Background Paper

"Electricity Storage & Grid Management for Maximum RES Penetration"

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ELECTRICITY STORAGE & GRID MANAGEMENT FOR MAXIMUM RES PENETRATION

BACKGROUND PAPER

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Introduction

2021 was yet another record year for renewable energy, despite continued disruption from the COVID-19 pandemic and the rising costs for raw materials around the world. Yet in the future, we may well look back and see 2021 just as importantly as the beginning of the energy storage decade.

Declines in cost for wind, solar PV and energy storage technologies have profoundly impacted the rate of deployment of renewable energy in global power systems. Solar PV and onshore wind have become the cheapest sources of new generation for around two-thirds of the world population. As the share of variable renewable energy sources, primarily used for power generation, increases compared to conventional fossil fuel generation, energy storage is becoming increasingly important to grid resilience and flexibility. The massive deployment of wind and solar generation which is planned for the next 10 years practically necessitates the mass adoption of energy storage as a balancing asset.

Analysts from Bloomberg New Energy Finance (BNEF) predicted in November 2021 that globally there will be $262 billion worth in investment in making 345 GW of new energy storage by 2030. And this forecast may yet prove to be conservative, with new technologies and storage applications coming into the picture. **(1)**

Primarily driven by intense research and development into electric vehicles, lithium-ion batteries takes up the majority of new energy storage capacity, both installed and under construction, with older battery technologies being replaced or retained only for smaller projects. Yet as battery costs continue to fall, battery energy storage has already become a cost effective new-build technology for “peaking” services, particularly in natural gas-importing areas where new-build gas generation is no longer being pursued (such as California).

The development of the global energy storage sector has many similarities with earlier years of the renewable energy sector. With costs declining, private investors are entering the market introducing new business models to commercialise the technologies. Governments of countries with a high share of renewable energy, or looking to facilitate development of the same, have seen the need to support energy storage from policy and regulation perspectives, even if the efforts in some countries are still nascent. Using the renewable energy sector as a guide, the energy storage market will accelerate over the next few years with the continued scaling up of manufacturing processes, technology innovation and the maturing of business models.

Yet there are differences as well. Energy storage competes with demand-side response, since they both provide flexibility services to the grid. Despite the current ascendancy of lithium-ion technology, the battle over core technologies is also still being waged, with emerging technologies (such as flow batteries and renewable-hydrogen) poised to potentially disrupt the business case for new projects.

1. Why Energy Storage?

The growth and expansion of renewable generation globally has been one of the energy sector's greatest successes over the last decade. However, with this success comes the challenge of maintaining efficient and effective power grids by properly integrating variable renewable energy sources, such as solar and wind. As the penetration of renewable energy increases, maintaining grid reliability becomes ever more challenging and costly.

Meeting rising flexibility needs while decarbonizing electricity generation is a central challenge for the entire sector and all sources of flexibility need to be utilized. While the use of energy storage in national networks is not new, energy storage, and in particular battery storage, has emerged in recent years as a key piece in this puzzle. Furthermore, the deployment of energy storage is seen by many RES entrepreneurs as a useful additional source of power provision to the grid when renewable output is minimal or zero.

Hence, energy storage systems are seen as satisfying a dual role. At this level of technology development, the first task is to provide grid stability through energy storage, while the second is to augment RES input to the grid.

2. Energy Storage Applications

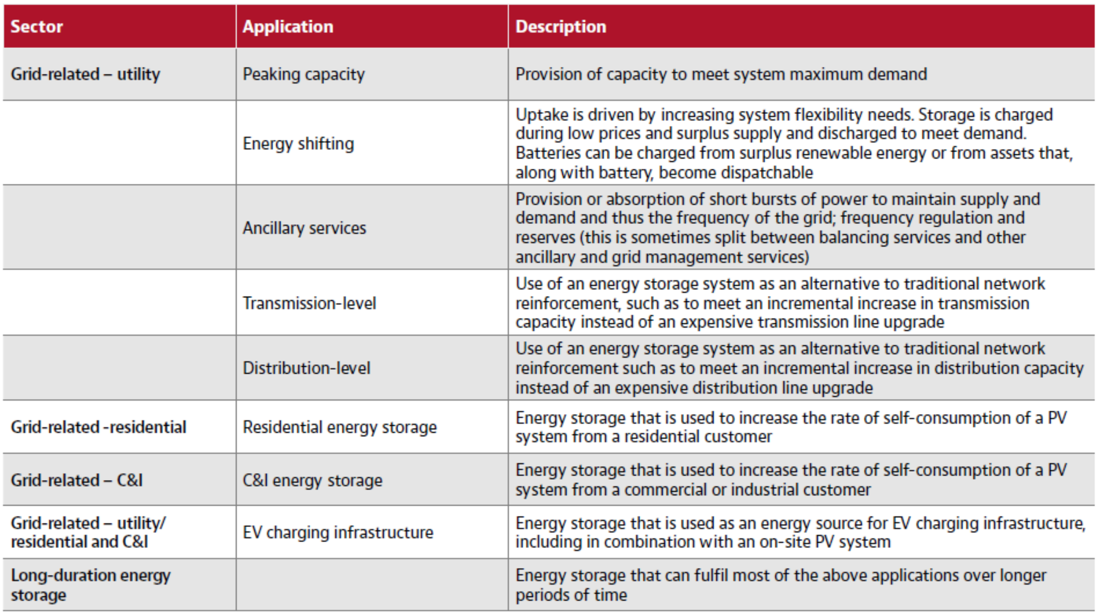
Energy storage projects generally have a more complicated part to play in energy grids than renewable energy generation. Storage systems can fulfil different roles and storage technologies need to be understood in the context of the applications and services they provide. These range, for example, from short-term balancing of supply and demand, to restoring grid operation following a blackout, to providing operating reserves or deferring investment in new transmission and distribution lines.

Several applications that energy storage can fulfil can also be performed by alternative measures and/or infrastructure, such as demand response, power plant retrofits, smart-grid measures that enhance power networks and other technologies that improve grid flexibility. The advantages and disadvantages of these other measures compared to energy storage need to be considered in the context of the particular energy market.

