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Research on Energy Storage Technologies to Build Sustainable Energy Systems in the APEC Region

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Introduction and Project Background

Energy storage has increasingly been recognized as a crucial technology to enable the global transformation towards low-carbon, resilient power systems. In addition to enabling more efficient uptake of renewable resources, energy storage can directly service the power grid, enhancing grid operations and safety. According to the China Energy Storage Alliance (CNESA) global storage project database, by the end of 2016, over 168.7 GW of energy storage has been installed across the world. This number is only expected to grow.

In this report, we have synthesized the information gathered through desk research, interviews, site visits, along with the contributions from expert speakers during the two workshops held under this project in November 2016 and May 2017. Our goal is to provide accurate information and objective analysis for APEC economies regarding the technologies, applications, and cost-effectiveness of energy storage. To conclude our report, we provide an overview of existing storage-related policies implemented across the APEC region, facilitating an exchange of best practices among economies. We aim to assist utilities, industry players, and government officials in efforts to develop and procure energy storage technology in APEC economies to build sustainable energy systems, address energy insecurity, and improve the integration of renewable energy sources.

Part I: Technology Status

A major strength of energy storage lies in its flexibility of use due to a wide array of technologies (and costs) able to store electrical energy. (Thermal energy storage has not been included in the scope of this report). These range from physical, chemical, to electromagnetic, along with emerging technologies like hydrogen fuel cell storage. Each technology possesses its own characteristics and suitability for different applications. This section provides an overview of existing electrical storage technologies, methods to quantify cost and revenue streams, along with future technology advancements.

Existing Storage Technologies

According to the China Energy Storage Alliance Global Project Database, the world's energy storage technology up through 2016 is overwhelmingly comprised of pumped hydro storage, as shown in Figure 1.

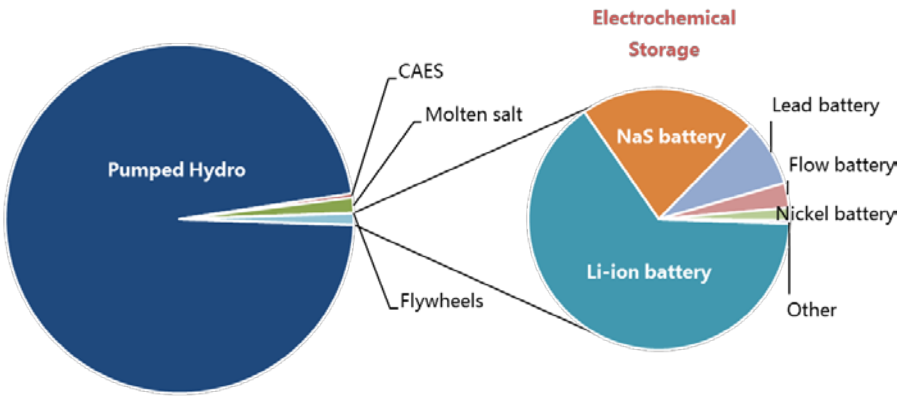


Figure 1 Global energy storage capacity by technology type. Source: CNESA White Paper 2017.

Growth in pumped hydro has slowed, however with only a 1.8% annual increase since 2015. Molten salt thermal energy storage comes in second in terms of cumulative global capacity, with projects are mainly centered in Spain, Italy, the United States, South Africa, Morocco, and Chile. Electrochemical energy storage capacity comes in third, with a total capacity of 1769.9 megawatts, having experienced the fastest growth, up 56% from the previous year. Among electrochemical energy storage technologies, lithium-ion energy storage has the largest global installed capacity, accounting for 65% of capacity. This figure has grown 89% since 2015.

	Technologies	Characteristics
Physical Storage	• Pumped Hydro • Compressed Air (supercritical CAES) • Flywheel	✓ Uses water/air as storage medium ✓ No chemical change ✓ Mechanical → electric energy
Chemical Storage	• Lead-acid Battery • Li-ion Battery • Flow Battery (Vanadium, Zn-Br) • Na-S Battery	✓ Uses chemicals as storage medium ✓ Battery charges/discharges with chemical change/valence change
E&M Storage	• Supercapacitor	✓ Fast response, can release large amounts electric power in short times, high number of cycles
Other Storage	• Fuel Cell* • Metal-air Battery*	✓ Does not posses "charging" characteristics

Figure 2 Energy storage technologies. Image Source: CNESA.

Mechanical Storage

Methods for mechanical storage involve the conversion of mechanical energy to store and release electrical energy.

Pumped Hydro Storage

Currently the most mature form of storage technology, pumped hydro storage accounts for around 95% of global energy storage capacity[1]. Most commonly, water held in two reservoirs at different heights, is pumped up against gravity, stored, and then released to run through a turbine generating electricity. More traditional open-loop systems connect with a natural water formation that refills either the upper or lower reservoir. The main drawbacks include geographic limitations along with impacts on aquatic life and stream flows. To overcome these challenges, many recent design concepts and demonstration projects favor closed-loop schemes separate from naturally flowing water, including underground systems with a smaller footprint and environmental concerns.

Current pumped hydro projects can serve many functions for the electricity grid provide energy-balancing, reserve power, and stability functions. Modified pumped hydro set-ups with variable-speed turbines are better suited for renewable generation and providing frequency regulation services. Most existing projects with variable speed turbines currently exist in Japan and Europe.

Pumped hydro technology has been in use since the 1920's, but improvements continue to be made to turbine technology and project engineering.

Compressed Air Energy Storage

Compressed air energy storage (CAES) uses the expansion of compressed air to drive a turbine and produce electricity. Relatively few projects are currently operating in the world, but reported capital and operating costs can be competitive to pumped hydro. In adiabatic set-ups, the heat created during compression of the air is lost, requiring new heat to be generated during expansion (often through burning natural gas). Adiabatic schemes instead store the heat in a heat-sink, to reinject during expansion greatly increasing the round-trip efficiency. In an isothermal set up, heat is continuously stored during compression and continuously reintroduced in expansion to mimic isothermal conditions and increase efficiency.

