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Battery Storage to Efficiently Achieve Renewable Energy Integration

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About Renewable Energy Institute

Renewable Energy Institute is a non-profit tank which aims to build a sustainable, rich society based on renewable energy. It was established in August 2011, in the aftermath of the Fukushima Daiichi Nuclear Power Plant accident, by its founder Mr. Masayoshi Son, Chairman & CEO of SoftBank Group, with his own resources.

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Table of Contents

List of Charts

List of Tables

List of Pictures

Introduction

As of the beginning of 2023, reaching global carbon neutrality by mid-century looks like a roughly 30-year long marathon that should be run at the speed of a sprint.

Among good news are the explosive growths of solar and wind power. However, the outputs of these two technologies fluctuate depending on weather conditions. It is then understood that additional clean energy technologies should also be rapidly developed to ensure the continuous quality of power supply.

Renewable Energy Institute recognizes five sustainable and complementary technological solutions to enhance power system flexibility enabling the smooth integration of solar and wind power: electrical grid interconnections, batteries, decarbonized thermal (using fuels based on renewable energy such as green hydrogen), demand response, and pumped storage hydro.

Among these technologies, batteries are promising innovative solutions expanding particularly quickly which is critical given the urgency to accelerate efforts towards carbon neutrality.

This report aims at shining a light on the great potential of batteries and the challenges it faces. To achieve this objective, the report contains five chapters including the following key findings:

Chapter 1 draws the picture of a world in which solar and wind power will dominate the future of electricity generation thanks to their explosive growths based on their unrivaled economic competitiveness and technological simplicity. Recent landmark energy outlooks presenting visionary power systems compatible with the objective of carbon neutrality are analyzed. It is found that to enable the smooth integration of high shares of solar and wind power (70-90% of total electricity generation) the key contribution of battery storage is clearly highlighted. It is also found that among the four major valuable applications of batteries energy shifting is and will remain particularly useful. Seven concrete battery projects, sources of inspiration and excitement are also showcased to go from theory to reality.

Chapter 2 underlines the record annual growth of stationary energy storage capacity excluding pumped storage hydro (i.e., primarily batteries) in 2021: nearly +10 GW, bringing the global cumulative capacity to more than 27 GW. It is noted that while the cumulative capacity of stationary energy storage is six times smaller than that of pumped storage hydro (165 GW), its annual growth pace is now twice faster. The four leading markets for stationary energy storage excluding pumped storage hydro are: the United States, Europe, China, and South Korea (over 80% of global cumulative capacity). A key factor accelerating stationary energy storage growth is its economic competitiveness resulting from the widespread adoption of electric vehicles, enabling dramatic cost reduction over the past decade (-86%). It is found that already today for flexible peaking services at $0.11-0.22/kWh new utility-scale standalone batteries may outcompete new demand response, gas reciprocating engine, open-cycle gas turbine, and pumped storage hydro. It is also found that for dispatchable generation, at $0.10/kWh or below new utility-scale battery + solar photovoltaic and battery + onshore wind may outcompete both new and existing coal, combined-cycle gas turbine, and nuclear. Moreover, it is observed that at the residential level small-scale battery + rooftop solar photovoltaic at $0.17/kWh may outcompete household electricity prices, as for examples in the State of California in the United States or in Germany.

Chapter 3 emphasizes the overwhelming domination of short-duration lithium-ion batteries (i.e., discharge duration of 0.5-6 hours, typically 4 hours) among utility-scale stationary energy storage projects: 96% based on power output in 2021 (excluding pumped storage hydro). It is considered that to complement this short-duration energy storage solution and further facilitate the integration of solar and wind power, long-duration energy storage solutions (i.e., over 6 hours) would certainly be beneficial. Yet, it is found that with the main exception of pumped storage, progress in this area is lagging with most technologies being costly and technically unproven today.

Chapter 4 presents seven powerful supporting policies, inspired by examples from all over the world, to further accelerate the growth of stationary energy storage. Targets (i.e., voluntary) and mandates (i.e., compulsory) setting deployment objectives to be achieved in the coming years and decades are the first two supporting policies highlighted. Investment tax credits, auctions, market designs, RE certificate multipliers, and time-of-use discounted rates, five enabling policies to fulfill deployment objectives, are then underlined.

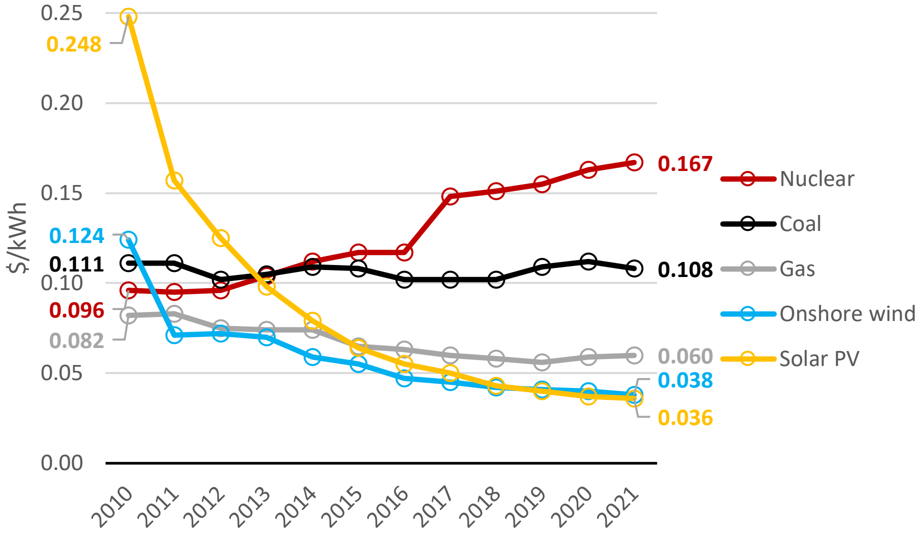
Chapter 5 stresses the geographical concentration issues lithium-ion batteries are currently confronted with. It is first found that in 2021, around 75% of the world's lithium and cobalt (i.e., two key raw materials for lithium-ion batteries) productions and reserves were concentrated in only three countries Australia, Chile, and the Democratic Republic of Congo, and that nearly 80% of the world's lithium battery manufacturing capacity were concentrated in a single country: China. To cope with this energy security problem, solutions advanced in the European Union, the United States, and Japan are then presented. These solutions include developing domestic extraction of lithium, domestic manufacturing capacity, and recycling.

Chapter 1: Role of Battery Storage in a Solar and Wind Power Future

1) Future Power Systems – Key Contribution from Batteries

Thanks to their unrivaled economic competitiveness resulting from dramatic cost reductions (Chart 1) and their technological simplicity – enabling fast deployment – solar and wind power are set to dominate the future of electricity generation.

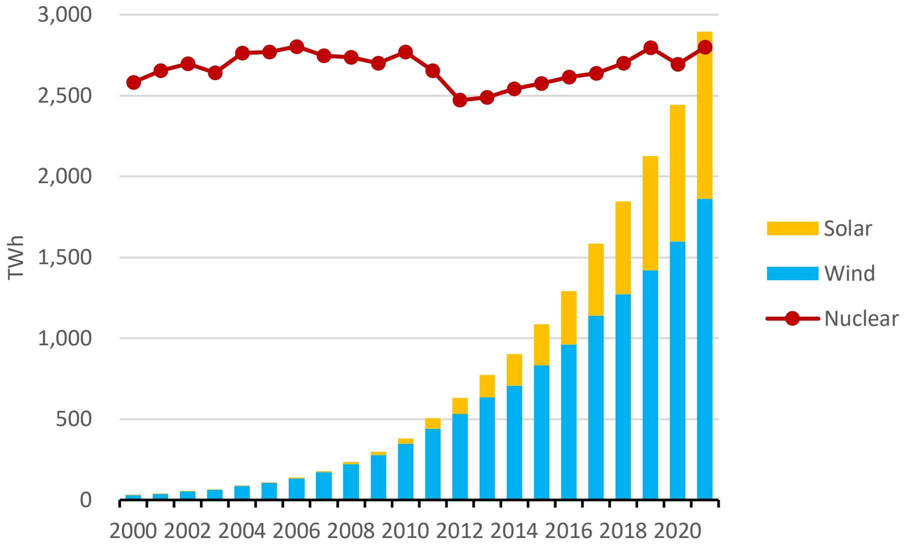
Chart 1: LCOE by Generating Technology 2010-2021



Source: Lazard, Levelized Cost of Energy Analysis – Version 15.0 (October 2021).

In 2021 already, the combined volume of electricity generated from these two technologies surpassed that of well-established nuclear power (i.e., the main low carbon alternative to renewable energy (RE)) – an historical achievement unthinkable twenty years ago (Chart 2 on next page).

Chart 2: Gross Electricity Generation from Nuclear, Solar and Wind 2000-2021



Source: BP, Statistical Review of World Energy 2022 (June 2022).

Around the world in recent years, different types of organizations: intergovernmental organizations, governmental organizations, non-governmental organizations, power sector businesses… advanced various landmark energy outlooks presenting visionary power systems.

Hereinafter, four of these recent energy outlooks are referred to, and in each of them one carbon neutral compatible scenario has been selected (Table 1).

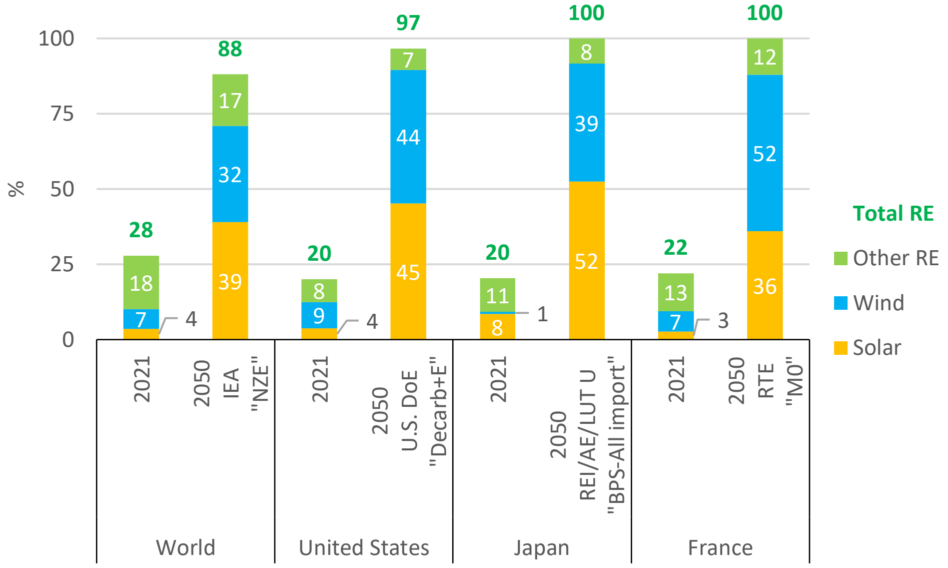
Table 1: Selected Visionary Power Systems

Organization (Country)	Type of organization	Publication year	Outlook title	Selected scenario (abbreviation)	Objective
International Energy Agency (World)	Intergovernmental	2022	World Energy Outlook 2022	Net-Zero Emissions ("NZE")	Carbon neutral global energy system by 2050
United States Department of Energy (United States)	Governmental	2021	Solar Futures Study	Decarbonization with Electrification ("Decarb+E")	Carbon neutral American power sector by 2050
Renewable Energy Institute (Japan)/Agora Energiewende (Germany)/LUT University (Finland)	Think tank/think tank/academic	2021	Renewable Pathways to Climate-Neutral Japan: Reaching Zero Emissions by 2050 in the Japanese Energy System	Base Policy Scenario – All import (i.e., power and fuels can be imported) ("BPS-All import")	Carbon neutral Japanese energy system by 2050
Réseau de Transport d'Electricité (France)	Transmission system operator	2021	Energy Pathways to 2050: Key Results	Nuclear power phaseout ("M0")	Carbon neutral French power sector by 2050

Source: Selected and presented by Renewable Energy Institute.

The four selected scenarios commonly project very high RE shares: approximately 90-100% in total electricity generation by 2050. Also, they all unsurprisingly forecast solar and wind power to become the main generating technologies: shares of about 70-90% (Chart 3).

Chart 3: RE Share in Electricity Generation 2021 Achievements and 2050 Projections



Note: Other RE includes bioenergy, geothermal, hydro, and marine.

Sources: For 2021 achievements; BP, Statistical Review of World Energy 2022 (June 2022). And for 2050 projections; International Energy Agency, World Energy Outlook 2022 (October 2022), United States Department of Energy, Solar Futures Study (September 2021), Renewable Energy Institute/Agora Energiewende/Lappeenranta-Lahti University of Technology University, Renewable Pathways to Climate-Neutral Japan: Reaching Zero Emissions by 2050 in the Japanese Energy System (March 2021), and Réseau de Transport d'Electricité, Energy Pathways to 2050: Key Results (October 2021).

To achieve these high shares transforming power systems will be necessary. Disruptive technologies will play a key role to balance the fluctuating outputs of solar and wind power.

In the four scenarios considered, a set of solutions is implemented to maintain grid resource adequacy, reliability, and resilience in power systems composed primarily of solar and wind power.

Some of these solutions are not recognized as sustainable by Renewable Energy Institute (REI). For examples, the International Energy Agency (IEA) hypothesizes the use of carbon capture and storage (CCS) for electricity generation, thus keeping the door open to the continuous use of heavily polluting fossil fuels – a real risk if costly, immature, and inefficient CCS never really materializes. Moreover, both the IEA and United States Department of Energy (U.S. DoE)'s scenarios do not phaseout nuclear power which means continuous production of dangerous radioactive waste.

The other technologies assumed to help keeping power systems in balance are recognized as sustainable by REI and include: electrical grid interconnections (i.e., transmission and distribution (T&D) networks), batteries, decarbonized thermal (using fuels based on RE), demand response, and pumped storage hydro.

All these five technologies provide power system flexibility in complementary ways. Electrical grid interconnections enable to move electricity from where it is produced, such as RE rich areas, to where it is consumed, like large demand centers. Demand response provides a price signal to customers to adjust their consumption depending on system needs for a few hours. And batteries, pumped storage hydro, and decarbonized thermal make it possible to take advantage of storage opportunities over different timeframes. For instance, lithium-ion batteries (today's overwhelmingly dominating technology for batteries) for typically 4 hours, pumped storage hydro for 5 to 175 hours, and decarbonized thermal for seasons – which is very strategical (see also Chapter 3).[1]

In developed economies, the potential of pumped storage hydro has often already been exploited to a large extent. Furthermore, because of pumped storage hydro environmental and social constraints (i.e., pumped storage hydro projects require two large dams which impacts natural life and local populations) prospects for its further expansion of are often limited. Therefore, the main growth areas for storage are batteries and decarbonized thermal.

According to the four scenarios studied in this section both batteries and decarbonized thermal will prove useful flexible resources, but most of the growth is often expected to come from batteries with a strong increase expected in stationary batteries particularly (Table 2).

Table 2: Solar, Wind Stationary Batteries, and Decarbonized Thermal Installed Capacity 2050

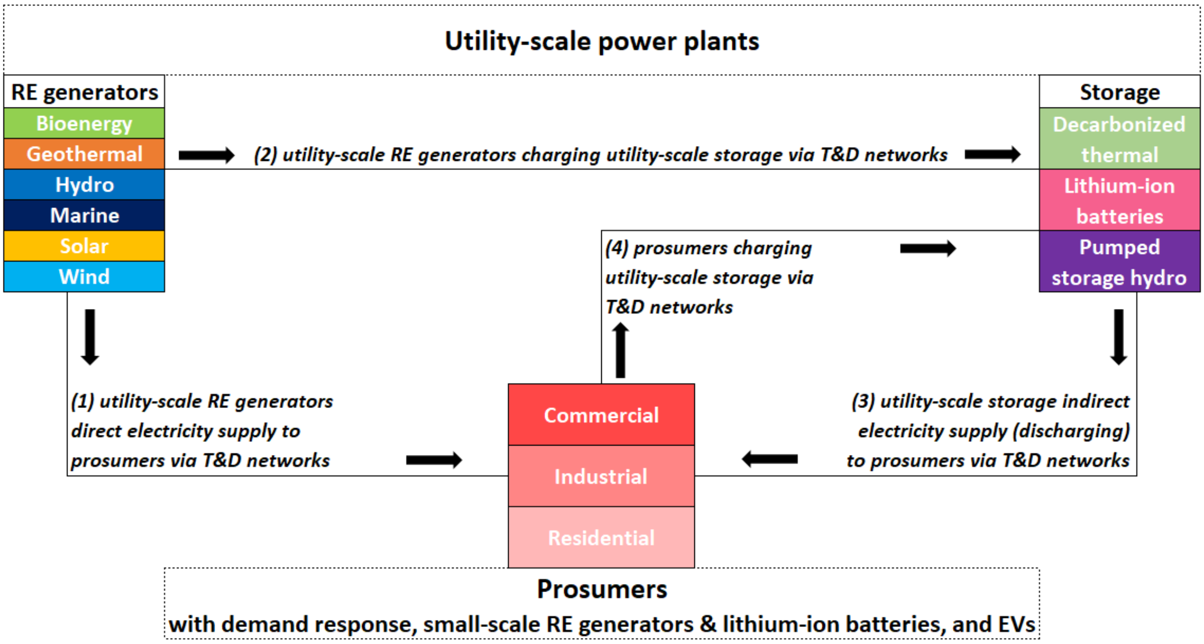
Scenario	Solar (GW)	Wind (GW)	Batteries (GW)	Decarbonized thermal (GW)
IEA "NZE" World	15,905	7,795	3,860	573
U.S. DoE "Decarb+E" United States	1,568	977	1,676	305
REI/AE/LUT U "BPS-All import" Japan	524	151	87	52
RTE "M0" France	208	136	26	29

Sources: International Energy Agency, World Energy Outlook 2022 (October 2022), United States Department of Energy, Solar Futures Study (September 2021), Renewable Energy Institute/Agora Energiewende/Lappeenranta-Lahti University of Technology University, Renewable Pathways to Climate-Neutral Japan: Reaching Zero Emissions by 2050 in the Japanese Energy System (March 2021), and Réseau de Transport d'Electricité, Energy Pathways to 2050: Key Results (October 2021).