For example, in coming years, natural gas fuelled power stations with carbon capture and storage can act as "peakers", generating power quickly to ensure capacity is sufficient to meet system demand while still curtailing emissions. For gas-importing regions (i.e. much of Asia) or those without much gas generation, energy storage may provide that application more cost effectively. This is exactly the scenario that California faces in coming years, with its grid estimated to need 12 GW of storage for balancing after solar PV power generation replaces 9 GW of retired gas generation. **(2)**

There have been various attempts to categorize energy storage applications for stationary storage systems, as shown in Table. The Table excludes industrial uses such as use of batteries for uninterruptible power and data centers, telecom backup power and use of battery systems on forklifts. The deployment of storage for such industrial uses currently exceeds grid related applications, but that is quickly reversing. Of these potential applications, some are more likely to be implemented and become in demand more than others. BNEF has forecast that 55% of energy storage projects built by 2030 will predominantly be performing energy shifting (i.e. by storing solar or wind power to discharge later).

Table: Description of Stationary Storage Applications



Sector	Application	Description
Grid-related – utility	Peaking capacity	Provision of capacity to meet system maximum demand
	Energy shifting	Uptake is driven by increasing system flexibility needs. Storage is charged during low prices and surplus supply and discharged to meet demand. Batteries can be charged from surplus renewable energy or from assets that, along with battery, become dispatchable
	Ancillary services	Provision or absorption of short bursts of power to maintain supply and demand and thus the frequency of the grid; frequency regulation and reserves (this is sometimes split between balancing services and other ancillary and grid management services)
	Transmission-level	Use of an energy storage system as an alternative to traditional network reinforcement, such as to meet an incremental increase in transmission capacity instead of an expensive transmission line upgrade
	Distribution-level	Use of an energy storage system as an alternative to traditional network reinforcement such as to meet an incremental increase in distribution capacity instead of an expensive distribution line upgrade
Grid-related -residential	Residential energy storage	Energy storage that is used to increase the rate of self-consumption of a PV system from a residential customer
Grid-related – C&I	C&I energy storage	Energy storage that is used to increase the rate of self-consumption of a PV system from a commercial or industrial customer
Grid-related – utility/ residential and C&I	EV charging infrastructure	Energy storage that is used as an energy source for EV charging infrastructure, including in combination with an on-site PV system
Long-duration energy storage		Energy storage that can fulfil most of the above applications over longer periods of time

Source: US Department of Energy

Other applications, such as distribution-level and transmission-level, are less likely to be available for a particular project as demand for these kind of services relies mostly on a permissive regulatory scheme and incentives. For a network owner to wish to utilize these types of services, he/she needs to have both the ability and excuse to do so as opposed to relying on traditional infrastructure investment.

Energy storage is also being considered more and more for incorporation into distributed generation networks or “mini-grids” (or “micro-grids”). While mini-grids have tended to be associated with developing nations with smaller networks and limited renewable generation, energy storage is increasingly being tried in developed countries such as the UK and Japan for discrete or remote areas (in the case of Japan, small islands) with renewable generation powering a mini-grid with storage at its heart. **(3)**

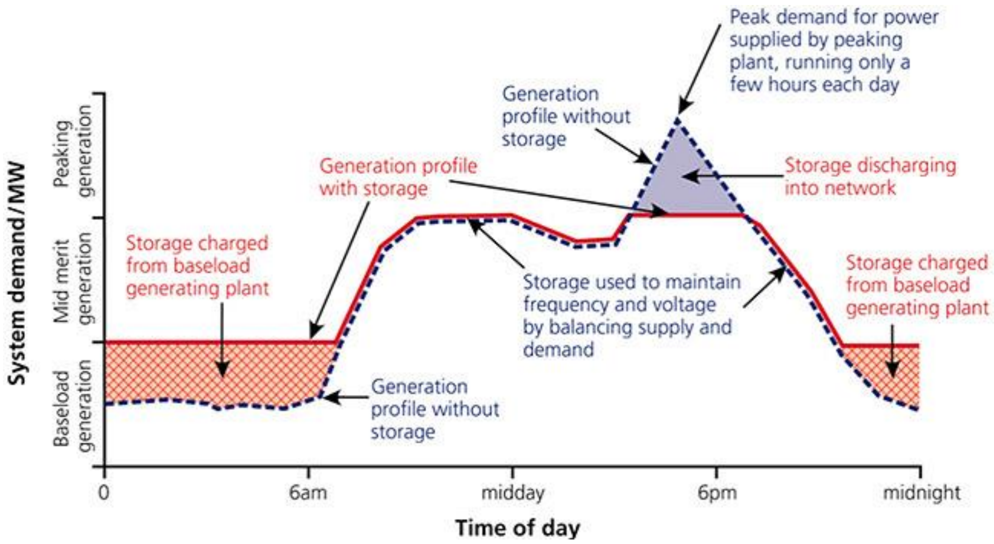
“Hybrid” Renewables Plus Storage Projects

So-called “hybrid” co-located, renewable generation plus storage projects are becoming increasingly common, particularly in the US due to its particular market features and incentives. This is due in part to steadily falling costs.

In addition to generation, hybrid projects facilitate energy shifting applications with rising renewable capacity and changing energy consumption patterns creating opportunities for price arbitrage, allowing developers to shift dispatch to times of higher prices. In addition to improving grid flexibility, this can unlock greater value for hybrid project developers as higher volumes of zero marginal cost renewables are connected to the grid, allowing developers some mitigation during periods of zero of negative prices, depending on market conditions.

Hybrid projects (i.e. RES production linked to storage) also become economically more attractive as developers gain access to the power balancing market and are able to provide grid services. In some markets, hybrid projects can currently provide peaking applications even more cheaply than natural gas generation.

Figure 1: Energy Arbitrage (Discharging At Peak) and Peak Shaving (New Flatter Profile At Peak)



Source: Zhang et al. (2021)[1]

While integrating the energy storage system with the rest of the plant, this adds an additional technical challenge during commissioning. This can also add cost savings and other technical benefits, such as increasing utilization of the transformer (which can reduce system cost) and a higher capacity factor.