Due to the low storage density, a major consideration in CAES systems is how to store the compressed air. Underground CAES has been to date mostly applied in constant volume

[1] DOE Energy Storage Database.

underground salt caverns, introducing, of course, geographic limitations. Emptied natural gas wells and abandoned mines are also another option. Some projects have also used above-ground piping system to store compressed air, presenting an increase in cost but offering greater site flexibility.

Air can also be stored under constant pressure with a variable volume vessel, for example the Canadian CAES company, Hydrostor, achieves this through constructing an underwater cavern with a changing volume of water to keep the air at constant pressure. Isobaric systems can achieve even greater efficiencies as pumping equipment works optimally under constant pressure.

Flywheel Storage

Flywheels use kinetic energy of a rotating mass, often suspended on magnetic bearings under vacuum, to either discharge by slowing rotational frequency and powering a generator, or by inputting energy through a motor to increase kinetic energy. The material used for the rotating mass has a great effect on the cost, weight, and performance often either steel or carbon composite, carbon composite outperforming steel being lighter and stronger.

Key advantages of flywheel compared to battery systems include fast response speed and durability. Flywheels can charge/discharge on a scale of seconds and most systems can last in 170,000 full depth of discharge cycles. Several flywheel units can be integrated together to provide longer discharge duration. In particular, they are well-suited to high power, low energy uses such as an intermediate resource while slower generations ramp up, ensuring power reliability, and frequency response. Their use is also being explored in regenerative break systems in vehicles. Figure 3 plots select energy storage technologies with rated power and discharge time. Flywheels are one of the fasted responding resources.

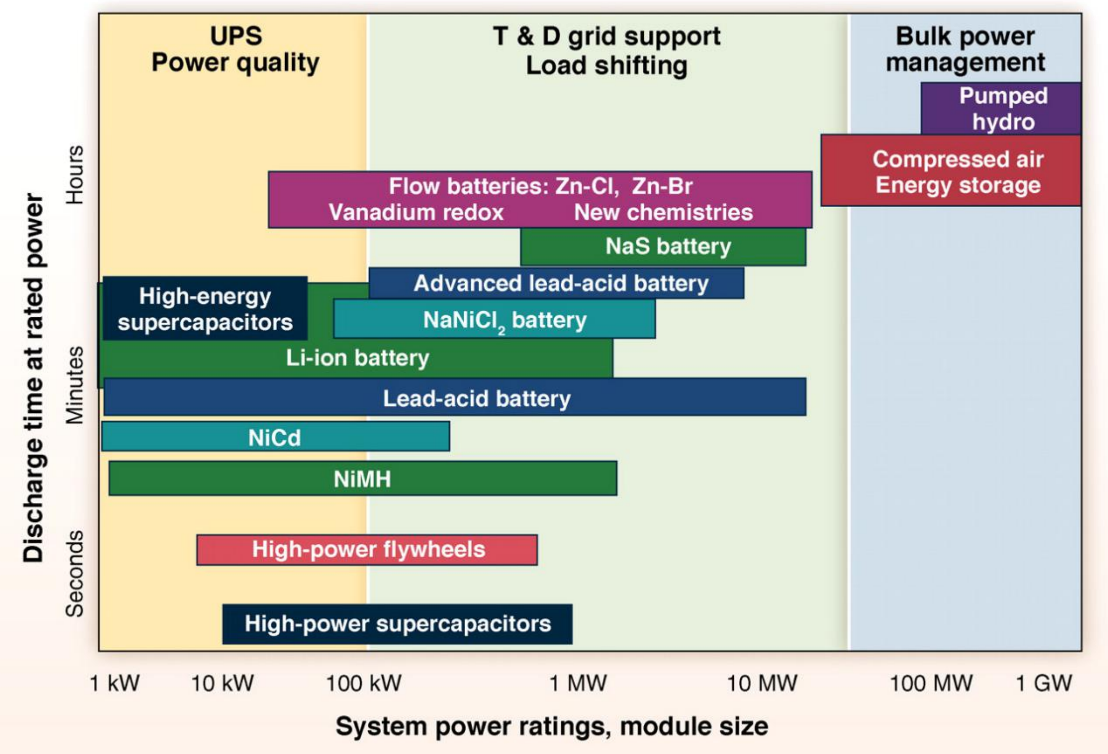


Figure 3 Energy storage rated power and discharge time across technology types. Source: US EPRI.

Chemical Storage

Chemical storage methods use the exchange of electrons between battery electrodes via chemical reactions to release energy. With the pervasiveness of lead and Li-ion battery chemistries, this is one of the most visible forms of energy storage, especially with small power applications such as in electric vehicles or personal electrics. Recent advancements have considerably improved power densities allowing chemical storage to hold larger capacities and carry out grid-scale services.

Lead Battery

The lead-acid battery, the oldest type of rechargeable battery, is a low initial cost energy storage solution. Traditionally lead-acid batteries contain lead based electrodes and a sulfuric acid electrolyte, however buildup of lead sulfate on the electrode plates severely decreases battery performance over time making lead battery unsuitable for larger-scale applications. As such, several modifications have been made to the battery chemistry to mitigate erosion, for example by adding carbon to the cathode, thereby giving the battery supercapacitor properties and significantly improving performance. According to the CNESA project database, lead-based chemistries make up 6% of operational global energy storage (excluding pumped hydro, CAES, and thermal storage)[2].

While lead-based batteries provide a low initial cost investment, their durability remains inferior to other chemistries such as Li-ion, and with the decreasing costs of other chemistries, long-term high-power applications favor other battery forms. Safety and environmental concerns have spurred research into how to safely recycle lead components and ensure they do not leak into the environment.