In these four scenarios, the contribution from transportation batteries (i.e., from electric vehicles (EVs)) is also considered in less detailed analyses. It is found that with the massive electrification of the transport sector additional storage capacity (sometimes significant) could be available. However, the output of transportation batteries available for the power sector appears to be smaller or much smaller (depending on studies) than that of stationary batteries. The key reason to explain that is the fact that stationary batteries' main purpose is to provide storage services, whereas transportation batteries' main purpose is to provide mobility services. Moreover, the U.S. DoE points out that: "[…] with existing battery technologies, the costs of vehicle-to-grid applications from more rapid battery degradation currently outweigh the benefits." However, progress is taking place to optimize the value of transportation batteries limiting their aging.

A simple illustration is provided below to better visualize how a 100% RE power system, such as those envisioned by REI and Réseau de Transport d'Electricité, could look like and function (Chart 4). In this system: two types of utility-scale power plants would exist (RE generators and storage), customers would have become "prosumers" (i.e., both producing and consuming electricity) – taking advantage of demand response, small-scale RE generators (e.g., rooftop solar photovoltaic (PV)) paired with small-scale stationary energy storage systems (e.g., lithium-ion batteries) and transportation batteries (i.e., from EVs), and electricity would flow across the T&D networks (sometimes back and forth between utility-scale storage and prosumers).

Chart 4: Simple Illustration to Visualize the Possible Functioning of a 100% RE Power System

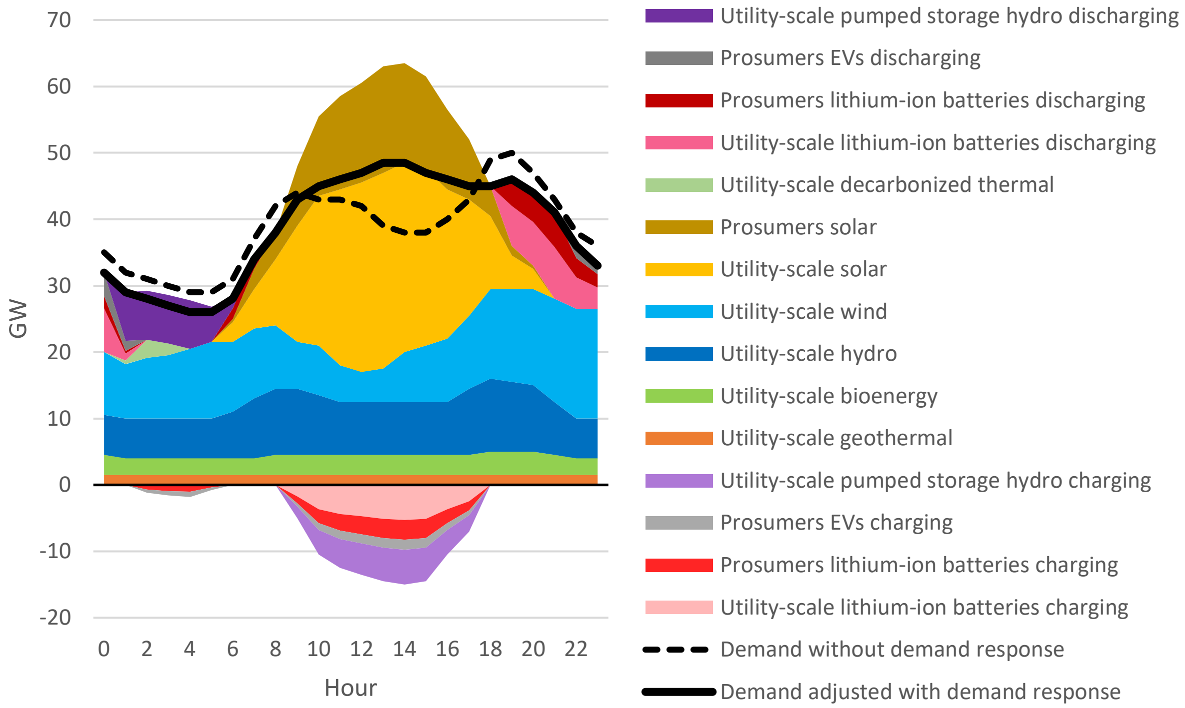


Source: Created by Renewable Energy Institute.

Into more details, utility-scale RE generators (largely solar and wind) would on the one hand directly supply electricity to prosumers who could either consume or store it (1), on the other hand charge utility-scale storage (mainly lithium-ion batteries) (2). Utility-scale storage would indirectly supply electricity to prosumers by discharging stored electricity generated by utility-scale RE generators and prosumers (3). Prosumers would not only consume electricity from utility-scale power plants and from their own small-scale RE generators, but they would also be able to adjust their demand depending on the power system needs, contribute to charging utility-scale storage and meeting other prosumers' demand by supplying excess electricity from their small-scale RE generators and/or discharging their small-scale stationary batteries as well as their transportation batteries (4).

To illustrate how this combination of complementary solutions could work, a fictional example of a 100% RE power system's 24-hour operations is provided (Chart 5 on next page). In this power system, solar and wind are the cornerstones of electricity generation and most of flexibility is provided by battery storage (stationary utility-scale and prosumers lithium-ion batteries). Flexibility is key, and stability of supply has become an obsolete concept (only geothermal provides a small constant output). It is important to note that the demand curve has been reshaped thanks to demand response, which enables not only to flatten peaks (e.g., in the evening), but also to increase consumption at times of supply surplus (i.e., in the afternoon).

Chart 5: Fictional Example of a 100% RE Power System 24-hour Operations



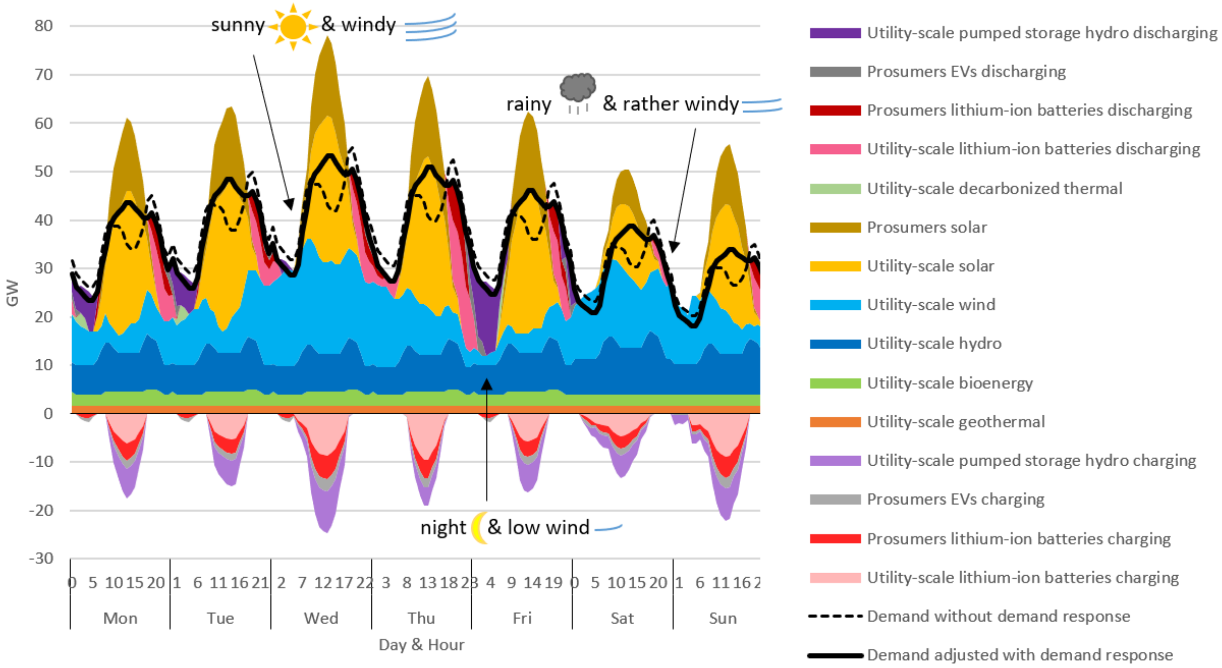
Source: Created by Renewable Energy Institute.

Into more details, it may be envisioned that thanks to abundant electricity generation from solar during daytime, batteries (including utility-scale, prosumers, and EVs) and pumped storage hydro are being fully charged (green hydrogen can also be strategically produced in this period). After the sunset, electricity generation decreases below the demand adjusted with demand response. At that time utility-scale and prosumers stationary batteries start to be progressively discharged. In addition, some flexibility is found by ramping up the output of hydro (e.g., from non-pumped storage hydro reservoirs) and bioenergy power plants. In this example, the increasing output of wind in the evening is a coincidence (i.e., not the result of a volunteer ramp up by a market participant).

Moreover, it is envisioned that the batteries of EVs start to be discharged after utility-scale and prosumers stationary batteries to prioritize mobility needs first (i.e., after returning home). Also, the batteries of EVs are never completely discharged, should a transportation emergency suddenly arise, and they are partly recharged during the night (e.g., in preparation of leaving home in the morning). Pumped storage hydro enters action in the early morning only after batteries are discharged because batteries have higher round-trip efficiencies (i.e., percentage of electricity put into storage that is later retrieved): 85-95% for lithium-ion batteries against 70-85% for pumped storage hydro. Finally, as a last resort – when other storage technologies have reached their limits (in our example this happens in the early morning), a small amount of electricity from more expensive and less efficient decarbonized thermal may also be generated by burning green hydrogen that was previously produced and stored.

Finally, to complement Chart 5, Chart 6 is provided below to show how a 100% RE power system could operate over a week with large variations in solar and wind outputs as well as in demand (i.e., during weekends electricity consumption is lower than from during weekdays due to a slowdown of economic activity).

Chart 6: Fictional Example of a 100% RE Power System Weekly Operations



Source: Created by Renewable Energy Institute.

In this example, three specific cases are interesting to note: high solar and wind outputs on Wednesday, low solar and wind outputs on Thursday evening-Friday night, and a rainy, but windy Saturday. In the first case, supply largely exceeds demand until the sunset enabling a lot of electricity to be stored. After the sunset, demand exceeds supply by a rather small margin, and the gap is essentially met by electricity stored in lithium-ion batteries. In the second case, after the sunset, demand largely exceeds supply. Storage – especially lithium-ion batteries and pumped storage hydro – plays a major role in filling the gap. In the third case, because of the rain the output of solar is greatly reduced. On the other hand, thanks to the rain a little extra amount from hydro is generated. Despite favorable wind conditions, and lower electricity consumption on Saturday the maximum hourly volume of electricity stored is much lower than on Wednesday when the outputs of solar and wind were high. Still, there is sufficient electricity for the continuous smooth operations of the power system.

2) The Four Major Applications of Batteries

Batteries have four major applications: energy shifting, customer-sited, ancillary services, and T&D (Table 3).

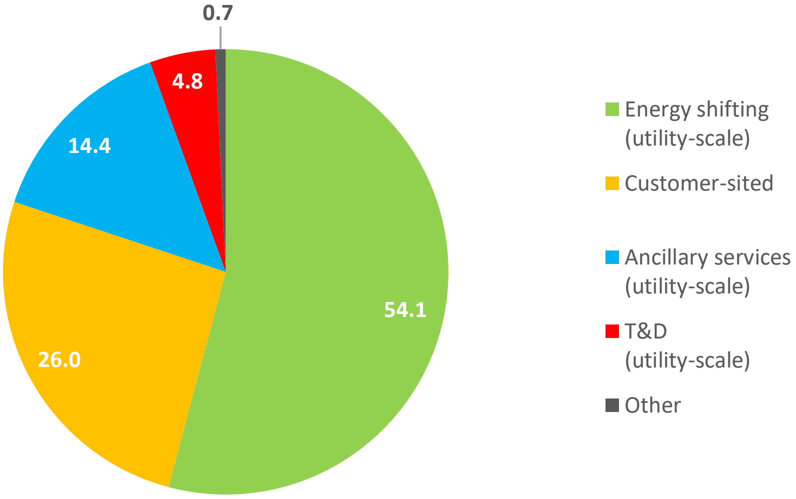
Table 3: Description of the Major Applications of Batteries

Application	Description
Energy shifting	Predominantly utility-scale energy storage performing arbitrage and providing reliable capacity to meet peak demand. This application has great value in power systems with high shares of solar and wind power because it takes advantage of abundant solar and wind's close to zero marginal costs to charge electricity into batteries at low prices, to discharge it later when power systems need it the most.
Customer-sited	Installed at residential, commercial, or industrial facilities for peak shaving (reducing peak demand) and time-of-use optimization (shifting consumption from peak-time to off-peak time). When combined with solar, self-consumption can be increased and backup energy is available.
Ancillary services	Energy storage used to provide operating reserves (frequency regulation, contingency spinning…) through absorption or injection of short bursts of power. Often procured by the system operator.
T&D	Energy storage installed at specific locations on the grid to better utilize existing T&D assets and defer reinforcement investment. For instance, storage assets located at grid congestion points performing as virtual power lines or providing an instantaneous response during peaking hours when an existing network substation is overloaded.

Source: BloombergNEF, 2H 2022 Energy Storage Market Outlook (October 2022) – subscription required.

In 2021, based on the power output of stationary energy storage projects worldwide, energy shifting accounted for the majority of applications (54.1%). The two other most observable applications were customer-sited (26.0%, that can be broken down between residential 20.0% and commercial & industrial 6.0%) and ancillary services 14.4%. Among the four major applications introduced above, T&D was the least widespread (only 4.8%) (Chart 7 on next page).

Chart 7: World Stationary Energy Storage Projects by Application 2021 (%)

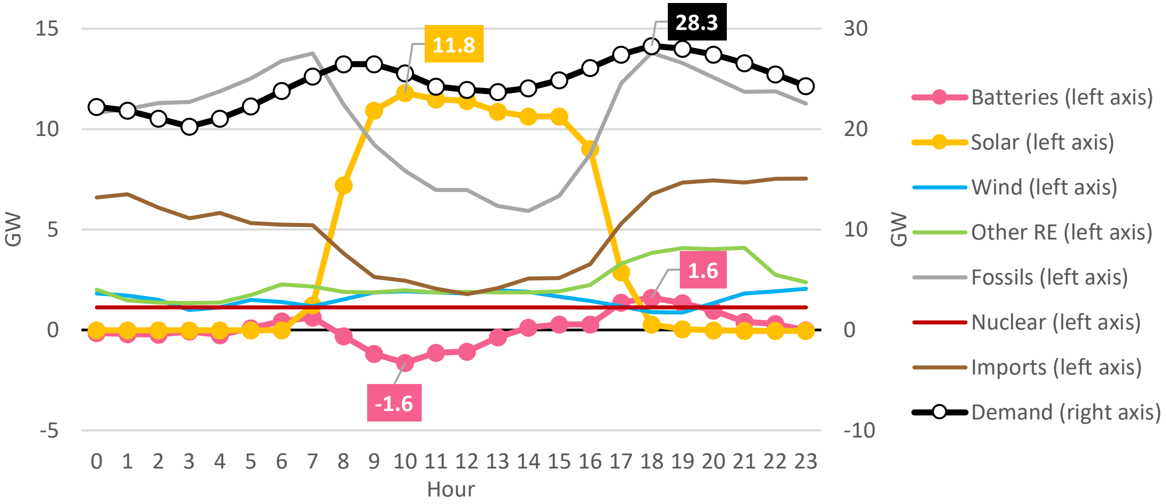


Notes: Capacity primarily accounting for stationary batteries. Excluding pumped storage hydro. Other includes minor applications such as microgrid and virtual power plants as well as unspecified. Based on power output.

Source: BloombergNEF, 2H 2022 Energy Storage Market Outlook (October 2022) – subscription required.

To visualize how energy shifting is implemented the illustrative example of the California Independent System Operator (CAISO)'s hourly power system operations on October 24, 2022, is provided below (Chart 8). The only criterion for selecting this date is that it is recent, therefore it should be representative of an up-to-date situation. In this example, it is possible to see that batteries' maximum charging (-1.6 gigawatt (GW)) occurs at 10 AM when solar output reaches its maximum (11.8 GW). After the sunset at 6 PM, as demand reaches its peak (28.3 GW), batteries' maximum discharging is achieved (1.6 GW or 5.7% of peak demand). In comparison to fossils and imports from other States, the contribution of batteries in providing flexible peaking services to CAISO, is admittedly smaller, yet it is already somewhat significant.

Chart 8: CAISO Hourly Power System Operations October 24, 2022



Notes: Other RE includes bioenergy, geothermal, and hydro. Fossils essentially includes gas.

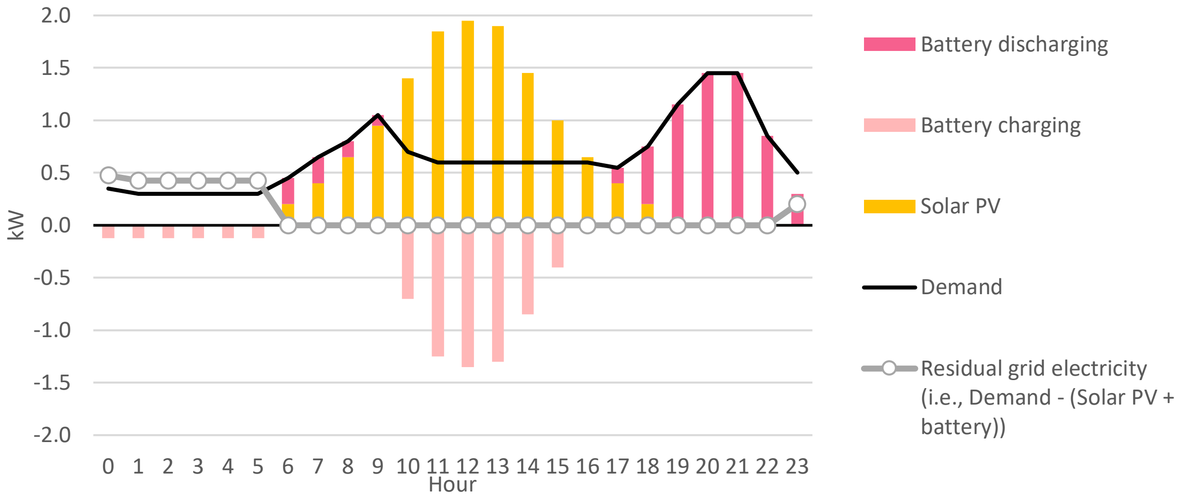
Source: California Independent System Operator, Today's Outlook: Supply October 24, 2022 (accessed October 26, 2022).

