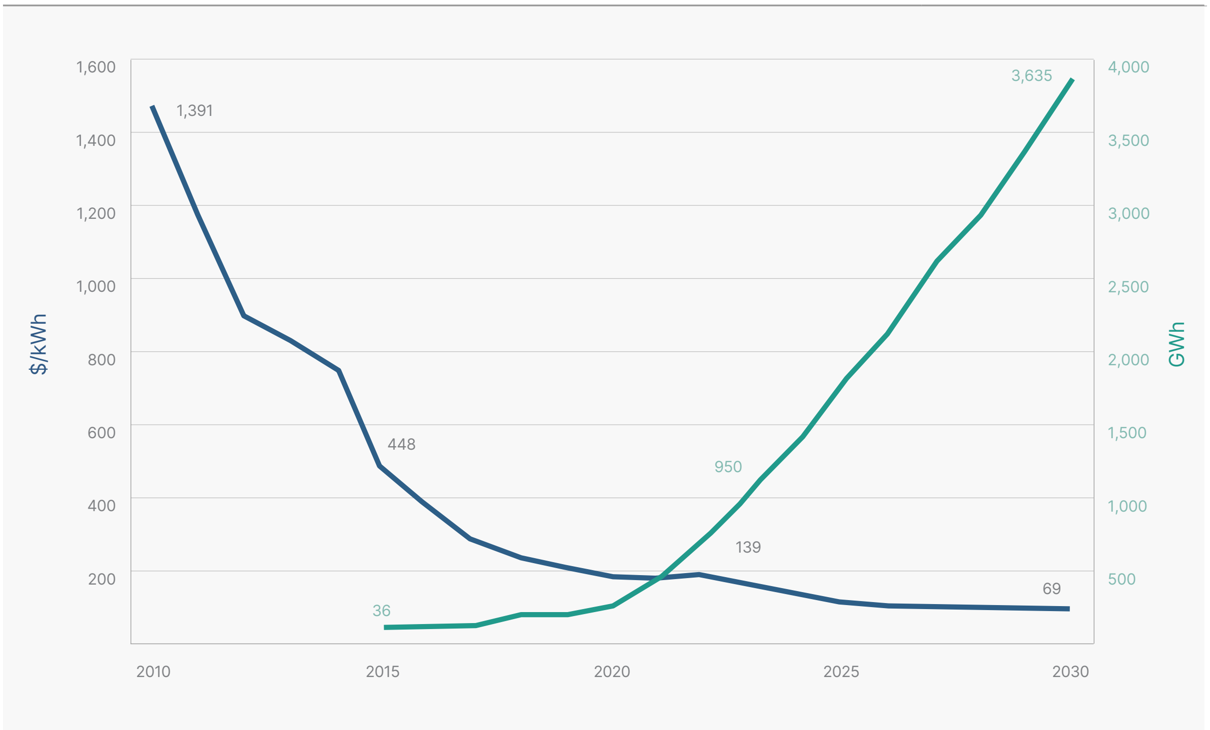
The price of a lithium-ion battery pack decreased 50% from 2016 to 2022, with an additional decrease of 40% expected by 2025.[31] Furthermore, performance has improved, with the energy density of products increasing from 111 watt-hours per kilogram (Wh/kg) in 2016 to 300 Wh/kg in 2023.[32] The improved performance and lower costs allow for utilisation in a wider array of applications as well as facilitating greater adoption.

A 2020 IEA report[33] on battery innovation looks at patents filed at the European Patent Office and concludes battery storage activity has outstripped overall patent activity. Specifically, lithium-ion innovation has been the primary driver of development since 2003, accounting for 40% of all patents.

While lithium-ion batteries currently dominate the market, the quest for better performance and lower costs has led to the exploration of alternative materials both through variant improvements in Li-Ion chemistries as well as innovation in solid-state batteries which promise to offer higher energy densities and improved safety compared to standard lithium-ion counterparts. Meanwhile, research into materials such as silicon, sulfur, niobium, sodium and polymer push the boundaries of what's possible in terms of energy density, cycle life, charge and discharge rate, and safety. These material innovations not only promise to improve performance, energy density, charge rate, safety and operable temperature ranges, but also reduce costs.

Li-Ion battery pack prices and estimated demand

Source: Goldman Sachs, BNEF and Alexa Capital

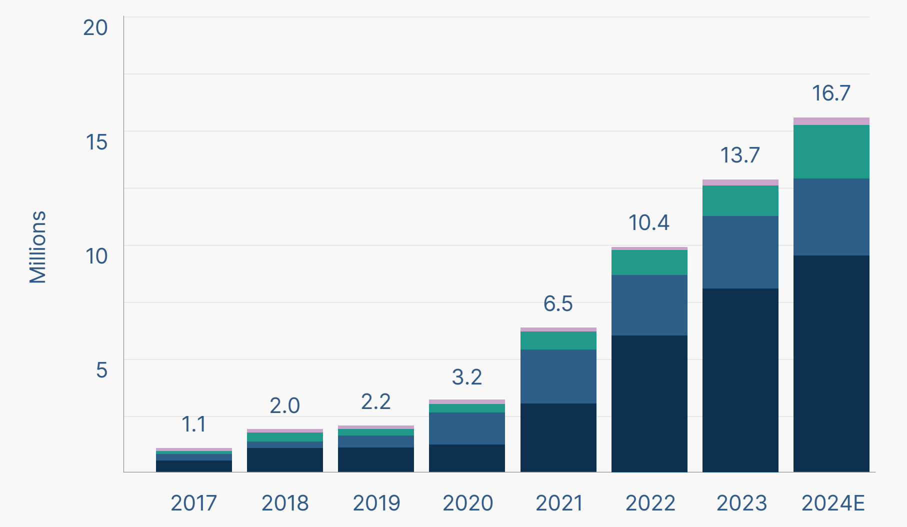


Electrification of transport fuelling innovation and scale

The battery domino effect, so named by RMI[34], describes how technological advancements in one area can catalyse development in others. Innovation has optimised the integration of batteries into the digital devices that make up our modern way of life. Those same batteries were used in the first Tesla electric vehicle, the Roadster, and the resulting surge in EV popularity has not only increased demand for high-performance batteries but also incentivised advancements in battery technology. Manufacturers and researchers are in a constant race to improve energy density, extend lifespan and enhance safety, all while keeping an eye on reducing costs. This focus on performance and affordability has yielded remarkable results, making electric vehicles more accessible and appealing to a broader audience.

Demand for electric vehicles has incentivised massive improvements in battery manufacturing and performance that have resulted in lower costs, despite the volatility of commodities prices for key inputs.

According to BNEF, close to half of all two wheelers sold globally today are fully electric, with EVs at 17.7% of global automobile sales in 2023. BNEF estimates that 705 GWh or 75% of 2023 battery demand was for passenger vehicles and this is expected to rise to 2,370 GWh (65%) by 2030. Familiarity with the technology has resulted in new applications in other forms of transport (buses and commercial vehicles) as well as stationary storage, with estimates of total battery demand of 3,635 GWh by 2030.[35] Additionally, many geographies have set stationary storage targets in anticipation of the transition to renewable generation.



EV passenger sales are accelerating, especially in China and Europe

Source: Bloomberg and Alexa Capital

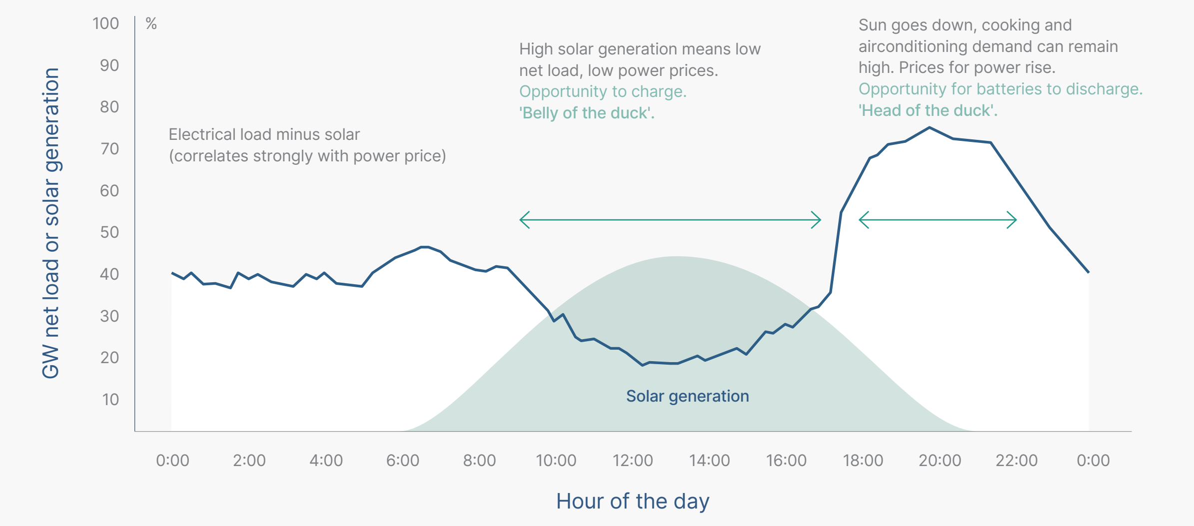
A growing need for fast-responding storage on the grid

Flexibility is needed to balance the grid as more variability in generation and consumption are introduced from an increase in renewables and DER that will impact the predictability of demand patterns.

The dual nature of energy storage, as both an injector and off-taker of electricity, uniquely positions it to assist in managing grid imbalances. A system that is dependent on renewable generation has operating costs associated with intermittency and requirements to reduce generation to match the supply of electricity relative to fluctuating demand.

In the case of solar, the 'Duck Curve' illustrates this challenge; peak electricity generation at the height of the day does not always coincide with peaks in demand. A grid system without flexibility would fall out of balance and collapse when demand outstrips available generation or when generation outpaces demand. Furthermore, accelerating demand for electricity from EV charging, data centres, air conditioning and heat pumps are impacting the ability to forecast demand and appropriately plan capacity. This is further complicated by the proliferation of behind-the-meter DER; consumers will be able to manage their consumption to minimise cost, also impacting future planning. Fortunately, the aggregation of DER via virtual power plants can address some of the same imbalances it creates. In addition, battery storage is well suited to enhancing integration of solar PV given the predictability of irradiation. Wind generation favours longer-duration storage, as wind generation patterns are less deterministic.

'Duck Curve' of energy consumption versus solar energy generation



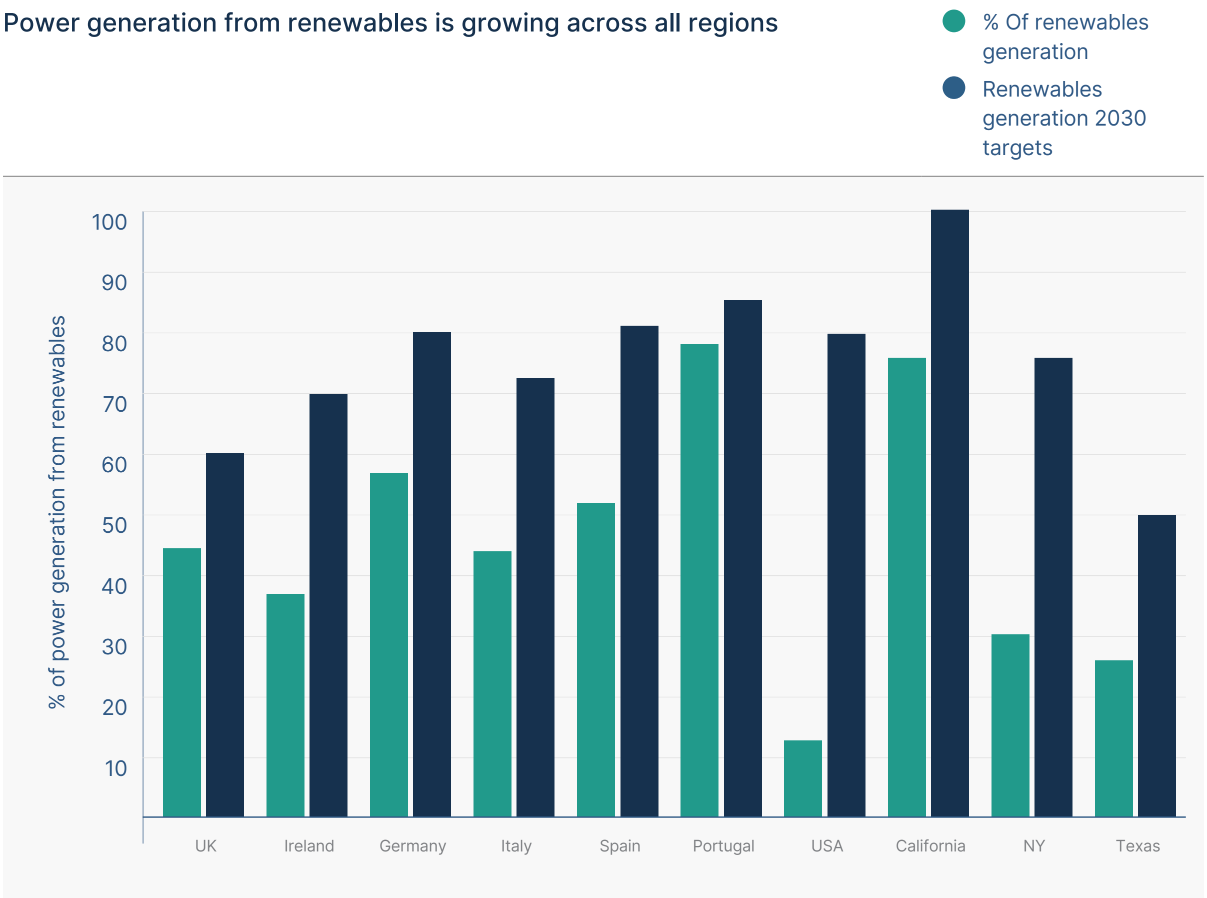
Source: BNEF and Alexa Capital

The UK has been on the forefront of best practice in handling power market volatility. National Grid has redrafted market rules to include batteries and address the challenges of grid management. As regulatory reform catches up with technology, developers will gain greater market access and new revenue opportunities as familiarisation with the technology increases.

Growing demand for clean electricity

BP forecasts electricity consumption in the energy mix to increase from 20% in 2019 to between 40-50% by 2050.[36] The surge in demand for electricity, with a pronounced focus on renewables, is propelled by a combination of global demographic trends, urban expansion and a heightened awareness of environmental issues. As the world's population grows and more people gravitate towards cities, the need for electricity to support the increasing numbers of homes, businesses and industrial operations in urban centres is critical. Moreover, the economic ascent of emerging markets fuels industrial growth and elevates living standards, leading to more widespread use of electrical appliances and a consequent rise in overall electricity demand.

Power generation from renewables is growing across all regions



Source: IEA, Ofgem and Alexa Capital

Another significant factor is the transition towards EVs. EVs not only require electricity for propulsion but also for the battery and vehicle production processes. The digital transformation of economies and the integration of technology into everyday life, from powering the internet through data centres to enabling smart home functionalities, are also key contributors to the escalating demand for electricity. In response to these developments, there is a concerted effort worldwide to move away from fossil fuels in favour of renewable energy sources such as wind, solar and hydroelectric power, driven by the urgent need to combat climate change.

Governmental policies and regulations are fostering this transition by incentivising the adoption of renewables through various measures, including financial subsidies and the introduction of carbon pricing mechanisms. Additionally, consumer preferences are increasingly aligning with environmentally friendly products and services, prompting a surge in demand for renewable energy sources. This collective pivot towards renewables not only challenges us to meet the growing demand sustainably, but also presents an unparalleled opportunity to modernise global energy infrastructures and build out energy storage. Infrastructure investments in cable and grid connections will put upward pressure on retail prices as grid operators pass through capex costs to customers, incentivising self-generation and greater market penetration of storage in the consumer market. BNEF estimates there could be 195.7 GWh of residential storage capacity globally by 2030, with a CAGR of 30%.[37]

The decarbonisation pivot towards renewables presents an unparalleled opportunity to modernise global energy infrastructure, integrating the dynamic digital capabilities of energy storage

Industry development areas on the frontier of change

Market reform unleashing industry potential

The liberalisation of power markets has increased the number of participants that provide the critical services delivering power 24 hours a day. The rules that govern market participation were drawn when fossil fuel generation dominated. As a result, many markets limit storage power market participation or have fee structures that do not suit. In non-liberalised markets operated by vertically integrated single-entity providers, regulatory approval is needed. Fortunately, regulation is catching up to technology as regulators respond to the challenges of renewable generation and increased electric demand. An overview of the subsidies and tax incentives is available in Appendix II.

Regulation is catching up with technology as policymakers respond to the challenges of renewable integration and increased electricity demand

Selected notable market reforms include:

- Battery storage accessing long-term capacity contracts in the UK, Italy and some US states. Spain is looking to approve access in late 2024.
- UK and Texas reforming ancillary services market to ensure storage has market access.
- German and Italian subsidies jumpstarting residential storage.
- Net metering in the US and feed-in tariffs guaranteeing above-market compensation for small energy producers and homeowners who export electricity to the grid.
- The US Federal Energy Regulatory Commission mandating grid operator reforms to allow storage participation in wholesale markets as well as the aggregation of distributed energy resources.

Other examples of regulation addressing obstacles to industry growth include contractual exclusivity terms that preclude value stacking and extremely long wait times for grid connections. Grid connections are a global problem with wait times of a couple of years in parts of the US and up to 15 years in the UK.[38] Grid connection delays have a significant impact on project returns because without the connection, storage cannot provide the services to generate revenues.

Battery storage market development status

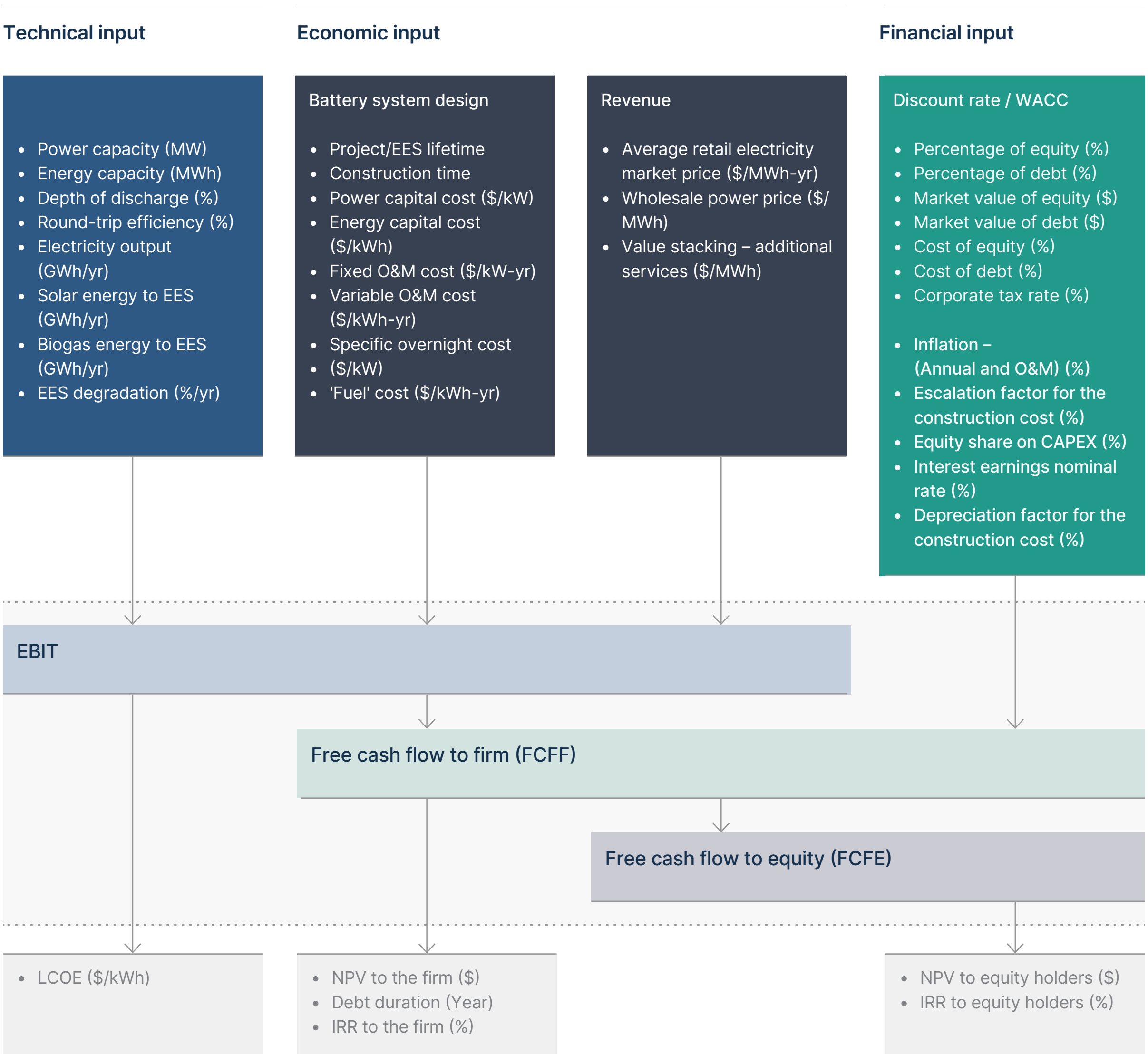
Geography	Capacity Market	Ancillary Services	Grid Double Charging*
UK	Open	Open	Yes
Italy	Open	**Closed**	Yes
Germany	Open	Open	Yes
Spain	**Proposed**	**Closed**	Yes
California, USA	Open	Open	Yes
New York, USA	Open	Open	Yes
Texas, USA	Open	Open	Yes

Source: BNEF, Energy Storage Coalition and Alexa Capital
*Grid double charging is when storage is charged a fee for supplying electricity as well as for withdrawing electricity from the grid

Track records alleviating financial underwriting risks

A lack of familiarity with battery storage infrastructure and unfit regulation governing storage participation in power markets and have been obstacles to attaining cost-effective project capital. Financiers and lenders still struggle to value battery storage projects due to the operating environment and a lack of standard performance metrics contributing to revenue visibility. Formalisation of markets and greater adoption will significantly alleviate these risks as operational and financial performance records are amassed.

Experience curves are providing cashflow track records which reduce financial underwriting risks



Source: Sandia National Laboratories and Alexa Capital

The dominant valuation method is discounted cash flow, due to its flexibility in incorporating and integrating project variables including technical specifications and value stacking of revenue streams. The main limitation is the model's assumptions, which must closely align to the actual asset performance.

A standardised track record of operating performance as well as formalised markets with a deep history will alleviate many of the challenges contributing to the difficulties in forecasting the profitability of a project. Adaptations to mitigate these risks in the near term include product warranties and long-term contracts from capacity payments. In addition, the predominance of storage in the ancillary services market adds to the visibility of future revenues by understanding past performance.

Energy storage is now emerging as an infrastructure asset class 'hedge' against structural volatility in our decarbonising power system

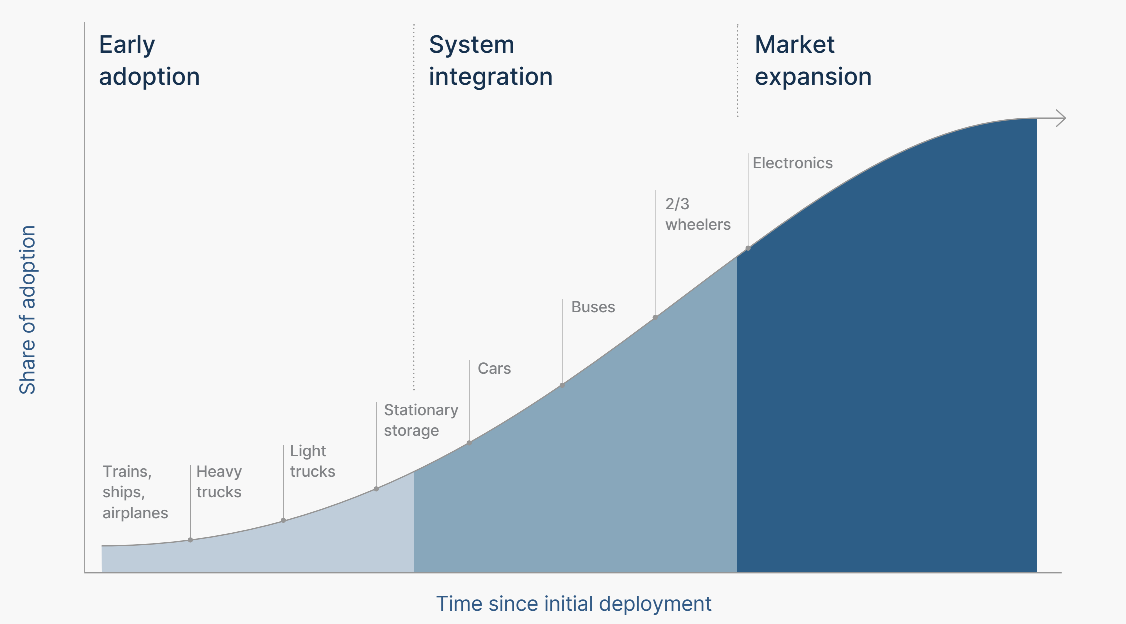
Forward power curve projections from global power market experts (such as AFRY, Aurora, Baringa, Cornwall Insight and S&P Platts) are solid tools for assessing demand growth and factors impacting longer-term supply-demand balances. But they have limitations around forecasting the day-to-day, hour-to-hour and minute-to-minute power market volatility associated with changeable weather patterns impacting solar irradiation, such as cloud formation and wind, unscheduled maintenance of conventional power flows, grid outages and the geopolitical impacts of gas and fossil fuel input prices and un-forecast climate change-induced storm conditions. These impacts all drive volatility and energy storage is emerging as an infrastructure asset class 'hedge' against structural volatility in our decarbonising power system.