Li-ion Battery

Li-ion battery chemistries represent an array of systems with lithium-based electrolytes. They are used from small electronics, electric vehicles, and even in multi-megawatt grid-scale energy storage projects. Currently Li-ion is the most widespread storage technology taking up an estimated 66% of global operational energy storage (excluding pumped hydro, CAES, and thermal storage)[3].

The battery's energy density and voltage vary across electrode materials. The most common cathodes include cobalt $LiCoO_2$, however cobalt is expensive to source and has low thermal stability. Manganese-based $LiMn_2O_4$ is attractive due to its low cost and durability, but manganese is known to dissolve into the electrolyte decreasing performance.

Li-ion batteries are sensitive to temperature and as such battery must include appropriate heating and ventilation systems. Lithium is also highly reactive and short-circuiting can result in fires or explosions.

[2] CNESA Project Database as of 1 March 2017.
[3] CNESA Project Database as of 1 March 2017.

Flow Battery

A flow battery differs from traditional batteries in that the energy is not stored on the electrodes, but rather in a liquid electrolyte solution. The electrolyte is stored in external tanks and run through a flow cell where the chemical energy is converted to electricity. A flow battery's capacity, thus is dependent on the electrolyte volume and surface area of the electrodes. Flows batteries have dual properties able to behave like a rechargeable battery, and as a fuel cell by replacing the "spent" discharged liquid electrolyte solution with previously "charged" electrolyte.

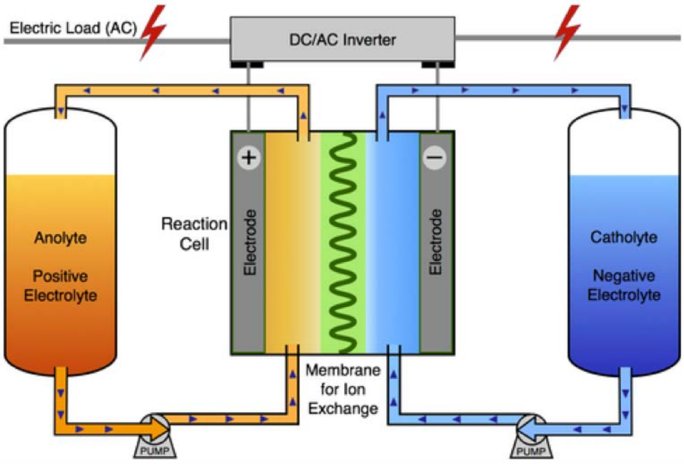


Figure 4 Traditional flow battery configuration with a membrane. Image Source: SolarChoice Australia.

The flow battery family has various subtypes such as redox flow batteries, hybrid flow batteries and membraneless batteries. One of the most expensive and fragile components of a flow battery is the membrane, since many membrane materials corrode easily when exposed to the battery reactants. The membraneless flow battery design uses laminar flow allowing for the electrodes to slide past each other, unmixed, with no need for a membrane. This eliminates this need for membranes and can provide a high-energy density, and more cost-effective solution when compared to other flow battery chemistries.

In general, flow batteries are long-lasting batteries that operate at much higher power densities than Li-ion battery systems, making them an ideal solution for large-scale energy storage. Since flow batteries require storage of liquid electrolyte, current technology limitations translate to a lower energy density compared to Li-ion making, today's flow batteries poorly suited for mobile applications, such as in electric vehicles.

Na-S Battery

Sodium sulfur (Na-S) batteries use a molten sulfur positive electrode and molten sodium as the negative electrode. With molten components, the system operates at extremely high temperatures between 300-350°C, usually requiring an external heating device to reach the necessary operating temperatures. The molten sodium and sulfur are separated by a ceramic layer that, during discharge, allows for positively charged sodium-ions to pass through towards the positive electrode after donating electrons to the external circuit. Na-S batteries are highly efficient, with overall efficiency close to 90% and are made with low cost materials. However they pose some safety risk due to the extreme reactivity of the sodium when exposed to air and moisture.

Na-S batteries are made in cylindrical and block-shaped configurations with the majority of projects located in Japan and the United States. They are well-suited for high-power, long discharge applications in providing power quality control for renewable energy projects along with grid services. Grid scale Na-S batteries are unique, in that, unlike other newly developed battery technologies, they have been in commercial operations for a relatively long time, with around 10-years of operating experience on a grid-level scale.

Electromagnetic Storage

Electromagnetic storage devices consist of ultracapacitors where energy in stored in an electric field. Without having to rely on chemical reactions, ultracapacitors advantages lie in much faster discharge and recharge times when compared to electrochemical battery storage types and have a power-density up to 60 times larger than batteries. Additionally, they are highly durable and can withstand up on a million charge and discharge cycles and work near to 100% efficiency. Ultracapacitors are much smaller and lighter than batteries and don't require the use of toxic chemicals and metals.

At present, ultracapacitors are not suitable for long-duration applications, and are instead better suited for extremely short bursts of power. With many applications in electric vehicles, ultracapacitors also can be used to enable renewable energy by firming power output, and recent work has also been done to provide power to wind turbines to change their pitch, or angle to better capture wind energy.

Ultracapacitors show immense promise in conjunction with longer-duration battery systems as a holdover, providing short-term energy before the batter system kicks in, and can be recharged quickly using the additional battery power source.

Other Storage

Technologies classified as "other technologies" for purpose of this report include fuel cells and metal-air batteries. Fuel cells, like batteries, undergo an electrochemical reaction to provide power, but differ in that electricity is generated via a hydrogen-containing fuel source reacting with oxygen, usually supplied from the air. Fuel cells can continuously provide power output so long as they have both fuel and air supply and as such do not fit into the traditional battery mold of charge and recharge cycles.

Metal-air batteries are also a promising technology with an anode made of pure metal and oxygen from the air acting as the cathode. Different metals are currently under investigation, this technology remains largely in the R&D phase.