In terms of RE integration, the positive impact of batteries will increase at their installation expands. It is then unsurprising that already dominant today, energy shifting is expected to further extend its lead as the main application of stationary batteries in a solar and wind power future.

Since customer-sited is the second biggest application of battery storage and because it is particularly popular among residential customers, a fictional example is also provided here supported by and illustration (Chart 9). These should help to better visualize how this application works.

In our fictional example, it is considered that a residential household has installed a battery + solar PV system. At night (0-5 AM), electricity demand is low, generation from solar PV is 0 and the battery is charging a little volume of electricity from the grid at low prices in preparation of discharging it for the morning peak. In the morning, from the moment people wake up and until they finish to prepare for the day ahead (e.g., work, school…) (6-9 AM) electricity consumption increases. At this time, the sun rises solar PV starts to generate electricity, and in combination the battery is discharged to meet demand. From the late morning until the end of the afternoon (10 AM-4 PM), demand is moderate and solar PV generation exceeds demand, the surplus generation is stored in the battery in preparation of the evening peak. Then, the evening begins (from 5 PM) demand rises significantly and stay high until people go back to sleep (from 10 PM). In this period, people have returned home and needed electricity, for lightening purposes among others as the sun sets which also means solar PV progressively decreases to 0. At that time, the fully charged battery starts discharging until it is empty (at 11 PM).

Chart 9: Fictional Example of Residential Customer-Sited Battery + Solar PV



Source: Created by Renewable Energy Institute.

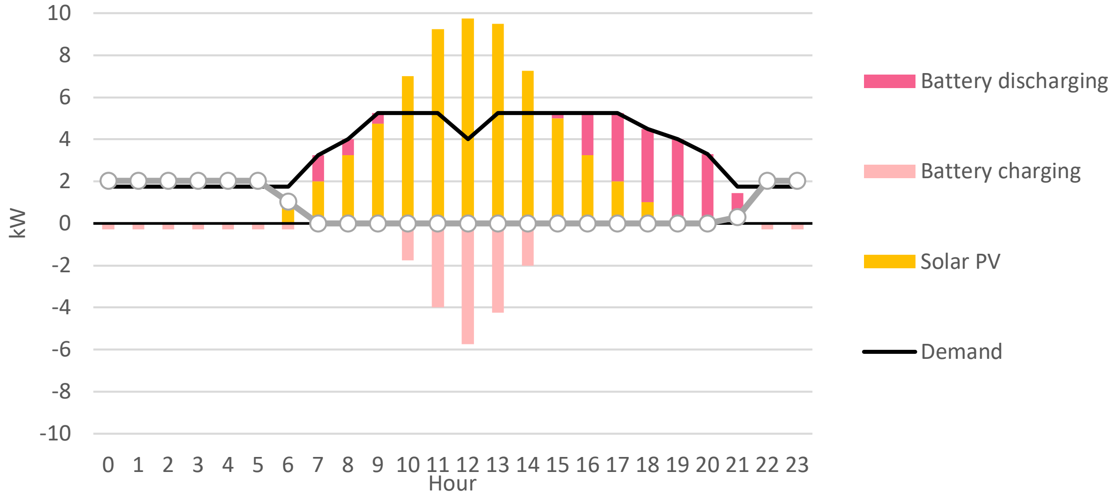
In our example, looking at the residual grid electricity there are three clear benefits of having a battery + solar PV system: (1) much less electricity is needed from the grid (i.e., without such system all demand would have to be met by grid electricity), (2) the electricity that is needed from the grid is only imported at night – when both electricity demand and usage tariff are low, and (3) since peak demand is essentially met by battery + solar PV, the customers' base tariff (based on their peak monthly usage) should be low as well.

The customer-sited application for commercial and industrial customers is relatively like that described for residential customers, but with a few non-fundamental differences due to distinctive demand patterns. Another fictional example is provided below, also with an illustration (Chart 10).

In this new fictional example, it is considered that a medium-size non-energy intensive commercial company has installed a battery + solar PV system. Until the staff arrives at the office (from 7 AM) electricity demand is low, electricity generation from solar PV is almost always 0 because it is mostly nighttime (until 6 AM), and the battery is charging a little volume of electricity from the grid at low prices in preparation of discharging it later in the morning after businesses has started and solar PV is ramping up, but insufficiently to cover demand (7-9 AM).

From the late morning until the middle of the afternoon (10 AM-2 PM), demand is moderate (the small drop at noon reflects the launch break) and solar PV generation exceeds demand, the surplus generation is stored in the battery in preparation of meeting demand once the output of solar PV decreases as the sun progressively goes down (3-6 PM). In the first hours of the evening, as some staff has already started to return home, all demand is met by stored electricity (7-8 PM). After the last workers have left the office, the battery is fully discharged, and grid electricity is needed to meet a low demand and to recharge the battery in preparation of the next morning (10-11 PM).

Chart 10: Fictional Example of Commercial Customer-Sited Battery + Solar PV



Source: Created by Renewable Energy Institute.

The three benefits of having a battery + solar PV system for commercial and industrial customers are the same as those for residential customers.

3) Seven Illustrative Battery Projects

Battery projects may greatly differ: for examples, there can be stationary batteries (standalone or paired with a generating technology) or transportation batteries, and energy storage capacity may significantly vary (from a few kilowatts (kW) to hundreds of megawatts (MW)).

In this section, seven recent examples of battery projects advanced across the world have been selected and are briefly showcased to provide instructive information toward wider application. (Table 4).

Table 4: Selected Batteries Projects

Project	Country	Operational year	Battery type	Storage capacity
Hornsdale Power Reserve	Australia	2017 (phase 1) 2020 (phase 2)	Stationary (standalone)	100 MW/129 MWh (phase 1) 50 MW/64.5 MWh (phase 2)
Moss Landing	United States	2020 (phase 1) 2021 (phase 2) 2023 (phase 3)	Stationary (standalone)	300 MW/1,200 MWh (phase 1) 100 MW/400 MWh (phase 2) 350 MW/1,400 MWh (phase 3)
Minami-Hayakita	Japan	2022	Stationary (standalone)	17 MW/51 MWh
Rajnandgaon	India	2023	Stationary (+ solar)	40 MW/120 MWh
Olkiluoto	Finland	2022	Stationary (+ nuclear)	85 MW/unspecified
Wattsmart	United States	2020	Stationary (+ solar)	Small-scale aggregation
EV Aggregation Platform	Europe	2016	Transportation	Small-scale aggregation

Source: Selected and presented by Renewable Energy Institute.

First, the Hornsdale Power Reserve battery project in the State of South Australia, Southern central part of Australia, is a project developed by Tesla for Neoen, a RE producer (Picture 1 on next page). When the first phase of this pioneering project was completed in November 2017 it was the world’s largest lithium-ion battery project (100 MW of power output – i.e., total possible instantaneous discharge capability/129 MWh of energy output – i.e., maximum amount of stored energy).[2] This project was launched in response to a devastating storm that damaged critical infrastructure in South Australia in September 2016, causing a state-wide blackout. After a few years of successful operations, the project was expanded into a second phase (50 MW/64.5 MWh) in September 2020. It now provides inertia support services to the electrical grid and effectively contributes to the integration of RE in South Australia, which is the leading country’s State for the deployment of wind and solar power (almost two-thirds of total electricity generation in 2021).[3]

Picture 1: Hornsdale Power Reserve Battery

Source: Tesla, World's Largest Battery Installed at Hornsdale, South Australia – July 29, 2019 (accessed October 21, 2022).

Second, the Moss Landing battery project in California, Pacific Coast of the United States, is a project developed by Vistra, an integrated retail electricity and power generation company for Pacific Gas & Electric Company (Picture 2 on next page). This project features the world's largest battery energy storage facility: 400 MW/1,600 megawatt-hours (MWh).[4] The first phase of this project (300 MW/1,200 MWh) was completed in December 2020, and the second phase (100 MW/400 MWh) in July 2021. A third phase (350 MW/1,400 MWh) is expected to be completed prior to June 2023. This project, relying on lithium-ion batteries, replaces installed capacity from a gas power plant and provides flexibility contributing to the integration of RE, especially solar power. The track record of this project in a very limited period of time is rather mixed because of a couple of extended outages following incidents related to a similar malfunctioning of some non-battery systems (i.e., a failed bearing in an air handling unit and failures of a small number of couplings on flexible hoses and pipes) in September 2021 (phase 1 facility) and February 2022 (phase 2 facility).[5]

Picture 2: Moss Landing Battery – Phase 1 Facility

Source: LG Energy Solution: [New TR1300 Operational at World's Largest Utility-Scale Battery Energy Storage Project – June 17, 2021](#) (accessed October 11, 2022).

Third, the Minami-Hayakita battery project in Hokkaido, Northern Japan, is a project developed by Sumitomo Electric for Hokkaido Electric Power Company (Picture 3 on next page). With 17 MW/51 MWh of capacity, it is much smaller than the Moss Landing project, yet it is one of the largest in Japan. The objectives of this project which operation started in April 2022 are frequency regulation and RE integration. Flow batteries (vanadium redox) are used. Flow batteries are more expensive and space-consuming than lithium-ion batteries because of their lower energy density (i.e., 10-120 watt-hour/kilogram against 50-260 watt-hour/kilogram for lithium-ion batteries), but they have a longer life span and are considered safer (i.e., they do not contain flammable electrolytes unlike lithium-ion batteries.[6] Fire incidents have sometimes affected the operations of lithium-ion batteries). As of mid-November 2022, no report assessing the performance of this system since the beginning of its operation could be found.

Picture 3: Minami-Hayakita Battery

Source: Sumitomo Electric, Redox Flow Battery (August 2022).

Fourth, the Rajnandgaon battery project in Chattisgarh, Central India, is a project being developed by Tata Power, an integrated power company, for Solar Energy Corporation of India. Unlike the Hornsdale Power Reserve, Moss Landing, and Minami-Hayakita standalone battery projects, this project pairs solar power with batteries. It should be commissioned by June 2023 and would become India's largest solar + battery project: 100 MW + 40 MW/120 MWh.[7] The objective of this project is to contribute to meet peak demand during evening hours by discharging solar based electricity stored during daytime.

Fifth, the Olkiluoto battery project in Finland is a project developed by Hitachi Energy for Teollisuuden Voima Oyj, a nuclear power company (Picture 4 on next page). This project interestingly pairs nuclear power with batteries. The goal of this 85 MW battery, which operation start was planned for the summer 2022 (no official update identified on the operating status of the battery as of mid-November 2022), is to support the power system in case of any production disruptions at the Olkiluoto-3 nuclear reactor (1,600 MW), Europe's latest nuclear reactor connected to the grid in 2022 after an interminable construction period of 17 years. In other words, this battery serves as a backup to partly compensate for potential significant power fluctuations caused by the unplanned outages of a large nuclear reactor.

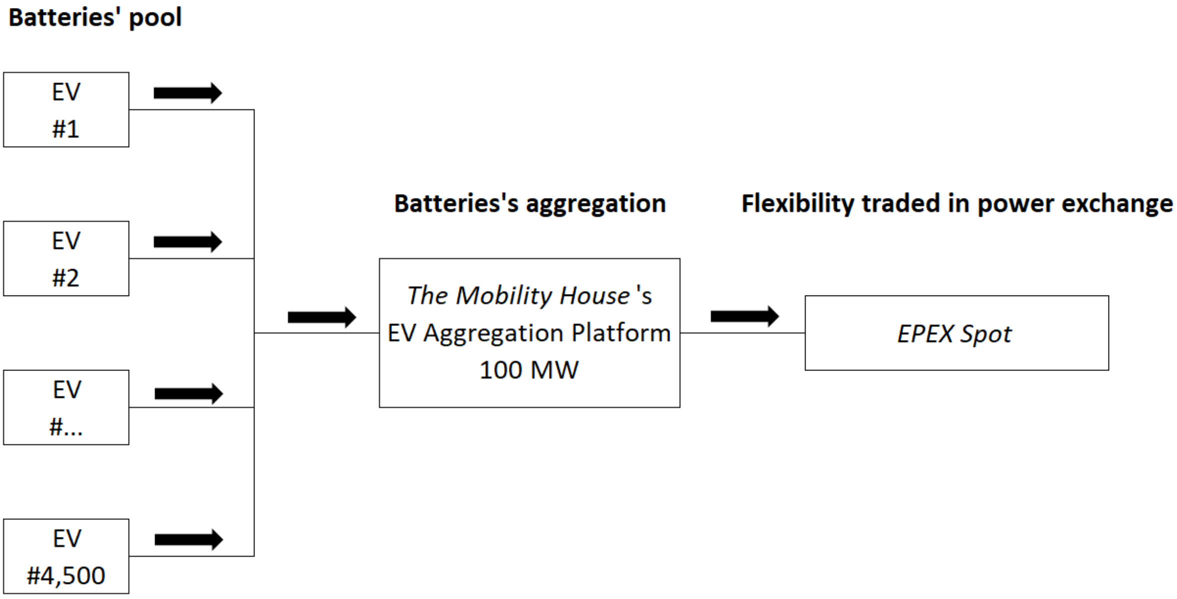
Picture 4: Olkiluoto Battery

Source: Teollisuuden Voima Oyj, The Operation of the Battery Energy Storage System to Start During the Summer – May 20, 2022 (accessed October 11, 2022).

Sixth, the Wattsmart battery project in Utah, Mountain West subregion of the Western United States, is a collaborative project including three companies: Sonnen (small-scale batteries), ES Solar (solar power), and Rocky Mountain Power (utility). Launched in December 2020, this pioneering program allows the local utility to control the outputs of residential and commercial customers' solar + battery systems to meet power system needs.[8] In return, participants in the program receive a double incentive: a one-time upfront cash payment of $400-600 per kW (maximum 30 kW) and an annual bill credit of $15/kW starting in the second year of the program.

Seventh, the EV Aggregation Platform is a project led by the technology company The Mobility House in Europe providing services in France, Germany, and the Netherlands. This company has been marketing the storage value of EV batteries since 2016. From August 2022, it joined the European Power Exchange EPEX SPOT in which it trades day-ahead and intraday the aggregated flexibilities of 4,500 electric car batteries (100 MW) (Chart 11 on next page). According to the company, the first bidirectional vehicles and charging stations allow the specific flexibility of electric cars to be traded in the best possible way without aging the battery. In return for their participation in this trading program, electric car batteries generate financial advantages which details could unfortunately not be clearly identified.

Chart 11: The Mobility House Trading EV Batteries' Flexibility in EPEX Spot



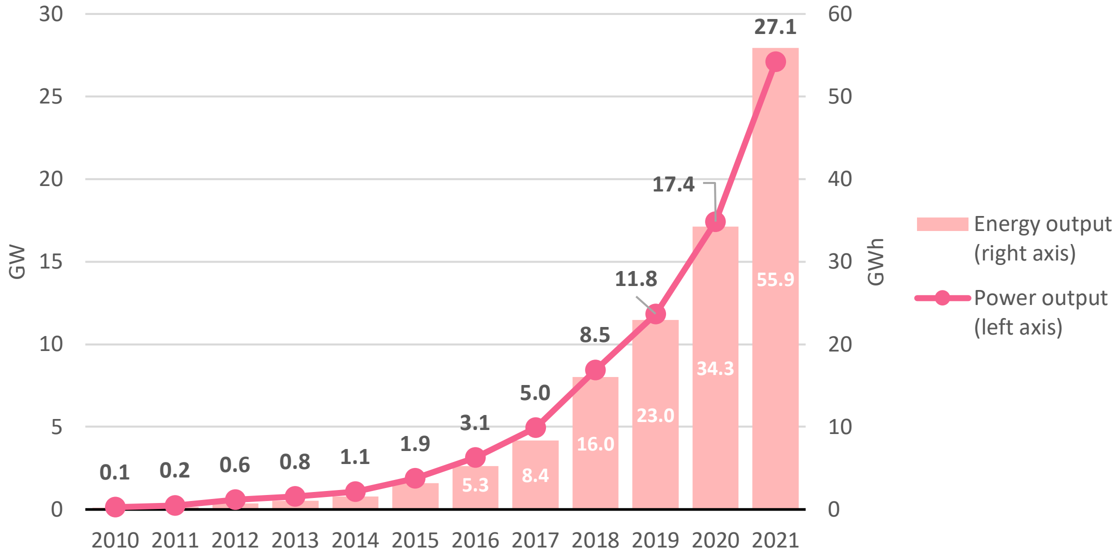
Source: The Mobility House, The Mobility House Trades Electric Car Batteries on the EPEX SPOT SE – August 25, 2022 (accessed October 2022).

Chapter 2: Deployment Accelerates with Economic Competitiveness

1) 2021 Record Growth and Leading Markets

The annual growth of the world stationary energy storage capacity – primarily batteries, excluding pumped storage hydro – reached a new record in 2021: +9.7 GW of power output/+ 21.6 gigawatt-hours (GWh) of energy output. Compared to the previous year-over-year growth records achieved in 2020 (+5.6 GW/+11.3 GWh), these new records correspond to increases of 73% and 91%, respectively. Thanks to this sharp acceleration, in 2021, the world stationary energy storage cumulative capacity totaled more than 27 GW, capable of providing 55.9 GWh of energy (Chart 12).

Chart 12: World Stationary Energy Storage Cumulative Capacity Power & Energy Outputs 2010-2021



Notes: Capacity primarily accounting for stationary batteries. Excluding pumped storage hydro.

Source: BloombergNEF, 2H 2022 Energy Storage Market Outlook (October 2022) – subscription required.