Battery storage is an evolving technology

While lithium-ion batteries currently dominate the market, the quest for better performance and lower costs has led to the exploration of alternative materials and battery chemistries. Innovations in solid-state batteries, for example, promise to offer higher energy densities and improved safety compared to their lithium-ion counterparts. Meanwhile, research into materials for improved anodes and cathodes aims to push the boundaries of what's possible in terms of energy storage capacity and cycle life. These innovations could further accelerate the disruption, opening new applications and market opportunities, from portable electronics to grid-scale energy storage projects.

However, this evolving landscape also presents challenges, including the need for investments in infrastructure, the development of regulatory frameworks that support energy storage integration, and addressing the environmental impact of battery production and disposal. This dynamic landscape not only challenges manufacturers to stay ahead of the curve but also creates customer acquisition opportunities. First-time buyers of a new technology will need assistance with product selection, installation, and local regulatory compliance. Familiarisation with the technology is also likely to identify new use cases, opening new markets.

Battery integration into infrastructure and mobility is still at an early stage of adoption

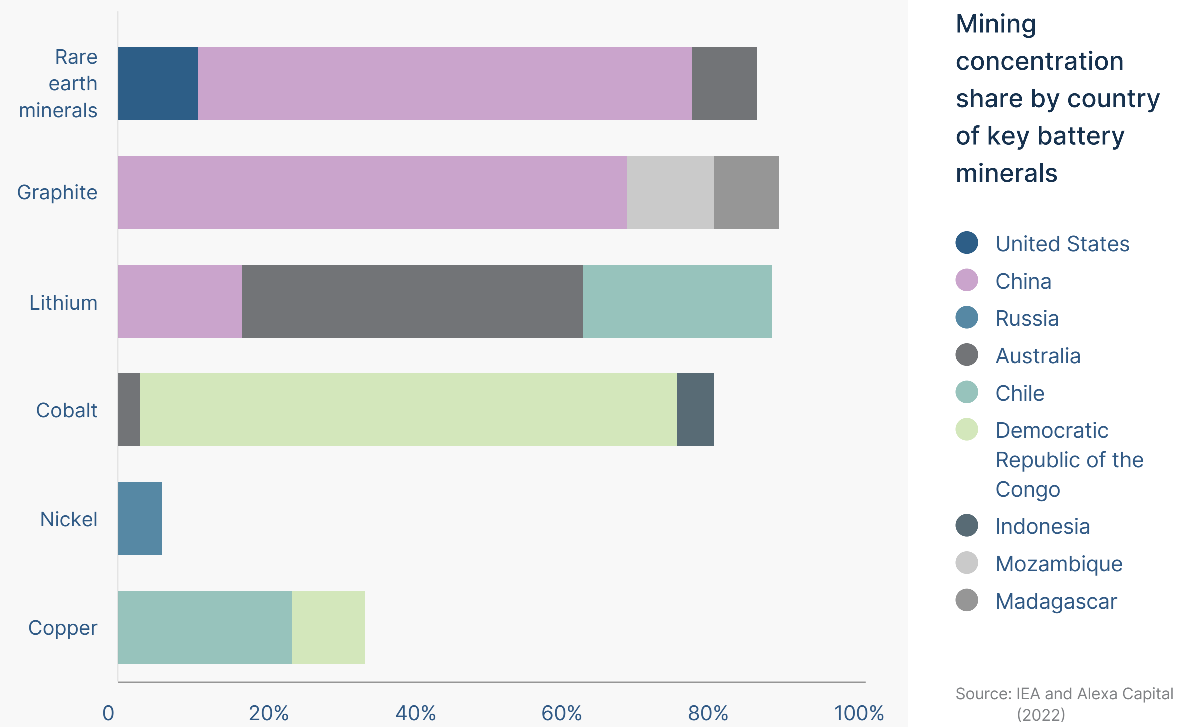


Source: RMI analysis and Alexa Capital

Raw materials and manufacturing capacity

National targets for zero-emission cars are likely to support EV sales into 2030 and beyond, with S&P Global estimating 16.2% of new car sales in 2024 will be electric.[39] The sustained demand for EVs is likely to put pressure on resources, particularly copper, in part due to the 10-year lead time for building a new mine. The lack of synchronisation can create short term pressure points that cause the price of materials to increase. In 2022, a 103% increase in EV sales[40] resulted in the price of lithium increasing two and a half times the following year.[41]

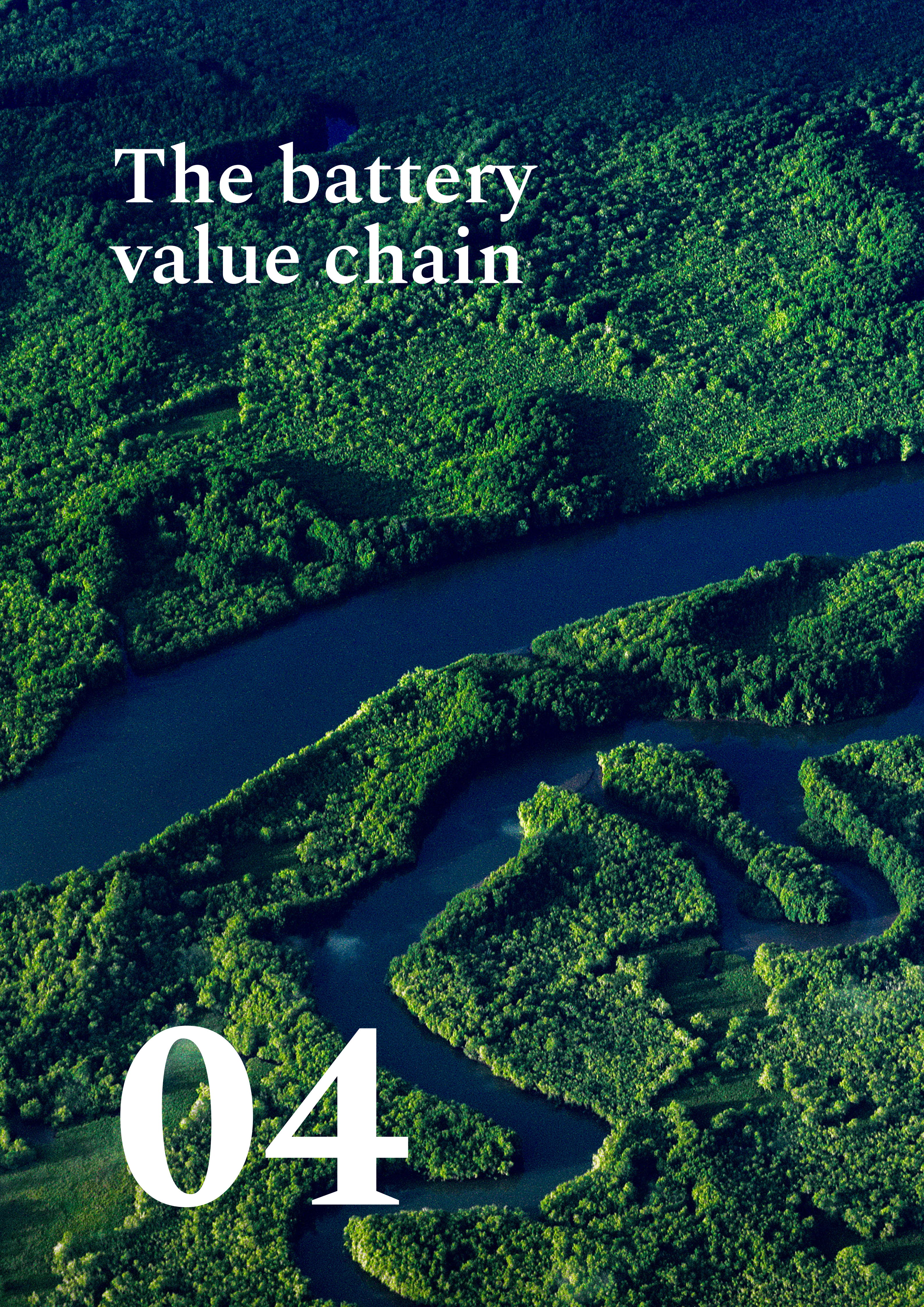
To accelerate the industry's growth, supply chain constraints need resolving. Most battery storage is currently reliant on lithium-ion battery technology and 90% of lithium mining is concentrated in three countries: Australia (47%), Chile (30%), and China (15%).[42] The concentration of resources increases further when one considers that 90% of Australian lithium exports are sent to China for processing.[43] Fortunately, increased demand has led to an increase in lithium supply, which grew over 230% from 2016 to 2022.[44] Furthermore, a burgeoning recycling industry for scrap materials aims to ensure the circularity of the industry and inevitably adding to supply.



Mining concentration share by country of key battery minerals

Source: IEA and Alexa Capital (2022)

The battery value chain



04

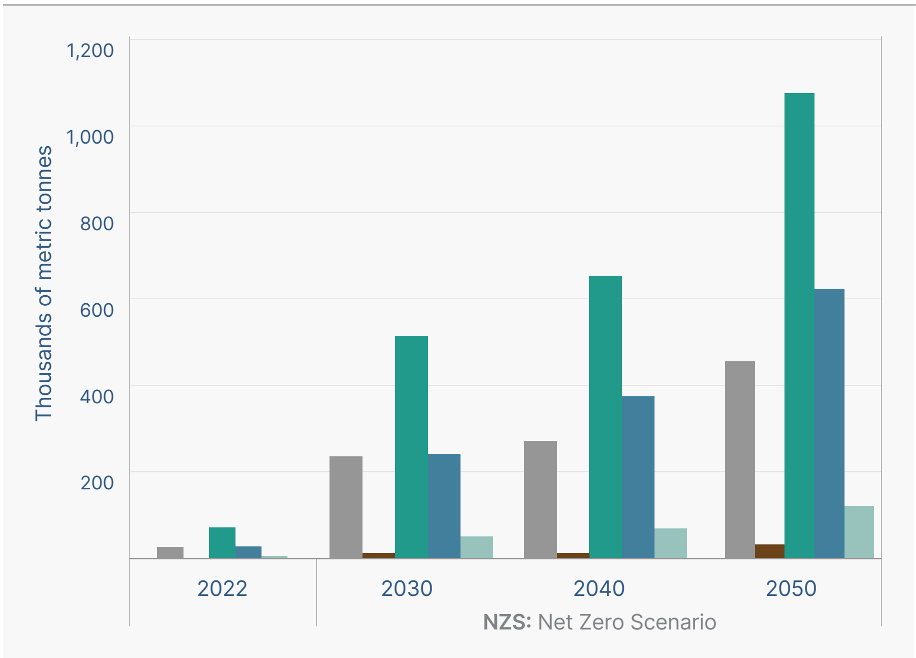
The upstream value chain

Raw materials

Our view is that the backbone of modern technology is the lithium-ion battery including its range of chemistry derivatives, such as Li-Ion NMC and LFP. We see significant growth in demand for raw materials in the coming years, in contrast to declining demand for traditional rechargeable batteries such as lead-acid batteries that are predominantly used in automotive and backup power applications, and nickel-cadmium products, still used in batteries for small consumer devices. An overview of the main materials is available in Appendix VII.

One of lithium-ion batteries' advantages is the broad range of materials and thus chemistries that can be used. The critical materials like lithium and graphite are abundant, other needed materials, such as cobalt, manganese, iron phosphate and nickel, they are all somewhat interchangeable. The raw materials market is estimated to be valued at $58.4 billion by 2030, growing at a CAGR of 15.2%.[45]

The growing demand for lithium-ion batteries has intensified the battery industry's focus on developing alternative materials that improve performance while reducing cost. While no clear battery chemistry leader has emerged, two materials are needed independent of the specific chemistry: lithium and copper.



Growth in key battery raw materials

Source: BNEF and Alexa Capital

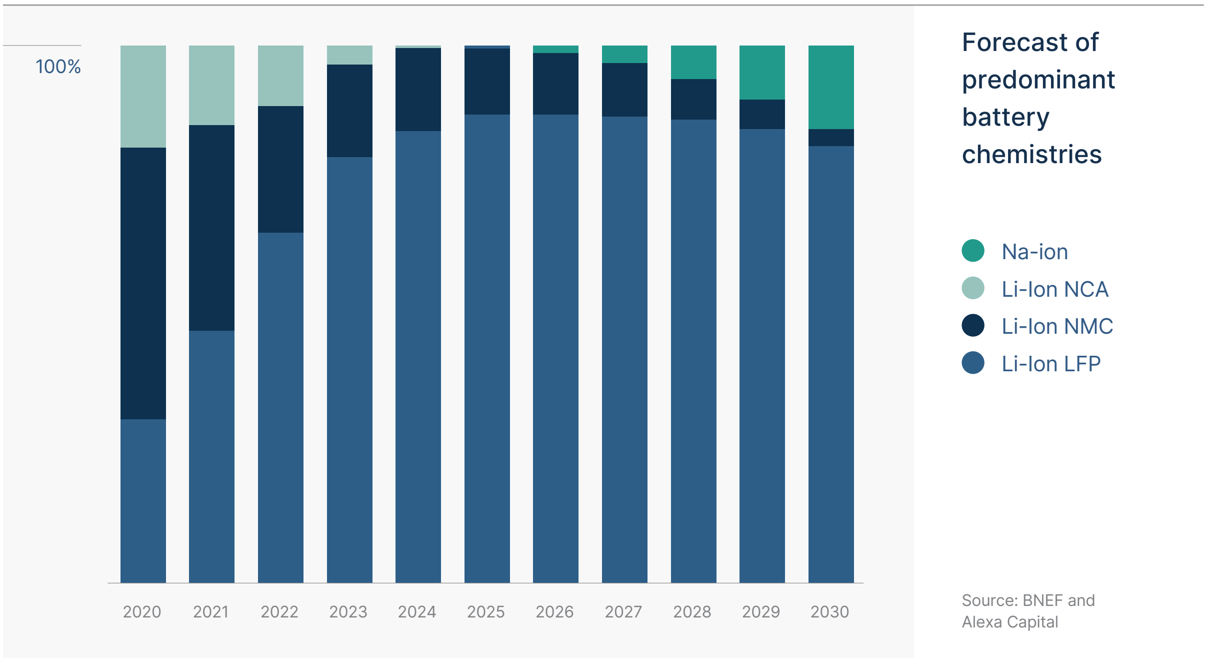
The lithium market

This is one of the largest markets for investment, given that overall demand for use in EVs and battery storage is forecast to grow 30x to 2040[46]. Lithium is the lightest metal on the periodic table, offers the highest electrochemical potential and ensures superior energy density. In the near term, lithium is expected to dominate battery chemistries thanks to the escalating use of lithium-ion technology in EVs and increased deployment in electronic devices.

Lithium market dynamics

Competition primarily revolves around securing access to high-quality reserves, investing in sustainable mining practices and developing efficient processing technologies, which are all resource endowment specific and highly capital intensive, creating high industry barriers to entry. The top five lithium suppliers account for over 90% of global production[47].

For now, we are seeing a near-term oversupply of lithium, which was a necessary safeguard to ensure countries reach renewable generation targets by 2030. This oversupply has resulted in a market correction. According to Benchmark Minerals, the global weighted average lithium prices have fallen 81% since the beginning of 2023[48] thus indicating an investment opportunity to catch a market upside as near-term demand catches up with supply.



Lithium miners

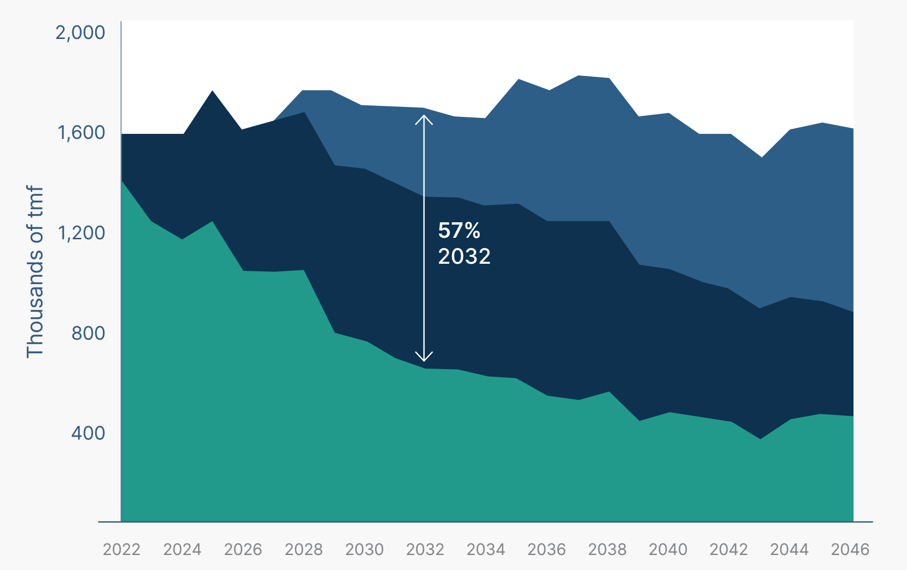
Direct investment into lithium miners is one way in which investors can express a bullish view on the commodity. Key players are carefully managing capital expenditures, which is likely to put pressure on future supply and drive prices up. Albemarle is scaling back capital spending by 24% in 2024[49] and Pilbara Minerals is planning to halt dividends to preserve capital.[50]

Copper markets

Copper has long been the preferred choice for electricity grids due to its high electrical and thermal conductivity. Decarbonisation will necessitate significant grid expansion, which will require wires, cables and transformers all made with copper. Experts expect the share of global copper demand from renewables and EVs to double over the next 10 years, from about 8% to 16%.[51]

Copper market dynamics

Supply for copper is not likely to keep up with demand. New copper mines can take 10 years to develop, limiting additional supply up to 2033. Therefore, supply is expected to fall well short of demand in the second half of this decade. The world's largest copper producer, Codelco, has highlighted the inability of current and projected mining to keep up with copper demand. At present, most of Codelco's projects under construction won't be available until 2032 at least. In addition, the quality of copper at existing mines has declined, with no major discoveries in recent years.[52]



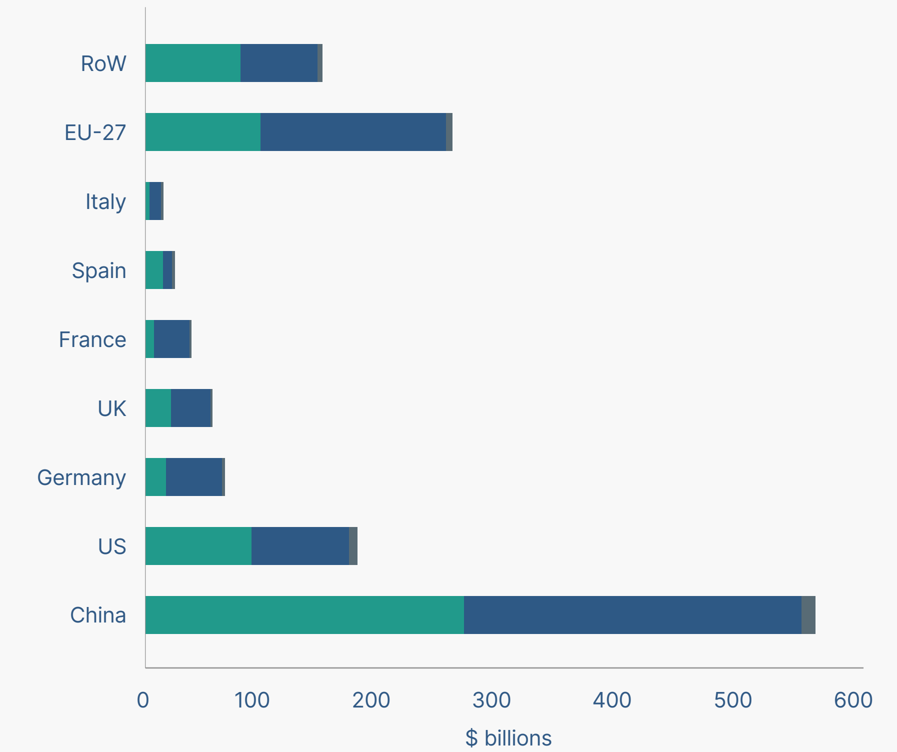
The copper challenge: There is a gap between current extraction and future projects

Source: Codelco and Alexa Capital

Copper prices have increased at a 7% CAGR from 2018 to 2023. They were also up 10% in the year to date, above consensus estimates, with some analysts revising June 2024 targets upward.[53] This demand has prompted copper miners to find faster ways to produce the metal. Therefore, we expect miners such as Glencore, BHP and others to increase capital expenditure over the next couple years. Rio Tinto and Freeport-McMoRan are also interesting ones to follow, because they have invested technologies that can extract low concentrations of copper from waste rock and help avoid lengthy mine permitting delays.[54]

China is in the lead

A risk to be aware of is China, which is expected to produce around 50% of the world's refined copper.[55] As a result, Chinese companies have made significant investments to source and increase production to 3 million tonnes a year in the Democratic Republic of the Congo over the past two decades.[56] In addition, China has led in renewables deployment, adding more than 301 GW of renewable generation capacity including solar, wind and hydro in 2023. This accounted for around 59% of the world's renewable capacity additions last year.[57]



China's energy transition investment dwarfs all major economies

- Renewable energy
- Electrified transport
- Energy storage

Source: BNEF and Alexa Capital

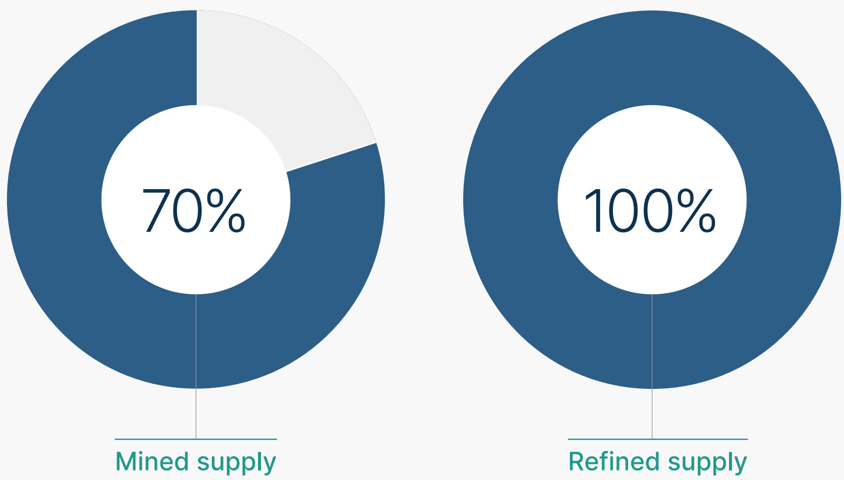
Material processing

Minerals are refined into battery-grade chemicals and components to make anode and cathode electrodes that are placed into battery cells, which store energy.

The Volta Foundation estimates the materials processing market to experience 8.75% CAGR, reaching $62 billion by 2030.[58]

Challenging Asia's dominance

China accounts for 60% of global battery-grade lithium refining capacity[59] and more than 90% of anode and electrolyte production.[60] The leading public companies are headquartered in Asia, like GanfengLithium, GEM Co. and EcoPro, and they all have significant expertise, advanced processing technologies and economies of scale, leading to high barriers to entry from competition.