Energy Storage Systems Costs and Values

Studies aiming to present benchmark figures for energy storage system costs and services values encounter enormous difficulty. Calculating the associated costs and service values for energy storage systems is a challenge not only due to the wide array of technologies, but also due to a myriad of external conditions.

One way to create an apples-to-apples comparison between storage technologies is through using the Levelized Cost of Energy (in this case, the Levelized Cost of Storage "LCoS") where the technology per kWh is calculated as a function of the total lifetime project costs divided by the expected lifetime power output. For example, where a compressed air energy storage (CAES) system may have a higher initial capital investment than a Li-ion battery system, a CAES system lifetime power output is much greater than a Li-ion battery system (which usually lasts only 10 years) thereby lowering the LCoS.

The LCoS formula however, fails to accurately reflect other key points including geographic constraints (crucial for CAES and pumped hydro), safety concerns over battery fires, and technical properties better suited for different applications. Lazard, a global financial advisory firm attempted to correct for this by comparing LCoS only within defined application categories.[4] However, the

[4] Lazard, "Lazard's Levelized Cost of Storage 2.0"

report's usefulness is limited, since actual project planning would require a site-specific analysis taking into account land needed, the local electricity system, climate, etc.

Further complicating efforts to evaluate the economics of energy storage, is the difficulty of successfully evaluating storage equipment's value over its lifetime. The US-based organization, The Rocky Mountain Institute, conducted a metastudy of US reports estimates for energy storage service value per kWh of power generated[5], shown in Figure 4 below. The results of the metastudy reveal little consensus, further driving the point that the most appropriate way to calculate energy storage costs and values is rather on a case-by-case basis.

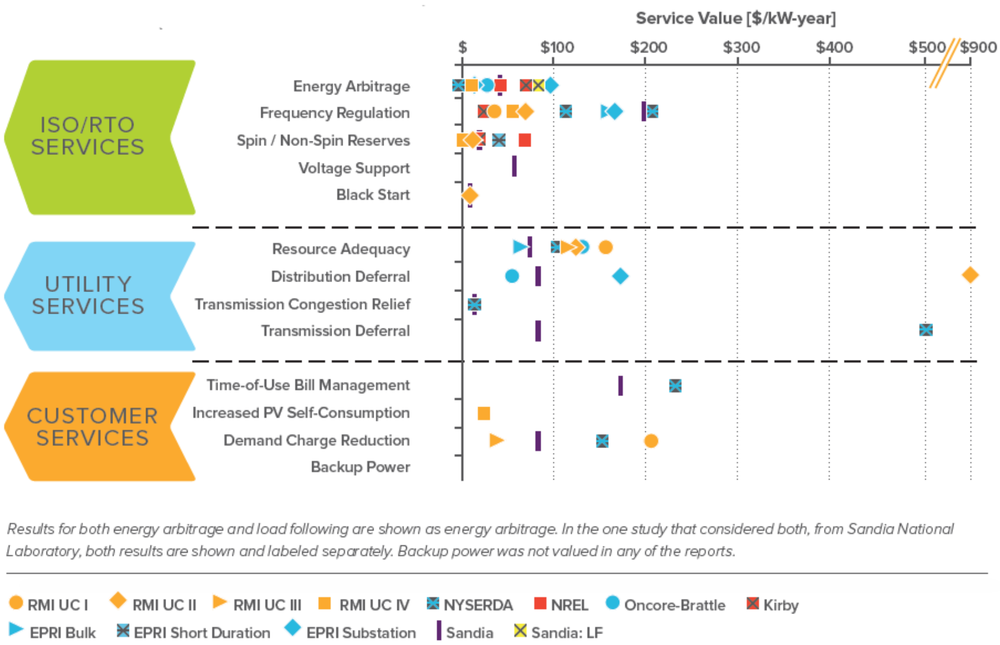


Figure 5 Service value of energy storage across application sectors according to several leading studies (US) show little consensus. Source: Rocky Mountain Institute.

Technology Frontiers

Recent years have seen costs fall across all storage types along with improvements in battery operations and safeties.

Improvements in Traditional Battery Technology

Flow batteries: Breakthroughs include improvements in and selection of different solid and liquid electrolytes, production methods with decreased toxicity, lower costs, and higher energy density flow batteries. Many research efforts were directed towards different redox non-aqueous flow battery systems such as low cost all-iron flow batteries and organic polymer electrolyte irrigated flow batteries.

Molten salt batteries: Research efforts worked towards reducing battery operating temperatures and raising energy density in molten salt batteries such as sodium-sulfur and sodium-nickel batteries.

Metal-air batteries: Research in zinc-air, lithium-air, and other metal-air batteries focused on development of low-cost non-platinum catalysts.

[5] Rocky Mountain Institute, "The Economics of Battery Energy Storage"

Lithium-Ion Battery Safety Research

Li-ion batteries are already widely applied in personal electronics, electric vehicles, as well as grid scale storage systems. Aside from battery performance and lifetime, operational safety has become a major issue for practical applications. Research directions include external monitoring and heating directions and moving instead towards using internal components (electrolytes, membranes, electrode materials, etc.) to regulate battery functioning and safety.

Solid-State Battery R&D

Solid-state Li-ion batteries are Li-ion batteries that use solid materials for the electrolyte. Solid-state batteries generally have a good safety performance, high energy density, and a wide operating temperature range. Given these benefits, many researchers hope to apply this technology to the next generation of Li-ion batteries. This has spurred on researches to develop solid and quasi-solid electrolytes.

Some research teams are working on improving the compatibility of solid-state electrolytes, conventional cathode materials, and metallic lithium anodes, all while inhibiting lithium dendrite formation in these setups. Others are focusing on the construction of high-rated power and stable cycle solid-state Li-ion battery systems. Gel-type electrolyte materials have also become a major subject of materials science research.