3. Energy Storage Technologies

Current Technologies

The main parameters for evaluating current and alternative energy storage technologies are: (i) technical and economic feasibility, (ii) locational constraints and (iii) system size. Stationary energy storage has been in use for decades, with the first pumped storage projects implemented in the early 1900s. More recently, other technologies have advanced

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[1] Zhang, X. et al. (2021), "Arbitrage analysis for different energy storage technologies and strategies", *Energy Reports, Volume 7*, November 2021, pp. 8198-8206, https://www.sciencedirect.com/science/article/pii/S2352484721008143

rapidly along with the use of portable consumer electronics, electrification of the transport sector (in large part due to the increased popularity of EVs and the growth and increasing penetration of renewable generation).

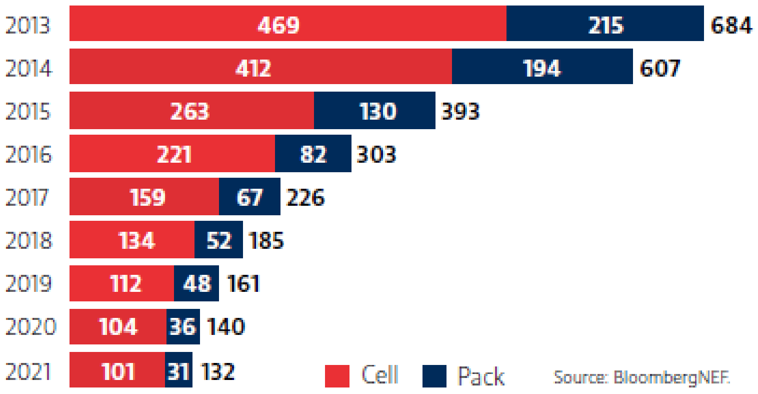
Legacy energy storage is dominated by pumped-hydro storage (PHS), one of the most conventional storage solutions and the oldest, but its potential is limited by suitable hydropower and the availability of sites, as well as political and environmental issues and other challenges. The hydropower market in Europe, for example, is nearly built out. While several countries, including the US and China, are still exploring avenues for PHS growth, the capability of most countries to substantially increase PHS capacity relative to current and future needs is limited and the share of global PHS capacity to total global energy storage is in steady decline.

In contrast, the great majority of new energy storage projects use battery storage, a market being driven by rapidly evolving battery technology, a steady decline in the cost of batteries and the reduction in the cost of renewable generation itself. As of 2021, almost all new battery storage used lithium-ion battery technology, with lithium-ion systems comprising over 90% of stationary battery capacity. Of the balance, the majority is made up of sodium-sulfur (NaS) batteries, a technology that is generally considered to be inferior to lithium-ion and with more safety concerns, and lead-acid batteries.

The latter deserves some note. While, lead-acid technology is older than lithium-ion, it is already used widely as electricity storage for data centers and is still being used to a large extent in the transport sector. However, in stationary storage projects it is being gradually replaced with lithium-ion (which is cheaper and has a longer life cycle) or is being used only in smaller storage installations.

Lithium-ion deployment is of course primarily driven by intense research and development in EVs, making this technology the easiest and fastest to deploy. Lithium-ion and its derivatives are winning out based on price competitiveness, an established supply chain (dominated by Asia and China in particular) and as at 2021, a significant track record.

Figure 2: Average Lithium-Ion Battery Cost in USD/kWh (2021)



Source: Bloomberg New Energy Finance

Interestingly though, while it is the increasing deployment of lithium-ion in the automotive sector that has facilitated the cost competiveness of similar batteries in the relatively smaller stationary energy storage market, these batteries are not optimized for storage applications in all respects. For instance, the lithium-ion batteries developed for use in EVs have high power density and output, making them lighter and very well suited for energy storage in the transport sector. These characteristics are of course helpful for stationary applications, such as those used to provide “peaking” services where electricity needs to be capable of being discharged from the batteries almost instantaneously, but high energy density is less important for stationary applications where space and weight aren’t as restricted.

Stationary applications, depending on their application, may also have different priorities in terms of durability (of both the batteries and related infrastructure such as inverters), discharge rates, life cycle, temperature stability and safety, among others.

Accordingly, while the continued evolution of lithium-ion technologies in the automotive sector works to advance energy storage in terms of innovations and cost reductions, the different priorities of energy storage applications are leading to increased divergence in the technologies used for these two markets. This is not necessarily a negative factor for the energy storage market. As the ideal battery technology for EVs sees increased use amongst automotive battery supply chains, technology that is less suitable for EVs may be deployed in storage for reduced cost. However, it is important for storage developers to keep this growing divergence in mind, particularly in the medium-to-long-term.

A good example of the divergence to be found in lithium-ion technologies is the growing use of lithium-iron phosphate (LFP) chemistry in grid-scale storage, particularly in China, over nickel-manganese-cobalt (NMC) chemistries predominantly used in EV supply chains. LFP chemistries see less use overall (counting EVs), but in 2021 became the most common choice for grid-scale stationary applications for the first time. LFP chemistries offers several advantages for stationary storage, having higher durability (in turn reducing maintenance costs) and reducing some safety concerns. In turn, LFP chemistries have lower energy density than NMC, a disadvantage for use in EVs. LFP chemistry deployment in storage is expected to increase over the next decade, again due to increased use by Chinese storage developers, with costs expected to continue to fall.

Another very important consideration for lithium-ion batteries is that their performance is better for short-duration storage, which is where the storage duration is less than eight hours before discharge. This does not present substantial issues for most storage projects in the short or medium-term as the average grid-scale storage project currently aims for around four hour storage. However, in the long-term, and particularly after 2030, rising penetration of renewable energy will require not just increasing amounts of energy storage but long-duration storage (i.e. eight hours or more), depending on the country and the characteristics of its energy market.

The rush to develop cost-competitive, long-duration storage to use in place of lithium-ion batteries has already commenced, particularly in locations such as California where the expected future need for long-duration storage is likely to be huge.

Alternative Technologies

Lithium-ion batteries in their various chemistries are expected by most analysts to dominate the storage market over the next decade to 2030. While research continues on alternative lithium-ion chemistries on silicon-based anodes, some researchers do not see truly significant improvements over more or less conventional lithium-ion technology in terms of cost reductions and improvements in energy density until the advent of lithium-metal anode all solid-state batteries (ASSBs). However, these are generally considered to be some years away from being commercially available and, from that point, the technology would require a considerable build-up of manufacturing capacity before it could be deployed at scale. It is also worthwhile, given the incredible rate of evolution in battery technologies to date, to consider the most likely potential alternatives to lithium-ion.