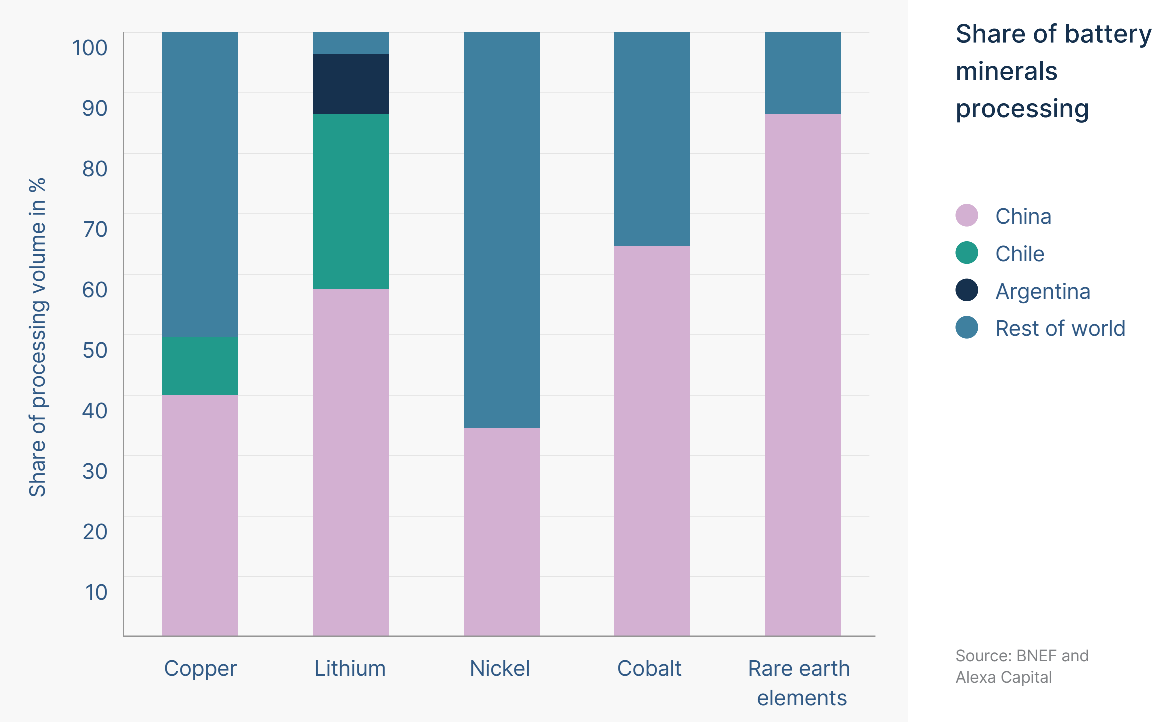


China's percentage share of transition metals

Source: BNEF and Alexa Capital Markets

Despite this, demand for components is likely to see significant growth as adoption of EV and stationary storage accelerates.

Therefore, we expect Western companies to strengthen their supply chain operations and challenge Asian markets. Albermarle, headquartered in the USA, is a leader in processing lithium compounds battery manufacturing, and many private companies in North America and Europe, such as Lithium Americas (USA), CobaltBlue (Australia), Novalith (France), Jervois (Australia) and more, have been investing in capacity expansion to shift supply chains away from Asia.



Share of battery minerals processing

Source: BNEF and Alexa Capital

Upstream: Materials – Public Companies

Select list of companies, non-exhaustive

Company	Description
ALBEMARLE	**Albemarle Corporation (NYSE:ALB)**, headquartered in the United States, is a global leader in lithium production, with mining operations in Chile and Australia.
arcadium lithium	**Arcadium Lithium (NYSE:ALTM)**, headquartered in the United States, is a leading lithium producer with mining operations in Argentina, specializing in the production of high-purity lithium compounds.
BHP	**BHP (NYSE:BHP)**, headquartered in Australia, is one of the world's largest diversified mining companies with significant copper mining operations. The company operates copper mines in various regions, including Chile, Peru, and Australia, contributing to global copper production.
EcoPro	**EcoPro (KRX:247540)** based in South Korea, is a leading materials processing company specializing in lithium-ion battery materials.
FREEPORT-MCMORAN	**Freeport-McMoRan (NYSE:FCX)**, based in the United States, is a leading copper producer with mining operations primarily located in North and South America, with a portfolio that includes significant copper reserves in regions such as Indonesia, Peru, and the United States.
GanfengLithium	**Ganfeng Lithium (SHE:002460)**, based in China, specializes in lithium extraction and processing, supplying high-quality lithium products.
GEM 格林美 资源有限 循环无限	**GEM Co. Ltd (SHE:002340)**, headquartered in China, is a prominent materials processing company with a focus on nickel and cobalt products for battery manufacturing.
GLENCORE	**Glencore (LON: GLEN)**, headquartered in Switzerland, is one of the world's largest diversified mining companies, with significant operations in copper and other commodities, as well as trading activities.
LithiumAmericas	**Lithium Americas (NYSE:LAAC)**, a public company operating mainly in North and South America, focuses on lithium exploration and aims to supply raw materials for batteries.
Pilbara Minerals	**Pilbara Minerals (ASX: PLS)**: Pilbara Minerals, based in Australia, is a leading lithium and tantalum producer. The company's flagship lithium mine, Pilgangoora, is one of the world's largest lithium-tantalum projects.
RioTinto	**Rio Tinto (LSE:RIO)** a multinational mining corporation with dual headquarters in Australia and the UK, is a major producer of copper, with operations spanning across several continents. The company's copper assets include mines in Mongolia, the United States, and Chile.
SQM	**SQM (NYSE:SQM, BCS:SQM-B)**, based in Chile, is a prominent lithium producer with extensive mining operations in the Salar de Atacama, one of the world's largest lithium-rich salt flats. The company plays a significant role in the global lithium market, supplying lithium products for diverse applications.
umicore	**Umicore (EBR:UMI)** headquartered in Belgium, is a global materials processing company with expertise in advanced materials and recycling technologies.

Upstream: Materials – Private Companies

Select list of companies, non-exhaustive

Company	Description
CobaltBlue	Founded in 2017 in Australia, **CobaltBlue** specializes in cobalt exploration and plans for materials processing to provide a sustainable source of cobalt for batteries.
CODELCO	**Codelco**, a state-owned entity headquartered in Chile, plays a pivotal role in shaping the global copper market, contributing significantly to the country's economy.
Jervois	Australia-based **Jervois**, established in 2006, focuses on mineral exploration and development, with potential involvement in materials processing for nickel and cobalt projects.
nanoOne	Canada-based **NanoOne**, established in 2011, specializes in advanced battery materials through innovative materials processing techniques using nanotechnology.
Novalith	France-based **Novalith**, founded in 2005, produces high-quality lithium compounds through advanced processing techniques for battery-grade chemicals.

The midstream value chain

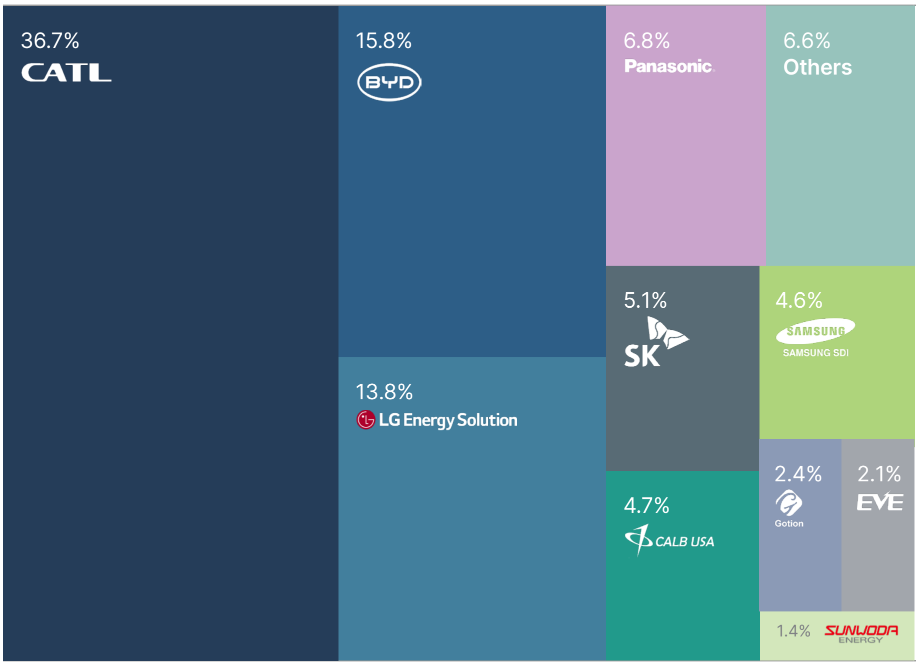
Cell and pack manufacturing

Cell and pack manufacturing involves the production of battery cells and their assembly into larger packs. It plays a crucial role in determining the performance, reliability and cost-effectiveness of energy storage.

The global market for lithium battery manufacturing is expected to reach $184 billion by 2030, a CAGR of 18.5%.[61] This growth is fuelled by declining costs and the proliferation of electric cars globally. Additionally, favourable regulation towards lithium, such as the US Environmental Protection Agency's restrictions on lead contamination, along with regulations on lead-acid battery storage, disposal and recycling, have reduced the market for lead-acid batteries and increased the need for lithium-ion batteries in automobiles.

Concentrated market

China's leadership in energy storage extends from raw material extraction to manufacturing. China, South Korea and Japan are the world's three top battery manufacturing countries[62], with Chinese companies accounting for more than 56% of the EV battery market, followed by Korea (with a 26% market share) and Japan (with 10%).[63] The top five manufacturers have 70% market share and are all based in Asia.



Battery cell & pack manufacturers market share

Source: SNE Research and Alexa Capital (2023)

Competing with incumbents

There are multiple barriers for new entrants to manufacturing markets, including incumbents' access to equipment manufacturers and expert knowledge, extensive vertical integration, and economies of scale.

New players in the market struggle to obtain vital equipment needed to boost production, as there are only a few European companies specializing in battery cell manufacturing machinery for tasks like slurry mixing, electrode manufacturing, cell assembly, and finishing.[64] The majority are in China, Japan and South Korea. Furthermore, suppliers are operating near capacity and prioritising orders of return customers. For example, even well-capitalised new entrants such as Northvolt have had to source equipment from Japan.[65]

Furthermore, leading players such as CATL and BYD also serve the largest EV manufacturers, with clients including Volkswagen, Nissan, Nio, Tata and Tesla. This has favoured the incumbents disproportionately, evidenced by the fact that CATL's sales in Europe almost doubled during 2023.[66] This makes it hard for challengers to penetrate the automobile market as car manufacturers seek to reduce the expense associated with electric vehicles. In addition, even the top players are struggling with skilled labour shortages, which impose additional challenges for new entrants.

Investment themes across cell and pack manufacturers

Investors should be on the lookout for vertical integration and diversification of product lines.

Vertical integration can result in resilient margins. Joint ventures and acquisitions of suppliers establish long-term access to input materials, allowing manufacturers to compete on cost. BYD and Tesla are great examples of vertical integration lowering prices. For example, Tesla has decreased prices c.20%[67], which has put pressure on competitors with less pricing power.

Other options include diversification by product or customer segment. CATL and LG Energy Solutions (LGES) are two good examples. CATL has exposure to nickel and lithium battery technologies, and LGES, historically focused on nickel, plans to increase exposure to lithium batteries catering to energy storage systems and small-range EVs. Both companies have laid out plans for next-generation batteries, including CATL's sodium-ion batteries[68] and LGES's lithium-sulfur solid-state batteries, creating further optionality[69].

There are also specialist cell and pack manufacturers developing differentiated products. For example, European-based Leclanche SA (SWX: LECN) has developed both a sustainable and proprietary water-based cell manufacturing process, which is more environmentally friendly. They also designed a differentiated cell and module with longer cycle lives that are highly suitable for infrastructure applications such as marine and rail electrification. This group has exciting technology, but with a challenging capital structure which has limited its access to capital.

As the market grows and competition increases, input costs will likely continue their upward trajectory, offset by manufacturing advancements that will lower the cost of storage and facilitate adoption. The price of lithium-ion battery packs will fall about 40% leading up to 2030.[70]

Vertical integration has been a major driver of battery cost efficiency, noting there may be emerging room for specialist differentiated products

Midstream: Cell & Pack Manufacturers – Public Companies

Select list of companies, non-exhaustive

Company	Description
amprius	**Amprius Technologies (NASDAQ: AMP)**, headquartered in the United States, is developer of high-energy-density lithium-ion battery technology, focusing on silicon anode materials to enhance battery performance for electric vehicles, portable electronics, and energy storage applications.
BYD	**BYD (HKG:1211)**, headquartered in China, is a leading manufacturer of electric vehicles and lithium-ion battery packs. The company's diversified product portfolio includes battery cells, battery modules, and complete battery systems for various applications.
CALB 中创新航	**CALB Group (HKG:3931)**, headquartered in China, is a leading manufacturer of lithium-ion batteries for electric vehicles, energy storage systems, and other applications.
CATL	**CATL (SHE:300750)**, based in China, is one of the world's largest manufacturers of lithium-ion batteries and battery cells. The company supplies batteries for electric vehicles, energy storage systems, and other applications.
EVE	**EVE Energy (SHE:300014)**, based in China, is a prominent manufacturer of lithium-ion battery cells and packs. The company's batteries are used in electric vehicles, energy storage systems, and other applications.
Gotion	**Gotion High-Tech (SHE:002074)**, headquartered in China, is a leading manufacturer of lithium-ion battery cells and packs for electric vehicles and energy storage systems.
LG Energy Solution	**LG Energy Solution (KRX:373220)**, based in South Korea, is a global leader in lithium-ion battery technology and manufacturing. The company supplies battery cells and packs for electric vehicles, energy storage systems, and consumer electronics.
Panasonic	**Panasonic Corporation (TYO:6752)**, headquartered in Japan, is a prominent manufacturer of lithium-ion battery cells and packs. The company's batteries are widely used in electric vehicles, hybrid vehicles, and energy storage systems.
SAMSUNG SDI	**Samsung SDI (KRX:006400)**, based in South Korea, is a global manufacturer of lithium-ion battery cells and packs. The company's batteries are used in electric vehicles, energy storage systems, and consumer electronics.
SK innovation	**SK Innovation (KRX:096770)**, based in South Korea, is a major manufacturer of lithium-ion battery cells and packs. The company supplies batteries for electric vehicles, energy storage systems, and portable electronic devices.
SUNWODA ENERGY	**Sunwoda Electronic (SHE:300207)**, headquartered in China, is a manufacturer of lithium-ion battery cells and packs for electric vehicles, consumer electronics, and other applications.
TESLA	**Tesla (NASDAQ:TSLA)**, headquartered in the United States, is a leading manufacturer of electric vehicles and energy storage solutions. The company produces lithium-ion battery cells and packs for its electric vehicles, energy storage products, and solar energy systems.

Midstream: Cell & Pack Manufacturers – Private Companies

Select list of companies, non-exhaustive

Company	Description
ADDIONICS	**Addionics**, founded in 2017 out of the United Kingdom, the company aims to enhance battery performance and safety through innovative engineering solutions.
ASCEND ELEMENTS	**Ascend Elements**, based in Asia, is a key provider of raw materials for energy storage systems, specializing in lithium extraction and processing to support the growing demand for lithium-ion batteries in electric vehicles and renewable energy storage projects.
CARBON X	Netherlands-based **CarbonX' graphite technology** has potential for lower energy / lower cost vs synthetic and natural graphite. The company developed the technology for the tire industry and is now addressing the battery market with aim to supply anode materials at scale.
E-MAGY on with silicon	**E-Magy**, headquartered in the Netherlands, is an advanced materials manufacturer that supplies nano-porous silicon dominant anode material for lithium-ion batteries that delivers 40% higher energy density.
ECHION TECHNOLOGIES	UK-based **Echion's** niobium-based anode material enables lithium-ion batteries to fast charge in less than 10 minutes, with high energy density and a cycle life of more than 10,000 cycles. Target markets include heavy duty transport and industrial applications
GROUP14	**Group14**, based in the United States, is a leading developer of silicon-carbon composite materials for lithium-ion batteries, aiming to improve energy density, cycle life, and cost-effectiveness for electric vehicles and energy storage applications.
MORROW	**Morrow Batteries**, established in 2020, develops industrialized graphene-enhanced lithium-sulfur batteries that significantly improve the performance of the battery and reduce its environmental footprint, providing clients with cost-effective and sustainable battery cells.
nexeon	**Nexon**, headquartered in South Korea, is a prominent player in the energy storage industry, offering advanced lithium-ion battery technologies for electric vehicles, consumer electronics, and stationary storage applications.
northvolt	**Northvolt**, founded in 2016 and headquartered in Sweden, is a prominent player in the European battery industry, specializes in component and cell manufacturing for lithium-ion batteries, with a focus on environmentally friendly production
REDWOOD MATERIALS	**Redwood Materials**, established in 2017 and operating out of the United States, the company focuses on sustainable practices to recycle and recover valuable materials from end-of-life batteries.
Sila	**Sila Nanotechnologies**, stablished in 2011 in San Francisco, the company aims to improve battery performance and longevity through innovative materials design for next-generation lithium-ion batteries.
Sion Power	**Sion Power**, founded in the United States in the mid 1990s, the company aims to develop high-energy-density batteries for electric mobility and aerospace applications.
Superdielectrics	UK-based **Superdielectrics**' energy storage technology combines electric fields (physics) and conventional chemical storage (chemistry) to create a new aqueous polymer-based energy storage technology. The technology completed one million hours of testing demonstrating ability to charge 10x faster vs lead-acid batteries with high cycle life targeting applications across several markets such as off grid (solar + storage) and e-mobility.
VERKOR	**Verkor**, headquartered in France, is an emerging leader in battery cell manufacturing, focused on producing high-performance lithium-ion battery cells for electric vehicles and energy storage applications.

System integrators

System integrators are responsible for procuring components such as battery modules, PCS and other equipment to construct a battery. They assemble, offer warranties and integrate controls and software to ensure the proper operation of storage installations. We expect integrators to capture at least 25% of the profit share from the battery energy storage value chain, which will undoubtedly attract competition.[71]

The leading integrators are characterised by having strong supply chain networks, often partnering with EPC firms to provide a suite of services, including project development and operation and maintenance contracts.

Independent system integrators require scale to maintain sustainable margins, noting the tension between these and large battery manufacturers which have expanded into downstream services

Investment opportunities within a concentrated market

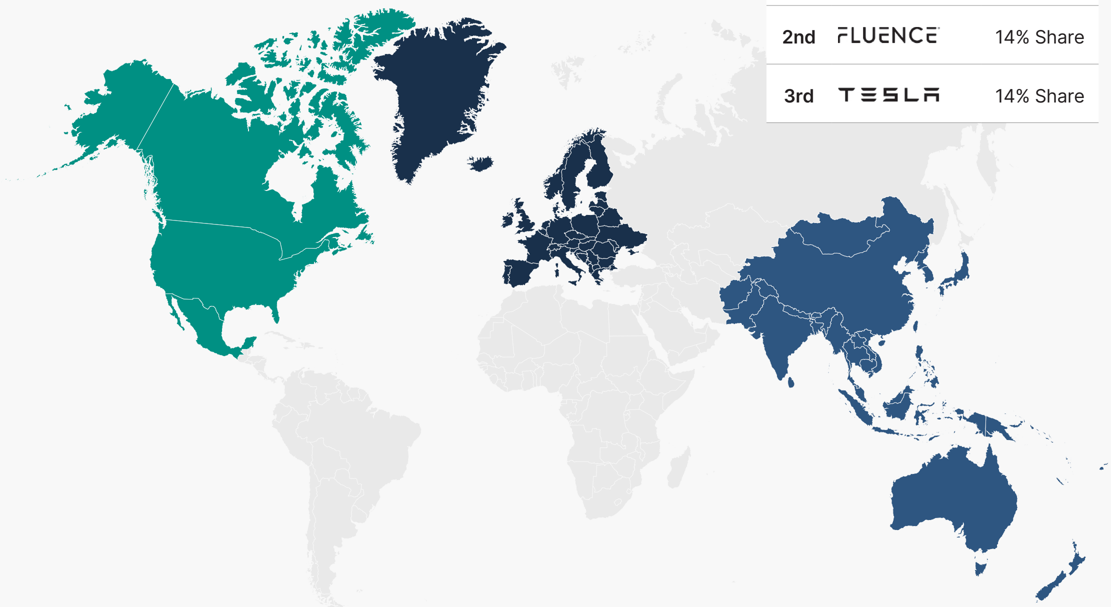
The market is concentrated, with the top five system integrators accounting for 62% of global shipments measured in MWh. Sungrow holds a commanding position, with a 16% share of the global market by shipments, trailed by Fluence and Tesla, each commanding around 14%. Followed closely by Huawei and BYD, both capturing a 9% market share.[72]

We anticipate a more diversified landscape, with increased competition from new entrants and alternative technologies. System integrators are likely to vertically integrate to secure their supply chains amidst a boom in growth, which also erects a barrier to entry. For example, disintermediation would reduce the one-year lead time on transformers of all sizes.[73] Additionally, new entrants among component manufacturers may look to enter markets further down the value chain, with inverter manufacturers like Huawei[74] and Sungrow[75] expanding into solar-plus-storage applications.

Energy storage system integrator market share by geography

Global

1st	SUNGROW	16% Share
2nd	FLUENCE	14% Share
3rd	TESLA	14% Share



North America

1st	TESLA	25% Share
2nd	FLUENCE	22% Share
3rd	SUNGROW	13% Share

Europe

1st	FLUENCE	19% Share
2nd	Nidec	18% Share
3rd	BYD	17% Share

Asia Pacific

1st	SUNGROW	25% Share
2nd	中国中车 CRRC	24% Share
3rd	海博思创	16% Share

Source: Wood Mackenzie

With favourable policies such as the US Inflation Reduction Act, UK Battery Strategy, European Green Deal and more, we expect the global system integrator market to expand, supporting profits for all major players. Challengers such as Wartsila and Powin Energy will seek strategic opportunities to fuel their expansion efforts.

System Integrators – Public Companies

Select list of companies, non-exhaustive

Company	Description
FLUENCE	**Fluence (NASDAQ: FLNC)**, based in the United States, Fluence specializes in energy storage system integration, offering advanced solutions for grid-scale and commercial applications worldwide.
stem	**Stem (NYSE:STEM)**, based in the United States, is a leading provider of intelligent energy storage solutions, such as BMS software with proprietary algorithms, enabling real-time monitoring, and predictive maintenance for commercial and industrial customers.
SUNGROW	Sungrow **(SHE:300274)**, headquartered in China, is a prominent system integrator specializing in solar and energy storage solutions, contributing to the global transition towards renewable energy.
TESLA	**Tesla (NASDAQ:TSLA)**, headquartered in the United States, is a leading system integrator in the energy sector, known for its innovative electric vehicle and energy storage solutions.
WÄRTSILÄ	**Wärtsilä (HEL:WRT1V)**, based in Finland, is a leading provider of power solutions, including energy storage systems, enabling the integration of renewable energy sources into the grid.

System Integrators – Private Companies

Select list of companies, non-exhaustive

Company	Description
HYPER STRONG	**Hyperstrong**, based in the United States, is a system integrator specializing in advanced energy storage solutions for commercial and industrial applications.
nyobolt	**Nyobolt**, headquartered in the United Kingdom, specializes in advanced battery technology and system integration for EVs and stationery storage solutions.
POWIN	**Powin Energy**, headquartered in the United States, offers system integration services for energy storage projects, focusing on scalable and modular battery solutions.
RIMAC	**Rimac**, based in Croatia, is a system integrator known for its expertise in EV technology and ESS, driving the advancement of sustainable transportation and energy systems.
VOLTA TRUCKS	**Volta Trucks**, headquartered in Sweden, specializes in electric vehicle system integration, including ESS, contributing to the electrification of urban transportation.

Battery controls

Originally, battery manufacturers installed BMSs in vehicles to monitor and share information with OEMs and fleet operators, or manage cell health in stationary storage systems. However, the demand for better applications is growing and these systems are now present in every electronic device around us.

Battery analytics solutions leverage advanced machine learning algorithms and predictive modelling to extract actionable insights from battery performance data. These insights enable operators to optimise energy storage system performance, prolong battery lifespan and prevent failures, or even hazards, with batteries in use.