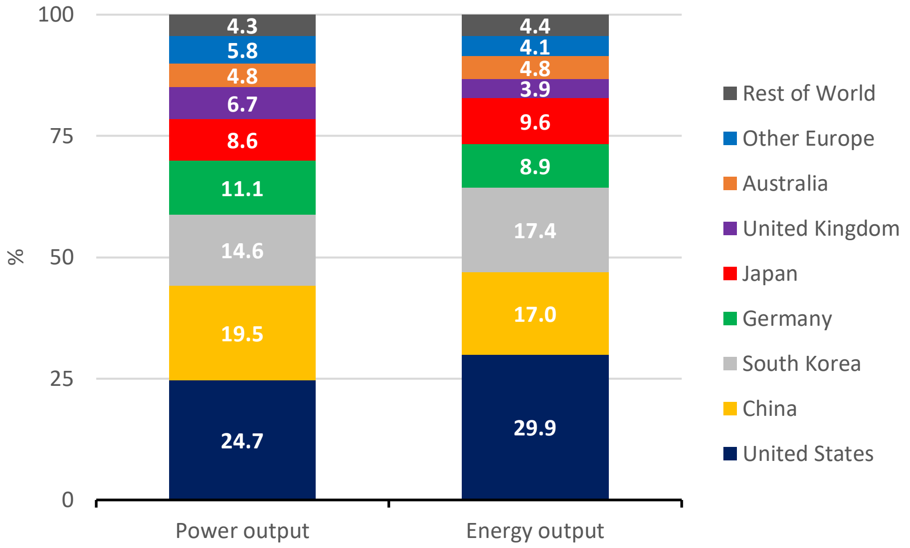
In 2021, global solar cumulative capacity reached 855 GW and global wind cumulative capacity reached 823 GW.[9] So, the ratio between stationary energy storage capacity (power output) and solar + wind capacity was 1.6%. This means that despite strong growth, at the global scale the impact of batteries generally remains limited. Yet, situations differ from one country to another as explained on pages 25-26.

It is also interesting to put into perspective stationary energy storage excluding pumped storage hydro and pumped storage hydro – the historical leading technology for stationary energy storage. In comparison, the annual growth of the world pumped storage hydro capacity reached 4.7 GW in 2021 – an excellent year compared to 2019 (+0.3 GW) and 2020 (+1.5 GW), and the world pumped storage hydro cumulative capacity totaled 164.8 GW.[10] Thus, even if stationary energy storage excluding pumped storage hydro is six times smaller than pumped storage hydro, it is now growing twice faster. Should both stationary energy storage excluding pumped storage hydro and pumped storage hydro maintain their respective 2021 growth pace, stationary energy storage excluding pumped storage hydro global cumulative capacity would overtake pumped storage hydro global cumulative capacity in 2049. This projection appears, however, excessively conservative since the growth trajectory of stationary energy storage excluding pumped storage hydro, unlike that of pumped storage hydro, is exponential not linear. This turning point should thus happen much earlier, probably by the end of this decade.

In addition to economic competitiveness that is discussed in this chapter, another two key factors are also driving the rapid expansion of stationary energy storage: technological progress (Chapter 3) and supporting policies (Chapter 4). To a lesser extent, another couple of factors is also positively contributing to the deployment of stationary energy storage: prosumerism (e.g., Australia, and Germany) and resilience (e.g., Japan, and California, Florida, and Texas in the United States).

The United States, Europe (especially Germany and the United Kingdom), China, and South Korea were the four largest markets in terms of stationary energy storage cumulative capacity in 2021. Together, of the world's stationary energy storage cumulative capacity they accounted for 82.3% of power output and 81.2% of energy output. Following these four markets were another two dynamic markets in Asia-Pacific: Japan, and Australia which together accounted for 13.3% of the world's stationary energy storage cumulative power output and 14.3% of the energy output. All the other countries of the world (i.e., "Rest of World") accounted for the remaining "only" 4.3% of power output and 4.4% of energy output. This indicates a strong concentration of stationary energy storage cumulative capacity in a few markets – largely developed economies – to date (Chart 13 on next page).

Chart 13: Stationary Energy Storage Cumulative Capacity Share by Country 2021 (%)



Notes: Capacity primarily accounting for stationary batteries. Excluding pumped storage hydro.

Source: BloombergNEF, 2H 2022 Energy Storage Market Outlook (October 2022) – subscription required.

In leading countries, the ratio between stationary energy storage cumulative capacity and solar + wind cumulative capacity was typically in the range of 2.5-5.0% – significantly higher than the world's average, with two exceptions: South Korea (19.9%) and China (0.8%) (Table 5 on next page). Therefore, among leading countries the impact of stationary energy storage on the integration of solar and wind was the biggest in South Korea and the smallest in China. South Korea's leadership within the scope of this indicator may be explained by four factors. First, successful supporting policies in favor of stationary storage (i.e., RE certificate multipliers and time-of-use discounted rates) (Chapter 4). Second, the country's power system reliance on inflexible coal (35% of total electricity generation) and nuclear (26%), with most of flexibility coming from expensive gas (29%) – not cheap hydro (only 1%).[11] Third, the fact that the country's electrical grid is operated in isolation (i.e., no cross-border interconnections with neighboring countries). And fourth, the relatively limited penetration of solar and wind due rather high costs (both around $0.12-0.13/kilowatt-hour (kWh)) and space constraints.[12]

Table 5: Ratio between Stationary Energy Storage Cumulative Capacity and Solar + Wind Cumulative Capacity in Selected Countries 2021

Country	Ratio storage capacity (power output) / solar + wind capacity (%)
United States	2.9
China	0.8
South Korea	19.9
Germany	2.5
Japan	2.9
United Kingdom	4.6
Australia	4.1

Notes: Capacity primarily accounting for stationary batteries. Excluding pumped storage hydro.

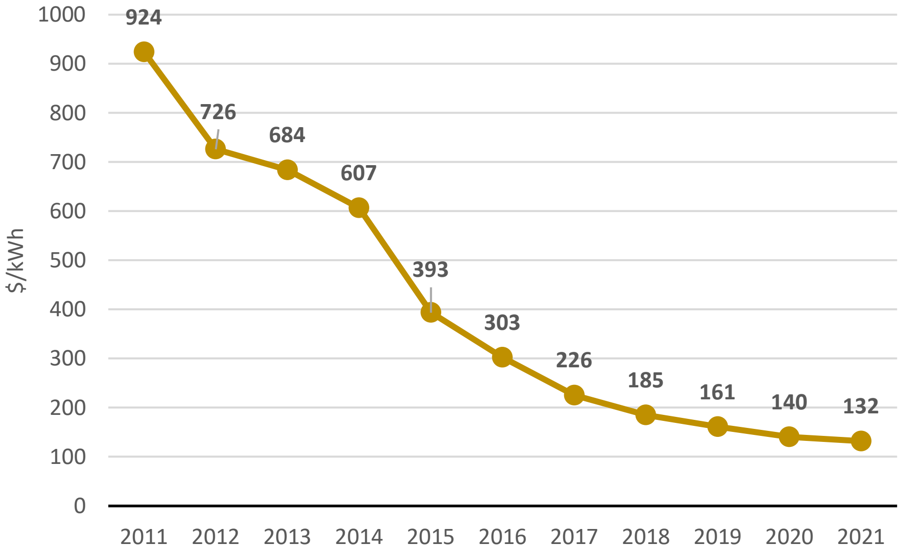
Sources: For storage; BloombergNEF, 2H 2022 Energy Storage Market Outlook (October 2022) – subscription required, and for solar and wind; International Renewable Energy Agency, Renewable Energy Statistics 2022 (July 2022).

The current concentration of stationary energy storage capacity in a few markets is probably temporary as solar and wind power spread everywhere across the world. Also, as battery technologies mature, and costs come down, widespread adoption of stationary energy storage in emerging and developing economies will certainly be facilitated. As a reminder, according to the IEA's Net-Zero Emissions scenario, global cumulative battery storage capacity will reach 3,860 GW in 2050 (Table 2 on page 9).

2) Dramatic Cost Reduction and Competitiveness in the Power Sector

The economic success of stationary batteries largely results from dramatic cost reductions owing to the widespread adoptions of EVs which was made possible thanks to technological progress, economies of scale, and supporting policies. In 2019, while the global energy output of transportation batteries was 200 GWh, that of stationary energy storage was 30 GWh – that is almost 7 times bigger (the estimate for stationary energy storage by the International Renewable Energy Agency presented in this paragraph slightly differs from that by BloombergNEF (i.e., 23 GWh) presented in Chart 11 for a reason that could not be identified).[13] Thus, stationary batteries benefitted from spillovers in EV deployment. Between 2011 and 2021, while the world's stock of EVs increased from less than 1 million to more than 16 million, the average pack price of lithium-ion batteries decreased from $924/kWh to $132/kWh – an 86% reduction (Chart 14 on next page).[14]

Chart 14: Average Pack Price of Lithium-Ion Batteries 2011-2021



Source: International Energy Agency, Critical Minerals Threaten a Decades-long Trend of Cost Declines for Clean Energy Technologies – May 18, 2022 (accessed October 13, 2022).

In the future, transportation batteries and stationary batteries could diverge as performance priorities evolve separately. For instance, EVs push for batteries with higher density (i.e., how much energy a battery contains in proportion to its weight), and stationary storage seeks higher cycling capability (i.e., the number of charge and discharge cycles that a battery can complete before losing performance). For the time being, however, it is difficult to predict how this potential divergence would result in terms of cost trajectories.

In countries for which data are available, standalone batteries and batteries paired with solar or wind power are often demonstrating cost competitiveness, both at the utility and distributed scales.

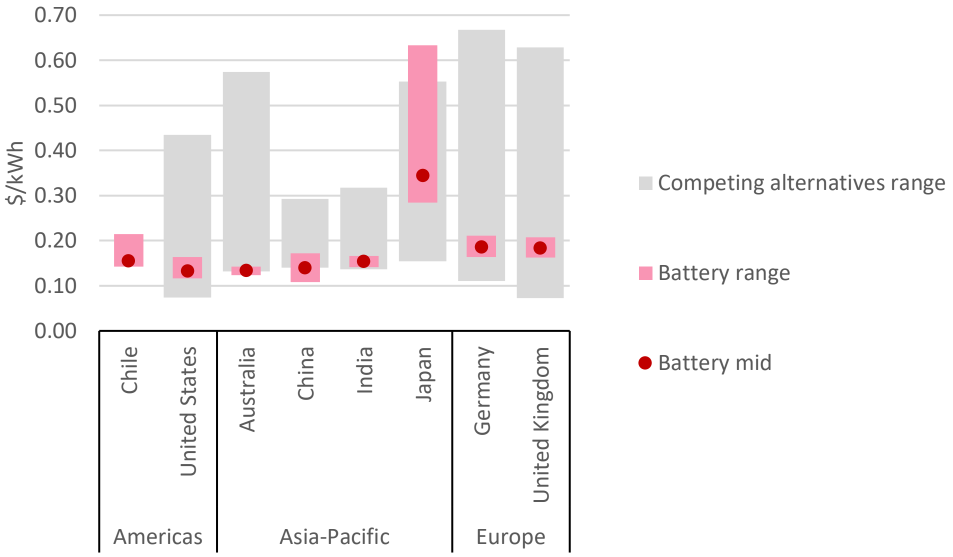
Starting at the utility-scale: the unsubsidized levelized cost of electricity (LCOE) of new standalone batteries is typically in the range of $0.11-0.22/kWh, except for Japan ($0.28-0.63/kWh). This range favorably compares with the LCOE of new other technologies providing flexible peaking services such as demand response, gas reciprocating engine, open-cycle gas turbine (OCGT), and pumped storage hydro (Table 6 and Chart 15 both on next page).

Table 6: Utility-Scale Standalone Batteries and Competing Alternatives' Key Features

Technology	Flexibility type	Principle	Fuel required	Typical size	Speed reaction
Batteries	Storage	Stores and reutilizes power through reversible chemical reaction in active materials through electrolyte	None	MW to hundreds of MW	Sub-seconds
Demand response	Demand	Aggregates the load of multiple consumers who, based on price signals, increase or decrease their demand	None	Aggregated basis – hundreds of MW to GW	Seconds
Gas reciprocating engine	Supply	Converts pressure into rotating motion using pistons	Fossil fuels (e.g., natural gas)	MW to a few hundreds of MW	Few minutes
OCGT	Supply	Uses the pressure from the exploding fuel to turn a turbine and produce thrust	Fossil fuels (e.g., natural gas)	MW to hundreds of MW	Few minutes
Pumped storage hydro	Storage	When supply exceeds demand, water is pumped from a lower elevation reservoir to a higher elevation reservoir to be stored. When demand exceeds supply, stored water is released to generate electricity	None	Hundreds of MW to GW	Few minutes

Source: Created by Renewable Energy Institute.

Chart 15: LCOE of Utility-Scale Battery (4 hours) and Competing Alternatives by Country 2022 H1

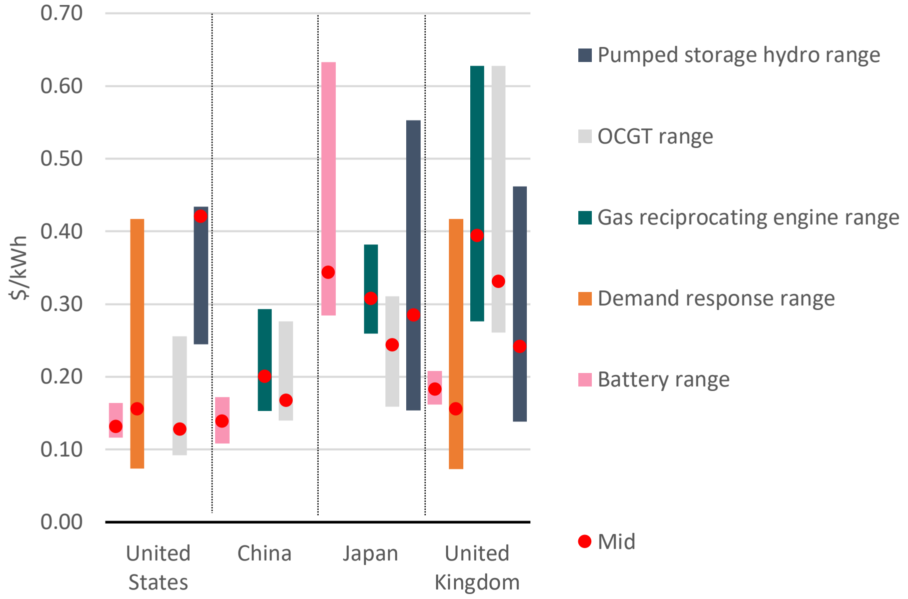


Note: Competing alternatives includes demand response, gas reciprocating engine, OCGT, and pumped storage hydro.

Source: BloombergNEF, 1H 2022 Levelized Cost of Electricity (June 2022) – subscription required.

To complement Chart 15, Chart 16 is provided showing the LCOE of new standalone batteries' competing alternatives into greater details in four selected countries: the United States, China, Japan, and the United Kingdom. With the exception of Japan, standalone batteries are often the cheapest options for peak power. Their main competitor is demand response which can sometimes be procured at lower costs (i.e., United States and United Kingdom). Gas reciprocating engine, OCGT, and pumped storage hydro are usually outcompeted.

Chart 16: LCOE of Utility-Scale Battery and Competing Alternatives into Greater Details: United States, China, Japan, and United Kingdom 2022 H1



Source: BloombergNEF, 1H 2022 Levelized Cost of Electricity (June 2022) – subscription required.

An example of merchant standalone utility-scale battery project is the Hazelwood project in Victoria, Southeastern Australia where RE (largely wind and solar) accounted for one-third of the State's total electricity generation in 2021.[15] This 150 MW/150 MWh project reached financial close without government support in December 2021 (the cost information has not been disclosed).[16] It is specified that the battery will participate in frequency control ancillary service markets what should provide enough revenue streams to cover the costs of the project and make profits for the investors. It is also interesting to note that this project scheduled to be operational very quickly – by November 2022 – will take advantage of the existing transmission infrastructure of the permanently shut down Hazelwood coal power plant (1,600 MW retired in 2017).

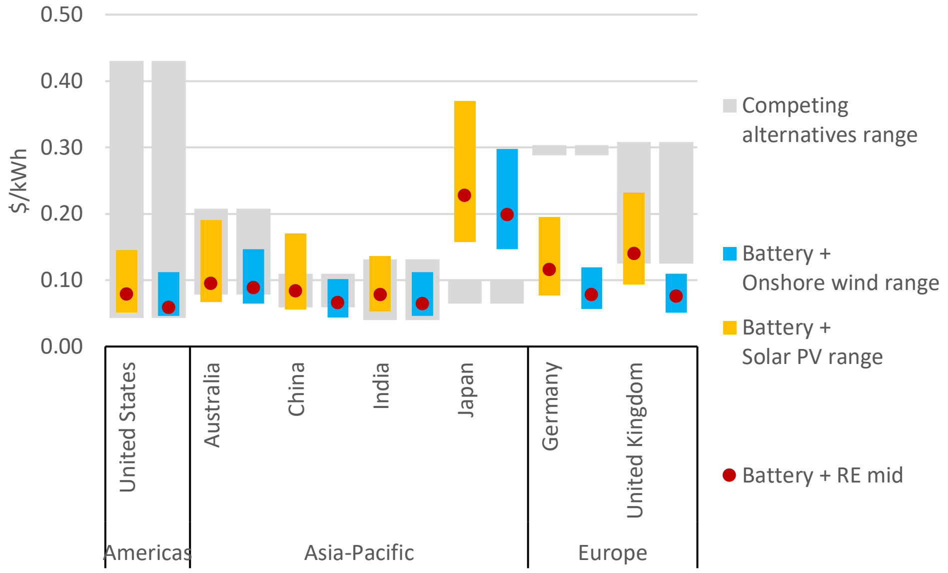
In the United States in Texas, South Central region of the United States, battery projects are typically merchant. Deployment in this State is particularly dynamic and profitable with many developers rushing into the battery market in hopes to get an early advantage in volatile merchant ancillary-service products. Apart from the profitable economics of batteries, another reason that boosted the interest of Texans in batteries is the winter storm Uri in February 2021 that caused significant damage to the perception of their electrical grid.[17]

In comparison to other countries, the economic competitiveness of batteries in Japan is for now unfortunately less evident. Two important factors explain the current negative situation. First, the 20-year flat subsidies under RE feed-in tariffs disincentivized developers from installing batteries due to a lack of price arbitrage opportunities. The introduction of RE feed-in premiums (i.e., a margin added to fluctuating market prices) for new RE projects in April 2022 should now incentivize developers to invest in batteries to optimize the timely delivery of electricity generated and stored. And second, until recently the competition among Japanese battery manufacturers was not fierce, preventing significant cost reductions. This is, however, changing with the entrance in the Japanese market of overseas players with cheaper batteries such as Tesla notably.