Flow-batteries (also referred to as redox flow batteries or RFBs) are aqueous-based batteries that use tanks of liquid electrolyte. The electrolyte is run through electrodes to charge and then run in reverse to discharge, hence “flow”. Large flow-battery storage projects operate or are being developed in China and Japan and are in the planning stage elsewhere.

The technology is relatively new and has advantages. It is easily scalable, and has a long life cycle and effectively unlimited capacity. However, flow-batteries have lower energy density than lithium-ion and are not currently cost competitive (although that could change given that large-scale flow-battery projects have only been in operation for a few years). Commentators have suggested that the emergence of iron-based chemistries to solve some of the cost issues of flow-batteries could improve their economic feasibility sufficiently to compete with lithium-ion for just under half of the stationary storage market by 2030.

Vanadium, a transition metal, is currently the preferred electrolyte for flow-batteries due to its stability, although the metal faces supply issues which, may in turn, affect cost. The largest vanadium-based storage project, a 200 MW installation in Dalian, China is due to be commissioned in late 2021. However, several countries have announced recent investments in vanadium production in order to facilitate flow-battery storage projects, including Australia and the US **(4)**. Vanadium flow-batteries are also being trialed in South Korea and Australia with the view of supporting EV charging systems.

Aside from batteries, there are also many other potential energy storage technologies such as the previously mentioned PHS, compressed-air energy storage (CAES), hydrogen, flywheel and thermal energy storage, all being further refined and developed. Again, all these technologies have various advantages and disadvantages. Several can dispatch for longer periods compared to batteries, supplying more energy during prolonged periods of low renewable energy. CAES, which stores energy as compressed air and is generally deployed in large underground caverns, may be the technology closest to cost competiveness, with batteries with projects in operation in the US and China providing peaking and energy shifting applications.

Hydrogen technology is often considered to have the highest long-term potential, with enormous flexibility of use in both the energy storage and transportation sectors and much lower dependence on critical metals. Many countries have targeted hydrogen as a key part of their carbon-reduction goals, and recent changes in several of these have provided a much more favourable policy context for further research and development. However, while producing renewable hydrogen via renewable energy-driven water electrolysis is gaining traction globally, it still represents a small fraction of total global hydrogen production and is some way from being cost competitive.

Research and development into hydrogen storage for use as energy storage is also at relatively early stages. Gaseous hydrogen storage is achievable with current technology but is dependent on locating appropriate sites, such as large salt caverns or depleted gas fields. Accordingly, while large-scale hydrogen storage projects do exist in the US, UK and elsewhere, and there is further capacity planned in US and Europe (particularly Germany), there is currently limited potential for commercial deployment.

Long-Duration Technologies

A further key issue is the suitability of the various technologies for the long-duration storage (more than eight hours of storage) that national grids will require in the coming years. As renewable content on the grid increases, the duration of storage needed to provide reliability also increases. For very high (i.e. more than 80%) renewable penetration, storage duration as long as over 120 hours (sometimes termed as “seasonal storage”) will be needed.

While lithium-ion batteries are, at present, generally the most economical solution for short-duration storage, that technology is not optimized for lifecycle or durability and lithium-ion systems do not scale as effectively for long-duration storage. Longer or more frequent dispatch of lithium-ion battery systems accelerates degradation, eventually requiring replacement or upgrade of the battery components, and tends to shorten maintenance cycles for shared components such as inverters (another key maintenance cost).

Several technologies are currently available or in the development stage to address the need for long-duration storage. These include PHS, flow-batteries, chemical (including hydrogen) and thermal storage, gravity-based approaches and electrochemical couples. Flow-batteries can provide long-duration storage but as above have cost issues, including, at least historically, the high and volatile cost of vanadium. Other chemistries using earth-abundant materials may end up being more cost-competitive. For example, iron based flow-batteries have been tested at small-scale and are now being scaled up.

At present, hydrogen for energy storage typically requires appropriate cavern storage to be economical, which obviously limits locations. Hydrogen systems with the right site conditions can even provide seasonal or even inter-seasonal storage and projects with geological storage and natural gas (combined with carbon capture and storage) are viewed by many commentators as a key technology for the future.

Electrochemical couples include a number of unconventional battery systems. These include “aqueous air” batteries, the product of a US start-up that has promised 150 hours of storage at a competitive cost although few details about the technology have been made public. The technology has already received a utility contract from Minnesota-based utility Great River Energy to provide a 1 MW/150 MWh grid-connected system that would allow storage and discharge even through extreme weather events such as a polar vortex or heat wave. If this pilot is successful (the project is due to be commissioned in 2023/2024), and the technology could be scaled up, it could open up several new business models around low utilization and with low capital cost.

Hydrostar, a Canadian company that claims a proprietary "advanced" CAES, has applied for licenses in California for a 500MW/4GWh project in Kern County and a 400 MW/3.2 GWh project in San Luis Obispo County **(5)**. Other companies have also made bold announcements about building cheap MW-scale long-duration storage but these remain to be demonstrated.

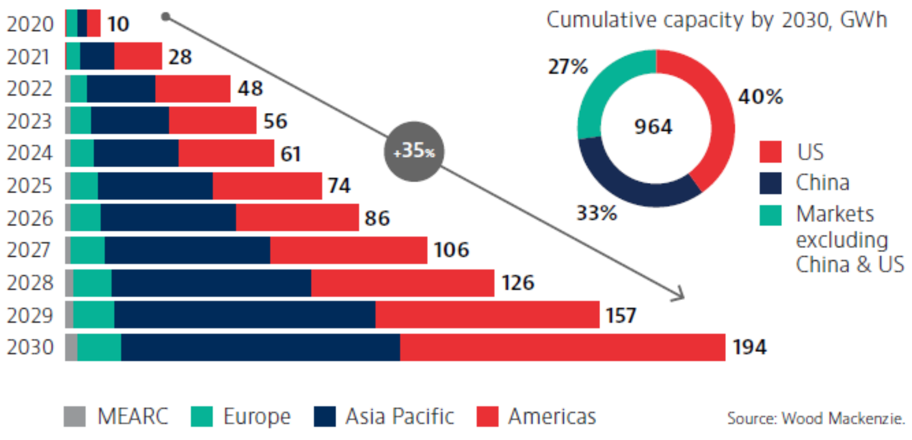
4. The Global Energy Storage Market

Performance and Forecasts

2021 was a strong year for global energy storage with reports from November 2021 showing 12.4 GW of new installed capacity, an over 150% increase from 2020 **(6)**, which saw supply chain disruptions and travel restrictions arising from COVID-19. Utility-scale FTM installations accounted for around two-thirds added capacity. While significant, this investment is just the early stages of the ramp up in capacity that is critical to meet flexibility needs in a decarbonized electricity system.