Battery Controls - Public & Private Companies

Select list of companies, non-exhaustive

Design/R&D analytics	Process control	Manufacturing analytics	In-field analytics
Example: simulation, predictive medelling, cell design improvement	**Example:** simulation, predictive medelling, cell design improvement	**Example:** simulation, predictive medelling, cell design improvement	**Example:** simulation, predictive medelling, cell design improvement
AIONICS, VOLTAIQ	ABB, BECKHOFF	VOLTAIQ, PDF/SOLUTIONS	Honeywell, TWAICE
TWAICE, ionworks	SIEMENS, camLine	SIEMENS, APPLIED MATERIALS	VOLTAIQ, BattGenie.
ABOUT:ENERGY, ENERGSOFT	Honeywell, MITSUBISHI ELECTRIC	AmpLabs, E7 eyelit7	novo, zitara
BATEMO, GT AutoLion	INFICON, Schneider Electric		ACCURE, volytica diagnostics

Source: Volta Foundation

A market driven by innovation in the private markets

Sales entities, project development organisations, commissioning and other customer acquisition activities are estimated to capture at least 15% of the battery energy storage value chain profit share.[76]

While this market is still fragmented, battery performance analytics are increasingly recognised as the key to greater battery adoption and profitability. We see this as a growing market, but with most of the opportunities currently showing in the private markets accessed by venture capital, private equity and large conglomerates. A few examples are WAE's Elysia platform[77] and Qnovo, whose algorithms provide better estimates to streamline operations, allowing for the optimisation of the battery.[78]

Another theme is battery system safety. The storage industry will incur manufacturing challenges as it continues to scale, highlighting the importance of continuous monitoring throughout the battery's lifecycle. As a result, many system integrators have invested in advanced monitoring systems and predictive maintenance technologies to ensure battery system safety.

Recycling

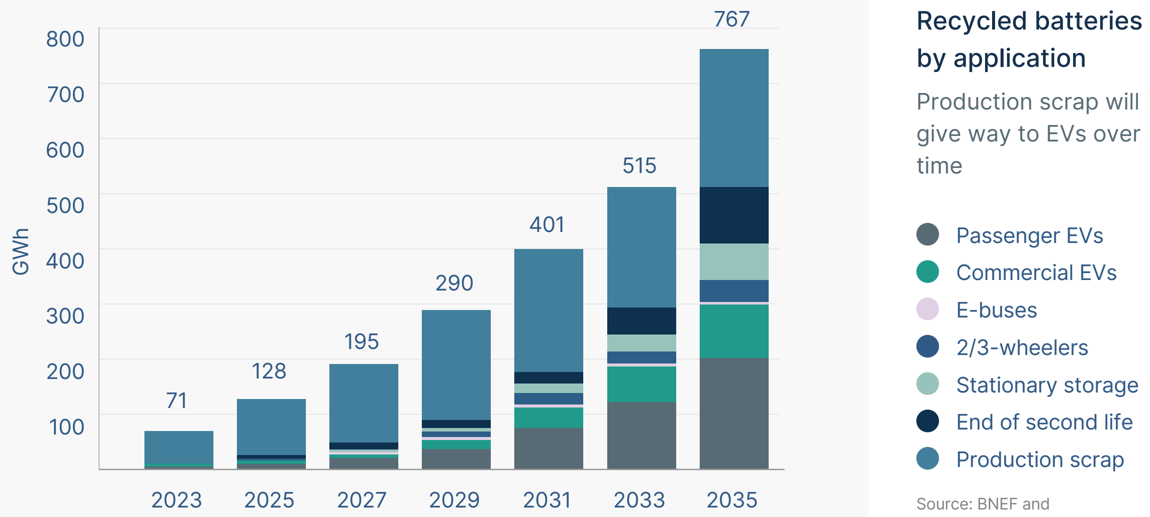
Batteries physically degrade over time, which reduces performance and eventually makes them unsuitable for use. As more batteries are deployed, repurposing or recycling batteries is necessary to alleviate pressure for rare minerals as well as reduce waste. Although this market is still in its infancy, the Volta foundation estimates the recycling and second life market will reach $40.6 billion by 2030[79], growing at a CAGR of 26.5% per year[80].

Near-term opportunities

This market remains early-stage and yet to mature with only 0.35 million metric tons recycled in 2023 but estimated to grow to 3.7 million metric tons expected to be recycled by 2035[81]. In the near-term, the rise of fully electric vehicles, which are expected to constitute 40% of global car sales by 2030, ensures a reliable source of battery materials for recycling, particularly lithium-ion cathodes.[82] The circularity of the storage market will require a significant expansion of recycling capacity, with the EU aiming to double it by 2025, announcing over 30 recycling projects.

Battery recycling is asset- and capital-intensive, requiring sophisticated equipment to treat hazardous emissions. BCG breaks down EV battery recycling into four steps, with the corresponding estimated industry profit (EBITDA)[83]:

- Battery collection, logistics and sorting ($100 million).
- Battery discharge and dismantling ($60 million).
- Pre-treatment of battery shreds and black mass production ($180 million).
- Battery materials recovery with chemical processes ($500 million).



Recycled batteries by application

Production scrap will give way to EVs over time

Source: BNEF and Alexa Capital

Key drivers behind battery recycling

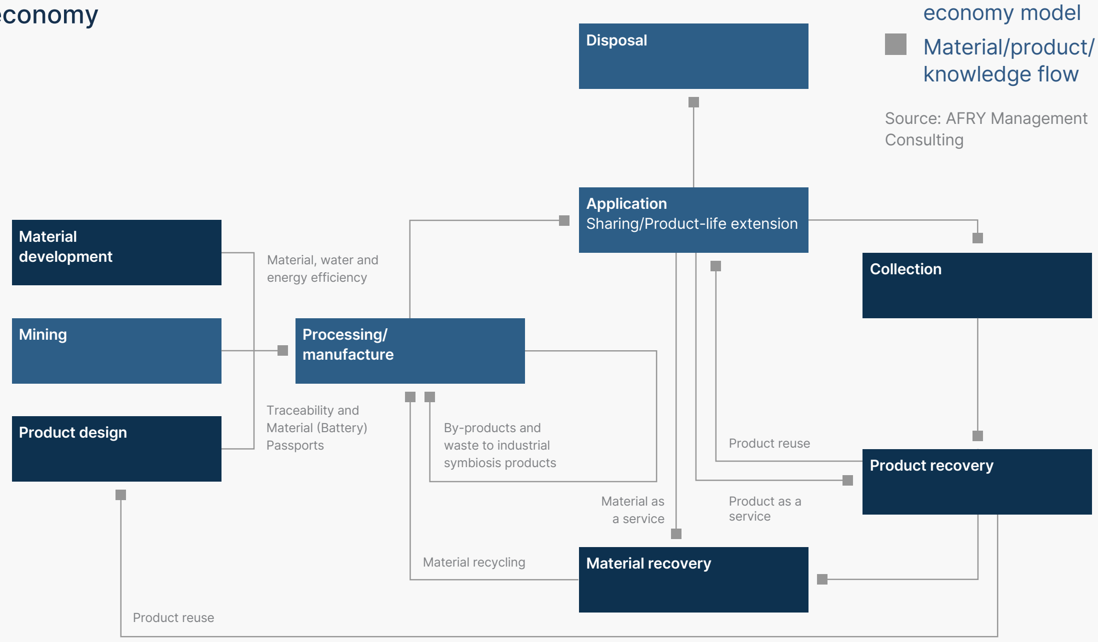
The complexity and high capital expenditure of recycling batteries affect the recoverable value of recycled assets. However, recycling profitability hinges primarily on cell chemistry, with recovered materials from nickel-based chemistries fetching around 25-42 $/kWh, compared to lithium iron phosphate (LFP) batteries, which earn about 15 $/kWh.[84]

There are three potential pathways for extracting additional value from used vehicle batteries:

- Remanufacture: Refurbishing used battery packs through component replacement or upgrades for reuse in the same or other applications.
- Repurpose: Using the battery for a different purpose than its original production intent.
- Recycle: Breaking down the battery to retrieve valuable raw materials. Additionally, during EV manufacturing, batteries that fail to meet quality standards create opportunities for recycling technology companies to collaborate with gigafactories.

By 2040, recycled minerals are projected to fulfil 12% of cobalt, 7% of nickel, and 5% of lithium and copper supply needs, while reused batteries are expected to contribute only 1-2% for each mineral.[85]

Framework for transitioning the battery sector from the linear economic model to the circular economy



Stages from linear economic model

Additional stages in a circular economy model

Material/product/ knowledge flow

Source: AFRY Management Consulting

Battery Recycling & 2nd Life – Public Companies

Select list of companies, non-exhaustive

Company	Description
GEM 格林美 资源有限 循环无限	**GEM (SHE:002340)**, headquartered in China, is a public company specializing in battery recycling and second-life solutions.
HUAYOU	**Huayou (SHA:603799)**, headquartered in China, is a public company that integrates recycling processes into its supply chain, promoting sustainability and resource efficiency in the battery industry.
Li-Cycle	**Li-Cycle (NYSE:LICY)**, based in Canada, employs a closed-loop recycling process to recover and refine critical battery materials, supporting the circular economy.
SungEel HiTech	**SungEel HiTech (KOSDAQ:365340)**, based in South Korea, is a public company that utilizes environmentally friendly processes to recover valuable materials from end-of-life batteries, contributing to resource conservation and waste reduction efforts.
umicore	**Umicore (EBR:UMI)**, headquartered in Belgium, is a global materials technology and recycling company that offers comprehensive recycling solutions for batteries, reclaiming valuable metals and providing high-quality recycled materials for battery manufacturing.

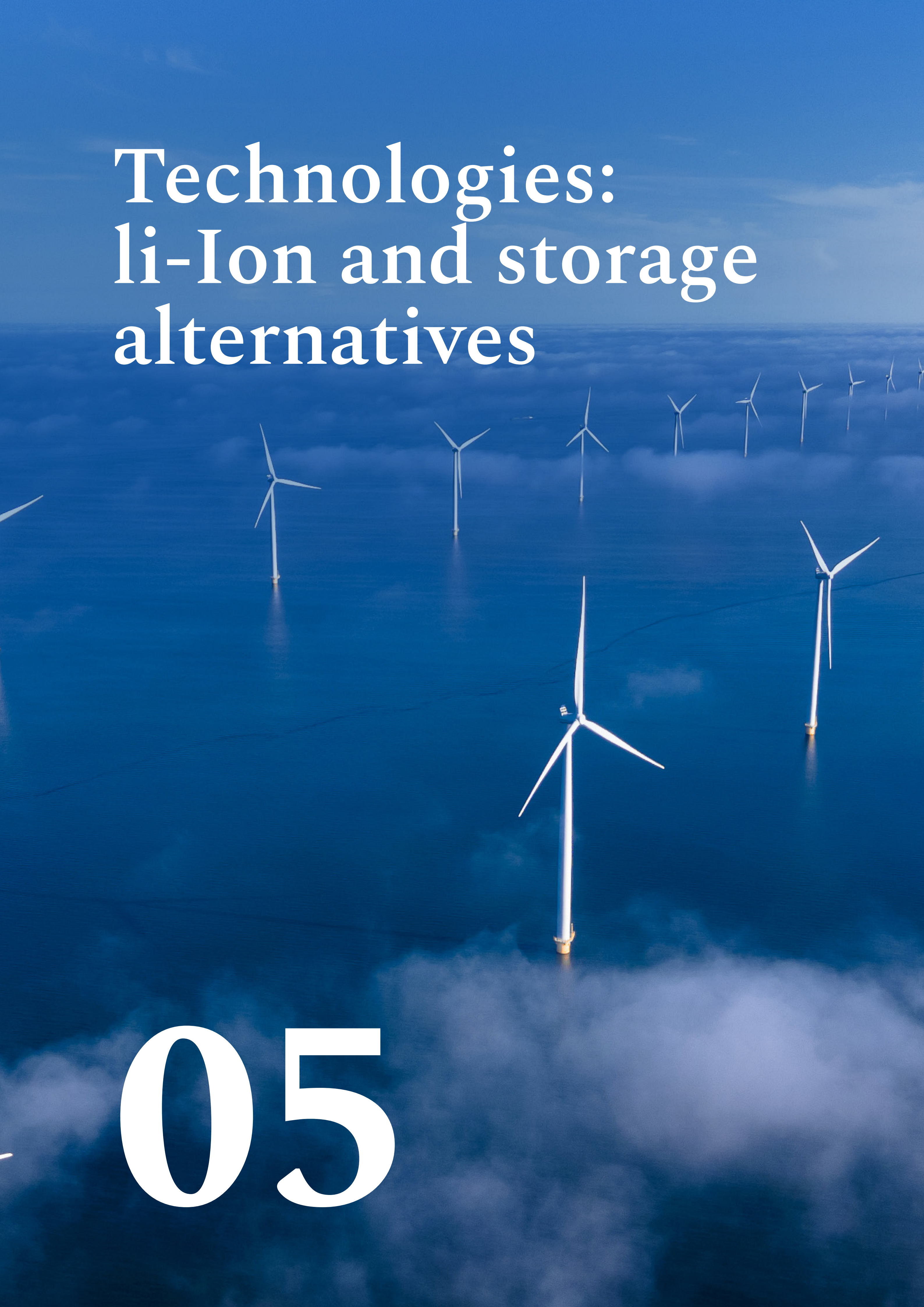
Battery Recycling & 2nd Life – Private Companies

Select list of companies, non-exhaustive

Company	Description
hydrovolt	**Hydrovolt**, based in Norway, is a private company focused on lithium-ion battery recycling, utilizing innovative processes to recover and refine critical battery materials.
REDWOOD MATERIALS	**Redwood Materials**, headquartered in the United States, is a private company specializing in advanced battery recycling utilizing sustainable processes.
ReVolta	**Revolta**, based in Brazil, is a private company focused on battery recycling and second-life applications using friendly processes to recover and repurpose materials from end-of-life batteries, contributing to resource conservation and waste reduction efforts.
SAMSAR	**Samsar**, headquartered in Australia, employs advanced technologies to recycle batteries and recover valuable materials, supporting the sustainability goals of the energy storage industry.
moment energy	**Moment Energy**, based out of Vancouver, British Columbia, provides commercial-scale clean, affordable, and reliable energy storage by repurposing retired electric vehicle batteries.

Technologies: li-Ion and storage alternatives

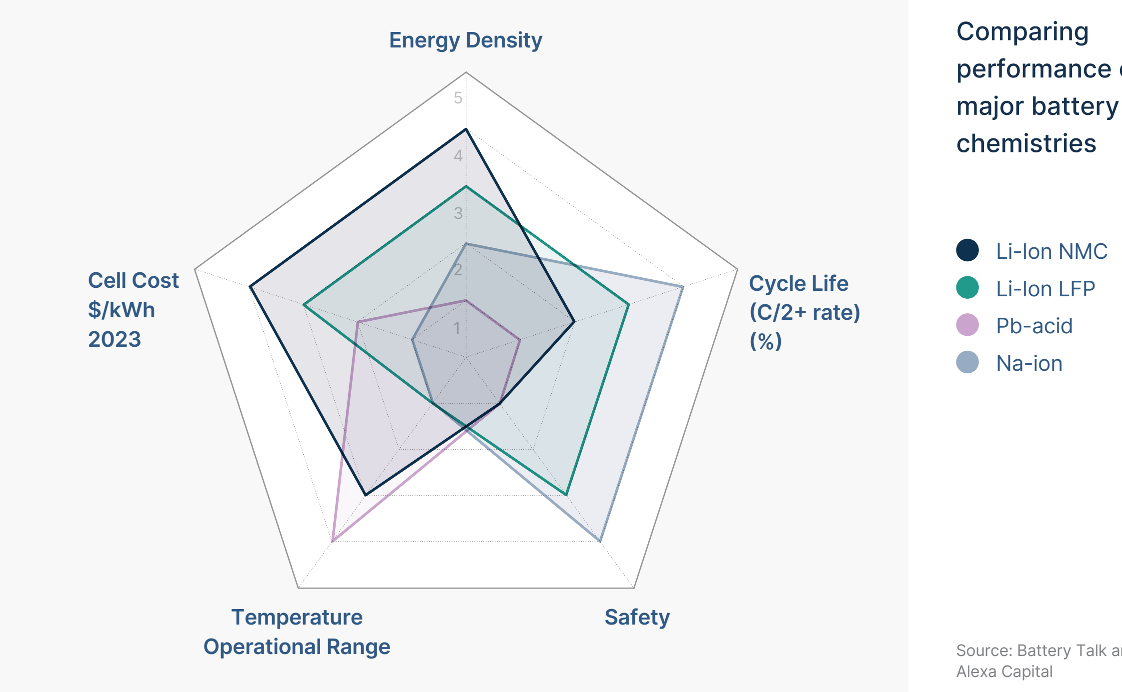
05



Electrochemical batteries and investment themes

Cutting through the alphabet soup of battery chemistries

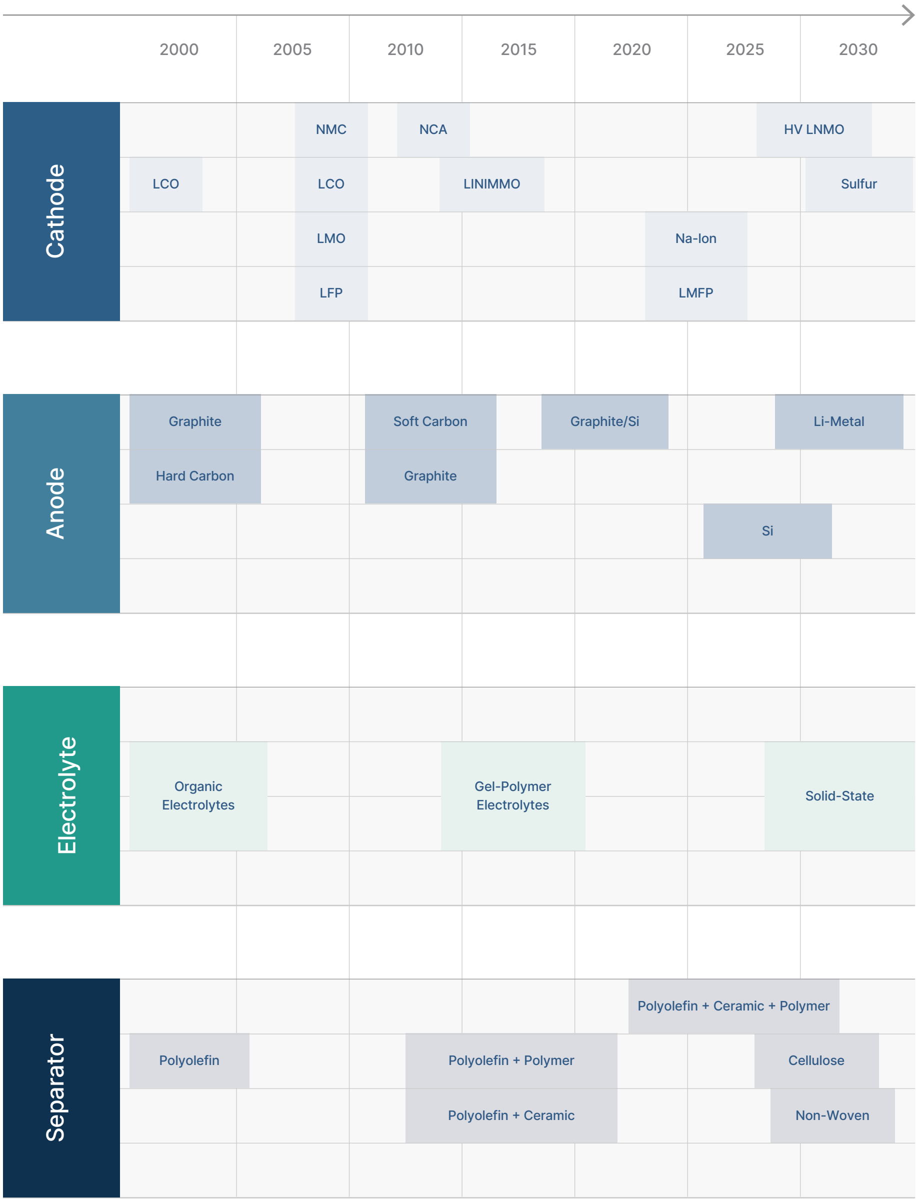
The last two decades has shown steady progress on battery development, with an array of (mainly lithium) chemistries supporting advancement around a range of performance metrics. These include cost ($/kWh), energy density (Wh/kg), cycle life, safety and operational temperature range. While lead-acid batteries have been a stable provider of energy storage applications for many years, Li-Ion nickel-manganese-cobalt (NMC) chemistry has delivered the competitive energy density for performance mobile applications. The downside, reliance on rare earth or difficult-to-source metals, including cobalt, which prevents thermal runaway and delivers the range of operating criteria required for advanced computing and electric vehicle and stationary storage applications. LFP has increasingly offered a competitive alternative to NMC where there is less sensitivity to energy density—especially for applications such as municipal buses, mid-market automobiles and stationary applications. And for the more cost-conscious stationary applications, for example in backup power, sodium-ion solutions are being adopted.



Comparing performance of major battery chemistries

Source: Battery Talk and Alexa Capital

There is market visibility around further derivations of Li-Ion, incorporating a range of cathode and anode technologies. Niobium (NbO) is showing promise for longer cycle-life applications, such as for the marine, rail and certain other long-lived infrastructure-grade use cases. Lithium sulfur (Li-S) has potential benefits, with competitive cost and energy density for performance mobility applications. It also avoids rare earth procurement issues or Chinese-controlled supply chains, but with a trade-off of shorter cycle lives for the upcoming generation of modules. The chemistry is well placed to meet the demands for storage in defence and drones, as well as other high-end mobility applications.



Timeline of battery cell chemistry development

Substantial innovation underway across cathode and anode technologies in particular

Source: Volta Foundation

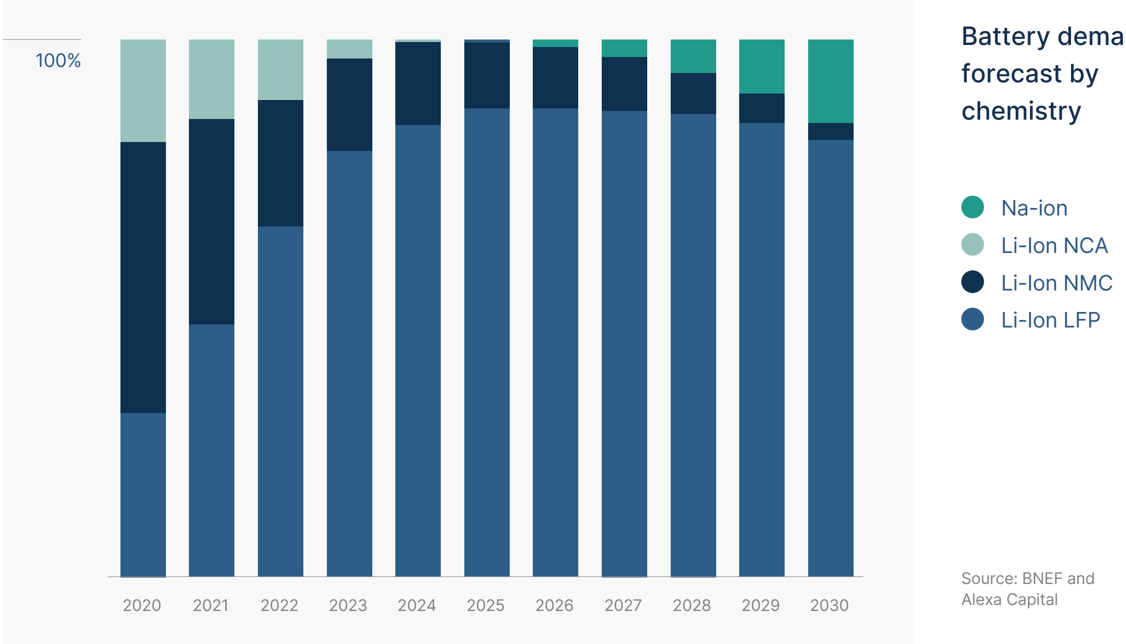
Lead-acid batteries

Lead-acid batteries have been around for so long that they are practically a commodity. Key manufacturers such as Trojan, Rolls/Surrette and MK/Deka have been producing lead-acid batteries for decades. Lead-acid storage is about 2.8 times cheaper than lithium-based storage[86] but the batteries share similar science. They use lead electrodes and sulfuric acid electrolytes to store and release electrical energy through chemical reactions. However, low temperature can cause significant reduction to lead-acid batteries' stored capacity.

Our view

We believe that the days of lead-acid batteries are numbered and they will predominantly serve as backup power sources going forward. Their use in EVs will become obsolete due to their limitations in energy density and performance.