Regarding utility-scale batteries paired with solar PV or onshore wind now: the unsubsidized LCOEs of new batteries + solar PV and of batteries + onshore wind are generally $0.05-0.23/kWh and $0.04-0.15/kWh, respectively, except for Japan once again ($0.16-0.37/kWh for battery + solar PV and $0.15-0.30/kWh for battery + onshore wind). The LCOE benchmarks (i.e., "mid") of battery + solar PV and of battery + onshore wind are mostly below $0.10/kWh, a cost level that compares well with the LCOE of new generating technologies providing dispatchable generation such as coal, combined-cycle gas turbine (CCGT) (i.e., shares the same basic components as an OCGT, but the heat associated to the gas turbine exhaust is used in a heat recovery steam generator to produce steam that drives a steam turbine and generates additional electric power), and nuclear (Chart 17 on next page).

Furthermore, it may be noted that the ongoing global energy crisis characterized by extremely high fossil fuel prices makes battery + solar PV and battery + onshore wind very attractive solutions against existing polluting power plants as well. These robust observations make it crystal clear that claims about prohibitively expensive solar and wind integration costs are unfounded.

Chart 17: LCOE of Utility-Scale Battery (4 hours) + RE and Competing Alternatives by Country 2022 H1

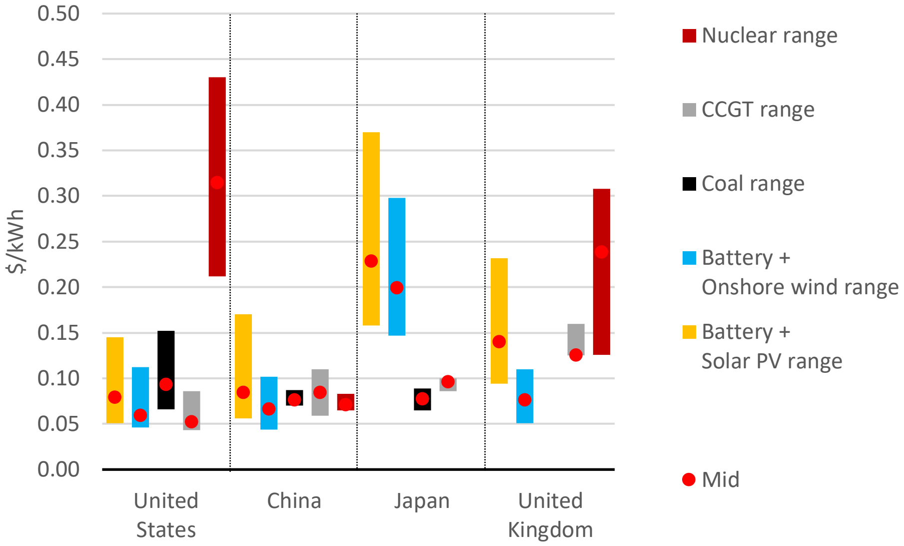


Note: Competing alternatives includes coal, CCGT, and nuclear.

Source: BloombergNEF, 1H 2022 Levelized Cost of Electricity (June 2022) – subscription required.

To complement Chart 17, Chart 18 (on next page) is provided showing the LCOE of new battery + RE's competing alternatives into greater details in four selected countries: the United States, China, Japan, and the United Kingdom. It may be noted here that in these projections for new power plants, BloombergNEF sometimes assumes the future fuel costs of coal and gas to decrease from their current highs, and to return to their levels before the invasion of Ukraine by Russia in February 2022 (e.g., for liquefied natural gas in Japan: around $10/million British thermal units in 2019-2021, against almost $24/million British thermal units in October 2022).[18] These assumptions may appear optimistic insofar as uncertainty about future fossil fuel supply predominates today. If future fuel costs of coal and gas are higher than those assumed by BloombergNEF, then LCOE for coal and CCGT power plants will be higher than the projections displayed below.

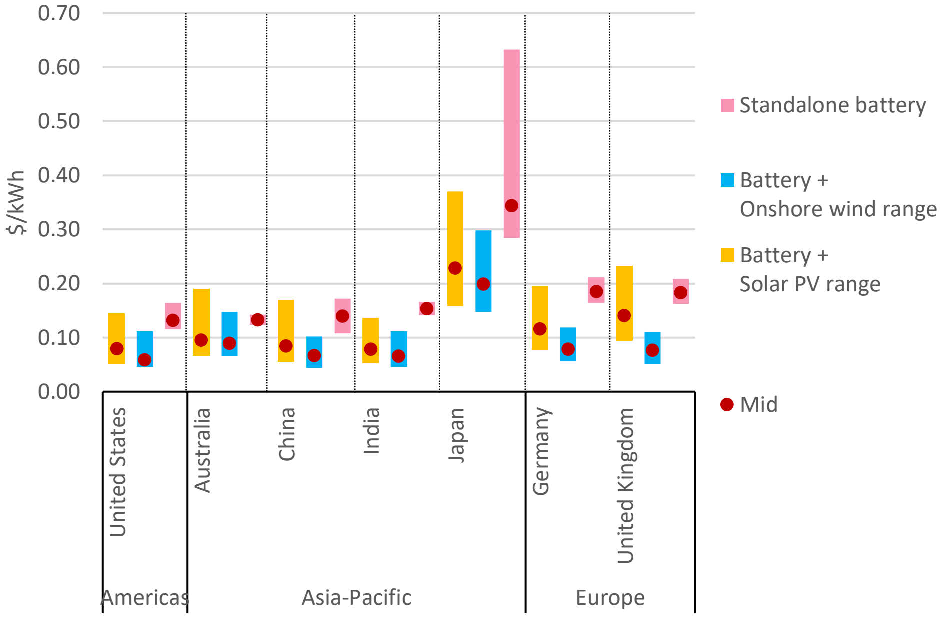
Chart 18: LCOE of Utility-Scale Battery + RE and Competing Alternatives into Greater Details: United States, China, Japan, and United Kingdom 2022 H1



Source: BloombergNEF, 1H 2022 Levelized Cost of Electricity (June 2022) – subscription required.

There are two reasons why the LCOEs of battery + solar PV and battery + onshore wind are lower than the LCOE of standalone battery. First, there is an efficiency gain from charging a battery directly with the electricity from the paired solar PV or onshore wind rather than buying it from the grid (especially if the electricity charged would have otherwise been curtailed). Second, from an investor perspective, batteries paired with solar PV or onshore wind have a lower risk profile than that of standalone batteries because solar PV and onshore wind are more established technologies with solid track-records what mitigates project risks. This results in a lower cost of capital (Chart 19 on next page).

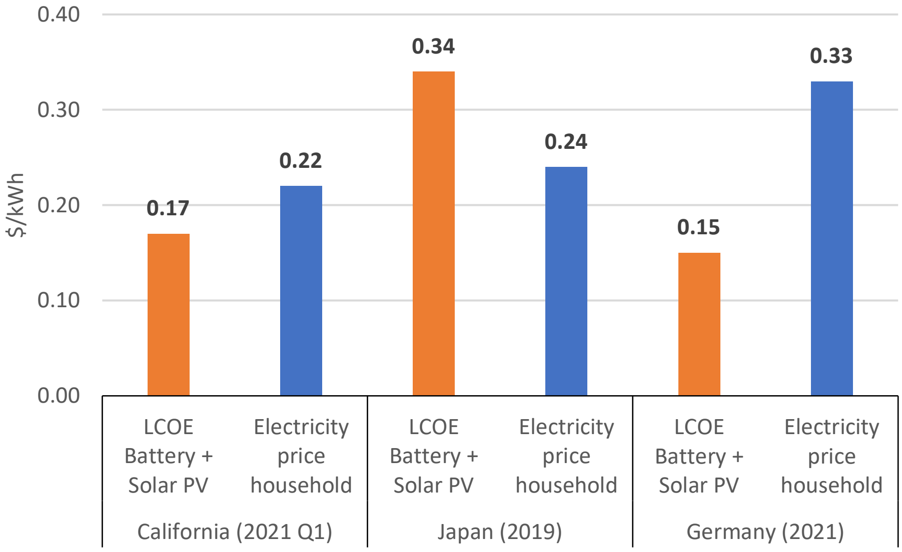
Chart 19: LCOE of Utility-Scale Battery +RE and Standalone Battery by Country 2022 H1



Source: BloombergNEF, 1H 2022 Levelized Cost of Electricity (June 2022) – subscription required.

As for small-scale battery + rooftop solar PV, which can be installed at residential premises, economic competitiveness is also sometimes observed as for examples in California and Germany (Chart 20 on next page). In these two markets, the LCOE of battery + solar PV was about $0.15-0.17/kWh, in 2021 (data for California are for the first quarter of the year/January-March only). This LCOE range favorably compared with retail electricity prices for households which were moderate in California ($0.22/kWh) and high in Germany ($0.33/kWh). In Japan in 2019 (the latest year for which data could be found), however, the LCOE of battery + solar PV was double that of California and Germany $0.34/kWh (which is somewhat similar to what was observed at the utility-scale level). In comparison, in 2019 electricity prices for households in Japan were much cheaper ($0.24/kWh). Since 2019, however, the situation has dramatically changed; battery + solar PV have become more cost competitive and household electricity prices have increased (average regulated tariff of incumbent power companies; from ¥24/kWh in December 2019 to ¥29/kWh in August 2022, or +17%), once again because of the ongoing energy crisis the world is going through.[19] Therefore, at least part of this gap should now have been filled in.

Chart 20: Residential Battery + Solar PV LCOE VS. Household Electricity Price in California, Japan, and Germany 2019-2021



Sources: For California; LCOE battery + solar PV from United States National Renewable Energy Laboratory, U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks: Q1 2021 (November 2021) and electricity price household from United States Energy Information Administration, Electric Power Monthly with Data for March 2022 (May 2022), for Japan; LCOE battery + solar PV from BloombergNEF, Batteries too Expensive? No Problem if You Sell in Japan (December 2019) – subscription required and electricity price household from BloombergNEF, Countries: Japan (accessed November 1, 2022) – subscription required, and for Germany; SolarPower Europe, European Market Outlook for Residential Battery Storage 2021-2025 (November 2021).

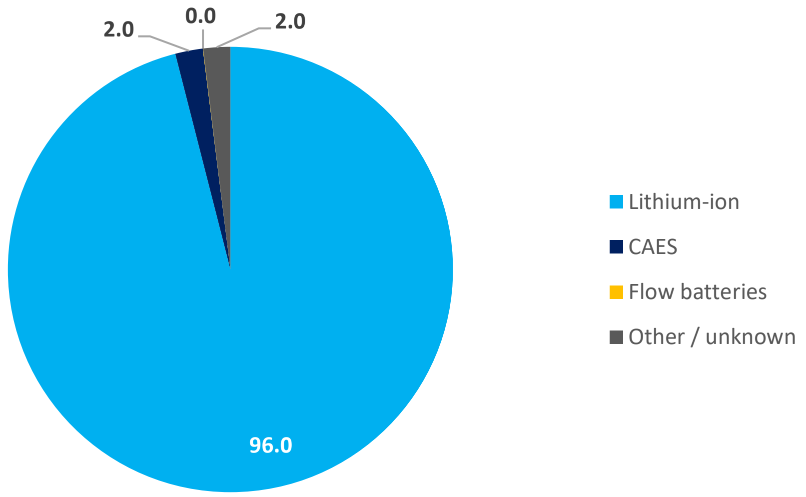
Finally, it may be mentioned here that inflationary trends (e.g., battery metal prices and freight costs) seen in 2022 are to some extent negatively impacting the economics of batteries, solar PV, and onshore wind. However, these negative impacts are relatively small compared to those of surging fossil fuel prices. Nonetheless, the current situation should be taken as an opportunity to redouble efforts to reduce the costs of clean energy technologies via technology innovation, efficiency improvements and economies of scale. Regarding batteries specifically, recent high lithium prices present an opportunity for developing alternative cheaper technologies. For instance, in the years to come, sodium-ion batteries might start becoming cheaper than lithium-ion batteries, if the supply chains mature and economies of scale are realized.[20]

Chapter 3: Technological Progress and Improvements to Come

1) Short-Duration Lithium-Ion Overwhelming Domination

Thanks to their unrivaled economic competitiveness and technological maturity short-duration lithium-ion batteries (i.e., discharge duration 0.5-6 hours) are continuously overwhelmingly dominating the stationary energy storage market. Indeed, since 2016 the share of lithium-ion batteries in the world's commissioned utility-scale energy storage projects (excluding pumped storage hydro) always ranged between around 90% and 95%. In 2021, the share of lithium-ion batteries was a very impressive 96%. Other technologies (e.g., compressed air energy storage (CAES), flow batteries) are for now completely left behind (Chart 21).

Chart 21: World Utility-Scale Stationary Energy Storage Projects by Technology 2021 (%)

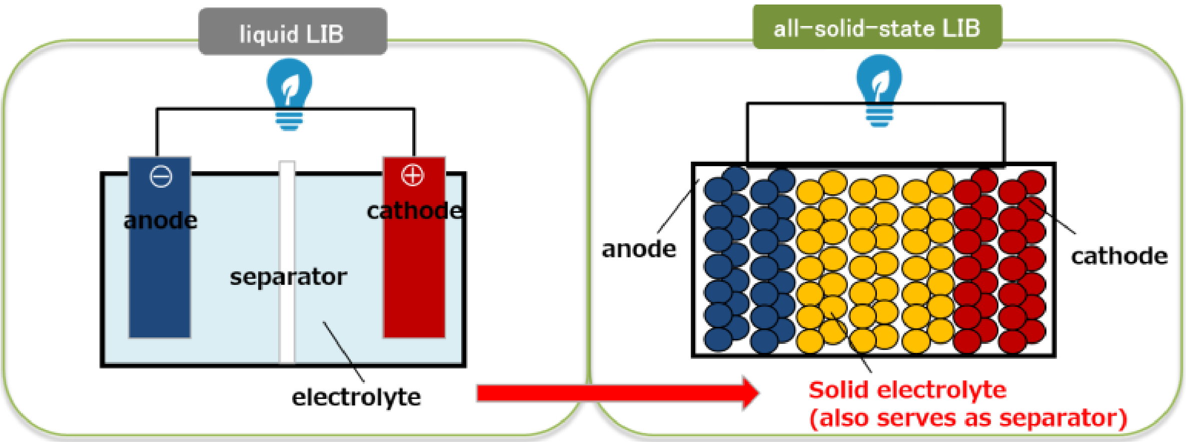


Notes: Excluding pumped storage hydro. Other / unknown is unspecified. Based on power output.

Source: BloombergNEF, 2H 2022 Energy Storage Market Outlook (October 2022) – subscription required.

Thus, lithium-ion batteries are thriving, and further progress is expected with the emergence of solid-state lithium-ion batteries in the second half of the 2020s. These next-generation of lithium-ion batteries hold the promises to be safer (by eliminating ignition and leaks caused by flammable electrolytes – Chart 22 on next page), have a double utilization range (i.e., capacity), and be shorter to charge (only one-third of the time of today's liquid lithium-ion batteries).[21]

Chart 22: Illustration of Liquid Lithium-Ion Batteries and Solid-State Lithium-Ion Batteries



Note: The abbreviation LiB used in the chart stands for lithium-ion batteries.

Source: Japan Ministry of Economy, Trade and Industry, Battery Industry Strategy – Interim Summary – (April 2022).

By the end of this decade, short-duration sodium-ion batteries, which three key advantages are affordability (if potential cost reductions are achieved thanks to technological progress and economies of scale), a more geographically diverse distribution of raw materials, and safety – and which main drawbacks are a relatively lower energy density and shorter life span than lithium-ion batteries, could begin to offer some competition to lithium-ion batteries. For the time being, however, sodium-ion batteries are in their infancy.

For information purposes Table 7 below summarizes the key characteristics of lithium-ion batteries and sodium-ion batteries.

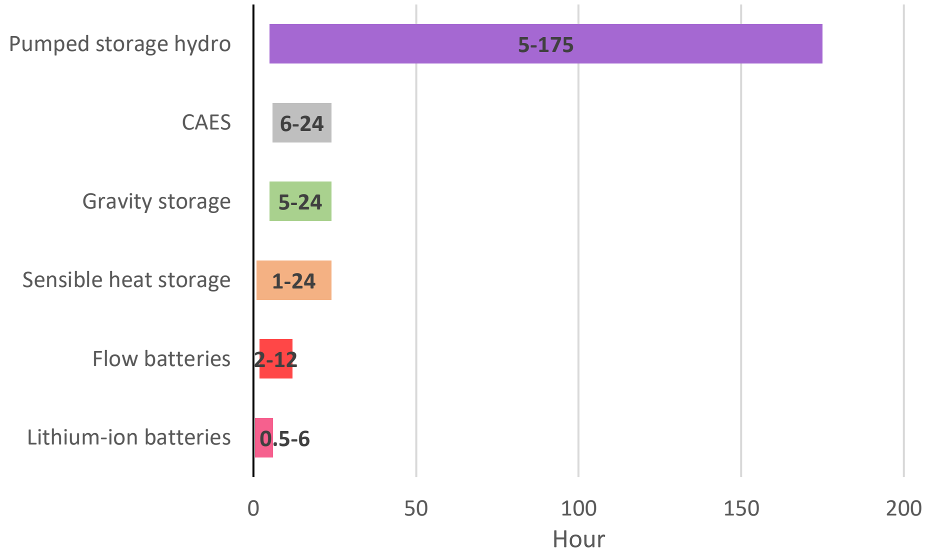
Table 7: Lithium-Ion Batteries and Sodium-Ion Batteries' Key Characteristics

Characteristic	Lithium-ion batteries	Sodium-ion batteries
Discharge duration (hours)	0.5-6	Similar to lithium-ion batteries
Energy density (watt-hour/kilogram)	50-260 (typically 170)	140-220 (typically 140)
Cycle life	6,000-12,000	4,000-5,000
Round-trip efficiency	85-95%	Similar to lithium-ion batteries

Source: BloombergNEF, for Lithium-ion batteries; Beyond Lithium-Ion: Long-Duration Storage Technologies (April 2022), and for sodium-ion batteries; Technology Radar: Sodium-Ion Batteries (October 2022) – both subscription required.