Wood Mackenzie estimates that 346.2 GW/964 GWh of new energy storage capacity **(7)** will be added globally between 2021 and 2030, with well over half of that capacity in the US and China (see Figure 3). That is more than 20 times the 17 GW in operation at the end of 2020. Supportive government policy, ambitious climate commitments and the growing need for grid flexibility are the common drivers.

Figure 3: Global Energy Storage Annual Capacity in GWh, 2020-2030



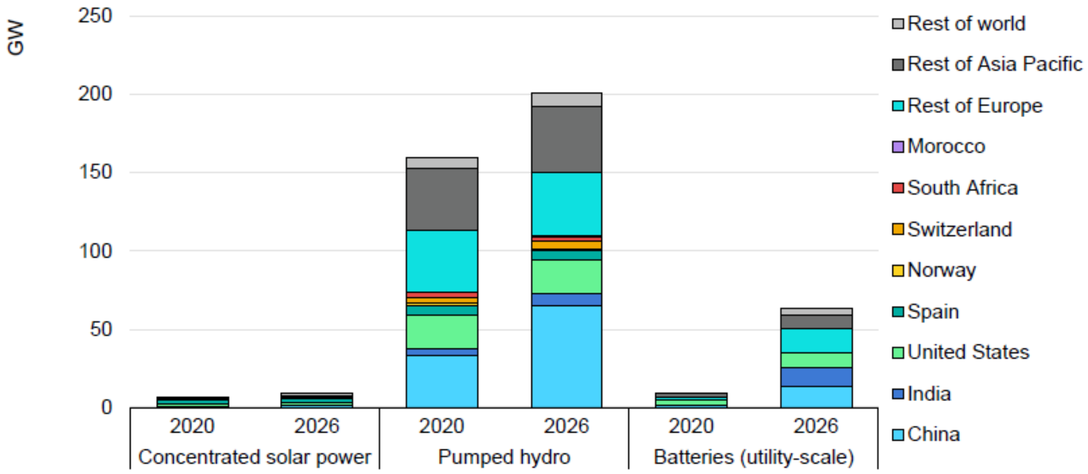
Source: Wood Mackenzie

Importantly, the 2030 estimate itself falls well short of the 585 GW needed to align with the IEA's Net Zero Emissions by 2050 Scenario, 585 GW of energy storage is estimated to be required to address the variability of renewables, especially as their share of generation increases in that Scenario.

Global installed storage capacity is forecast to expand by 56% in the next five years to reach over 270 GW by 2026. The main driver is the increasing need for system flexibility and storage around the world to fully utilise and integrate larger shares of variable renewable energy (VRE) into power systems.

Utility-scale batteries are expected to account for the majority of storage growth worldwide. Their installed capacity increases sixfold over the forecast period, driven by incentives and a greater need for system flexibility, especially where the share of VRE covers almost all demand in certain hours of the day. Hybrid auctions combining wind or solar PV with storage have emerged in India and Germany, with contracts in the range of $40-$60/MWh over last year. In the United States federal tax incentives, combined with high peak prices in several markets, are driving expansion, while long-term government targets in China see battery storage increasing fivefold over 2021-2026.

Figure 4: Concentrated Solar Power, Pumped Hydro and Batteries, Installed Storage Capacity in 2020 and 2026



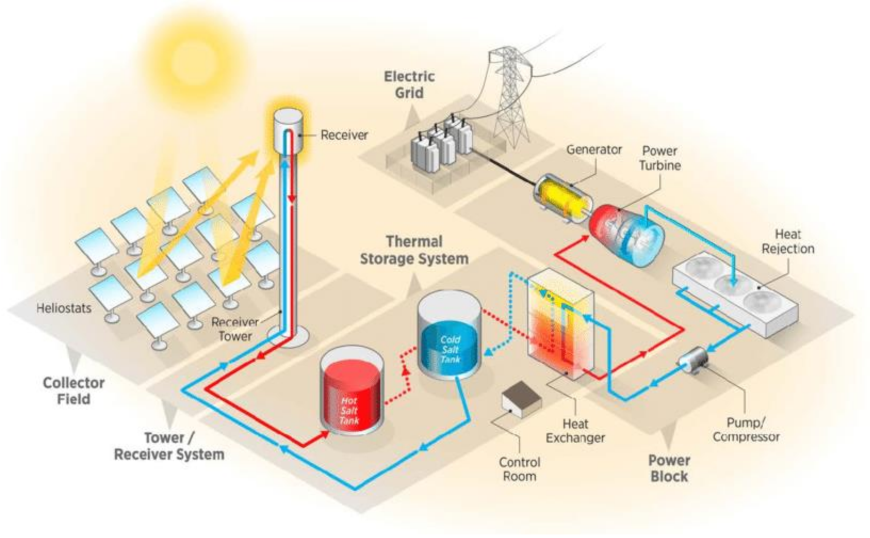
Source: IEA

Pumped storage hydropower (PSH) provides 42% of global expansion in electricity storage capacity. With over 40 GW expansion in the next five years, PSH remains the largest source of installed storage capacity, achieving 200 GW cumulatively installed by 2026, three times larger than batteries. China alone accounts for three-quarters of global PSH capacity growth thanks to the government's long-term targets and a new remuneration scheme aimed at reducing VRE curtailment.