Lithium batteries are increasingly replacing lead-acid across sectors as they offer faster charging times, lower weight (9 kg versus 30 kg) and greater depth of discharge (1,500 to 2,000 cycles versus 500 to 1,000 cycles) making them more efficient and reliable despite their higher upfront cost.[87] Some estimates forecast more than 82% of EV batteries will be lithium-ion by 2030.[88]



Battery demand forecast by chemistry

Source: BNEF and Alexa Capital

Comparing densities

Lithium-ion has three times higher energy density than the best lead-acid batteries. This energy density advantage is why consumer electronics such as smartphones use lithium-ion instead of lead-acid batteries.

A lithium-ion battery has an energy density between 150 and 200 Wh/kg and weighs approximately 0.24 kg.[89] Assuming a lithium-ion battery energy density of 150 Wh/kg for a 0.24 kg device, it would have a capacity of 36 Wh.

To achieve the same 36 Wh capacity with 50 Wh/kg lead-acid technology[90] would require 0.72 kg of batteries.

Factor	Lead Acid Battery	Lithium Battery
Charging efficiency	Low-only 70%	Fast charged — 100% of capacity, a lithium battery can be charged 50% in just 30 minutes
Weight	30 kg/kWh	9 kg/kWh, On average, Lithium-ion batteries weight 3 times less than standard lead acid batteries
Maintenance	High maintenance cost, Watter top up required every 3 months	No maintenance
Battery Life	500-1,000 cycles	1,500-2,000 cycles
Safety	Have no safety devices, are not sealed, and releases hydrogen during charging, in fact, the use is not permitted in food industry	Releases no emissions, are suitable for all applications

Source: Indiamart (Loom Solar 12 V CAML 20 Ah / 250Wh)86

Lead-Acid Batteries – Public Companies

Select list of companies, non-exhaustive

Company	Description
AMARA RAJA	**Amara Raja Batteries (NSE:ARE&M),** based in India, is a leading manufacturer of lead-acid batteries for automotive and industrial applications, serving customers globally.
COSLIGHT	**Coslight Technology International Group (HKG: 1043)**, based in China, is a manufacturer of lead-acid batteries, lithium-ion batteries, and energy storage systems for automotive, telecom, and other industries.
EnerSys	**EnerSys (NYSE:ENS)**, headquartered in the United States, is a global leader in stored energy solutions, including lead-acid batteries for various applications such as automotive, aerospace, and telecommunications.
EXIDE INDUSTRIES LIMITED	**Exide Industries (NSE:EXIDEIND)**, based in India, is a leading manufacturer of lead-acid batteries, serving diverse sectors such as automotive, industrial, and renewable energy.
GS YUASA	**GS Yuasa Corporation (TYO:6674)**, headquartered in Japan, is a multinational battery manufacturer that produces lead-acid batteries along with lithium-ion batteries for automotive, industrial, and other applications.

Lead-Acid Batteries – Private Companies

Select list of companies, non-exhaustive

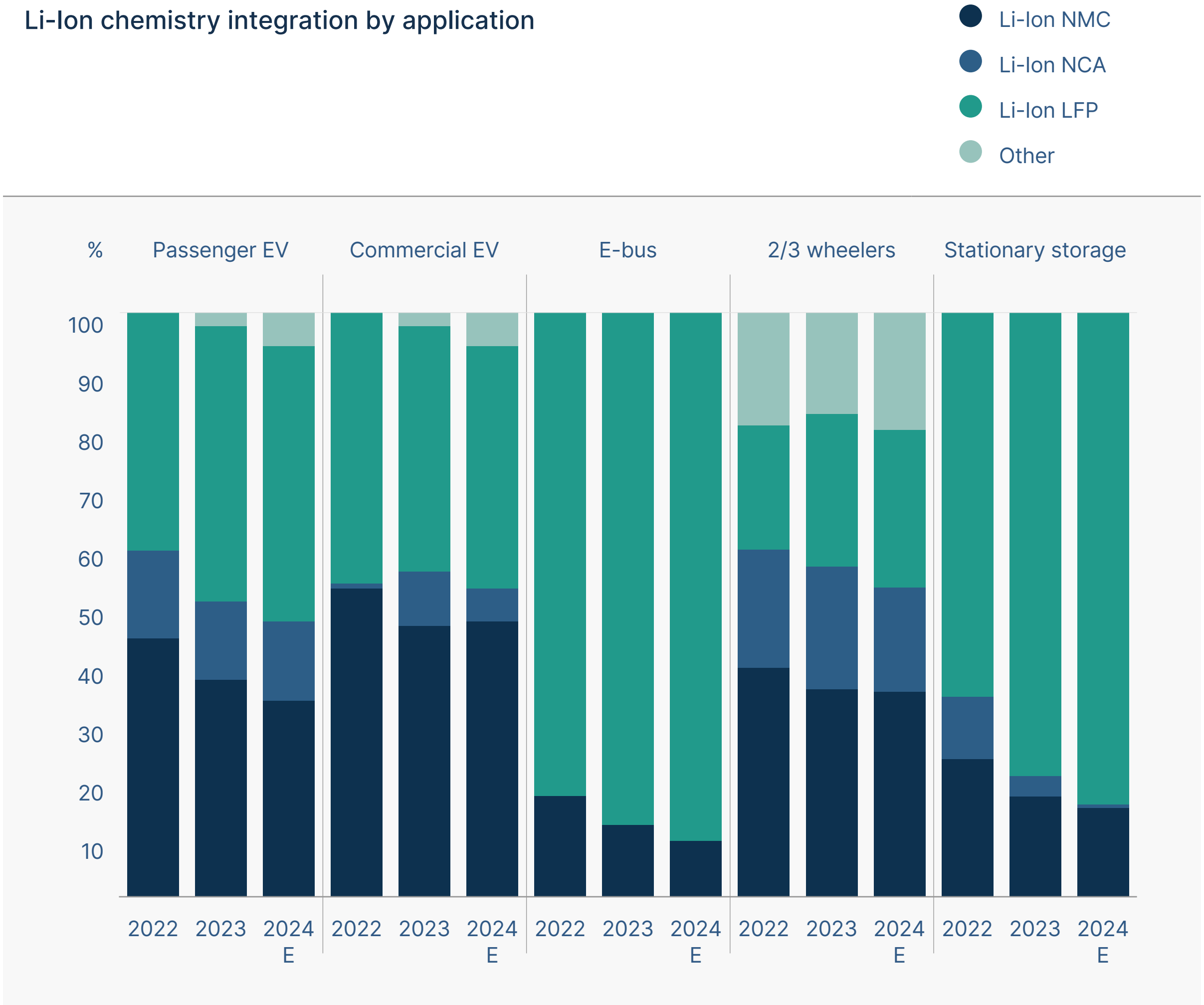
Company	Description
C&D TECHNOLOGIES	**C&D Technologies** headquartered in the United States, is a privately held company that manufactures and markets lead-acid batteries for telecommunications, UPS (uninterruptible power supply) systems, and renewable energy storage.
CROWN	**Crown Battery Manufacturing Company** based in the United States, is a privately owned company that produces lead-acid batteries for various applications, including golf carts, industrial equipment, and renewable energy systems.
EASTPENN	**East Penn Manufacturing Co**. based in the United States, is a private company specializing in lead-acid battery manufacturing for automotive, marine, and industrial applications.
NORTHSTAR	**NorthStar Battery Company** headquartered in the United States, is a private company specializing in the manufacture of high-performance lead-acid batteries for automotive, marine, and industrial applications.
TROJAN BATTERY COMPANY	**Trojan Battery Company** based in the United States, is a privately held manufacturer of lead-acid batteries for golf carts, renewable energy systems, and other applications.

Lithium-ion batteries

Lithium-ion battery technology dominates the energy storage landscape due to its established supply chain, technical performance and scalability. However, its cost-effectiveness for long-duration storage is limited by the interdependence of power and energy components, reliance on specialised materials, recycling challenges and thermal risks.

While lithium-ion batteries can achieve up to eight-hour durations, most operate at four hours or less, with longer durations requiring costly non-linear increases in battery packs. Despite these limitations, lithium-ion projects are highly scalable and modular, suitable for utility-scale and small-scale applications. The technology boasts a roundtrip efficiency of 85% to 95%, but has a relatively short storage lifetime of up to 16 years or 6,000 to 12,000 cycles.[91] Projects such as California's Moss Landing demonstrate the rapid growth of utility-scale lithium-ion installations.

Li-Ion chemistry integration by application



Source: BNEF and Alexa Capital

Lithium-ion technologies

There are various types of lithium-ion technologies, including NMC and LFP. NMC batteries are favoured for their high energy density, making them suitable for applications requiring compactness and range, such as electric vehicles and electronics. On the other hand, LFP batteries are prized for their long cycle life and low cost, making them ideal for stationary energy storage applications.

LFP has become the dominant lithium-ion battery chemistry in stationary storage, with Chinese manufacturers, CATL, BYD, EVE Energy CALB and Hithium leading global production and expanding into international markets.

Our view: continued growing adoption for lithium-ion

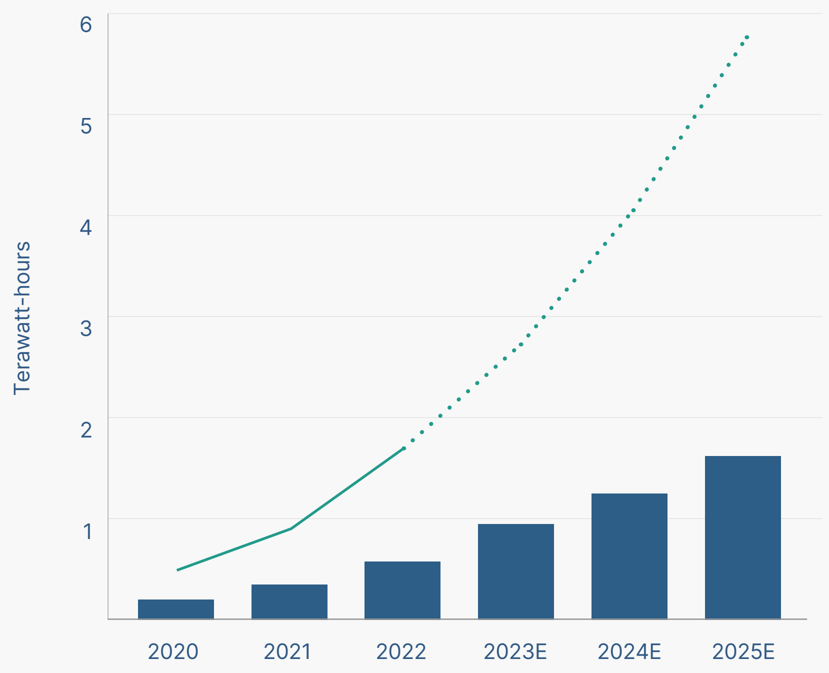
Going forward, innovation in the lithium-ion area will continue as Europe and North America attempt to catch up with Asian producers. This will mean further improvements in capacity, safety, charging speed and costs, which will open markets and opportunities. It is difficult to bet against the leading lithium-ion producers given their scale and their multiyear locking agreements with EV manufacturers.

The price of a lithium-ion battery packs dropped 53% from 2016 to 2022[92], while performance has improved from 111 Wh/kg in 2016 to 300 Wh/kg in 2023.[93] These trends will continue to drive adoption of lithium-ion technologies in applications ranging from EVs to stationary storage. Stationary storage additions are expected to reach a record 57 GW (136) GWh in 2024[94] and EV sales are headed for another record year in 2024 although there is some caution with US and Europe markets following recent hyper growth.

In addition, promising alternatives such as lithium-sulfur or sodium-ion can be produced using existing production facilities.

Constrained supply and over capacity

A few issues surround lithium-ion batteries. First, lithium-ion battery manufacturers' capacity has recently outpaced near term demand, a trend that is set to continue over the coming years. This has caused downward pressure on prices as manufacturers seek to recover investments and mitigate losses, which should continue to drive adoption.



Selected Li-Ion battery manufacturers' capacity and battery demand

Source: BNEF and Alexa Capital

Second, c. 90% of global lithium mining is concentrated in Australia, Chile and China,[95] and 90% of Australian lithium exports are sent to China for processing.[96] Fortunately, increased demand has led to an increase in lithium supply, which grew over 230% from 2016 to 2022.[97]

Lithium-sulfur batteries

Li-S batteries are one of the most promising next-generation energy storage technologies thanks to their high theoretical energy density (2,500 Wh/kg), 10 times higher than that of conventional lithium-ion batteries. This high energy density could potentially enable very long-range batteries for EVs as well as opening markets such as long-distance air and sea transport.

Another advantage of sulfur, it's the 10th most abundant element in the world and has a low cost to mine. It is also a by-product of oil refining, where it is removed from crude oil and natural gas to prevent acid rain.

Despite the advantages, the limited life cycle life is a challenge that is driving up the price and inhibiting wider adoption. That said, companies such as Lyten are producing Li-S batteries for specialist applications such as drones. Also, Gelion (LON: GELN) owns the largest collection of intellectual property in the area, with more than 350 patents.

Our view

Every investor should have this technology on their radar. If commercialised, it could not only open new markets and also scale very quickly. We think lithium-sulfur batteries will initially be used in less price-sensitive areas, such as military applications, which should allow the technology to scale. Continuing innovation should also mean lithium-ion production lines could be retrofitted to allow faster and lower-production-cost ramp-ups. If that happens, lithium-sulfur costs will come down, enabling widespread adoption. The success of these efforts could transform energy storage and have a profound impact on transportation, renewable energy and numerous other sectors.

Lithium-sulfur Batteries

Select list of companies, non-exhaustive

Company	Description
gelion	**Gelion (LON:GELN)**, a British public company, is a pioneer in lithium-sulfur battery technology, known for its innovative approach to energy storage. They have raised over $50M, and boast a team of 30+ employees, with 450+ patents.
LG Chem	**LG Chem (KRX:051910)**, based in South Korea, is a global leader in lithium-ion battery technology, with a strong focus on developing lithium-sulfur batteries.
Li-S Energy	**Li-S Energy**, a privately held company, specializes in the development of lithium-sulfur battery technology, aiming to address the limitations of traditional lithium-ion batteries.
LYTEN	**Lyten**, a privately held company, specializes in next-generation lithium-sulfur battery technology, aiming to revolutionize energy storage solutions. The company raised $410M and have over 350+ patents.
Zeta ENERGY	**Zeta Energy**, a privately held company, is dedicated to advancing lithium-sulfur battery technology for sustainable energy storage solutions.

Sodium-ion batteries

Sodium-ion batteries are a potential alternative to lithium-ion technology. Both are based on alkali metals, which are highly conductive, and have similarly structured cathodes, anodes and electrolytes. While sodium-ion battery development commenced in the 1970s and 1980s, the commercial promise of lithium-ion batteries overshadowed the technology by the 1990s. However, a resurgence of interest in sodium-ion batteries emerged in the early 2010s due to rising lithium battery raw materials costs.

Comparing Sodium-Ion and Li-Ion technologies

	Na-Ion battery	Li-Ion battery
Elemental Abundance	~23,000 ppm	20 ppm
Gravimetric Energy Density	140-150 Wh/Kg	140-280 Wh/Kg depending on chemistry (NMC, LFP, LTO, NCA etc.)
Volumetric Energy Density	250-400 Wh/L	250-750 Wh/L depending on chemistry (NMC, LFP, LTO, NCA etc.)
Cycle Life	2,000-20,000	2,000-20,000
Fast Charging Capability	Demonstrated @ 4C for short period of time; R&D still ongoing	Depends on chemistry (NMC - <1C, LFP - <2C, LTO - <6C)
Operating Temperature	-20°C to 60°C	0°C -45°C (For LTO, -30°C - 60°C
Safety	Safe to transport at OV	Usually transported @ 50% SoC to avoid over-discharge

Source: Volta Battery Report 2023 and Alexa Capital

Our view

Sodium-ion will become the critical battery technology for stationary storage because of the low cost of sodium, improved safety over Li-Ion, and the potential retrofitting of existing lithium-ion production lines to produce sodium-ion.

Most of today's sodium-ion technologies use the same processes as lithium, which is an advantage over other storage solutions under development. Therefore, sodium storage technologies are likely to benefit from the economies of scale and knowledge in lithium manufacturing. Retrofitting an existing lithium plant to sodium-ion technology requires only an additional 10% of capital expenditure.

IDTechEx predicts that by 2025 approximately 10 GWh of sodium-ion batteries will be installed, due to an expansion of manufacturing capacity and the conversion of existing lithium-ion lines. The market is projected to grow at a 27% CAGR from 2025 to 2033.[98]

Sodium is the sixth most abundant element in the world, compared to lithium which is 25th. The resource abundance, charging speed, stability in extreme temperatures, and safety against overheating offer economic viability and versatility of applications. The batteries are environmentally friendly, lacking toxic materials such as lithium, cobalt, copper or nickel, and adaptable to various applications.

Despite their potential, sodium batteries face challenges due to their recent commercial introduction, limited manufacturing capacity and supply chain development, lower energy density, lower efficiency and shorter lifespan than lithium. Ongoing innovation in performance and manufacturing has the potential to lower the cost in the future.

Looking ahead

Sodium-ion batteries costs are likely to drop in the short term because of manufacturing efficiencies, scale and technology development, with ongoing research aiming to reduce the levelised cost of storage (LCOSE) below $0.1/kWh[99], compared to lithium-ion batteries, which can have an LCOSE of around $0.12/kWh.[100]

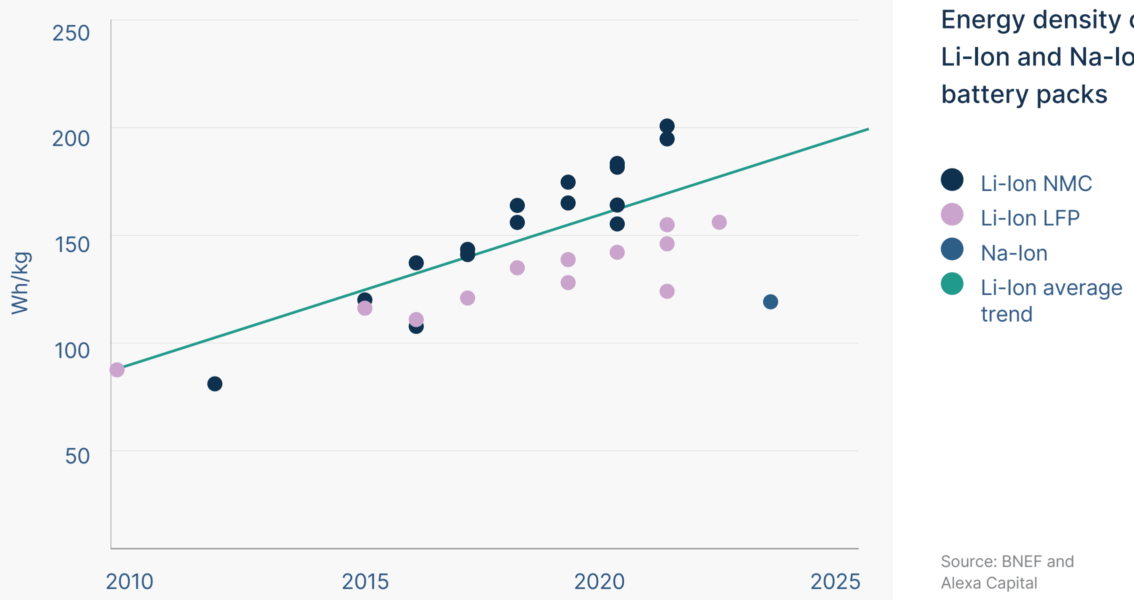
There is an opportunity for sodium batteries to differentiate themselves in the stationary storage market due to their higher charging speeds and better performance in cold temperatures. Nevertheless, key challenges still exist as the industry scales up, particularly around enhancing energy density for improved storage capacity and fast charging, critical for EV adoption.

In stationary applications where energy density is less critical, there is a significant opportunity for sodium batteries due to their low cost, safety advantages, and high charging speeds.

Publicly listed early adopters

Chinese media 36kr[101] announced that CATL planned to install sodium-ion batteries in EVs, with an energy density surpassing 200 Wh/kg, compared to LFP batteries that have an average of 90 to 160 Wh/kg. BYD began mass production of sodium-ion packs in 2023 to install them in its BYD Seagull and other Ocean series models.[102]

CATL's first-generation sodium-ion cell cost about $77 per kWh, with expectations for the second generation at $40 per kWh due to manufacturing efficiencies.[103] Some analysts in China speculate that the CATL sodium-ion battery initiative is meant to pressure lithium suppliers to lower prices following a spike in demand in 2022.[104]



Energy density of Li-Ion and Na-Ion battery packs

Source: BNEF and Alexa Capital

Sodium-Ion – Public Companies

Select list of companies, non-exhaustive

Company	Description
A123 SYSTEMS	**A123 Systems (NASDAQ: AONE)**, headquartered in the United States, is known for its expertise in lithium-ion battery technology. While primarily focused on lithium-ion batteries, the company has also expressed interest in exploring sodium-ion battery development.
BYD	**BYD (HKG:1211)** Similar to CATL, BYD's main expertise lies in lithium-ion battery technology. However, the company has shown interest in diversifying its battery portfolio and may be involved in research related to sodium-ion batteries.
CATL	**CATL (SHE:300750)**, based in China, CATL's primary focus is on lithium-ion battery technology, the company has indicated interest in exploring alternative battery chemistries, including sodium-ion batteries.
panaX etec	**PANAX ETEC Co. (KRX: 098460)**, based in South Korea, is a provider of energy storage solutions, including lithium-ion and sodium-ion batteries. The company has been involved in sodium-ion battery research and development for grid-scale energy storage applications.
SOLVAY	**Solvay SA (EBR: SOLB)**, headquartered in Belgium, is a multinational chemical company that has been exploring sodium-ion battery technology as part of its broader efforts in sustainable energy solutions.
TOSHIBA	**Toshiba Corporation (TSE:6502)**, based in Japan, is a multinational conglomerate with a focus on various technologies, including energy storage solutions. The company has been involved in the research and development of sodium-ion batteries for grid storage applications.

Sodium-Ion – Private Companies

Select list of companies, non-exhaustive

Company	Description
AQUION ENERGY	**Aquion Energy**, based in the United States, was a private company that developed and manufactured sodium-ion batteries for grid-scale energy storage applications. However, the company filed for bankruptcy in 2017 and its assets were acquired by a Chinese company, creating potential uncertainty about its current status.
LiNa Energy	**LiNa Energy**, headquartered in the UK, specializes in the development of low-cost solid-state sodium-ion battery technology, offering a promising alternative to lithium-ion batteries for grid-scale energy storage and other applications.
NAWA TECHNOLOGIES	**Nawa Technologies**, based in France, is a private company specializing in advanced materials and energy storage technologies. While primarily known for its ultracapacitor technology, the company has also been exploring sodium-ion battery development.
Reliance New Energy	**Reliance New Energy**, headquartered in India and subsidiary of publicly listed, Reliance Industries Limited (NSE:RELIANCE), is actively advancing sodium-ion battery technology for energy storage applications, including the acquisition of British battery manufacturer, Faradion Limited in 2021.
TIAMAT	**Tiamat Energy**, headquartered in the United States, is a private company focused on developing sodium-ion battery technology for grid-scale energy storage applications. The company aims to provide low-cost, high-performance energy storage solutions using sodium-ion batteries.

Solid State Batteries

Solid-state batteries are a family of lithium-based cells that use a solid rather than liquid electrolytes which mix directly with the battery cathode. This is a notable design change since electrolytes are critical battery components that enable ion transport between the anode and cathode. Electrolytes directly impact a battery's performance, including power density, cycle life and charge rate, among other factors.

Conventional Li-Ion batteries generally use a lithium salt dissolved in an organic solvent as an electrolyte. The main difference with solid-state batteries is the solid electrolyte utilised, with ceramic, polymer and sulfide variants being most prevalent.

Our view

The most significant advantage of solid-state batteries is the replacement of flammable organic solvent based electrolytes with a solid variant to improve safety, handling, and related balance-of-system control equipment to address safety considerations.

Lithium metal still provides the highest capacity as an anode material, but achieving stable and uniform lithium deposition during battery operation remains a challenge, impacting the overall efficiency and safety of solid-state batteries. There are some interesting advances announced by solid-state battery development groups such as private company QuantumScape, suggesting energy densities in excess of 800 Wh/l.[105] If achieved commercially, and subject to costs, this could support enhanced performance for a range of mobility applications.

Solid-state batteries are still some way from commercialisation, but we continue to monitor the sector with interest.