At present, since solid-state batteries have shown promising results, new research efforts are now transitioning away from electrolyte development and increasing towards total battery structural design and industrial production processes, with battery samples and prototypes constantly rolling off the assembly lines.

Emerging Battery Systems

Limited reserves of the raw materials required for Li-ion batteries and economic factors are driving efforts to find Li-ion alternatives such as metal-ion, metal-air, and metal-carbon dioxide batteries.

Developments in metal-ion battery technology built on the design principles behind Li-ion batteries in addition to continued research into sodium-ion batteries and sodium-ion supercapacitors. Researches made advances in developing battery systems employing other high valence metals such as aluminum-ion and calcium-ion batteries.

In metal-carbon dioxide and metal-air batteries, the metal acts as an anode and uses ambient air as the cathode. Because the cathode doesn’t need to be stored within the battery, these batteries have high energy density and are environmentally friendly. At present, research into lithium-air batteries is focusing on selecting high efficiency catalysts and protecting the cathode metal lithium. It will be some time yet before wide-spread application is available employing this technology.

Part II: Applications and Case Studies

In this section, to demonstrate the immense flexibility and diversity of energy storage applications, we draw from representative energy storage cases across the APEC region, which we have divided into four application groups: renewables integration, ancillary/grid services, commercial/residential use, and island applications. While, for convenience's sake, projects are classified as predominately fitting into one category, it is also crucial to note energy storage can also realize value through other services, often simultaneously in a process known as "value stacking." In fact, in the storage industry's early development, "value stacking" is often necessary for a project to be cost effective.

A common theme among all application sectors is energy storage's value through the flexibility and stability it provides to the grid. This can manifest in avoided costs of blackouts or outages, as well as in ways more difficult to quantify like increases in investor confidence. Storage, we demonstrate, works at all ends of the power system from enabling renewable generation assets, increasing and stabilizing power quality at generation, balancing grid load and services to transmission and distribution infrastructure, and end helping end-users optimize power use. In all, the following projects effectively demonstrate energy storage as a way to achieve sustainable, secure power systems.

Table 1 Overview of key storage applications.

Application Sector	**Key-Takeaways**
Renewables Integration	• Energy storage in some cases is a necessary technology needed to meet grid operator's requirements. • Most existing projects are still in the demonstration stage.
Ancillary/Grid Services	• Energy storage is already economical in ancillary services markets in several countries. • Current storage technology prices undercut costly T&D equipment upgrades.
Commercial/Residential Use	• Storage system economic feasibility varies widely based on user's load profile and local electricity prices. • In certain areas with high electricity prices, large TOU price differences, storage is already economical without incentives.
Island Use	• Current projects aim to cut diesel generation dependence and lower electricity prices. • Projects rely heavily on government support and subsidies.

Renewables Integration

Renewable resources like wind and solar are, by nature, variable depending on location and weather conditions. Cloud cover can cause massive voltage spikes in PV voltage outputs whereas wind speeds can vary dramatically over any given hour. These fluctuations bring about immense difficulties to grid planners in charge of dispatching renewable resources as well as to power generators as they try to meet their commitments to the grid. Several demonstration projects are currently exploring ways in which storage technology can alleviate these problems and ensure quality, stable, power output, ultimately enabling higher penetration of renewable energy sources into the grid. Unlike storage in ancillary services, and commercial/residential applications, a business model for energy storage providers has not yet emerged in renewables integration. Rather, these projects are largely in the demonstration phase, relying on government subsidies.

Case A: Japan Shin Chitose Kashiwadai Solar Power Plant + Storage

In the wake of the Fukushima nuclear reactor meltdown in 2011, Japan has seen a marked decrease in public support for nuclear energy, and as such the government responded by retiring all but two of Japan's 51 nuclear power plants. The decrease in nuclear power has also been accompanied by a push to increase the proportion of renewables solar and wind in the energy mix, in part, to help compensate for power lost from the retired nuclear plants. In the case of solar, as of 2016, solar energy met around 3.5% of Japan's energy demands with an installed capacity totaling 32 GW. The government aims to double this figure to 64 GW and 7% of energy demand by 2030. This increasing growth in renewable energy along with decreasing feed-in-tarrif (FIT) policies have proven to provide ample opportunities for energy storage to enable Japanese renewable energy facilities to enter the grid and ensure high power quality and stable operations.

The Shin Citose Kashiwadi Solar Plant is a 28 MW solar power plant located near the New Chitose Airport on the Japanese island of Hokkaido, with an estimated 35 GWh capacity, jointly financed by the Energy Products Corporation (Japan) and the Korea Electric Power Corporation (Korea). The project also used national subsidies under the "Renewable Energy Connection Reservation Emergency Response Grant."

The local power company, the Hokkaido Electric Power Company, having already integrated large amounts of solar and wind capacity on the island has reached grid stability limits, and as such maintains strict requirements for grid-integrated solar power plants requiring plants to not exceed a ramp rate of +/- 1% of the rated power each minute. Cloud cover throughout the day can cause high fluctuations in a solar farm's power output which interferes with the solar plant's ability to meet grid dispatch needs. The green line in figure 5 illustrates the fluctuations in simulated PV output along with showing how the battery compensation (red line) can result in a smoothed output curve (black line).