Concentrated Solar Power (CSP) storage expands by only 2.6 GW during the forecast period. China leads the expansion thanks to a generous FIT scheme, which is set to continue until the end of this year. Beyond China, the United Arab Emirates are expected to bring online the second largest volume of new capacity globally, thanks to phase four of the Dubai Electricity and Water Authority's Mohammed bin Rashid Al Maktoum Solar Park, which brings an additional 700 MW and aims to help the country achieve its target of 75% clean energy by 2050.

Installed capacity does not provide a full picture of each storage technology's capabilities. PSH and CSP can provide medium-term storage capabilities cost effectively. In the case of CSP, storage is usually in the range of 5-15 hours and is based on the molten salts proven method. The molten salts are heated and stored in an insulating container during off-peak hours. When energy is needed, the salt is pumped into a steam generator that boils water, spins a turbine, and generates electricity. In contrast, the most widely used lithium-ion battery technology can usually store electricity for less than 4 hours. For PSH, the storage duration ranges from 5 to 175 hours, but some installations, such as PSH units installed in cascading systems that link two or more large reservoirs, offer even greater storage capacity, according to IEA's Special Hydropower Market Report. **(8)**

Figure 5: Molten-salt Power Tower With Direct Storage of Salt

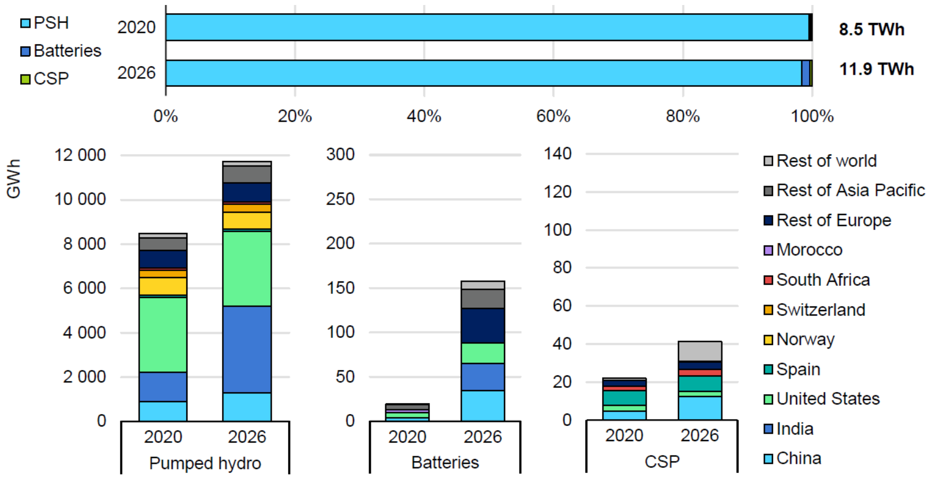


Source: IEA

Addressing global electricity storage capabilities, our forecast expects them to increase by 40% to reach almost 12 TWh in 2026, with PSH accounting for almost all of it. India dominates storage capability expansion by commissioning over 2.5 TWh (80% of the expansion) thanks to projects using existing large reservoirs. CSP storage capabilities almost double partly thanks to the longer storage hours (10 hours on average) of projects under construction in China, the United Arab Emirates, Morocco, South Africa, Chile and Greece. Similarly, global battery storage capabilities also increase eightfold by 2026.

In addition to PSH, CSP storage and batteries, the IEA Special Hydropower Market Report estimated the energy storage capabilities of hydropower. Accordingly, existing conventional reservoir hydropower plants can store up to 1,500 TWh of electricity, significantly more than all other storage technologies combined.

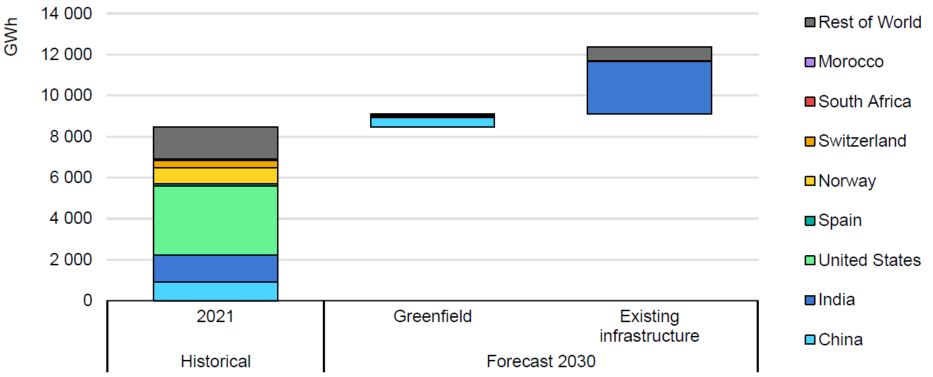
Figure 6: CSP, PSH and Battery Storage Capability in 2020 and 2026



Source: IEA

PSH and CSP storage can use already installed plant infrastructure instead of greenfield projects, providing cost-effective opportunities to accelerate storage capabilities locally. Currently, around half of CSP installations worldwide do not have any storage capability, especially in Spain and United States. Accordingly, IEA estimates that the potential for retrofitting CSP projects by adding storage could be significantly higher compared with its forecast for greenfield plants. CSP retrofits adding storage could help alleviate some of these grid constraints. For CSP retrofits to make economic sense, remuneration for existing projects would need to be extended and adjusted to reward flexibility and storage capabilities. For PSH, existing reservoir plants and dams can offer opportunities to achieve long-term storage cost effectively. In IEA's Special Hydropower Market Report, the outlook to 2030 indicated that adding PSH capabilities to existing reservoirs would add more storage capability than new projects.

Figure 7: CSP PSH Storage Capability, 2021-2030



Source: IEA

Technologies like CSP and PSH not only generate electricity and serve as daily or weekly balancing, but also provide additional services to the grid, such as system inertia, frequency response and grid regulation by means of their rotating mass. They are difficult to finance because of their high investment costs and, in many countries, the lack of remuneration schemes valuing grid services and therefore long-term revenue visibility.