Long duration energy storage

Flow batteries

Flow batteries, distinguished by their scalability, long cycle life and safety, are gaining recognition as a viable technology for large-scale energy storage applications. These systems, which store energy in external tanks filled with electrolyte solutions, stand out for their ability to independently scale power and energy capacity, providing a versatile approach to energy storage.

Despite these advantages, flow batteries, particularly vanadium redox and zinc-bromine, face challenges related to initial costs, energy density and market maturity.

Market dynamics and challenges

The upfront capital expenditure for flow batteries is significant. These batteries are primarily used in high-utilisation applications, for example, alongside industrial-scale solar generation for distributed, low-carbon energy projects.

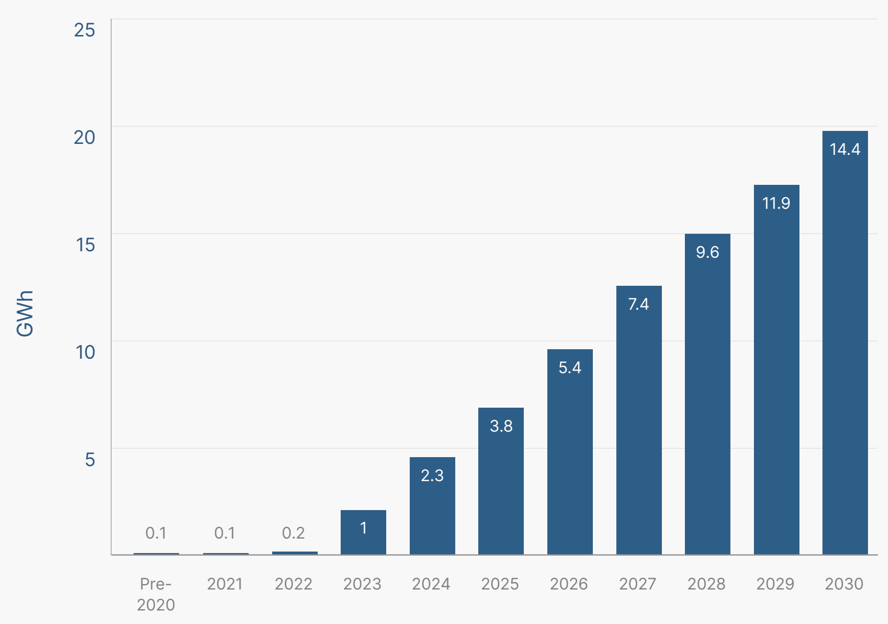
Flow batteries have relatively high round-trip efficiencies and discharge rates. The technology necessitates a large surface area in addition to pumps, plumbing and maintenance. This complexity, alongside the industry's relative immaturity, positions flow batteries as a more expensive option to lithium-ion.

The market has seen consolidation, with redT Energy and Avalon Battery merging to form Invinity Energy, a leader in vanadium flow batteries. Invinity boasts a portfolio of more than 40 projects worldwide and has a development pipeline that includes supplying vanadium flow batteries for the £41 million Energy Superhub Oxford, in the Oxford, UK.[106]

Adoption and cost challenges

The adoption of flow batteries presents moderate technical readiness but requires specialised components that complicate system integration and scalability. With current capital costs around $800 per kWh for flow batteries, compared to $139 kWh for lithium-ion, the financial barrier is significant. As a result, flow battery installations are smaller capacity than lithium, thus will not compete for the same applications. However, ongoing research into reducing the size and complexity of flow battery cells promises potential cost reductions in the future.[107]

Despite their advantages in safety, durability and lifespan—potentially spanning 20 to 25 years without degradation[108]— flow batteries face a slow path to broad adoption, having been in development for over a decade. The future, however, holds promise, with projections indicating that China's cumulative flow battery installations could reach 23 GW by 2030, driven by economies of scale expected to reduce capital costs substantially.



China's flow battery forecast of installed capacity by 2030

Source: BNEF and Alexa Capital

Looking ahead

For the flow battery market to scale effectively, cost and performance improvements are essential. This includes increasing manufacturing capacity, enhancing supply chain and technological efficiencies and exploring new business models.

While flow batteries currently compete with established technologies such as sodium and lithium batteries, their unique advantages in long-duration storage applications suggest potential for market differentiation and growth. In summary, flow batteries offer a promising yet challenging path forward in the energy storage landscape. Their unique features cater to specific needs in the renewable energy sector, but overcoming cost and technical barriers will be crucial for their wider adoption and commercial success. As the industry evolves, flow batteries could play a pivotal role in meeting the growing demand for flexible and sustainable energy storage solutions, especially for longer-duration industrial applications.

Flow Battery Companies

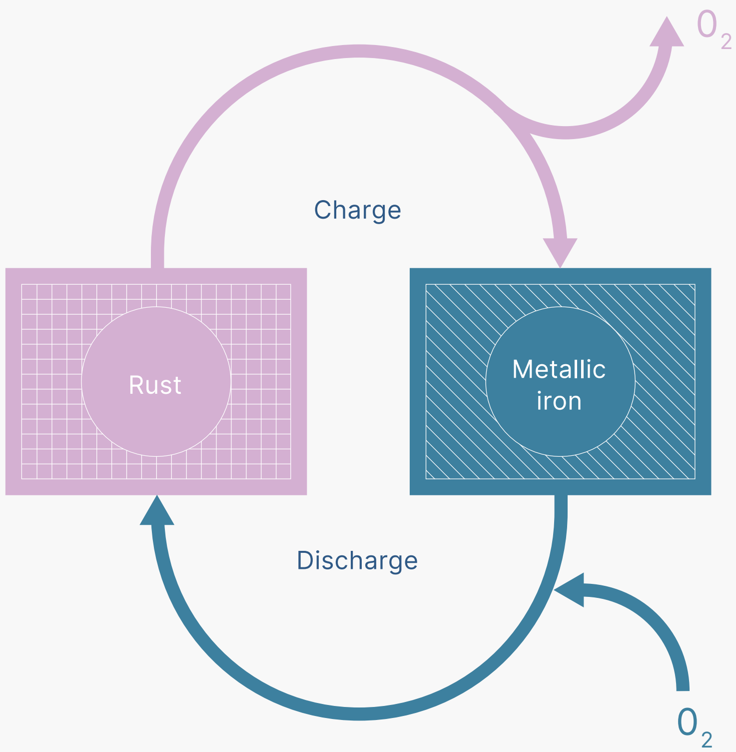
Select list of companies, non-exhaustive

Company	Description
cellcube	**CellCube Energy Storage Systems**, based in Austria, is a private company focused on storage battery manufacturing producing vanadium, vanadium electrolytes, vanadium redox flow batteries.
INVINITY ENERGY SYSTEMS	**Invinity Energy Systems (LON:IES)**, headquartered in the United Kingdom, specializes in vanadium flow battery technology for energy storage applications. The company provides scalable and long-duration energy storage solutions for grid stability and renewable energy integration.
SUMITOMO ELECTRIC	**Sumitomo Electric Industries (TYO:5802)**, based in Japan, is a global leader in flow battery technology, offering vanadium redox flow batteries for energy storage applications. The company's flow batteries provide efficient and reliable energy storage solutions for various grid-scale applications.
UET	**UniEnergy Technologies (Private)**, headquartered in the United States, specializes in advanced flow battery systems for long-duration energy storage. The company's vanadium flow batteries offer high-performance and cost-effective solutions for renewable energy integration and grid stability.

Iron-air batteries

Iron-air batteries were first developed in the 1960s by NASA.[109] Today, they present an interesting alternative to lithium-ion batteries due to their long durations and low cost. With a duration of 100 hours, iron-air batteries can bring critical reliability during gaps in renewable energy production lasting multiple hours and days. Given that their primary materials can be found in ample supply, they can also bring this reliability cost-effectively.

Rechargeable iron-air for multi-day storage



Cost	Lowest cost rechargeable battery chemistry. Less than 1/10th the cost of lithium-ion batteries
Safety	Non-flammable aqueous electrolyte. No risk of thermal runaway. No heavy metals.
Scale	Uses materials available at the global scale needed for a zero carbon economy. High recyclability.
Reliable	100+ hr duration required to make wind, water and solar reliable year round, anywhere in the world.

Source: Form Energy and Alexa Capital

Our view

Iron is the fourth most abundant element on earth, one of its main advantages in comparison to lithium. Iron-air battery technology is projected to cost 1/10th the amount of lithium-ion batteries – or around <$20 per kWh[110]. The main trade-off that the technology makes is around round trip efficiency - lower round trip efficiency vs. lithium-ion batteries is traded off for the ability to discharge power for longer periods of time, at a lower cost.[111]

Leading in this young market is Form Energy[112], which has raised over $820 million in venture capital to date. Global investment firm TPG led the latest, $450M Series E round, which had participation from the Canada Pension Plan Investment Board, Bill Gates' Breakthrough Energy Ventures, and steel giant ArcelorMittal, among others. Form Energy is set to begin high-volume manufacturing of its iron-air batteries in 2024 in the U.S.,[113] and will be deploying its first projects to leading American utilities starting in 2025.

Iron Air Batteries

Select list of companies, non-exhaustive

Company	Description
ESS TECHNOLOGY	**ESS Tech, Inc.**, headquartered in the United States, specializes in iron flow battery systems, offering reliable and cost-effective energy storage solutions for grid applications, including peak shaving and renewable integration.
Form energy	**Form Energy**, based in the United States, develops low-cost, long-duration iron-air batteries, providing scalable and sustainable energy storage solutions to enable the transition to renewable energy.

Pumped hydro energy storage

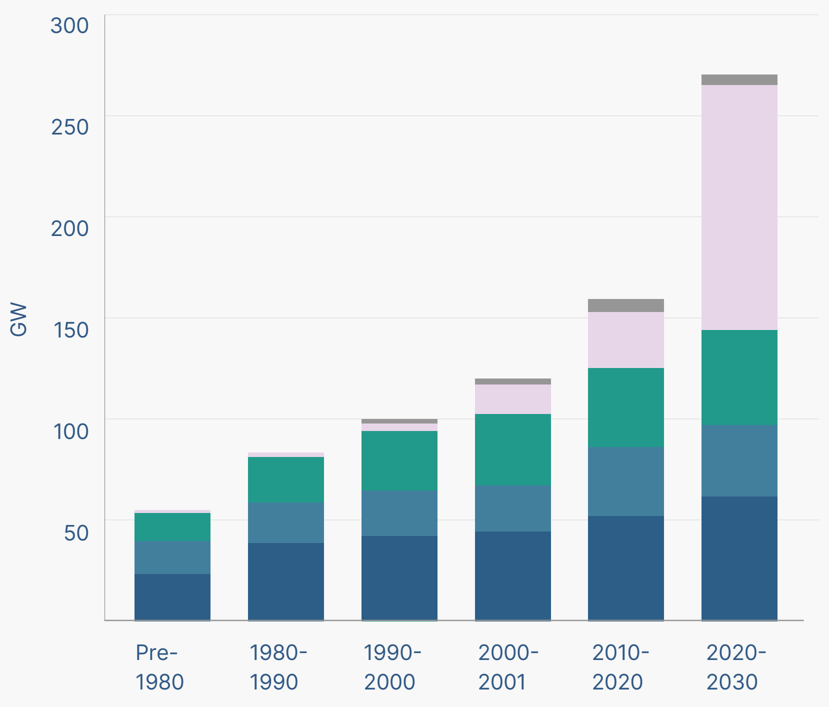
Pumped storage hydro (PSH), a form of mechanical energy storage, has been present in the energy storage market since its start in 1907, with more than 160 GW of capacity as of 2020[114]. It requires significant upfront costs and has stringent geographic requirements, necessitating two reservoirs of water at different elevations.

Although pumped hydro facilities are not typically co-located with nuclear power plants, power system infrastructure enables them to connect and operate in conjunction with each other. Surplus energy from nuclear power plants can be used for pumping water uphill during off-peak hours. This surplus energy is subsequently released to generate electricity during periods of high demand, thereby serving as a cost-effective and efficient means of energy storage. Notable examples of pumped hydro facilities include Dinorwig and Foyers in the UK, Navaleo in Spain and the Gordon Butte project in Montana, USA.

Our view

The pumped hydro storage market is expected to increase at a 5.9% CAGR during the next five years.[115] We expect growth to come from Asia—mainly China—as BNEF forecasts more than 123 GW of installed PSH between 2020 and 2030. However, concerns regarding its potential negative environmental contribute to hindering its adoption.

It's worth noting the immense hydro storage potential that exists globally. Despite this potential, environmental concerns often hinder the development of projects. Viable projects typically leverage a geography that favours implementation without significant civil works or disruption to community use of reservoirs. Despite these challenges, the substantial scale of projects in the pipeline suggests that pumped hydro will continue to dominate the long-duration storage landscape in the coming decade.



Forecast of pumped hydro storage capacity installations by market

Source: BNEF and Alexa Capital research

Pumped Hydro – Public Companies

Select list of companies, non-exhaustive

Company	Description
ANDRITZ	**Andritz AG (VIE: ANDR)**, based in Austria, is a multinational corporation that provides plants, equipment, and services for various industries, including hydropower. They offer solutions for pumped storage hydropower plants, among other types of hydroelectric projects.
	China Yangtze Power Co. (SHH:600900), based in China, is one of the largest hydropower companies in the world. While primarily focused on conventional hydropower generation, the company may have involvement in pumped hydro storage projects due to its extensive portfolio of hydropower assets.
GE VERNOVA	**GE Vernova (NYSE: GEV)**, headquartered in the United States, spun-off from General Electric, and operates across the power, wind and electrification sectors. It also provides equipment and services for pumped hydro storage projects globally.
Verbund	**Verbund AG (VIE:VER)**, based in Austria, is a leading European electricity company that specializes in hydropower generation. While not exclusively focused on pumped hydro storage, the company operates several hydropower plants that may include pumped storage facilities.

Pumped Hydro – Private Companies

Select list of companies, non-exhaustive

Company	Description
ABSAROKA ENERGY LLC	**Absaroka Energy**, headquartered in the United States, is a private company focused on developing renewable energy projects, including hydropower and pumped hydro storage. They are actively involved in the planning and development of pumped hydro storage facilities in various regions.
NATEL ENERGY	**Natel Energy**, based in the United States, is a private company that designs and manufactures innovative hydroelectric turbines and power generation systems. While not exclusively focused on pumped hydro storage, they may provide technologies suitable for such applications.
RIDGELINE ENERGY	**Ridgeline Energy**, based in the United States, is a private company specializing in renewable energy development, including hydropower projects. While specific information about their involvement in pumped hydro storage is limited, they may have interests in this area.
VOITH	**Voith Group**, headquartered in Germany, is a global engineering company that provides equipment and solutions for hydropower generation, including pumped hydro storage systems. They offer a range of products and services for the hydroelectric sector.

Thermal energy storage

Thermal energy storage (TES) systems harness and store heat for later use, through thermochemical reactions or by employing materials such as water or rocks.

A hot water tank is the simplest form of heat storage, used widely in residential and commercial water heating due to water's high thermal conductivity. The main forms of TES are:

- **Sensible heat storage (SHS)** heat materials such as molten salts to deliver temperatures above 1,000°C. Although there are some limitations regarding discharge rates and roundtrip efficiency.
- **Latent heat storage (LHS)**, phase change materials (i.e. liquid to gas) and offers higher efficiency than sensible technologies but does not have the same capacity to reach the high temperatures of SHS.
- **Thermochemical storage (TCS)** separates water molecules by exposing it to temperatures between 500 to 2,000°C. While promising high efficiency, it remains an area of ongoing exploration.

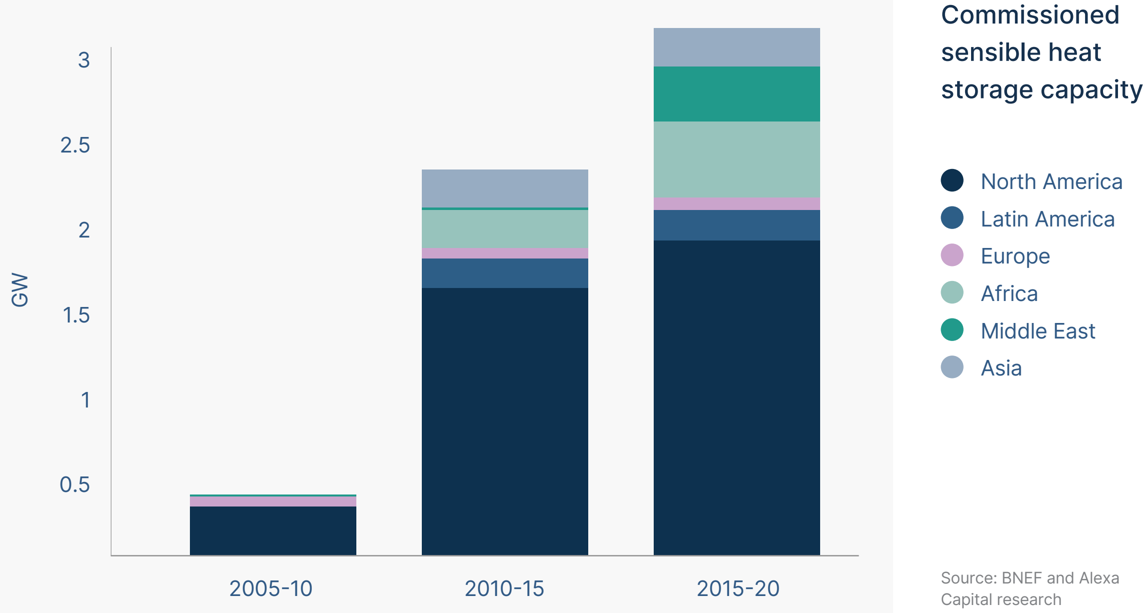
TES offers advantages in ease of deployment and flexibility, as it uses familiar components such as heat exchangers from power and processing industries. This makes facilities easy to build and scale, unlike alternatives such as pumped hydro or gravity-based storage, which are constrained by geographic requirements.

Despite these advantages, TES loses to alternative storage technologies in terms of roundtrip efficiency. It has a 30% to 70% conversion efficiency, compared 85% to 95% for lithium-ion batteries and 70% to 85% for pumped hydro power.[116]

Our view

TES systems are critical to decarbonisation because they reduce the use of fossil fuels in heating and cooling, as well as electricity, which make up about 40% and 20% of global energy-related carbon dioxide emissions, respectively.[117] Some experts estimate that the heating and cooling market size currently stands at $266 billion, and can reach 349 billion by 2032.[118] This growth is coming from Asia and Europe, which have the most projects under commission.[119]

Moreover, TES can be solution to the problem of reduced energy production when the sun sets.[120] Going forward, sensible heat storage offers the cheapest form of TES; however, its requirement for large storage volumes and consequent large physical footprint limits its adoption.



Commissioned sensible heat storage capacity

Source: BNEF and Alexa Capital research

Thermal Energy Storage Companies

Select list of companies, non-exhaustive

Company	Description
ANTORA	**Antora**, based in the USA, uses renewable electricity to heat blocks of solid carbon to glowing-hot temperatures in an insulated module. The stored heat is delivered at industrial scale. The system outputs electricity using proprietary heat-to-power thermophotovoltaic technology.
ENERGYDOME Our WORLD can't wait.	**Energy Dome**, headquartered in Italy, develops CO2 battery technology that uses a thermodynamic cycle, charging by drawing carbon dioxide from a 'Dome' gasholder, storing it under pressure, and then dispatching it by evaporating and expanding the gas through a turbine back into the gasholder.
MALTA	**Malta**, based in the USA, develops a system comprised of conventional components and abundant raw materials – steel, air, salt, and commodity liquids. The technology is based upon principles in thermodynamics, storing energy as heat (in molten salt) and as cold (in a chilled liquid).
RONDO	**Rondo**, based in the USA, produces batteries that have potential to store energy at half the cost of other technologies such as chemical batteries. Rondo based its technology on brick and iron wire, mitigating safety, durability, and supply chain risks faced by other storage technologies.
SaltX Technology	**SaltX (STO:SALT-B)**, a Swiss company, is making waves with their innovative high-temperature molten salt technology. Their focus on advanced materials and system optimization positions them well for the future of thermal energy storage, particularly in industrial applications.
SUNAMP	**Sunamp**, based off of the UK, produces heat batteries that are used for heating and cooling across a wide range of temperatures, and for a wide range of residential and industrial applications. The company's range of products for the residential market replaces bulky hot water cylinders with compact heat batteries
VATTENFALL	**Vattenfall AB**, based in Sweden and 100% owned by the Swedish state, is actively investing in thermal energy storage, particularly for integrating renewable energy sources into their grid. Their commitment to sustainability and large-scale deployment makes them a key player to watch.

Hydrogen energy storage

Hydrogen has the potential to store capacities in the terawatt-hour (1,000x 1GW) scale for long periods to time. A great solution for long-duration energy storage. Through electrolysis, surplus renewable electricity can be converted into hydrogen, which can later be transformed back into electricity via fuel cells when needed. Its high energy density and versatility make it a promising candidate for a broad range of applications. And its ability to be scaled up makes it a versatile energy carrier, with the potential to decarbonise sectors where direct electrification is challenging.

Our view: challenges to growth

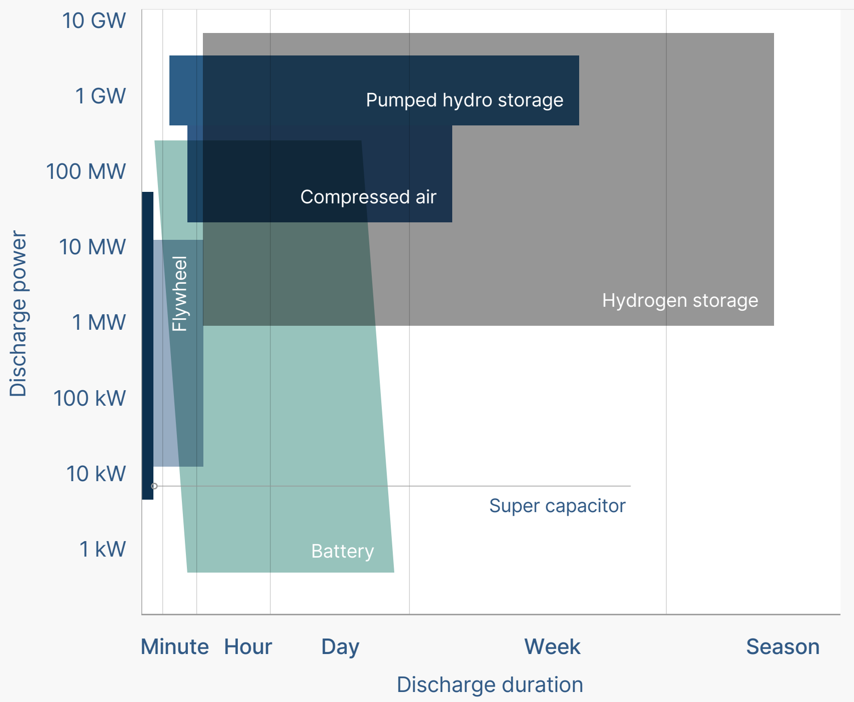
However, the energy conversion process from electricity to hydrogen and back introduces significant efficiency losses. Due to this, we believe hydrogen storage is still far from being a leader in long-duration energy storage. The roundtrip efficiency of hydrogen storage based on electrolysis and fuel cell systems stands around 40%[121], meaning that approximately it returns only 40% of the energy used to charge it. This is low compared the range of 70% to 90% for lithium-ion battery storage.[122]

Currently, most hydrogen production relies on fossil fuels, which detracts from its environmental benefits unless coupled with carbon capture and storage technologies. Transitioning to green hydrogen production, powered by renewable energy, is essential but demands substantial investment in renewable capacity.[123]

Moreover, the technical challenges of storing and transporting hydrogen—stemming from its low density and high flammability—require innovative solutions and rigorous safety standards. Building the infrastructure to support a hydrogen economy, including production facilities, pipelines and fuelling stations, remains a significant challenge.