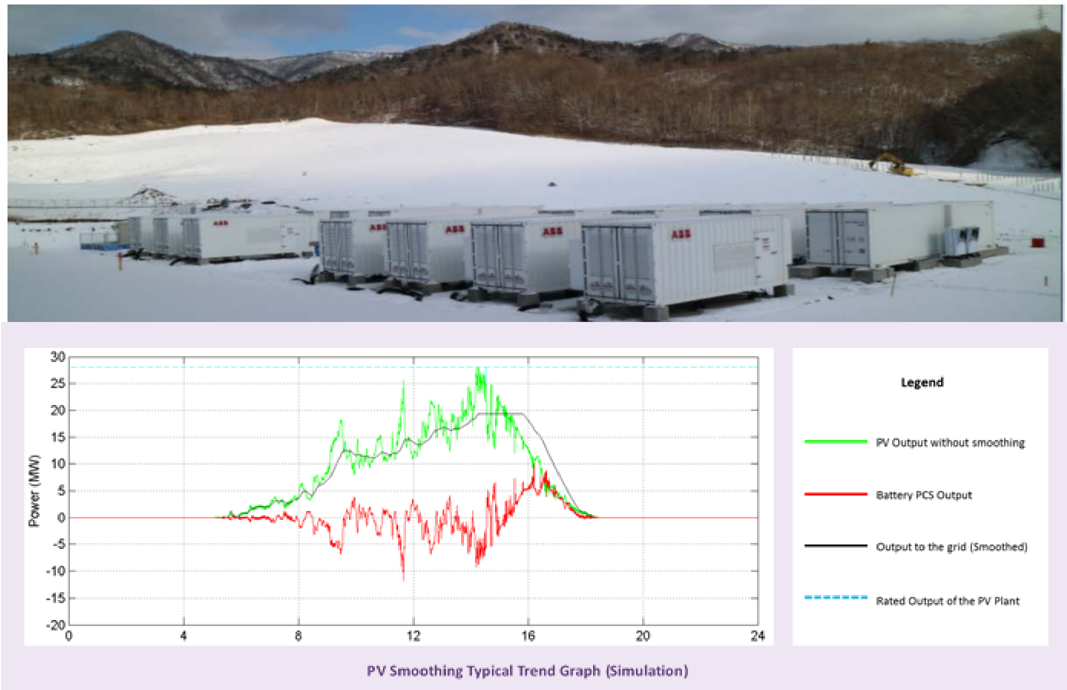


Figure 6 Shin Chitose PV + energy storage facility, containerized battery systems need to maintain operating temperatures for the Li-ion battery system during cold winter months (top). The black line represents smoothed power output after introduction of energy storage system (bottom). Source: ABB.

Such a strict ramping requirement by the local power company therefore necessitated a storage solution. Swiss company ABB provided the energy storage system integration including a 17 MW containerized storage system with Li-ion batteries powered by Samsung. ABB supplied all additional PV inverters, battery control management systems, power control systems, a 66 kV substation, along with remote maintenance and service.

As renewable energy sources grid penetration rises, energy storage's role as a load balancing and load smoothing source will become increasingly important. As this case study shows, in Hokkaido the local utility's grid strict ramping requirements necessitate an energy storage system.

Case B: China Hefeng Wind Farm Storage Project

China's Liaoning province has been quickly developing wind power resources. As of June 2013, roughly 5,180 MW of wind power had been installed across the province, accounting for 12.2% of total power generation. By 2020, this figure is expected to reach 13,800 MW, or nearly 20.5% of province's total power generation. However, despite increased wind capacity, wind curtailment continues to be a serious issue, and as such energy storage as gained attention for the role it could play in mitigating curtailment.

China Guodian Corporation has installed 66 wind turbines with a total capacity of 1500 kW in Hefeng wind farm. In 2015, a hybrid energy storage system consisting of a 5 MW/10 MWh Li-ion battery system, 2 MW/4 MWh vanadium redox flow battery system, and 2MW/2 MWh super capacitor system were commissioned to reduce wind power output fluctuation, track the dispatch curve, and engage in peak load shifting.

The different energy storage technologies were geared towards different applications. In this project, the Li-ion battery (lithium iron phosphate) is mainly used for tracking dispatch curve while super capacitor and flow battery is mainly used for reducing output fluctuations.

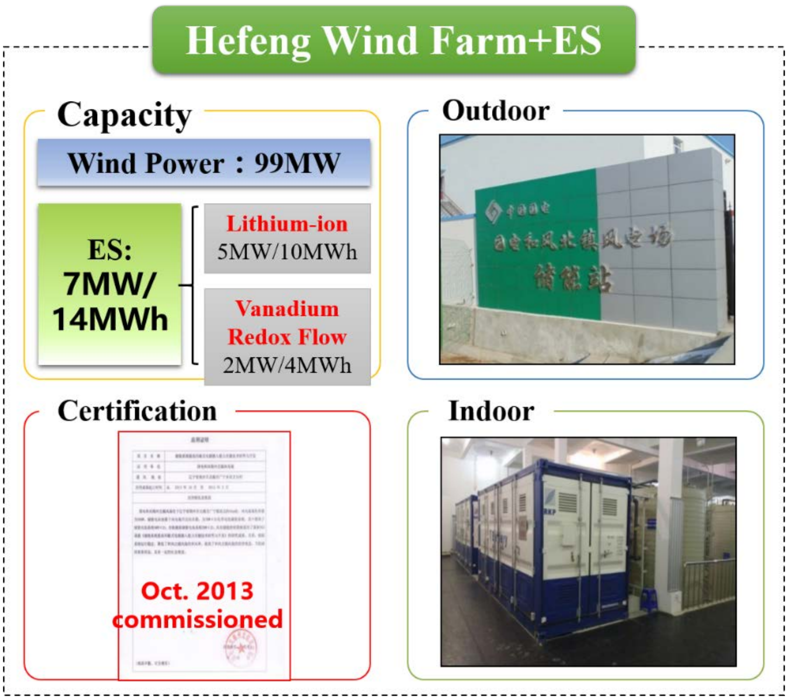


Figure 7 Hefeng Wind Farm Overview. Source: CNESA.

The total investment of hybrid energy storage was CNY10.46 million (US$1.54 million) to cover costs of the batteries, BMS, PCS, and other associated equipment.

The project identified three revenue streams: 1) peak shaving/load shifting; 2) additional power revenue due to high-priority dispatch; and 3) reduced penalties.