In addition to enhanced short-duration lithium-ion batteries and possibly sodium-ion batteries, a diversified suite of long-duration energy storage solutions (i.e., beyond 6 hours) would also certainly benefit to the integration of solar and wind power (Chart 23 on next page).

Chart 23: Typical Discharge Duration of Different Stationary Energy Storage Technologies



Sources: For all technologies except pumped storage hydro; BloombergNEF, Beyond Lithium-Ion: Long-Duration Storage Technologies (April 2022) – subscription required, and for pumped storage hydro, International Energy Agency, How Rapidly Will the Global Electricity Storage Market Grow by 2026? – December 1, 2021 (accessed October 11, 2022).

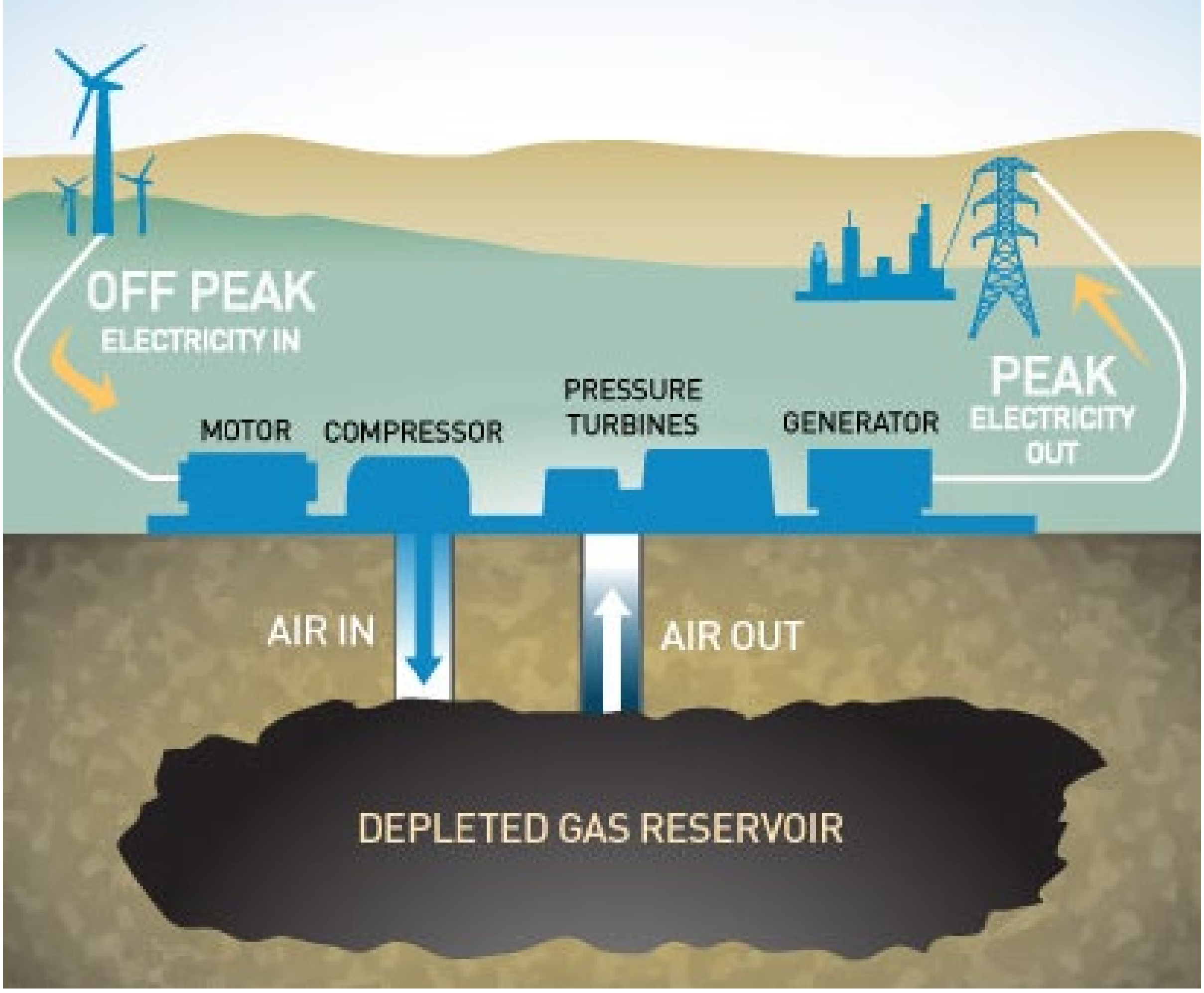
2) Long-Duration Energy Storage Lagging

With the exceptions of pumped storage hydro and – to a lesser extent – CAES, other long-duration technologies (e.g., flow batteries, sensible heat storage, gravity storage, and power-to-gas-to-power) are costly and technically unproven. This means that their contribution to power system operations is unlikely to be significant by 2030. To play a meaningful role over the long-term, establishing a track record and reducing costs are essential.

Considering pumped storage hydro, as explained in Chapter 1, prospects for the expansion of this technology are often limited in developed economies because of a lack of non-exploited potential and because of environmental and social constraints.

CAES is a technology that stores energy through pressurized air in large tanks or caves: air is compressed during off-peak times, and pressured air is heated and expands in a turbine to generate electricity at peak times. (Chart 24 on next page). In the case of current diabatic CAES, it is important to clarify here that the compressed air used to generate electricity is supplemented with fossil fuels (e.g., gas). This is not satisfying from a decarbonization perspective. As a result, new CAES alternatives functioning without the need for fossil fuels have recently started to be explored (e.g., adiabatic CAES, isothermal CAES, and absorption-enhanced CAES), but they are all only at the research & development stage which means they will not provide significant contributions in the coming decade at least.

Chart 24: The Basic Principle of CAES



Source: Pacific Gas & Electric, Discover Renewable Energy Technology with Compressed Air Energy Storage (accessed November 10, 2022).

Thus, it is important to advance additional long-duration energy storage solutions. These solutions can be broadly categorized into four types: electrochemical, thermal, mechanical, and chemical (Table 8 on next page).

Table 8: Selected Long-Duration Energy Storage Technologies Summary Key Characteristics

Characteristic	Electrochemical	Thermal	Mechanical	Chemical
Principle	Stores and reutilizes power through reversible chemical reaction in active materials through electrolyte (Usually called "batteries")	Stocks thermal energy by heating or cooling a storage medium. Energy can be used for heating/cooling and power generation later	Utilizes the movement of materials to store and release energy	Converts and stores power into the bond energy of new molecules via chemical reaction
Example	Flow batteries	Sensible heat storage (e.g., molten salts)	Gravity storage (e.g., discrete weighted blocks)	Power-to-gas-to power (e.g., hydrogen)
Power output	0-150 MW	0-300 MW	0-1,000 MW	No information
Discharge duration	2-12 hours	1-24 hours	5-24 hours	No information
Technical readiness	Fairly mature	Proven	Not mature	No information
Manufacturing readiness	Lack of robust, standardized supply chains to scale production	Some commercial projects	Moderate	No information

Source: BloombergNEF, Beyond Lithium-Ion: Long-Duration Storage Technologies (April 2022) – subscription required.

Among the selected long-duration energy storage technologies selected above, sensible heat storage such as molten salts, mostly co-located with concentrated solar power plants (e.g., Crescent Dunes power plant in the United States, Nevada – Picture 5 on next page), is the readiest technology from technical and manufacturing perspectives.

In the case of the Crescent Dunes concentrated solar power plant (110 MW, thermal storage system capable of generating electricity for 10 hours), salt is heated in a tower receiving concentrated sunlight from an array of mirrors. When electricity is needed, the molten salt is pumped through a heat exchanger to turn water into steam that spins a turbine to generate electricity. Cooler salt flows back to a storage tank and the cycle repeats.

One of the major drawbacks this technology faces, however, is that it requires very large volumes of storage medium due to low energy density. This is particularly problematic in countries with land scarcity issues, like Japan.

Picture 5: Crescent Dunes Concentrated Solar Power Plant in the United States, Nevada

Source: Cobra, Crescent Dunes Solar Thermal Power Plant (accessed October 17, 2022).

Finally, power-to-gas-to-power (i.e., decarbonized thermal) could complement other long-duration energy storage technologies thanks to its capability to provide useful seasonal storage. However, this process is necessarily costly due to on the one hand inherent double conversion losses, on the other hand lack of technical and manufacturing maturity (i.e., new-generation combustors for hydrogen-fired turbines able to burn efficiently with low nitrogen oxide emissions have yet to become widely available). Today this technology is not economically competitive neither for load following (e.g., $0.53/kWh in Japan in 2021) nor peaking (e.g., $0.82/kWh in Japan in 2021).[22] This does not mean that it has no future, but rather that short-term efforts should be focused on other priorities such as accelerating the deployment of solar and wind power as well as that of lithium-ion batteries.

This recommended strategical approach would rapidly and efficiently contribute to near-term decarbonization goals on which medium- and long-term decarbonization objectives are built upon. This is an important message to the attention of Japanese policymakers who are currently clearly failing at setting their immediate decarbonization priorities straight.

Chapter 4: Supporting Policies

1) Seven Powerful Possibilities to Further Accelerate Growth

Even if stationary energy storage, and especially batteries, are quickly spreading thanks to their economic competitiveness and technological relevance with regards to RE integration, supporting policies are key to further accelerate deployment.

Seven powerful supporting policies may be adopted, and some of them combined, to expand stationary energy storage: targets, mandates, investment tax credits, auctions, market designs, and RE certificate multipliers, time-of-use discounted rates (Table 9).

Table 9: Selected Stationary Energy Storage Supporting Policy Examples

Policy	Type	Country (State if applicable)
Target	Non-mandatory goal	China, Spain, United States (California and New York), and Australia (Victoria)
Mandate	Mandatory goal	United States (Virginia)
Investment tax credit	Fiscal incentive	United States
Auction	Public competitive bidding	Germany and India
Market design	Regulatory framework of power system	United Kingdom
RE certificate multiplier	Bonus award	South Korea
Time-of-use discounted rate	Incentive tariff structure	South Korea

Source: Selected by Renewable Energy Institute.

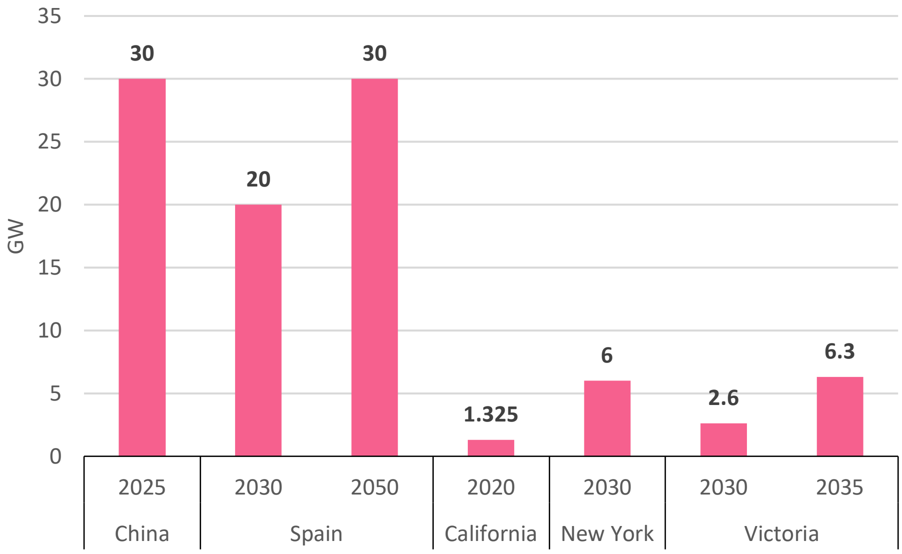
In this chapter, each of these supporting policies are separately briefly presented by describing their principle and by including at least one concrete example of implementation for illustration purposes.

2) Target

A target is an official commitment, plan, or goal set by a government to achieve a certain amount of stationary energy storage deployment by a future date. A target is usually backed by additional supporting policies to ensure it will be met.

Among today’s most ambitious stationary energy storage targets are those of: China 30 GW by 2025 (excluding pumped storage hydro), Spain 20 GW by 2030 (and 30 GW by 2050), California and New York States in the United States 1.325 GW by 2020 – achieved – and 6 GW by 2030, respectively, and Victoria State in Australia 2.6 GW by 2030 (and 6.3 GW by 2035) (Chart 25). It may be noted that Japan does not have such target.

Chart 25: Stationary Energy Storage Targets Selected Examples



Note: China's target excludes pumped storage hydro.

Sources: For China; International Energy Agency, China Guiding Opinions on Accelerating the Development of New Energy Storage 2021 – updated June 23, 2022 (accessed October 18, 2022), for Spain; International Energy Agency, Spain Energy Storage Strategy 2021 – updated March 23, 2022 (accessed October 18, 2022), for California; California Public Utilities Commission, Energy Storage (accessed October 18, 2022), for New York; New York State government, State of the State 2022 (January 2022), and for Victoria; Victoria State government, Australia's Biggest Renewable Energy Storage Targets (September 2022).

It may be briefly added here that in the case of the two countries with the highest targets identified, China does not have a target for solar and wind installed capacity by 2025, and Spain has targets of 46 GW of solar and 50 GW of wind by 2030.[23] So, in the case of Spain in 2030, the ratio between stationary energy storage capacity and solar + wind capacity will be about 21%, which will provide much more flexibility to the grid.

3) Mandate

A mandate (also sometimes called "obligation") is a measure that requires designated parties (e.g., suppliers, generators) to meet a minimum standard for stationary energy storage by a future date. The key difference between a mandate and a target is that a mandate is a goal with legal or financial liability for non-compliance.

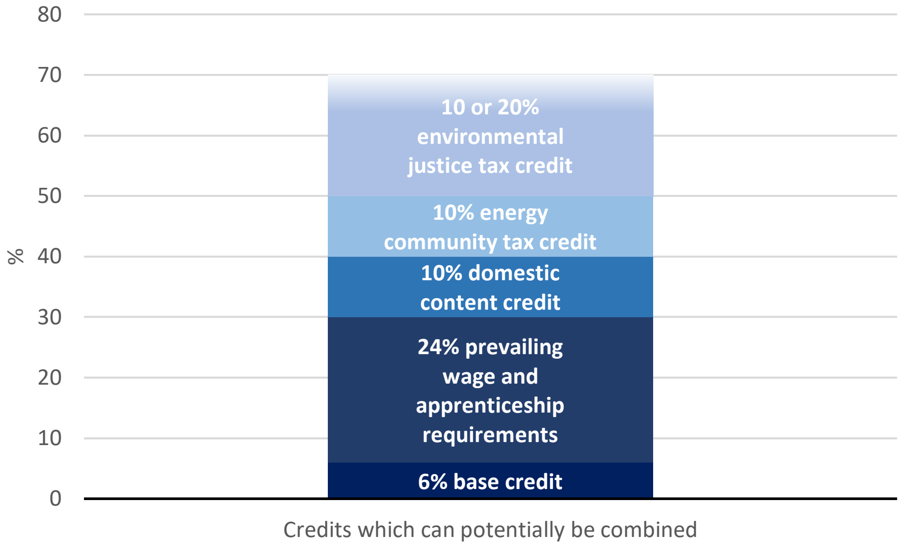
As of the end of 2022, the State of Virginia, Southeastern of the United States had the most ambitious mandate for stationary energy storage in the country (and possibly in the world as no more ambitious mandate could be identified): 3.1 GW by 2035 to integrate at least 16.7 GW of solar or wind (including 5.2 GW of offshore wind).[24] Into more details, two utilities are required to procure energy storage capacity: Dominion Energy Virginia (2,700 MW) and Appalachian Power (400 MW). Should these utilities fail at meeting their procurement requirements, they will be confronted with legal liabilities.

4) Investment Tax Credit

An investment tax credit (ITC) is a fiscal incentive that allows investments in stationary energy storage to be fully or partially credited against the tax obligations or income of, for examples, a project developer or building owner.

In the United States, the Inflation Reduction Act passed in August 2022 includes a 10-year ITC for lithium-ion batteries stationary energy storage projects starting construction before 2025 (to be eligible residential projects should be over 3 kWh and commercial projects over 5 kWh). The ITC is set at a base credit of 6% based on the installed equipment cost. This credit may be increased to 30% if a project meets prevailing wage and apprenticeship requirements. This provision steps down to 26% in 2033 and 22% in 2034. Moreover, three additional bonus credits may be combined: 10% bonus domestic content credit, 10% energy community tax credit, and 10% or 20% environmental justice tax credit (Chart 26). The goals of the energy community tax credit and environmental justice tax credit are to encourage the developments of stationary energy storage projects in locations impacted by the fossil fuel industry (e.g., brownfields) or where disadvantaged populations are living (i.e., Native American land and low-income residential buildings).