Forward looking interest

Although the initial cost per kilowatt of a hydrogen energy storage system may be high, the overall system cost decreases with greater energy demands due to the low marginal cost per kilowatt-hour of hydrogen.[124] A recent study asserts hydrogen-based storage to be more economical than battery energy storage for durations of more than 13 to 15 hours, considering present component prices.[125]



Hydrogen storage compared to other storage technologies

Batteries support dynamic applications

Molecular storage is suited to long discharge use cases

Source: Hydrogen Council, International Energy Agency

Many countries remain optimistic about its potential. Germany, for example, has been investing in hydrogen storage infrastructure and technologies to advance its energy transition goals. Companies such as Uniper are planning significant investments in hydrogen storage facilities, aiming to develop up to 600 GWh of storage capacity by 2030.[126] Additionally, German nationalised gas trader SEFE is considering adapting gas storage caverns and pipelines for hydrogen transport, aligning with the country's efforts use of hydrogen as a clean energy source.[127]

Hydrogen Energy Storage – Public Companies

Select list of companies, non-exhaustive

Company	Description
Air Liquide	**Air Liquide S.A. (EPA: AI)**, headquartered in France, is a multinational company specializing in industrial gases, including hydrogen. While not exclusively focused on hydrogen storage, Air Liquide may provide solutions for storing and distributing hydrogen.
HEXAGON	**Hexagon Composites ASA (OSL: HEX)**, headquartered in Norway, is a leading global provider of composite pressure vessels for storing compressed gases, including hydrogen. The company offers lightweight and high-capacity storage solutions for various applications.
McPhy	**McPhy Energy S.A. (EPA: MCPHY)**, based in France, is a manufacturer of hydrogen production and storage solutions, including solid-state hydrogen storage systems. The company offers innovative solutions for storing and distributing hydrogen in industrial, mobility, and energy sectors.
nel	**NEL ASA (OSL: NEL)** headquartered in Norway, is a global provider of hydrogen solutions, including electrolyzers for hydrogen production and hydrogen storage systems. The company offers high-pressure and cryogenic storage solutions for hydrogen.
plug	**Plug Power Inc. (NASDAQ: PLUG)**, based in the United States, is a leading provider of hydrogen fuel cell systems for electric vehicles and stationary power applications. While primarily focused on fuel cells, Plug Power may have involvement in hydrogen storage solutions.

Hydrogen Energy Storage – Private Companies

Select list of companies, non-exhaustive

Company	Description
ADVENT	**Advent Technologies Inc.**, based in the United States, is a developer and manufacturer of hydrogen fuel cells and hydrogen storage materials. The company offers advanced polymer electrolyte membrane (PEM) fuel cells and hydrogen storage solutions.
Hydrogenious LOHC	**Hydrogenious LOHC Technologies GmbH**, based in Germany, develops liquid organic hydrogen carrier (LOHC) technology for safe and efficient hydrogen storage and transportation. The company offers solutions for storing and releasing hydrogen using liquid carriers.
hystar	**Hystar Hydrogen Storage Solutions**, headquartered in Germany, specializes in solid-state hydrogen storage technology. The company develops advanced materials and systems for storing hydrogen safely and efficiently in solid form.

Gravity-based storage

Gravity-based storage dates to ancient Greece, with examples such as water wheels and dams, and more modern adaptations like pumped hydro. Gravity-based storage works by using energy to raise and then drop heavy masses, turning kinetic/mechanical energy into electricity.

Developing gravity-based storage entails significant capital expenditure, typically ranging from hundreds of millions to billions of dollars depending on the project's scale and complexity. Hydroelectric power plants require expensive man-made dams to produce energy. As of 2023, SSE will be investing £1.5 billion in the Coire Glas project to deliver 30 GWh. It will be Britain's biggest pumped hydro storage sytem in 40 years if approved for final delivery.[128]

Our view

We anticipate that gravity-based storage, except for pumped hydro, will likely remain a niche market in the foreseeable future. The intricate mechanical systems and high initial capital costs associated with gravity-based storage systems are expected to hinder their ability to compete with electrochemical batteries in mainstream energy storage applications.

Additionally, the significant height and space requirements may complicate permitting processes and limit the addressable markets. Moreover, the complexity of construction, operation and maintenance poses further challenges.

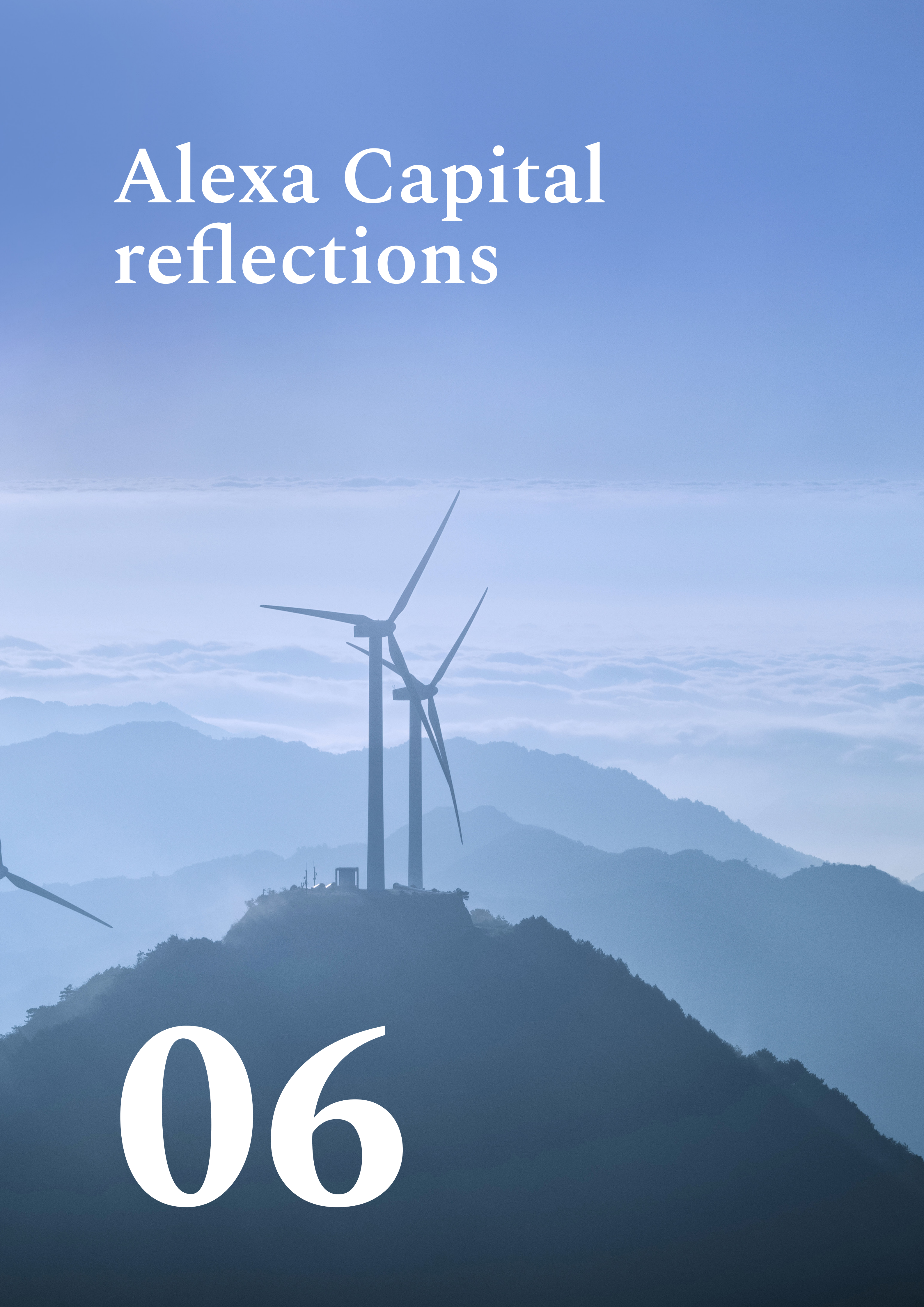
Despite these concerns, some investors remain optimistic, as evidenced by Energy Vault's fundraising of $458 million and its recent entry into the public markets through a SPAC merger. Energy Vault's gravity storage units, costing $7 million to $8 million, offer a lower LCOS than pumped hydro, below $0.05/kWh.[129] This cost is significantly lower than lithium-ion batteries, which can have an LCOS of around $0.12/kWh.[130] This affordability is attributed partly to lower material costs, as Energy Vault uses concrete from Mexican company Cemex.[131]

Gravity-Based Storage

Select list of companies, non-exhaustive

Company	Description
ENERGY VAULT Enabling a Renewable World	**Energy Vault (NYSE:NRGV)**, headquartered in Switzerland, specializes in gravity-based energy storage systems, utilizing kinetic energy to store and release electricity. Their innovative technology offers cost-effective and scalable solutions for renewable energy integration and grid stability.
gravitricity	**Gravitricity**, based in the United Kingdom, develops gravity-based energy storage solutions, utilizing heavy weights suspended in deep shafts to store and release energy. Their flexible and rapid-response systems provide reliable grid support and energy balancing services.

Alexa Capital reflections



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Our reflections

Alongside our equity research coverage across the extended energy storage landscape, Alexa Capital maintains an active investment banking activity across growth capital, structured finance, infrastructure projects and M&A for our energy transition clients. Energy storage and battery technology capital formation has been a meaningful part of our advisory work for over a decade, working with companies upstream (Panasonic [TYO: 6752], Nexeon, CENS), midstream (Leclanche [SWX: LECN], Corvus Energy, Younicos) and downstream (Alpiq Group, Anesco, Aggreko, Fluence [NASDAQ: FLNC], Generali/Sosteneo, Gridserve, Gore Street Energy Storage [LN: GRID], Habitat Energy, Flexitricity, Limejump/Shell [LON: SHEL], Mobility House, Quinbrook, Stem [NYSE: STEM], Peak Power, Wondrwall). Our perspective has been further informed by our engagements in adjacent sectors including flexible power, demand response, virtual power plants, and behind-the-meter service platforms.

Through our work we have come to appreciate the Swiss Army knife nature of battery technology and the increasing array of new energy services enabled by an ever-improving technology, especially leveraging the range of Li-Ion solutions.

At Alexa Capital we seek to add value to our clients, whether investors or corporate issuers, with insights, advice and execution capabilities. Accordingly, our recent move to augment our established investment banking services with the launch of Alexa Capital Markets, providing listed company research, capital markets advisory and equity sales – including this *Investing in the Energy Storage Revolution* report.

As ever, we welcome feedback on our analysis.

Through our investment banking activities, we have developed a depth of insights into the energy storage sector, and believe many capital flow projections are understated

Appendices

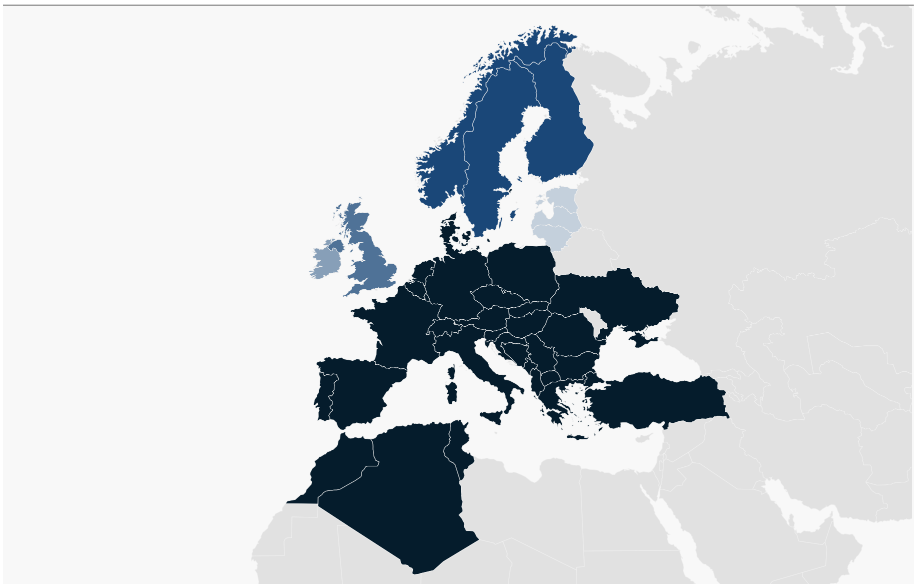
07

Appendix I: Europe and USA power market design

European power market overview

The liberalisation of power markets in Europe, initiated in the 1990s through EU directives, was aimed at breaking up monopolistic, state-controlled electricity sectors to foster competition, increase efficiency, lower consumer prices and encourage innovation. This process led to the unbundling of generation, transmission and distribution operations, preventing any single entity from dominating the market.

Grid Structures: In Europe, the liberalisation of the energy market led to the establishment of nationally appointed Transmission System Operators (TSOs) responsible for managing the high-voltage transmission networks within their respective countries. These TSOs ensure grid stability, manage cross-border electricity flows and provide access to various market participants. While Europe does not have a unified supranational independent system operator (ISO), cooperation among national TSOs is facilitated through organisations such as ENTSO-E to ensure efficient and reliable grid operation across borders. Europe's grid is managed by multiple TSOs, including a notable concentration in Germany due to its extensive power system. The continent includes several synchronous regions and specific countries like Cyprus and Iceland operate with unique grid configurations. The EU's goal for a 15% interconnection target by 2030 aims to enhance grid stability and sustainability by promoting cross-border electricity trade and the integration of renewable energies.[132]



Map of Europe's 5 Synchronous Energy Regions

Source: Grid operators: TSO and DSO explained – gridX

Power Market Structures: The competitive market environment in Europe emerged from these liberalisation efforts, contrasting with the United States, where market structures vary by region, with some areas having competitive markets and others not. The value proposition of energy storage, crucial for balancing and flexibility, hinges significantly on regulatory frameworks that either enable or restrict market access.

Today, European power markets are characterised by a competitive market structure where multiple entities can generate, buy, sell and trade electricity. The market is divided into several segments:

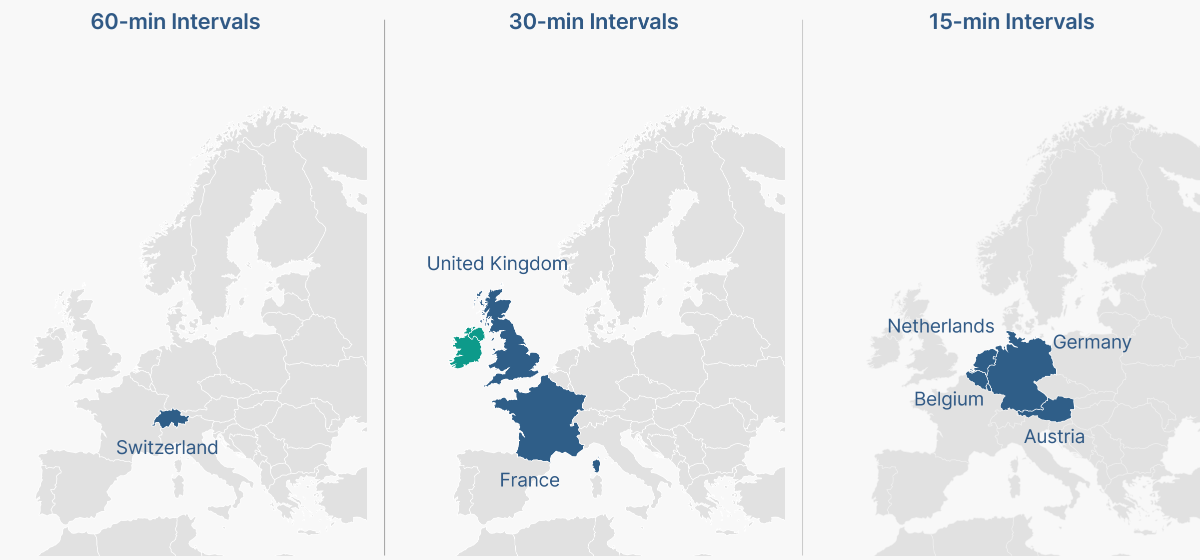
- **Wholesale Market:** Where electricity is bought and sold in bulk. It includes the day-ahead market, where electricity for the next day is traded, and the intraday market, which allows for closer to real-time trading to adjust positions.
- **Retail Market:** Where electricity is sold to end consumers, offering various tariffs and contracts from different suppliers.
- **Balancing Markets:** These are crucial for the operation of electricity systems. They ensure that supply and demand are balanced in real-time. Balancing services are provided by market participants that can quickly adjust their output (generation or consumption) in response to signals from the system operator. The system operator uses these services to balance the system in real-time, ensuring the stability and reliability of the power supply.
- **Capacity Markets:** Implemented in some countries to ensure that enough generation capacity is available to meet peak demand. These markets provide payments to generators for being available to produce electricity, regardless of whether they are actually generating.

Price setting and balancing markets

Wholesale electricity prices reflect supply and demand, traditionally following seasonal and diurnal patterns. However, distributed energy resources have made demand less predictable, challenging grid operators with the task of balancing the grid. This unpredictability necessitates greater system flexibility and underscores the importance of balancing markets. These markets are essential for real-time supply and demand management, involving various participants, including traditional power plants, renewable sources, energy storage and demand-side responses.

In conclusion, the liberalisation and regulatory evolution of power markets in Europe have created a complex but efficient landscape for electricity trading, balancing and grid management. This system ensures operational stability, encourages renewable integration and supports the transition towards a more sustainable and competitive energy market.

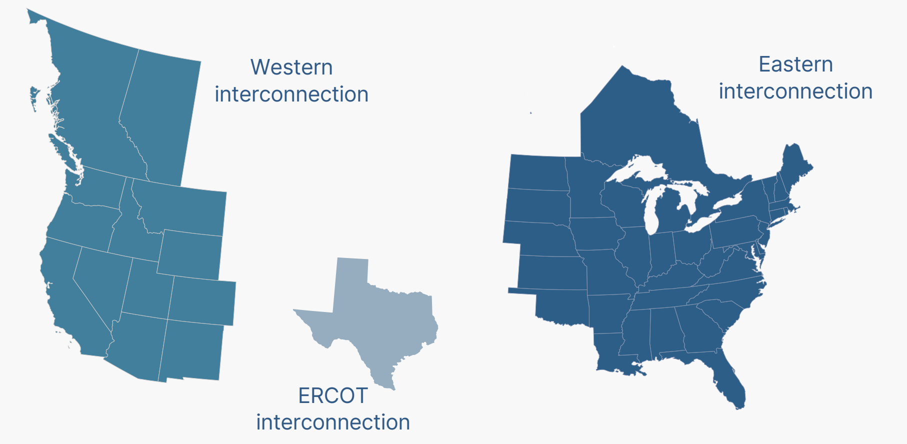
Map intraday market by auction call interval



United States power market overview

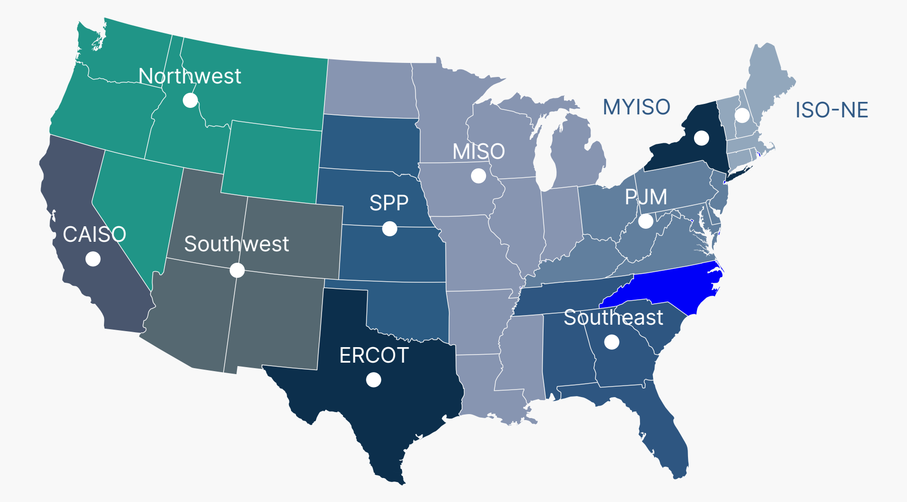
The power market and system in the United States feature a complex and diverse landscape, shaped by the interplay of federal and state regulations, various market structures and the overarching grid infrastructure that spans across North America, including seamless interconnections with Canada.

Grid Structures: The U.S. power grid is interconnected with Canada's and is divided into three major networks: the Eastern Interconnection, the Western Interconnection and the Texas Interconnected System (ERCOT). The Eastern Interconnection extends from Central Canada to the Atlantic Coast, south to Florida and west to the Rockies, excluding most of Texas. The Western Interconnection spans from Western Canada to Baja California and across the Rocky Mountain states to the Great Plains. ERCOT serves the majority of Texas and operates largely independently from the other networks.



U.S. region: 3 major interconnection power grids

Source: Electricity Markets – 101 - National Governors Association (nga.org)



U.S. region: 10 regional ISOs and RTOs

Source: RTOs and ISOs | Federal Energy Regulatory Commission (ferc.gov)

Power Market Structures: Power markets within the U.S. vary significantly by region. Some parts of the country have competitive power markets similar to those in the European Union, allowing multiple entities to generate, transmit and distribute electricity. In contrast, other regions are dominated by vertically integrated utilities that control all aspects of electricity service. These monopolies are primarily found in the Southeast, Southwest and Northwest. Their operations, characterised by bilateral transactions and power pool agreements, are regulated by state commissions to ensure reliability and fair access.

Federal and State Regulation: At the federal level, the Federal Energy Regulatory Commission (FERC) oversees interstate electricity transactions and wholesale electricity prices, promoting fair and reasonable rates. State regulators have authority over retail electricity sales and the siting of infrastructure, with each state's policies significantly impacting the energy mix and market dynamics within its borders.

Price Setting and Rate Design: In regulated markets, where vertically integrated utilities prevail, price setting diverges from market-based mechanisms. Instead, rates are designed based on the cost of service, incorporating strategies such as fixed charges, demand charges and time-of-use rates to encourage efficient consumption and mitigate system imbalances during peak demand periods.

- Fixed Charges: A flat rate charged per billing cycle, irrespective of consumption volume.
- Demand Charges: Based on the customer's maximum usage at any point in the year, to reflect the cost of ensuring capacity for peak demand.
- Time-of-Use Charges: Variable rates based on consumption during designated intervals, encouraging users to shift usage to off-peak times.

Conclusion: The U.S. power market's complexity is influenced by the diverse regulatory environments, market structures and the physical interconnectedness of the grid with neighbouring countries. This creates a multifaceted system where policy, market dynamics and infrastructure investment decisions intersect, impacting everything from price setting to how new technologies like renewables are integrated into the grid.

Appendix II: Regulation overview

Country	Incentive	Description
UK	**Capital Grants Scheme**	Upfront grants for battery storage installation (up to 45% of eligible costs)
	Feed-in Tariffs (FiTs)	Guaranteed payments for energy stored and injected back to the grid (limited availability)
	Storage Auctions	Competitive bidding for grid-scale storage projects with capacity payments contracts
	Demand Flexibility Service (DFS)	Payments for providing demand-side flexibility services, including storage
	Export Tariff Guarantee	Support for grid-connected projects exporting electricity to nearby countries
	Smart Grid Innovation Platform (SGIP)	Funding for innovative smart grid projects, including storage integration
Germany	**Capacity Payments**	Revenue for providing grid stability through capacity reserves
	Market Stacking	Priority grid access for renewables and storage in times of congestion
	Feed-in Tariffs (FiTs)	Guaranteed payments for energy stored and injected back to the grid (limited availability)
	Investment Grants	Upfront grants for battery storage installation (varies by project size and technology)
	Innovation Support Programmes	Funding for research and development of advanced storage technologies
	Pilot Projects and Demonstrations	Govt-funded initiatives to test and demonstrate new storage solutions
Italy	**Feed-in Tariffs (FiTs)**	Guaranteed purchase rates for stored energy injected into the grid
	Conto Termico 2.0	Incentives for building integrated photovoltaic and storage systems
	Superbonus 110%	Tax deductions for energy efficiency upgrades, incl. storage in residential buildings
	Storage Capacity Auctions	Competitive bidding for large-scale storage projects
	Innovation Funds	Grant programs for research and development of advanced storage technologies

Country	Incentive Name	Description
Portugal	**Grid Services Payments**	Revenue for providing specific grid services (e.g., peak shaving, frequency regulation) with storage
	Capacity Remuneration Mechanism (CRM)	Payments for providing grid stability through capacity reserves
	Feed-in Tariffs (FiTs)	Limited availability
	Energy Communities	Support for community-owned renewable energy and storage projects
	Innovation Programs	Funding for research and development of innovative storage solutions
Spain	**Investment Cost Subsidies**	Up to 65% coverage for co-located storage projects (>1 MWh, 2+ hours)
	Operational Support Mechanisms	Payments for providing specific grid services with storage (e.g., peak shaving, frequency regulation)
	Feed-in Tariffs (FiTs)	Limited availability
	Tax benefits	Accelerated depreciation for storage investments and reduced property taxes
	Pilot Projects and Demonstrations	Government-funded initiatives to test and demonstrate new storage solutions
USA	**Investment Tax Credits (ITC)**	30% credit for storage system costs, with potential bonus (domestic content, energy communities)
	Grants and Rebates	Varying state and local programs offering grants and rebates for storage (e.g., California Self-Generation Incentive Program, NY-Clean)
	Feed-in Tariffs (FiTs)	Limited state and utility programs offering FiTs for storage (e.g., Hawaii, Arizona)
	Net Energy Metering (NEM)	Allows storage owners to receive credits for excess energy exported to the grid
	Demand Response Programs	Payments for reducing electricity **Consumption** during

Appendix III: Annex of battery specifications

	Description
Internal Resistance	Indicates the resistance encountered by the energy storage system during charging and discharging cycles, influencing its overall efficiency.
Lifespan	Assessable through cycle-life, energy throughput, or calendar life, impacted by usage patterns and environmental conditions.
Ramp Rate	Denotes the speed at which power delivery or absorption changes over time, crucial for system agility, typically measured in megawatts per second or as a percentage change in rated power.
Response Time	Measures the duration required for an energy storage system to achieve 100% of its rated power once activated, providing insights into its responsiveness during dynamic demand (load) variations.
Reactive Power Ramp Rate	Evaluates the system's ability to adjust reactive power delivery or absorption over time, crucial for grid stability, expressed in MVAr per second or as a percentage change in rated apparent power.
Reactive Power Response	Indicates the time taken by the battery to attain 100% of its rated apparent power during reactive power operations from standby mode, essential for grid voltage control.
Reference Signal Tracking	Assesses the system's capability to accurately respond to reference signals, ensuring effective integration into grid control mechanisms.
Round-Trip Efficiency	Quantifies the efficiency of the battery by comparing energy output to input over one duty cycle, typically expressed as a percentage, providing insights into energy losses during storage and retrieval processes.
Scheduled Downtime	Allocated time for maintenance or non-operational activities, crucial for maximizing system availability and reliability.
Self-Discharge Rate	Measures the rate at which the battery loses stored energy in standby mode, influenced by environmental conditions, and impacting overall energy retention capabilities.
Standby Energy Loss	Quantifies the rate at which the battery loses energy when activated but not actively storing or releasing energy, encompassing self-discharge rates and auxiliary system loads, essential for estimating overall system losses.