1. **Peak Shaving and Load Shifting**
   Instead of wasting the power output that cannot go out to dispatch, the power can be storage in the energy storage system. The project organizers calculated that the total power stored by the energy storage system was equivalent to an additional 1.5 MW power-rated wind turbine. Additionally, in 2015 the wind power generation for the Hefeng Wind Farm was more than 2,100 hours, compared to the average generation time of 1,780 hours in the Northeast Power Grid. Therefore, the annual output from the energy storage system was 3,150 MWh, with the local wind FIT at CNY500/MWh, and a Li-ion battery system life of 10 years, the peak shaving and load shifting revenue is nearly CNY1.58 million (US$232,000).

2. **Additional Power Revenue from High-Priority Dispatching**
   Hefeng Wind Farm was awarded a high-priority dispatch rank compared to other wind farms since they had installed an energy storage system. The Liaoning Province average wind curtailment rate is 15%, however Hefeng Wind Farm only curtailed 7% of output. The revenue from extra power generated during the battery's lifetime, compared to a wind farm without storage, was calculated at CNY8.4 million (US$1.2 million).

3. **Penalty Reduction**
   Energy storage could improve the ability of wind turbines to meet the load curve designated by the utility and eliminate the deviations as much as possible, hence reducing the penalty for deviating from planned output. However, the penalty reduction is difficult to evaluate since more often than not, penalties are often not enforced. The actual value of penalty reduction may be smaller than expected.

The total calculated revenue during the 10 years lifetime of the energy storage system was CNY9.975 million (US$1.46 million), falling just short of recovering system installation costs.

As analyzed above, the hybrid systems consisting of wind turbines and energy storage are mostly still in the demonstration project stage. In China, the most common reason developers choose to install energy storage systems is because they believe it will help their project be approved. Revenue benefits and environmental benefits have yet to be compensated. Current rules detailing energy storage operation in conjunction with wind farms are still unclear leaving many hesitant to participate.

Ancillary/Grid Services

Aside from generation-sited energy storage, other front-of-meter storage projects provide services to the grid as a whole—with increasing numbers of power market reform geared towards configuring market structures that allow a third-party to supply dispatchable storage resources providing frequency regulation or grid-scale power reserves. In addition to increasing grid stability through ancillary services market, decreasing battery costs have also made storage resources an attractive, cost and time-effective option to defer T&D equipment upgrades where future power demand growth is uncertain. Ancillary service market design and the avoided costs in T&D equipment already have a clear economic case for storage technology in certain economies.

Case A: United States- PJM Regulation Markets

In 2011 the US regulatory agency FERC issued order 755, requiring system operators to structure market rates in a way that does not discriminate based on technology type. In order to capture the strengths of fast-ramping resources such as energy storage to participate in ancillary service markets they required system operators running ancillary services markets issue a capacity payment and performance-based payment that rewards for accurately following dispatch signal.

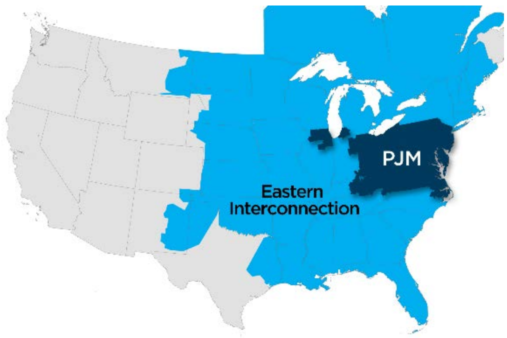


Figure 8 The PJM grid footprint in the Eastern US. Source: PJM.

PJM, the grid operating body covering several states in the Eastern Mid-Atlantic US, was the first in the US to implement market structures in line with FERC order 755. PJM operates three markets providing ancillary services in the grid include regulation, primary reserves, and synchronized reserves. The regulation market is the fastest response time of the ancillary services in the PJM market and also is the largest in the United States in terms of capacity and revenue. Regulation market resources function by helping regulate the power generation frequency when deviations occur to help keep stable grid operations. In moments where total generation is greater than total demand, this causes generators to momentarily speed up and the output frequency can exceed the set 60Hz. Similarly, in under-generation situations generators momentarily slow down causing frequency to dip below the set point of 60Hz.

PJM's regulation market allows four types of resources to provide regulation services including generation, grid energy storage, behind the meter storage, and demand response, which are further divided into two categories, RegA and RegD resources. RegA resources are ramp-limited and included most generation resources such as steam, combustion turbines, and hydroelectric power, whose ramping speeds are limited by the mechanical properties of the resource itself. The second category RedD is energy-limited designed for storage resources like batteries and flyhweels which can respond in a much quicker time but who have limited output, i.e. a battery's storage capacity.

To determine costs for resources participating in the ancillary services regulation market, PJM developed a set of formulas to reflect the value provided by different types of storage, in theory allowing an "apples-to-apples" comparison of RegA and RegD resources. Costs for resources participating in the regulation market are based on a formula including the resource owner's price offer, the mileage of the resource, a benefits factor, and historic performance score. The mileage-based mechanism rewards resources that travel more "mileage" i.e. respond to a dynamic signal causing greater fluctuations over time. Clearing prices are calculated every five minutes during a set operating hour interval.

It is no coincidence that the market rules enacted lead to the estimated 275 MW[6] of operating electrochemical energy storage today in the PJM region, leading the nation in installed electrochemical energy storage capacity.