Some markets, such as the United Kingdom, Ireland and some Nordic countries, provide market-based remuneration for grid services. However, electricity sales to the grid continue to be the primary source of revenue for both CSP and PSH, given that revenues from ancillary services range from 1% to 5% of total revenue in many markets. More income streams are therefore required for storage technologies to become bankable. Auctions that support hybrid plants can provide a good solution to scale up PSH and CSP. **(9)**

5. The Energy Storage Market in the EU

The EU is implementing its ambitious plan to achieve net zero carbon emissions across the bloc by 2050 **(10)**. It has recognised energy storage as a key enabler to achieve this goal. However, while overall investment in the energy transition (including renewables and electrified transport) surged in Europe over 2020, eclipsing both China and the US, investment in battery storage has lagged behind the two countries due in part to a less developed existing storage market more focused on grid balancing, less targeted storage policies and incentives, and a weaker battery supply chain. **(11)**

Against this background, the EU has intensified its efforts to support the expansion of battery storage infrastructure with the help of regulatory measures and massive funding programs. Regional growth is also expected to accelerate as a result of rising renewables penetration, the retirement of more fossil-fuel power plants and an expanding localized battery supply chain. It is estimated that the European storage market will exceed 100 GWh by 2030, which is 910% of growth since the end of 2019.

Regulatory Outline

The regulatory framework for battery storage in the EU dates back to 2006. Lately, the EU has come to the conclusion that, from today's perspective, there is a clear need for a fundamentally changed framework in view of the strategic importance of batteries for the European electricity market, but there are too many limitations.

In March 2019, the EC launched the Clean Energy for all Europeans initiative ("Clean Energy Package") **(12)**. The Clean Energy Package set forth uniform Regulations and Directives for the electricity market. The Regulations are binding legislative acts applicable to every EU member state. The Directives establish common principles for national regulatory frameworks and set a uniform definition for "energy storage", meaning, in the electricity system, deferring an amount of the electricity that was generated at the moment of use, either as final energy or converted into another energy carrier". **(13)**

Importantly, the Clean Energy Package defines storage as an "entity separate from generation, transmission or load", preventing developers of storage systems from having to pay fees twice when charging and discharging power. This removed a substantial disincentive affecting energy storage development, although it does not extend to potential double taxation, that being an issue for individual member states.

The following Regulations and Directives were released on 5 June 2019 as part of the Clean Energy Package:

- Regulation 2019/943: "The Internal Market for Electricity"

– This Regulation sets forth standards for the wholesale market and network operations and encourages market-based incentives for investment into energy storage.

– It provides that network tariffs should not discriminate against energy storage systems and that market rules shall enable the efficient dispatch of generation assets, energy storage and demand response.

– It mandates that network charges must not discriminate between production connected at the distribution level and production connected at the transmission level. Network charges shall not discriminate either positively or negatively against energy storage or aggregation and shall not create disincentives for self-generation.

- Directive 2019/944: "Common Rules for the Internal Market for Electricity"

– The purpose of this Directive is to establish common rules for the generation, transmission, distribution, energy storage and supply of electricity. It provides that the transmission system operator shall establish procedures for non-discriminatory connection of new generation installations and energy storage systems.

– Importantly, the Directive provides that transmission system operators should not own, develop, manage or operate energy storage facilities. In the new electricity market design, energy storage services should be market-based and competitive. Consequently, cross-subsidization between energy storage and the regulated functions of distribution or transmission should be avoided. Such restrictions on the ownership of energy storage facilities are to prevent distortion of competition, eliminate the risk of discrimination, ensure fair access to energy storage services to all market participants, and foster the effective and efficient use of energy storage facilities, beyond the operation of the distribution or transmission system.

More so than the US, the EU's regulatory landscape is beginning to shift towards differential standards for generators, energy-load facilities and energy storage. There is an increasing number of regulations that prohibit discriminatory market practices against energy storage, encourage market participation of energy storage and define energy storage as a separate asset category. The increased number of energy storage installations within EU member states suggests that it is invariable that member states will implement energy storage specific regulations distinct from the traditional energy market players. While most EU members states with significant renewable capacity do allow (or are at least in the process of reform) all energy storage technologies to participate in the wholesale market and perform ancillary services, barriers do remain in the short term.

In December 2020, the EC released its proposal for a Sustainable Batteries Regulation **(14)** in order to modernize the EU legislative framework. The Proposal is part of the EC's New Circular Economy Action Plan **(15)**, which is in turn one of the main building blocks of the European Green Deal, an action plan under which the EU is striving to be the first climate-neutral continent.

The Proposal, which focuses more on the localized battery supply chain, is meant to address three groups of highly interlinked challenges related to batteries:

1. lack of framework conditions providing incentives to invest in production capacity for sustainable batteries
2. sub-optimal functioning of recycling markets and insufficiently closed material cycles i.e. recovery and recycling of materials, which limit the EU's potential to mitigate the supply risk for raw materials
3. social and environmental risks that are currently not covered by EU environmental law, including (i) a lack of transparency on sourcing raw materials, (ii) hazardous substances and (iii) the untapped potential to offset the environmental impacts of battery life cycles.

The Proposal would establish mandatory requirements for all batteries (i.e. portable, automotive, electric vehicle and industrial batteries) placed on the EU market throughout their entire life cycle, relating to sustainability and safety as well as to labelling and information. It would establish requirements to facilitate the conversion of industrial and electric-vehicle batteries into stationary energy storage batteries and define obligations of economic operators linked to product requirements and schemes for supply-chain due diligence for raw materials in industrial and EV batteries. In addition, a battery passport would be established, allowing economic operators to gather and reuse in a more efficient way the information and data on individual batteries placed on the market and to make better-informed choices in their planning activities.

The EC claims that these measures shall strengthen the competitiveness of the EU internal battery market, increase the resilience of the EU battery supply chain and reduce the environmental and social impact in all stages of batteries' life cycle. However, the new measures would also place an increased regulatory burden on manufacturers, producers, importers and distributors of batteries, who will need to take necessary steps to ensure compliance.

Government/Investment Support

Support for research on electricity storage has been on the EC's plan for a more sustainable future for years and has widened over time, although some have suggested that the lack of targeted mandates for storage has slowed growth. Notably, the EU has taken steps to strengthen its regional battery manufacturing capacity, which lags behind China and the US.