Appendix IV: Definition of battery storage services

RMI has identified 13 battery services defined below. They are grouped into system operator services to balance the grid, utility services to defer infrastructure investments, or customer services to reduce electricity costs.

Type of Service	Services	Description
ISO / RTO Services	**Energy Arbitrage**	The practice of buying electricity when prices are low and selling it when prices are high to profit from the price difference.
	Spin/Non-Spin Reserve	Reserved capacity maintained by power systems to quickly balance supply and demand fluctuations to maintain grid stability.
	Frequency Regulation	The process of maintaining the power system frequency at the desired level by adjusting power output.
	Voltage Support	Services provided to maintain voltage levels within acceptable limits to ensure reliable power delivery.
Utility Services	**Transmission Deferral**	Measures taken to delay or eliminate the need for new transmission infrastructure by optimizing existing assets or implementing alternative solutions.
	Transmission Congestion Relief	Actions taken to alleviate bottlenecks or congestion in transmission lines to ensure efficient power flow across the grid.
	Resource Adequacy	Ensuring that there is sufficient generation capacity available to meet electricity demand under normal and contingency conditions.
	Black Start	The process of restoring power to a power station or a part of the grid without relying on the external power transmission network.
	Distribution Deferral	Strategies to postpone or avoid the need for costly distribution system upgrades by implementing alternative solutions.
Consumer Services	**Backup Power**	Systems or services providing electricity during power outages to ensure continuity of critical operations or comfort.
	Increased PV Self-Consumption	Increasing the portion of solar energy generated by photovoltaic (PV) systems that is consumed on-site rather than exported to the grid.
	Demand Charge Reduction	Strategies to reduce electricity demand during peak periods to lower demand charges on utility bills.
	Time-of-Use Bill Management	Implementing measures to adjust electricity **Consumption** patterns to take advantage of lower rates during off-peak hours and minimize costs during peak hours.

Appendix V: Payback period tables

Below are sensitivity tables for the residential solar PV + battery storage payback period.

We calculated the payback period for a variety of different sized rooftop solar systems, with and without storage. The payback analysis does not factor any subsidies or incentives but does include fix charges baked into the retail price.

The model controls for the level of consumption, defined as the national average per house size. It also adjusts for monthly and diurnal load patterns. The load profile, aka pattern of demand, was derived to calculate monthly energy use as a % and multiplied by the annual average to estimate monthly consumption. The hour of sunset was used to estimate the hours of electric demand (load) needed after sundown, when solar generation is no longer possible. Furthermore, the model assumes the entire system has a maximum life of 25 years, with additional capex to maintain operational battery storage equivalent to 50% of the original $/kWh estimate. Payback periods greater than 25 years are marked “n.a.”.

Payback analysis key inputs

	Retail Price (€/kWh)	Price of Solar (€ / kWp)	Price of Storage (€ / kWh)
Dublin Ireland	€ 0.2332	€ 1,895	€ 800
Rome, Italy	€ 0.2687	€ 1,647	€ 732
Lisbon, Portugal	€ 0.2277	€ 1,201	€ 732
Berlin, Germany	€ 0.3183	€ 1,556	€ 900
Madrid, Spain	€ 0.1766	€ 1,622	€ 774
	Retail Price (£/kWh)	Price of Solar (£ / kWp)	Price of Storage (£ / kWh)
London, UK	£0.2450	£1,928	£696
	Retail Price ($/kWh)	Price of Solar ($ / kWp)	Price of Storage ($ / kWh)
San Francisco, CA USA	$0.2911	$2,977	$1,220
New York City, NY USA	$0.2252	$3,362	$1,220
Houston, TX USA	$0.1458	$2,800	$1,220
	Retail Price (AU$/kWh)	Price of Solar (AU$ / kWp)	Price of Storage (AU$ / kWh)
Sydney, Australia	$0.2651	$1,463	$1,415
Brisbane, Australia	$0.2703	$1,435	$1,415

Consumption assumptions

kWh	1 Bedroom	2 Bedroom	3 Bedroom	4+ Bedroom
Europe	2,000	3,000	4,000	5,000
	Multi-Family with 5+ Units	Multi-Family with 2-4 Units	Single-Family Attached	Single-Family Detached
San Francisco, CA USA	4,695	5,525	6,644	9,244
New York City, NY USA	5,722	6,852	7,983	10,035
Houston,. TX USA	8,923	10,997	12,929	17,923
	1 person	2 people	4 people	5+ people
Sydney, Australia	3,108	5,236	7,312	9,008
Brisbane, Australia	3,412	5,128	7,684	8,804

CAISO: San Francisco, CA, United States

Payback in years – no storage

San Francisco, CA USA					Solar PV Capacity (kWh)
	2	4	6	8	10
Cost	€ 5,960	€ 11,910	€ 17,870	€ 23,820	€ 29,780
Consumption					
Multi-Family with 5+ Units	7.0	14.0	21.0	n.a.	n.a.
Multi-Family with 2 - 4 Units	6.1	11.9	17.8	23.8	n.a.
Single-Family Attached	5.2	9.9	14.8	19.7	24.7
Single-Family Detached	4.1	7.1	10.6	14.2	17.7

Payback in years with storage 4kWh – 5kWh

San Francisco, CA USA					Solar PV Capacity (kWh)
	2	4	6	8	10
Cost	€ 10,830	€ 18,010	€ 23,960	€ 29,920	€ 35,870
Consumption					
Multi-Family with 5+ Units	8.3	14.7	18.9	24.1	n.a.
Multi-Family with 2 - 4 Units	8.0	13.1	16.7	21.3	24.8
Single-Family Attached	7.2	11.8	15.0	18.2	22.2
Single-Family Detached	5.8	8.5	12.7	15.4	18.2

Payback in years – no storage: 10 kWh

San Francisco, CA USA			Solar PV Capacity (kWh)
	6	8	10
Cost	€ 30,060	€ 36,020	€ 41,970
Consumption			
Multi-Family with 5+ Units	24.6	n.a.	n.a.
Multi-Family with 2 - 4 Units	19.3	24.1	n.a.
Single-Family Attached	16.3	19.0	23.0
Single-Family Detached	12.7	14.8	16.9

ERCOT: Houston, TX, United States

Payback in years – no storage

Houston, TX USA					Solar PV Capacity (kWh)
	2	4	6	8	10
Cost	**€ 5,600**	**€ 11,200**	**€ 16,800**	**€ 22,400**	**€ 28,000**
Consumption					
Multi-Family with 5+ Units	7.00	12.3	18.4	24.5	n.a.
Multi-Family with 2 - 4 Units	6.4	10	14.9	19.9	24.9
Single-Family Attached	6.3	8.5	12.7	16.9	21.2
Single-Family Detached	6.2	6.2	9.1	12.2	15.3

Payback in years with storage 4kWh – 5kWh

Houston, TX USA					Solar PV Capacity (kWh)
	2	4	6	8	10
Cost	**€ 10,480**	**€ 17,300**	**€ 22,900**	**€ 28,500**	**€ 34,100**
Consumption					
Multi-Family with 5+ Units	12.7	17.5	23.5	n.a.	n.a.
Multi-Family with 2 - 4 Units	9.8	15.0	19.1	24.4	n.a.
Single-Family Attached	9.6	13.1	16.7	21.3	24.8
Single-Family Detached	9.6	8.5	12.6	15.3	18.0

Payback in years – no storage: 10 kWh

Houston, TX USA			Solar PV Capacity (kWh)
	6	8	10
Cost	€ 29,000	€ 34,600	€ 40,200
Consumption			
Multi-Family with 5+ Units	n.a.	n.a.	n.a.
Multi-Family with 2 - 4 Units	22.5	n.a.	n.a.
Single-Family Attached	18.4	22.9	n.a.
Single-Family Detached	14.9	17.2	19.6

NYISO: New York, NY, United States

Payback in years – no storage

New York, NY USA					Solar PV Capacity (kWh)
	2	4	6	8	10
Cost	**€ 6,730**	**€ 13,450**	**€ 20,170**	**€ 26,900**	**€ 33,620**
Consumption					
Multi-Family with 5+ Units	8.5	16.4	24.6	n.a.	n.a.
Multi-Family with 2 - 4 Units	7.4	13.7	20.6	n.a.	n.a.
Single-Family Attached	6.5	11.7	17.6	23.5	n.a.
Single-Family Detached	5.6	9.4	14.1	18.7	23.4

Payback in years with storage 4kWh – 5kWh

New York, NY USA					Solar PV Capacity (kWh)
	2	4	6	8	10
Cost	**€ 11,600**	**€ 19,550**	**€ 26,270**	**€ 33,000**	**€ 39,720**
Consumption					
Multi-Family with 5+ Units	12.5	18.0	24.5	n.a.	n.a.
Multi-Family with 2 - 4 Units	9.5	16.4	22.4	n.a.	n.a.
Single-Family Attached	8.7	14.7	19.0	24.3	n.a.
Single-Family Detached	7.7	12.6	16.4	20.9	24.6

Payback in years – no storage: 10 kWh

New York, NY USA			Solar PV Capacity (kWh)
	6	8	10
Cost	€ 32,370	€ 39,100	€ 45,820
Consumption			
Multi-Family with 5+ Units	n.a.	n.a.	n.a.
Multi-Family with 2 - 4 Units	22.9	n.a.	n.a.
Single-Family Attached	18.6	23.3	n.a.
Single-Family Detached	15.7	18.5	22.5

Germany

Payback in years – no storage

Germany					**Solar PV Capacity (kWh)**
	2	4	6	8	10
Cost	**€ 3,110**	**€ 6,230**	**€ 9,340**	**€ 12,450**	**€ 15,560**
Consumption					
1 Bedroom	7.0	12.9	19.4	n.a.	n.a.
2 - Bedroom	5.1	8.6	12.9	17.2	21.5
3 Bedroom	4.1	6.5	9.7	12.9	16.2
> 4 Bedrooms	3.4	5.3	7.7	10.3	12.9

Payback in years with storage 4kWh – 5kWh

Germany					**Solar PV Capacity (kWh)**
	2	4	6	8	10
Cost	**€ 6,710**	**€ 10,730**	**€ 13,840**	**€ 16,950**	**€ 20,060**
Consumption					
1 Bedroom	9.4	16.5	23.8	n.a.	n.a.
2 - Bedroom	6.8	9.5	14.8	17.7	21.6
3 Bedroom	5.3	7.4	9.6	13.3	15.4
> 4 Bedrooms	4.6	6.1	7.8	9.6	12.6

Payback in years – no storage: 10 kWh

Germany			**Solar PV Capacity (kWh)**
	6	8	10
Cost	€ 18,340	€ 21,450	€ 24,560
Consumption			
1 Bedroom	n.a.	n.a.	n.a.
2 - Bedroom	19.5	n.a.	n.a.
3 Bedroom	15	17.9	21.6
> 4 Bedrooms	9.8	14.3	16.1

Ireland

Payback in years – no storage

Ireland					**Solar PV Capacity (kWh)**
	2	4	6	8	10
Cost	**€ 3,790**	**€ 7,580**	**€ 11,370**	**€ 15,160**	**€ 18,950**
Consumption					
1 Bedroom	13.0	20.0	n.a.	n.a.	n.a.
2 - Bedroom	10.4	13.9	20.0	n.a.	n.a.
3 Bedroom	9.2	11.0	15.0	20.0	n.a.
> 4 Bedrooms	8.2	9.1	12.0	16.0	20.0

Payback in years with storage 4kWh – 5kWh

Ireland					**Solar PV Capacity (kWh)**
	2	4	6	8	10
Cost	**€ 6,990**	**€ 11,580**	**€ 15,370**	**€ 19,160**	**€ 22,950**
Consumption					
1 Bedroom	13.9	19.1	n.a.	n.a.	n.a.
2 - Bedroom	9.2	14.2	18.1	23.0	n.a.
3 Bedroom	7.7	9.9	14.0	17.4	21.3
> 4 Bedrooms	6.7	8.2	11.7	14.3	16.9

Payback in years – no storage: 10 kWh

Ireland			**Solar PV Capacity (kWh)**
	6	8	10
Cost	€ 19,370	€ 23,160	€ 26,950
Consumption			
1 Bedroom	n.a.	n.a.	n.a.
2 - Bedroom	23.8	n.a.	n.a.
3 Bedroom	16.9	21.4	24.2
> 4 Bedrooms	13.4	16.2	18.4

Italy

Payback in years – no storage

Italy	Solar PV Capacity (kWh)				
	2	4	6	8	10
Cost	**€ 3,300**	**€ 6,590**	**€ 9,880**	**€ 13,180**	**€ 16,470**
Consumption					
1 Bedroom	8.2	16.4	24.6	n.a.	n.a.
2 - Bedroom	5.5	10.9	16.4	21.8	n.a.
3 Bedroom	4.2	8.2	12.3	16.4	20.5
> 4 Bedrooms	3.4	6.6	9.8	13.1	16.4

Payback in years with storage 4kWh – 5kWh

Italy	Solar PV Capacity (kWh)				
	2	4	6	8	10
Cost	**€ 6,220**	**€ 10,250**	**€ 13,540**	**€ 16,840**	**€ 20,130**
Consumption					
1 Bedroom	12.6	22.9	n.a.	n.a.	n.a.
2 - Bedroom	6.9	14.2	18.1	23.0	n.a.
3 Bedroom	5.4	9.0	13.5	16.4	19.3
> 4 Bedrooms	4.5	7.3	9.6	13.2	15.5

Payback in years – no storage: 10 kWh

Italy	Solar PV Capacity (kWh)		
	6	8	10
Cost	€ 17,200	€ 20,500	€ 23,790
Consumption			
1 Bedroom	n.a.	n.a.	n.a.
2 - Bedroom	n.a.	n.a.	n.a.
3 Bedroom	18.4	22.9	n.a.
> 4 Bedrooms	14.7	17	19.4

Spain

Payback in years – no storage

Spain				Solar PV Capacity (kWh)	
	2	4	6	8	10
Cost	**€ 3,240**	**€ 6,490**	**€ 9,730**	**€ 12,980**	**€ 16,220**
Consumption					
1 Bedroom	14.2	n.a.	n.a.	n.a.	n.a.
2 - Bedroom	9.4	18.9	n.a.	n.a.	n.a.
3 Bedroom	7.2	14.2	21.2	n.a.	n.a.
> 4 Bedrooms	5.9	11.3	17.0	22.6	n.a.

Payback in years with storage 4kWh – 5kWh

Spain				Solar PV Capacity (kWh)	
	2	4	6	8	10
Cost	**€ 6,340**	**€ 10,360**	**€ 13,600**	**€ 16,850**	**€ 20,090**
Consumption					
1 Bedroom	20.0	n.a.	n.a.	n.a.	n.a.
2 - Bedroom	13.7	24.8	n.a.	n.a.	n.a.
3 Bedroom	8.6	17.3	23.6	n.a.	n.a.
> 4 Bedrooms	7.3	13.8	17.8	22.9	n.a.

Payback in years – no storage: 10 kWh

Spain		Solar PV Capacity (kWh)	
	6	8	10
Cost	€ 17,470	€ 20,710	€ 23,960
Consumption			
1 Bedroom	n.a.	n.a.	n.a.
2 - Bedroom	n.a.	n.a.	n.a.
3 Bedroom	n.a.	n.a.	n.a.
> 4 Bedrooms	n.a.	n.a.	n.a.

Portugal

Payback in years – no storage

Portugal					Solar PV Capacity (kWh)
	2	4	6	8	10
Cost	**€ 2,400**	**€ 4,810**	**€ 7,210**	**€ 9,610**	**€ 12,020**
Consumption					
1 Bedroom	7.2	14.3	21.5	n.a.	n.a.
2 - Bedroom	4.8	9.5	14.3	19.1	23.8
3 Bedroom	3.6	7.2	10.7	14.3	17.9
> 4 Bedrooms	2.9	5.7	8.6	11.4	14.3

Payback in years with storage 4kWh – 5kWh

Portugal					Solar PV Capacity (kWh)
	2	4	6	8	10
Cost	**€ 5,330**	**€ 8,470**	**€ 10,870**	**€ 13,270**	**€ 15,670**
Consumption					
1 Bedroom	12.7	19.8	n.a.	n.a.	n.a.
2 - Bedroom	6.6	13.2	16.3	19.3	23.6
3 Bedroom	5.2	8.2	12.3	14.6	16.9
> 4 Bedrooms	4.4	6.8	8.7	12.0	13.9

Payback in years – no storage: 10 kWh

Portugal			Solar PV Capacity (kWh)
	6	8	10
Cost	€ 14,530	€ 16,930	€ 19,330
Consumption			
1 Bedroom	n.a.	n.a.	n.a.
2 - Bedroom	n.a.	n.a.	n.a.
3 Bedroom	17.5	19.8	23.8
> 4 Bedrooms	14.0	15.8	17.7

United Kingdom

Payback in years – no storage

United Kingdom					Solar PV Capacity (kWh)
	2	4	6	8	10
Cost	**€ 3,860**	**€ 7,710**	**€ 11,570**	**€ 15,420**	**€ 19,280**
Consumption					
1 Bedroom	12	22.6	n.a.	n.a.	n.a.
2 - Bedroom	8.6	15.1	22.6	n.a.	n.a.
3 Bedroom	6.8	11.3	16.9	22.6	n.a.
> 4 Bedrooms	5.7	9.1	13.6	18.1	22.6

Payback in years with storage 4kWh – 5kWh

United Kingdom					Solar PV Capacity (kWh)
	2	4	6	8	10
Cost	**€ 6,640**	**€ 11,190**	**€ 15,050**	**€ 18,900**	**€ 22,760**
Consumption					
1 Bedroom	12.8	21.4	n.a.	n.a.	n.a.
2 - Bedroom	7.9	13.7	18.1	23.2	n.a.
3 Bedroom	6.8	9.3	14.3	17.5	21.4
> 4 Bedrooms	5.8	8.1	12.3	15.1	17.8

Payback in years – no storage: 10 kWh

United Kingdom			Solar PV Capacity (kWh)
	6	8	10
Cost	€ 18,530	€ 22,380	€ 26,240
Consumption			
1 Bedroom	n.a.	n.a.	n.a.
2 - Bedroom	n.a.	n.a.	n.a.
3 Bedroom	17.7	22.2	n.a.
> 4 Bedrooms	13.6	16.6	19.1

Sydney, Australia

Payback in years – no storage

Sydney, Australia					**Solar PV Capacity (kWh)**
	2	4	6	8	10
Cost	**€ 2,930**	**€ 5,850**	**€ 8,780**	**€ 11,700**	**€ 14,630**
Consumption					
1 person	5.3	10.6	15.9	21.1	n.a.
2 people	3.1	6.2	9.4	12.6	15.7
4 people	2.3	4.5	6.8	9.0	11.2
5 + people	2.0	3.7	5.5	7.3	9.1

Payback in years with storage 4kWh – 5kWh

Sydney, Australia					**Solar PV Capacity (kWh)**
	2	4	6	8	10
Cost	**€ 8,590**	**€ 12,930**	**€ 15,850**	**€ 18,780**	**€ 21,700**
Consumption					
1 person	15.1	n.a.	n.a.	n.a.	n.a.
2 people	7.0	13.6	16.0	18.4	22.2
4 people	5.5	7.8	9.6	13.4	15.1
5 + people	4.7	6.5	8.0	9.4	12.6

Payback in years – no storage: 10 kWh

Sydney, Australia			**Solar PV Capacity (kWh)**
	6	8	10
Cost with Batteries	€ 22,930	€ 25,850	€ 28,780
Consumption			
1 person	n.a.	n.a.	n.a.
2 people	n.a.	n.a.	n.a.
4 people	17.6	19.3	23.2
5 + people	14.0	15.4	16.8

Brisbane City, Australia

Payback in years – no storage

Sydney, Australia					**Solar PV Capacity (kWh)**
	2	4	6	8	10
Cost	**€ 2,870**	**€ 5,740**	**€ 8,610**	**€ 11,480**	**€ 14,350**
Consumption					
1 person	4.9	9.9	14.8	19.7	24.6
2 people	3.2	6.6	9.8	13.1	16.3
4 people	2.1	4.3	6.6	8.7	10.9
5 + people	1.9	3.8	5.7	7.6	9.5

Payback in years with storage 4kWh – 5kWh

Sydney, Australia					**Solar PV Capacity (kWh)**
	2	4	6	8	10
Cost	**€ 2,870**	**€ 5,740**	**€ 8,610**	**€ 11,480**	**€ 14,350**
Consumption					
1 person	4.9	9.9	14.8	19.7	24.6
2 people	3.2	6.6	9.8	13.1	16.3
4 people	2.1	4.3	6.6	8.7	10.9
5 + people	1.9	3.8	5.7	7.6	9.5

Payback in years – no storage: 10 kWh

Sydney, Australia			**Solar PV Capacity (kWh)**
	6	8	10
Cost with Batteries	€ 22,760	€ 25,630	€ 28,500
Consumption			
1 person	n.a.	n.a.	n.a.
2 people	n.a.	n.a.	n.a.
4 people	14.7	16.1	17.5
5 + people	13.1	14.4	15.6

Appendix VI: Overview of primary battery technology minerals

Mineral	Challenges
Cobalt	High reliance on DRC and China, around 70% each, likely to persist due to limited projects elsewhere.
	Artisanal mining significantly affects supply vulnerability.
	Cobalt's new supply depends on nickel and copper market dynamics, as it's mainly a by-product of these minerals.
Copper	Difficult to replace because of its outstanding performance in electrical uses.
	Existing mines are approaching maximum output levels as a result of diminishing ore quality and depletion of reserves.
	Decreasing ore quality is causing production expenses, emissions, and waste quantities to rise.
	Mining operations in South America and Australia face significant climate and water scarcity challenges.
Lithium	There's a risk of a bottleneck in lithium chemical production due to financial constraints on smaller producers following years of low prices.
	Global lithium chemical production is heavily centralized, with China contributing 60% overall (over 80% for lithium hydroxide).
	Mines in South America and Australia face significant climate and water stress.
Nickel	Continued dependence on the DRC for production and China for refining is likely as few projects are being developed elsewhere.
	Increasing environmental worries regarding CO2 emissions and tailings disposal are emerging.
Rare earth elements	China's control spans the entire value chain, from mining through processing to magnet manufacturing.
	Processing operations have poor environmental records.
	Varied demand projections for specific elements pose the risk of price surges for highly sought-after ones (such as Neodymium) and downturns for those with low demand (such as Cerium).

Source: IEA and Alexa Capital research

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