Chart 26: United States Structure of ITC for Stationary Energy Storage Projects 2022



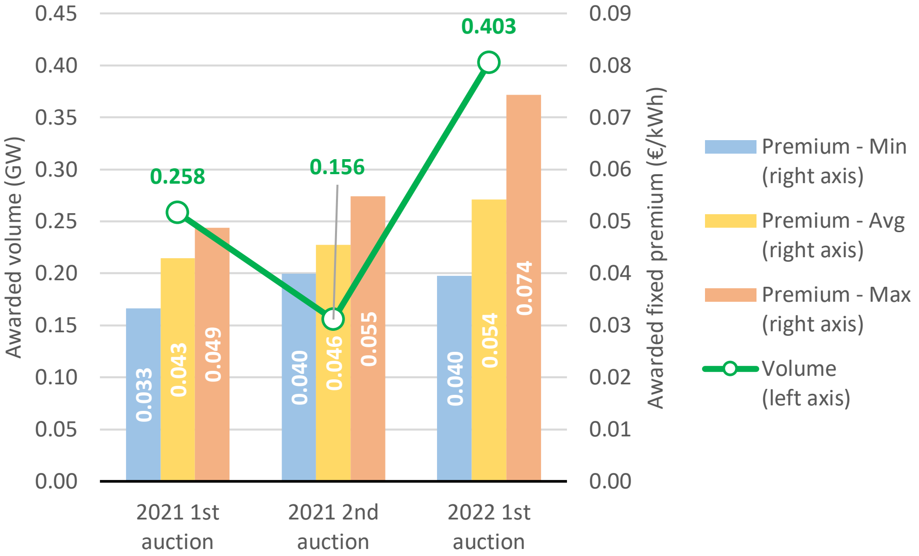
Source: BloombergNEF, 2H 2022 Energy Storage Market Outlook (October 2022) – subscription required.

5) Auction

Auction (also called "tender") is a procurement mechanism by which stationary energy storage or stationary energy storage + RE supply or capacity is competitively solicited from sellers, who offer bids at the lowest price that they would be willing to accept. Bids may be evaluated on both price and non-price factors.

Germany encourages the deployment of stationary energy storage in the framework of "innovation auctions" which should combine either two RE generating technologies (e.g., solar + biomass) or storage + RE (e.g., battery + wind). In the three auctions organized during 2021 and 2022, all winning projects were storage + solar projects: 0.8 GW in total. The fixed premiums awarded, to be added on top of market revenues, ranged between €0.03/kWh and €0.07/kWh and were in average around €0.04-0.05/kWh (Chart 27). Given the current LCOE of battery + solar PV (typically at €0.11/kWh for utility-scale projects in Germany in 2022 H1), and this year's high market price environment (i.e., average day-ahead power exchange price of €0.24-0.26/kWh in Germany from January to October 2022), these premiums appear to be rather significant.[25] This should make these projects very profitable in the short-term at least.

Chart 27: Germany Innovation Auctions Awarded Storage + Solar Projects 2021-2022



Source: Germany Federal Network Agency, Innovation Auctions: Completed Auctions (accessed October 19, 2022) [in German].

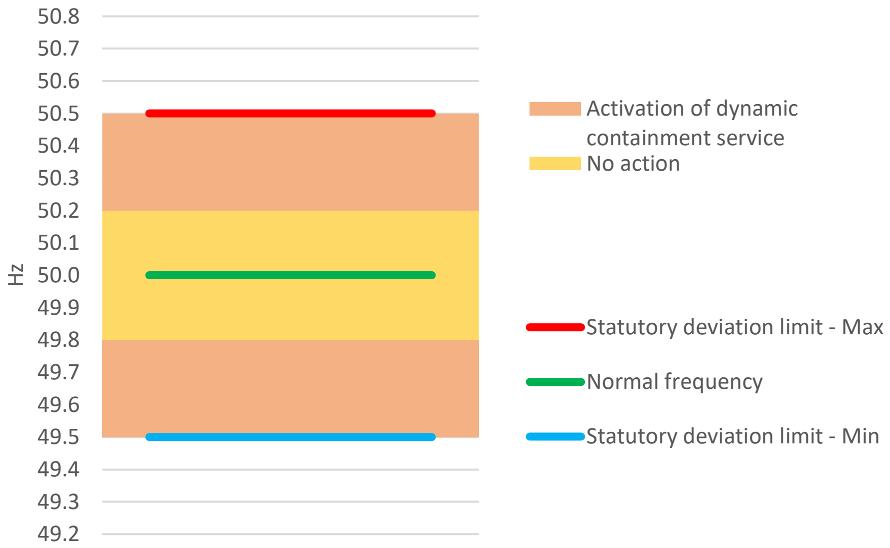
Furthermore, in August 2022, the Solar Energy Corporation of India conducted India's first standalone battery storage auction. Thanks to a winning bid of $13,590/MW the independent power producer JSW Energy has been awarded 500 MW/1,000 MWh worth of projects to help utilities shift surplus RE energy from off-peak times to be used during peaks (reducing curtailment) and to provide system capacity to the grid (e.g., ancillary services like frequency response).[26]

6) Market Design

Market design results from the rulebook of power systems. Establishing forward-thinking rules is a facilitator to attract investment in stationary energy storage.

A recent interesting initiative in this area is that of National Grid Electricity System Operator (National Grid ESO) in the United Kingdom. Launched in October 2020, its dynamic containment service requires faster frequency response innovative solutions to correct frequency deviations caused by imbalances. At normal times the normal frequency is 50 Hertz (Hz), and the dynamic containment service is activated, as a fast-acting post-fault service (i.e., sudden demand or generation loss), when frequency moves outside operational limits (i.e., +/-0.2 Hz) to ensure frequency is contained within the statutory range of +/-0.5 Hz (Chart 28).

Chart 28: United Kingdom Illustration of Dynamic Containment Service Functioning



Source: National Grid Electricity System Operator, Dynamic Containment (accessed October 19, 2022).

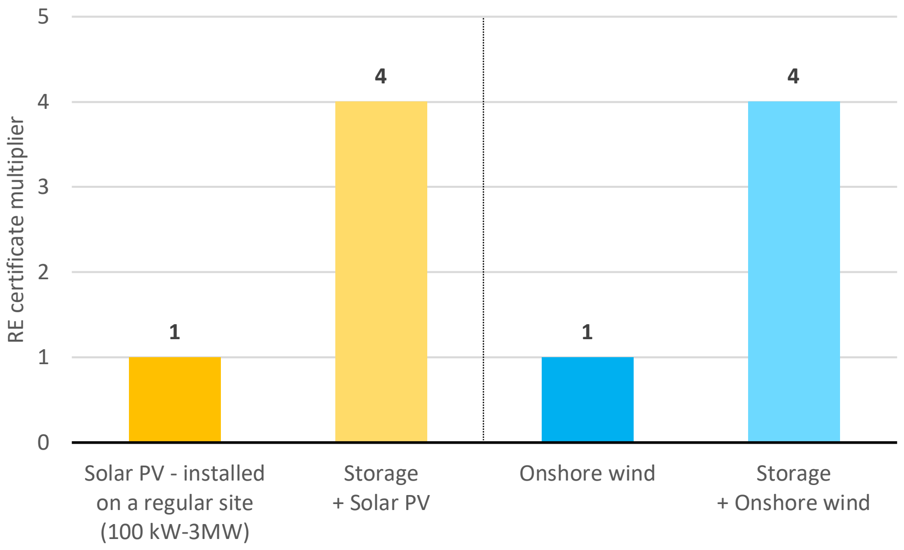
Batteries excelling at very quick ramping (i.e., sub-second), have perfectly seized this market opportunity: between the beginning of October 2020 and mid-September 2021 (period for which relevant data are available), they were the only technology procured by National Grid ESO for dynamic containment services thanks to their lowest bid prices.[27] This makes it a good example of positive contribution by the batteries to the flexibility of the British power system.

7) RE Certificate Multiplier

A RE certificate is a certificate awarded to certify the generation of one unit of RE (e.g., 1 MWh of electricity). Certificates can be accumulated to meet RE obligations and provide a tool for trading among consumers and/or producers. To spur the adoption of stationary energy storage, a RE certificate multiplier may be introduced. This means that projects pairing storage + RE are awarded more certificates for each unit of electricity generated than projects without storage.

Until the end of 2020 South Korea implemented RE certificate multipliers for storage + solar and storage + wind. RE certificate multipliers and time-of-use discounted rates (see next policy below) proved to be very successful policies which propelled South Korea as one of the world's leading markets for stationary energy storage capacity (excluding pumped storage hydro): in 2021, #4 in terms of power output and #2 in terms of energy output). However, energy storage system fire incidents (e.g., due to inadequate battery protective system or improper installation of the systems) discouraged the South Korean government to continue this policy. At the time this subsidy scheme was phased out, the same multiplier applied to both storage + solar and storage + wind: ×4 (Chart 29).

Chart 29: Two Examples of RE Certificate Multipliers for Storage + RE in South Korea December 2020



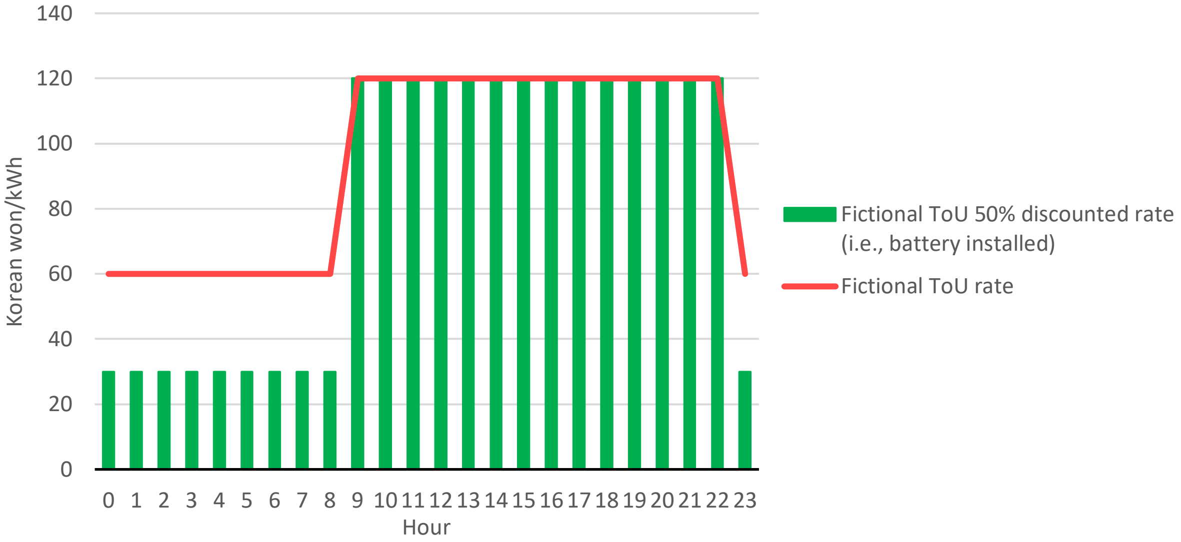
Source: International Energy Agency, Energy Policy Review: Korea 2020 (November 2020)

8) Time-of-use discounted rate

Time-of-use (ToU) rates differentiate pricing by season and time of the day to incentivize electricity consumption outside peak load periods (i.e., when electricity prices are substantially lower). Normal ToU rates already stimulate stationary energy storage by providing clear charging and discharging price signals. Yet, it is possible to be even more aggressive by offering ToU discounted rates.

In South Korea, ToU rates apply to commercial & industrial customers, consisting of: a base tariff (according to their peak monthly usage) and a usage tariff (according to their electricity consumption) – which is differentiated by peak and off-peak hours. To incentivize the uptake of stationary energy storage ToU discounted rates were introduced for both the base tariff and the usage tariff. For instance, in 2020, a 50% discount applied for charging an energy storage system during off-peak hours (11 PM-9 AM) (Chart 30).[28] This policy has been discontinued simultaneously as the RE certificate multipliers for the same reason explained above.

Chart 30: Fictional Illustration of ToU Discounted Rate for Battery Storage Inspired by South Korea's Example



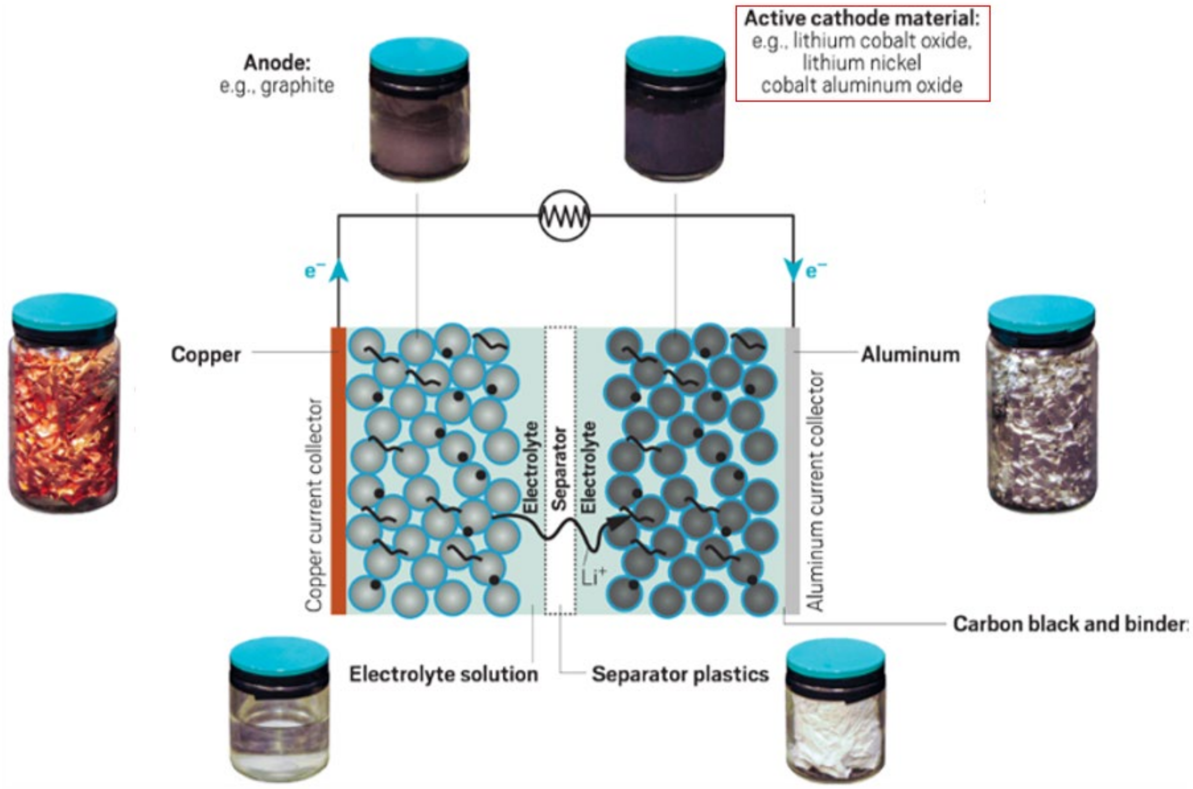
Source: Created by Renewable Energy Institute.

Chapter 5: Concentrations of Critical Minerals & Manufacturing Capacity and Solutions

1) Problematic Concentrations of Critical Minerals & Manufacturing Capacity

In addition to the current lack of cost competitive, technically proven long-duration energy storage solutions, the geographical concentration of critical minerals and the geographical concentration of manufacturing capacity are the other big challenges for stationary energy storage today. Indeed, considering lithium-ion batteries – the overwhelming dominating technology for energy storage excluding pumped storage hydro, some of its key cathode raw materials (i.e., lithium and cobalt) (Chart 31), and its manufacturing capacity are concentrated in a few countries only. This is quite problematic from an energy security perspective.

Chart 31: Lithium-Ion Battery Composition



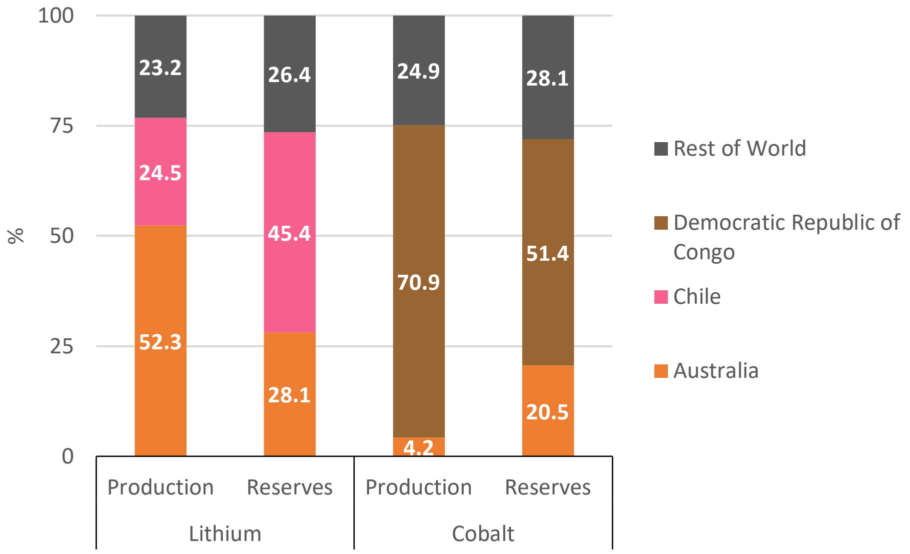
Note: Simplified by Renewable Energy Institute.

Source: Chemical & Engineering News, Mitch Jacoby, It's Time to Get Serious about Recycling Lithium-Ion Batteries – July 14, 2019 (accessed November 22, 2022).

Into more details, it may first be noted that among the key raw materials required in lithium-ion batteries around 75% of both the world's lithium production and reserves were concentrated in only two countries in 2021: Australia and Chile. And around 75% of both the world's cobalt production and reserves were concentrated in only two countries in 2021: the Democratic Republic of Congo and Australia.

More specifically, while Australia accounted for 52.3% of the world's lithium production and 28.1% of the world's lithium reserves, Chile accounted for 24.5% of the world's lithium production and 45.4% of the world's lithium reserves. And while the Democratic Republic of Congo, a country facing political instability, accounted for 70.9% of the world's cobalt production and 51.4% of the world's cobalt reserves, Australia accounted for 4.2% of the world's cobalt production and 20.5% of the world's cobalt reserves (Chart 32).