Projects and initiatives already in effect include the following:

- The European Battery Alliance (EBA) was launched by the EC in 2017 in order to address the fast growing need for efficient batteries for power, transport and industrial applications. The industrial development program of the EBA, i.e. the EBA250, is a project-driven community that brings together more than 700 industrial and innovation actors, from mining to recycling, with the common objective to build a strong and competitive European battery industry. **(16)**

- In January 2021, "Horizon Europe" kicked-off with a budget of €95.5 billion as a follow-up to the EU's flagship program "Horizon 2020". Under Pillar II, Cluster 5, Climate, Energy and Mobility, in the span of six years, several research projects on energy storage will be supported to ensure a competitive international position for Europe in a fast-paced worldwide energy market. Examples of these projects include the following:

– The European Battery Call Pilot Line Network, which aims to build a more competitive lithium-ion battery cell-manufacturing ecosystem and increase the production of lithium-ion cells towards industrial scale; and

– Support for research and development of redox flow batteries, which it is hoped will significantly reduce the costs of that technology by 2030

- The European Partnership for Batteries in Horizon Europe will, in close cooperation with the European Battery Alliance, help prepare and equip Europe to manufacture and commercialise the next generation battery technologies by 2030. Started in 2021, the partnership aims to enable the rollout of zero-emission transport and renewable energy storage solutions, contributing to key goals of the European Green Deal.
- The Just Transition Fund dedicates €40 billion to support the development of energy storage facilities in fossil-fuel dependent regions. In addition, the "Recovery and Resilience Facility", with a volume of €250 billion for COVID-19 recovery, dedicates 37% of its funding to sustainable climate spending. The development of energy storage is expected to profit from this.
- BATT4EU is a co-programmed partnership established under Horizon Europe that gathers the EU Commission and Batteries European Partnership Association, which regroups all the battery stakeholders from the European research community in order to establish by 2030 in Europe the best innovation ecosystem in the world to boost a competitive, sustainable and circular European battery value chain and to drive the transformation towards a carbon-neutral society. **(17)**

The Storage Research Infrastructure Eco-System Project (StoRIES) under the European Energy Research Alliance (consisting of more than 250 members from universities, associations, research organizations and industry) received €7 million in funding from the EU for a period of four years from 2021. According to their website, the main technological objectives of StoRIES are linked to energy storage development by providing access to 64 world-class research infrastructures and services.

EU Market Features

Until recent years, energy storage in Europe was generally limited to mechanical technologies, such as pumped hydro and liquid air energy storage, with Germany and Spain having the largest legacy capacity. However, the European hydropower market has reached near-maturity and possibilities for new, large installations are limited. Accordingly, new sources of large-scale pumped hydro are limited, with the only large pumped-hydro project coming online in the EU in 2020 being Greece's 680 MW Amfilochia complex. As battery costs have plummeted, new battery storage projects have become viable with lithium-ion technology representing the bulk of new capacity, following the global trend.

Within the EU-27, the localization of new battery capacity is uneven, with Germany having the largest capacity by some measure as at mid-2020: (103 MW with 406 MW in the pipeline). Several of its largest projects (Cottbus 50 MW (BigBattery Lausitz) and Cremzow 22 MW) are used for frequency regulation and grid protection. Germany also has surging residential behind-the-meter capacity with installations nearly doubling in 2020. Ireland and Spain also have substantial capacity either in operation or in the pipeline.

At the other end, several countries, particularly in Eastern Europe, have little or no capacity in operation or in the pipeline, due to either regulatory reasons or the fact that renewable energy has not sufficiently penetrated the market (or legacy mechanical storage is sufficient at least in the short to medium term). France and Italy, two countries that do have significant shares of renewable capacity, also have negligible capacity but are using interconnectors to acquire flexibility.

According to a Study on Energy Storage published by the EC in March 2020, the key barriers to the expansion of utility-scale energy storage projects are the following:

- Various member states' policy barriers (while, as above, the EU has passed measures to facilitate new storage projects and made recommendations for the removal of energy market impediments these are in various states of follow-through within the EU-27)
- Lack of a viable business case for some new projects mainly due to uncertainty as to revenue streams, especially with utilities taking a less pro-active stance compared to the US

In the short-to-medium term, the ability of various EU member states to trade electricity with each other (including from conventional power generation) does provide an important advantage to those states in terms of meeting required levels of flexibility. The Study found that, by 2030, the EU-27 will still need 97 GW of at least short-term storage (i.e. batteries and pumped hydro) for the provision of daily flexibility. Storage needs become more uncertain as we approach 2050 (when the EU aims to have reached its target of 80% renewable penetration) depending in part on the development of hydrogen technology and the extent to which the deployment of electrolysers or alternate technologies becomes cost effective. But even with hydrogen-based technologies providing short and long-term flexibility from as early as 2030, battery storage is still expected to play a significant role to at least 2050.

Notably, the EU has taken early steps in the development of renewable hydrogen with a number of projects in the pipeline of 1 GW electrolyser capacity or more. The largest is being developed by a consortium of European companies that plans to use 95 GW of solar capacity to power 67 GW of electrolysers across multiple European countries by 2030. **(18)**

6. Discussion

The world is rapidly adopting renewable energy alternatives at a remarkable rate as pressure grows to address climate change related challenges. Renewable energy systems offer enormous potential to decarbonize the environment because they produce no greenhouse gases or other polluting emissions. However, the RES rely on natural resources for energy generation, such as sunlight, wind, water, geothermal, which are generally unpredictable and reliant on weather, season, and year.

To account for these intermittencies, renewable energy can be stored using various techniques and then used in a consistent and controlled manner as needed. Several researchers from around the world have made substantial contributions over the last century to developing novel methods of energy storage that are efficient enough to meet increasing energy demand and technological breakthroughs.

In addition, there is a variety of energy storage systems that store energy in various forms. Some of these systems have attained maturity, while others are still under development. For large-scale energy storage applications, pumped-hydro and thermal energy storage systems are ideal, whereas battery energy storage systems are highly recommended for high power and energy requirements. Supercapacitors, Superconducting Magnetic Energy Storage and Flywheel Energy Storage are commonly used for shorter duration and fast response applications. Because of their low efficiency, hydrogen and methane are not frequently used for energy storage. However, because they offer excellent storage potential, they are expected to be used on a bigger scale in the future. Chemical energy storage devices are popular, although they are expensive.

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