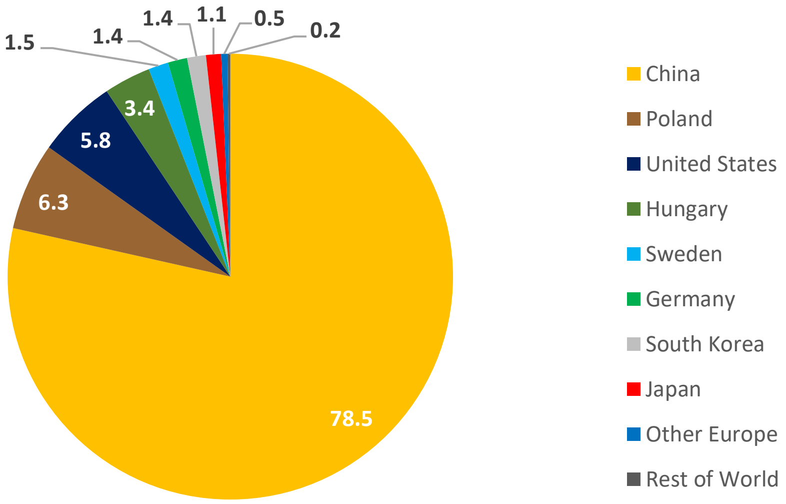
Chart 32: Lithium and Cobalt Production and Reserves by Country 2021



Source: BP, Statistical Review of World Energy 2022 (June 2022).

Then, it may be observed that nearly 80% of lithium-ion battery manufacturing capacity are currently concentrated in a single country: China, a country dominated by an authoritarian political regime, which massively subsidized its domestic lithium industry and consumption. Altogether European countries, led by Poland and Hungary, combined for 13.1% of the world's lithium-ion battery manufacturing capacity. The leadership of Poland and Hungary in Europe may be explained by their cheap, but skilled labor and their close ties to car making hubs, including Germany. The United States had a share of 5.8%, and South Korea and Japan an aggregated share of 2.5% only (Chart 33 on next page).

Chart 33: Lithium-Ion Battery Manufacturing Capacity by Country as of September 21, 2022 (%)



Note: Based on energy output.
Source: BloombergNEF, Battery Cell Manufacturers – Updated September 21, 2022 (accessed October 24, 2022) – subscription required.

This report does not focus on the sustainability of critical minerals mining for batteries. Nevertheless, it recognizes that critical minerals mining – as other industrial extractive activities (e.g., fossil fuels and uranium extractions) – deteriorates the environment which is not satisfying. For this reason, also, recycling should be actively pursued because the more recycle is done the less the environment will be damaged.

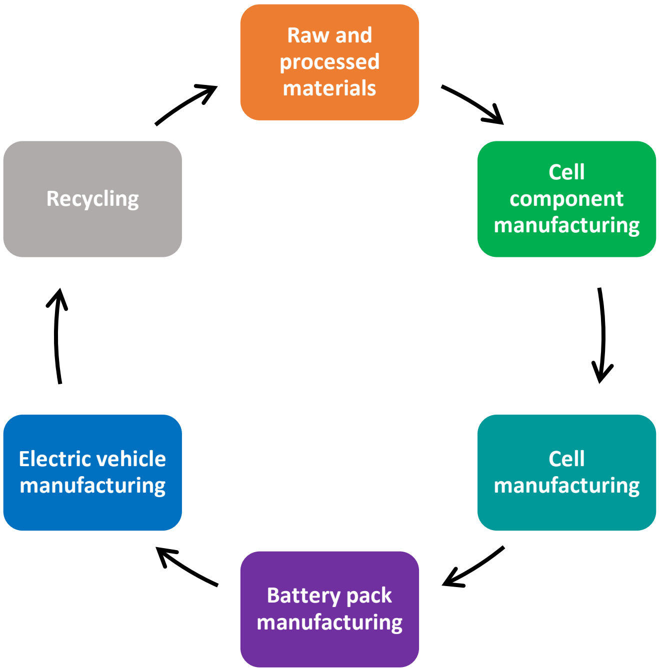
2) Solutions from Europe, the United States and Japan

To address the problematic concentrations of critical minerals and manufacturing capacity energy storage is confronted with, solutions exist. Insightful initiatives are pursued around the world. For instance, in Europe, the United States, and Japan. Indeed, in all these three markets, plans have recently been advanced plans to develop robust domestic battery supply chains.

- **Europe**

In Europe, following the launch of the European Battery Alliance (i.e., a cooperation platform with key industrial stakeholders, interested Member States and the European Investment Bank) by the European Commission in October 2017, the Commission announced the European Union (EU)'s Strategic Action Plan on Batteries in May 2018. In this action plan, batteries development and production is recognized as "a strategic imperative for Europe in the context of the clean energy transition." Therefore, the European Commission promotes a cross-border and integrated European approach covering the whole value chain of batteries ecosystem, and focusing on sustainability, starting with the extraction and processing of raw materials, the design and manufacturing phase of battery cells and battery packs, and their use, second use, recycling and disposal in a circular economy context (Chart 34).

Chart 34: European Commission's Envisioned Batteries Value Chain



Source: European Commission, Europe on the Move: Sustainable Mobility for Europe: Safe, Connected and Clean (May 2018).

Into more details, this Action Plan has six objectives – out which the first four specifically aim to address geographical concentration related issues: First, secure access to raw materials from resource-rich countries outside the EU, facilitate access to European sources of raw materials, as well as accessing secondary raw materials through recycling in a circular economy of batteries. Second, support European battery cells manufacturing at scale and a full competitive value chain in Europe by fostering collaboration (i.e., bringing key industry players and national and regional authorities together, working in partnership with Member States and the European Investment Bank). Third, strengthen industrial leadership through research and innovation support to advanced (e.g., liquid lithium-ion) and disruptive (e.g., solid-state lithium-ion) technologies in the batteries sector. Fourth, develop and strengthen a highly skilled workforce in all parts of the battery value chain by providing adequate training, re-skilling and upskilling, and making Europe an attractive location for world class experts in batteries development and production. Fifth, support the sustainability of EU battery cell manufacturing industry with the lowest environmental footprint possible (e.g., by using RE in the production process). And sixth, ensure consistency with the enabling and regulatory framework in support of batteries deployment (Table 10).

Table 10: European Commission's Strategic Action Plan on Batteries Six Objectives

#	Objective
1	Secure access to raw materials from resource-rich countries outside the EU, facilitate access to European sources of raw materials, and access secondary raw materials through recycling.
2	Support European battery cells manufacturing at scale and a full competitive value chain in Europe by fostering collaboration.
3	Strengthen industrial leadership through research and innovation support to advanced and disruptive technologies in the batteries sector.
4	Develop and strengthen a highly skilled workforce in all parts of the battery value chain by providing adequate training, re-skilling and upskilling, and making Europe an attractive location for world class experts in batteries.
5	Support the sustainability of EU battery cell manufacturing industry with the lowest environmental footprint possible.
6	Ensure consistency with the enabling and regulatory framework.

Source: European Commission, Europe on the Move: Sustainable Mobility for Europe: Safe, Connected and Clean (May 2018).

To achieve these objectives the European Commission has taken several key actions. For instance, in September 2020, it identified lithium as a critical raw material and indicated mobilizing investments with the goal of meeting 80% of Europe's lithium demand from European supply sources by 2025.[29] In addition, in December 2020, the European Commission adopted a proposal for a Regulation on batteries and waste batteries in which it aims at recovering by January 1, 2026, 35% of lithium and 90% of cobalt from waste batteries, and by January 1, 2030, 70% of lithium and 95% of cobalt from waste batteries, thanks to recycling.[30] More ambitious, in February 2022, the European Parliament amended the European Commission's proposal to seek a 70% recovery rate of lithium by 2026 and a 90% recovery rate by 2030 .[31]

As a result of these various efforts, lithium extraction projects are progressing in different EU Member States as for examples in Austria, the Czech Republic, Estonia, Finland, Germany, and Portugal. Moreover, the EU has also started to build strategic partnerships in critical raw materials with two countries: Canada and Ukraine.[32]

- **United States**

In the United States in June 2021, the U.S. DoE released a National Blueprint for Lithium Batteries to help guide investments to develop a domestic lithium-battery manufacturing value chain that creates equitable clean-energy manufacturing jobs in the country while helping to mitigate climate change impacts. In this plan, five goals and key actions are laid out which are to some extent quite like those of the European Commission: First, secure access to raw and refined materials and discover alternates for critical minerals for commercial and defense applications. Second, support the growth of a United States (U.S.) materials-processing base able to meet domestic battery manufacturing demand. Third, stimulate the U.S. electrode, cell, and pack manufacturing sectors. Fourth, enable U.S. end-of-life reuse and critical materials recycling at scale and a full competitive value chain in the country. And fifth, maintain and advance U.S. battery technology leadership by strongly supporting scientific research & development, science, technology, engineering, and mathematics education, and the development of human resources' skills (Table 11).

Table 11: United States Department of Energy's National Blueprint for Lithium Batteries Five Goals

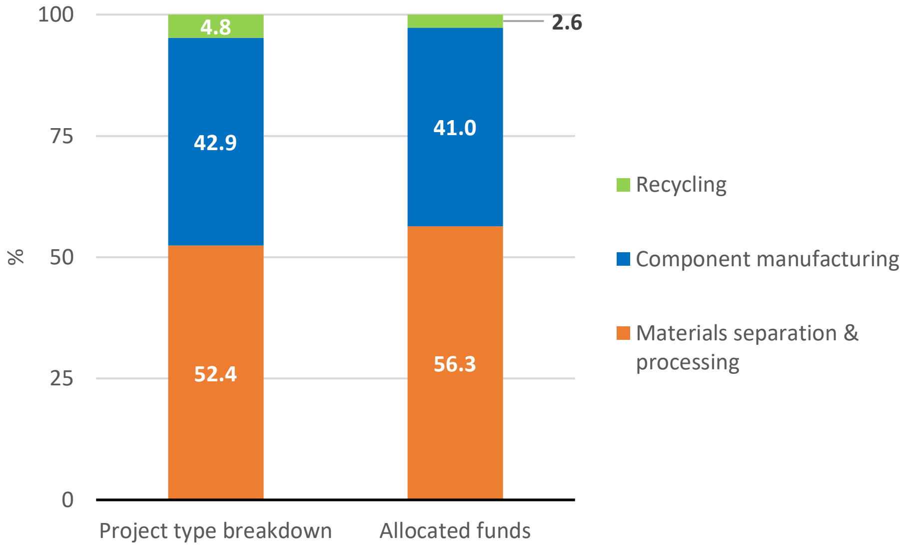
#	Objective
1	Secure access to raw and refined materials and discover alternates for critical minerals.
2	Support the growth of a U.S. materials-processing base able to meet domestic battery manufacturing demand.
3	Stimulate the U.S. electrode, cell, and pack manufacturing sectors.
4	Enable U.S. end-of-life reuse and critical materials recycling at scale and a full competitive value chain.
5	Maintain and advance U.S. battery technology leadership by supporting research & development, education, and workforce development.

Source: United States Department of Energy, Executive Summary: National Blueprint for Lithium Batteries 2021-2030 (June 2021).

Since the publication of this strategy, the administration of President Joseph Biden announced 3.16 billion from Bipartisan Infrastructure Law to Boost Domestic Battery Manufacturing and Supply Chains in May 2022.[33] The objective of this funding is to support transportation and stationary energy storages through increased domestic battery manufacturing, processing, and recycling. These investments cover new, retrofitted, and expanded commercial facilities as well as manufacturing demonstrations and battery recycling.

In October 2022, a first set of 21 projects (20 companies across 12 States) were awarded $2.8 billion, covering 31% of these projects' total costs.[34] At this occasion, three types of projects were awarded funds: materials separation & processing (e.g., lithium materials processing plant), component manufacturing (e.g., lithium anode manufacturing facility), and recycling (e.g., lithium-ion battery recycling to produce battery-grade raw materials). Most of the winning projects were materials separation & processing projects (52.4% of projects), and most of the funds were awarded to these projects (56.3%). Component manufacturing projects followed a little behind (i.e., 42.9% of projects and 41.0% of funds). And only one recycling project was awarded, receiving 2.6% of allocated funds (Chart 35). It may also be noted that neither raw materials extraction projects nor cell & pack manufacturing projects were selected.

Chart 35: United States Bipartisan Infrastructure Law Battery Materials Processing and Battery Manufacturing & Recycling Selected Projects October 2022



Source: United States Department of Energy, Bipartisan Infrastructure Law Battery Materials Processing and Battery Manufacturing & Recycling Funding Opportunity Announcement (DE-FOA-0002678) Selections (October 2022).

Furthermore, the economic and social contributions of these projects to revitalize some local areas may be highlighted: of the 20 companies selected, five will build new facilities in disadvantaged communities (e.g., low-income, underrepresented, and marginal communities in industrial reconversion areas and rural areas), and 15 in locations adjacent to disadvantaged communities.

Finally, at the same time that these projects were announced, President Biden also announced the launch of the American Battery Material Initiative to align and leverage federal resources for growing the end-to-end battery supply chain; work with stakeholders, allies, and partners to develop more sustainable, secure, resilient supply chains, and support faster and fairer permitting for projects that build the domestic supply chain. Additional information about this initiative could be expected in the coming weeks/months.

- **Japan**

In Japan in August 2022, the Ministry of Economy, Trade and Industry advanced its Battery Industry Strategy. In this important document the Japanese government acknowledges the key role of batteries to achieve carbon neutrality by 2050, thanks to their contributions in decarbonizing the transportation sector through vehicle electrification and in increasing flexibility in the power sector. When it comes to the battery supply chain, the importance of securing the manufacturing base is stressed. In this regard, it is noted that Japan is losing competitiveness and that there is a risk of increasing dependence on foreign countries. Therefore, it is necessary to maintain and strengthen the entire supply chain, including securing raw materials and securing manufacturing infrastructure for materials and cells.

The Battery Industry Strategy sets three goals. First, the Japanese government will support large-scale investment to strengthen the manufacturing infrastructure for liquid lithium-ion batteries, including securing upstream resources, and establish a domestic manufacturing infrastructure. Second, strategic development of overseas operations to ensure a global presence, based on technology established in Japan, so that world-leading companies can maintain and strengthen their competitiveness will be pursued. And third, technological development will be accelerated to lead the world in the commercialization of next-generation batteries, including solid-state batteries (which should reach full-scale commercialization around 2030), and steadily capture the next-generation battery market (Table 12). Though not established as targets, the Japanese government will also aim at strengthening human resource development, increasing domestic demand, and promoting reuse and recycling.

Table 12: Japan Ministry of Economy, Trade and Industry's Battery Industry Strategy Three Targets

#	Objective
1	Japanese government will support large-scale investment to strengthen the manufacturing infrastructure for liquid lithium-ion batteries and establish a domestic manufacturing infrastructure.
2	Strategic development of overseas operations to ensure a global presence, so that world-leading companies can maintain and strengthen their competitiveness.
3	Acceleration of technological development to lead the world in the commercialization of next-generation batteries and steadily capture the next-generation battery market.

Source: Japan Ministry of Economy, Trade and Industry, Battery Industry Strategy (August 2022) [in Japanese].

Of these three targets the first two are accompanied of quantified objectives for 2030. The first target sets an objective of establishing a domestic manufacturing base of 150 GWh/year of batteries and materials by 2030 at the latest, against about 20 GWh as of 2022 (i.e., a 7.5-fold increase). And the second target sets an objective of Japanese companies securing manufacturing capacity of 600 GWh/year in the global market in 2030.

To achieve the targets of the Battery Industry Strategy, the Japanese government’s policies will notably be based on public-private partnerships which investments should reach ¥3.4 trillion. It will be necessary to step up financial support.

With regards to financial support of upstream resources specifically, Japan Oil, Gas and Metals National Corporation, that provides financial support for resource exploration and development projects by Japanese companies, is now allowed to provide up to 75% (instead of 50% previously) of the funding necessary for critical raw materials procurement projects.

Finally, it may be noted that the Japanese government is also working on strengthening international cooperation with lithium and cobalt-rich countries (i.e., Australia), developing a skilled workforce (i.e., 22,000 workers in charge of battery storage manufacturing by 2030, and 30,000 people in charge of the entire supply chain, including materials), and seeking to achieve 70% and 95% recycling rates of lithium and cobalt, respectively, to be reused as storage battery material at competitive cost.

Conclusion

Today already, and even more in the future, battery storage will be key cost-efficient technologies to efficiency integrate large shares of solar and wind power.

However, to definitely establish themselves as versatile and unshakable major decarbonization technologies, batteries have to overcome two important challenges: long-duration energy storage and geographical concentrations of critical minerals & manufacturing capacity.

Regarding long-duration energy storage, cost reductions and technological improvements are indispensable. If sufficient progress takes place in the 2020s then commercialization could be envisioned in the 2030s – a necessity to significantly contribute to decarbonization efforts.

As for geographical concentrations, governments in leading countries have now recognized this issue and started to address it. The difficulty here will be to successfully implement advanced action plans in the coming years.

As efforts towards carbon neutrality urgently need to be accelerated, failure in dynamically and properly deploying batteries is certainly not an option.

List of Abbreviations

AE: Agora Energiewende

CAES: compressed air energy storage

CAISO: California Independent System Operator

CCGT: combined-cycle gas turbine

CCS: carbon capture and storage

EU: European Union

EVs: electric vehicles

GW: gigawatt

GWh: gigawatt-hour

Hz: Hertz

IEA: International Energy Agency

ITC: investment tax credit

kW: kilowatt

kWh: kilowatt-hour

LCOE: levelized cost of electricity

LUT U: Lappeenranta-Lahti University of Technology University

MW: megawatt

MWh: megawatt-hour

National Grid ESO: National Grid Electricity System Operator

OCGT: open-cycle gas turbine

RE: renewable energy

REI: Renewable Energy Institute

RTE: Réseau de Transport d'Electricité

Solar PV: solar photovoltaic

T&D: transmission and distribution

ToU: time-of-use

TWh: terawatt-hour

U.S.: United States

U.S. DoE: United States Department of Energy

Endnotes

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