[6] US DOE Energy Storage Database

Case B: New Zealand- Vector Power Glen Innes Substation

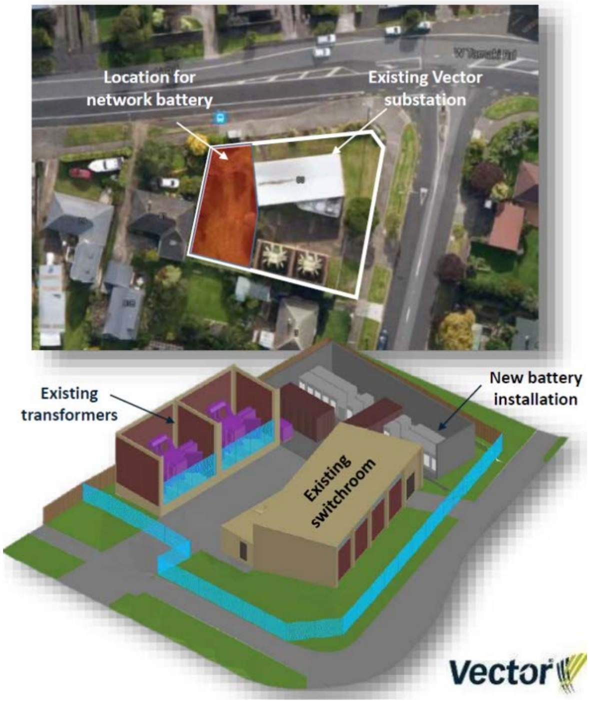


Figure 9 Glen Innes substation diagram. Source: Vector Power.

Vector Power is New Zealand's largest distributor of electricity and gas supply networks. Auckland, New Zealand's capital city, has one of the largest annual population growth rates in the world, causing strains on power resources with the quickly growing demand. One way to deal with the increased growth is to upgrade the T&D equipment, however these updates costly, disruptive, and run the risk of stranded assets when future growth is uncertain. With these concerns in mind Vector elected to install the southern hemisphere's largest grid-connected Tesla Powerpack at the Glen Innes Substation, located in the heart of one of Auckland's residential neighborhoods.

The facility includes 24 Tesla Powerpacks totalling 1 MW/ 2.3 MWh rating at the Glen Innes substatation, originally installed in 1954. According to Vector's calculations, the Powerpack installation resulted in a 70% cost savings ($5mil versus $12mil of conventional upgrade) when compared to traditional upgrades that would be required for the site. In addition to the avoided costs services, the Powerpacks also provide value as a backup source in the case of power outages with enough energy to power 450 homes for 2.5 hours. In addition, the technology is modular and movable, allowing the Tesla equipment to be relocated to other sites if required.

Moreover, the flexible storage solution provides Vector more time to analyze growth and prepare for better informed upgrades to network infrastructure. When and if Glen Innes is scheduled for new T&D equipment, the modular battery solution can be relocated to another site in need of additional power capacity.

Commercial/Residential Use

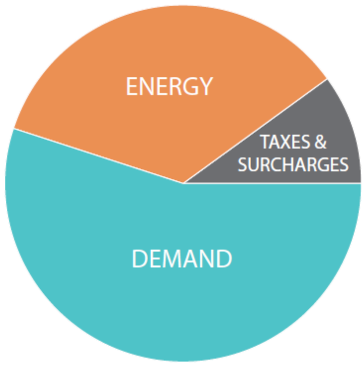
At the end-user level, behind-the-meter energy storage systems enable commercial and residential users to source back-up power, more intelligently manage power use, and ultimately save on electricity bills. The cost effectiveness of these systems depends heavily on local conditions including electricity prices, time-of-use tariffs, and the user load profile. Energy arbitrage methods store electricity when prices are cheap and discharge battery storage when grid electricity prices rise, allowing users to avoid buying electricity at peak prices. Storage can similarly enable higher rates of self-consumption of rooftop PV power generation, and increasing interest is also focused on in-home electric vehicle charging systems. Innovative ownership models such as Power Purchase Agreements (PPA) allow the PPA provider to maintain ownership of the energy storage system and install the system at no cost to the user.

Unlike specialized battery systems that can generate profit in well-defined niche ancillary services, user-level storage systems instead favor flexible battery system that can serve multiple purposes throughout the day. This, in turn, demands complex software controls that optimize battery performance among different use modules.

Case A: United States- GreenCharge Networks

The US-based company, GreenCharge Networks has built a business model providing energy storage and software solutions for behind-the-meter commercial and industrial users as part of a Power Efficiency Agreement. The so-called Power Efficiency Agreements, a modified version of a Power Purchas Agreement (PPA) is a 10-year agreement where Green Charge Networks provides the capital for equipment, installation, warranty, and maintenance, while sharing the calculated power bill savings with the client. The precise share percentage depends on site conditions, tariffs, and particular government incentive schemes in place. Green Charge Networks also includes options for sale and purchase of the power system.

DEMAND CHARGES (kW)	ENERGY CHARGES (kWh)
Measured in kW	Measured in kWh
Price is increasing 7% YOY	Price is falling 4% YOY
Highest 15-min kW during period	Total kWh cumulative during period
No packaged solution	Crowded—PV, energy eff.



The Trend in C&I Monthly Bills

Figure 10 Power demand charges have been increasing and represent more than half of a commercial & industrial user monthly bills. Source: Green Charge Networks

The key reasoning behind Green Charge Networks business model is that power efficiency (in kW) is an untapped market that can allow the user to save more money over time than energy efficiency measures (in kWh). Using historical rate tariffs from the southern Californian utilities that operate near Green Charge Network's home base in California, demand charges are increasing on average while energy charges have historically decreased. Figure 10 shows Green Charge's calculations where demand charges, despite having no packaged solution represent over 50% of a commercial & industrial power user's monthly bills.[7]

Green Charge network's packaged solution consists of a hardware and software solution. The battery hardware comes in available 30kW/60kWh or 250kw/500kWh units accompanied by a platform with five usage modules:

1. **Peak Shaving:** allows the users to pre-define peak setpoints, above which battery systems will discharge to avoid incurring expensive demand charges from power peaks.
2. **Energy Arbitrage:** helps users charge batteries when electricity prices are low and discharge when they are high.
3. **Demand Response:** Green Charge Networks also participates as a load aggregator in Southern California's demand response markets, operating its battery network as a distributed energy resource, pooling together sites to reply to a demand-response event.
4. **Solar Firming:** storage, in conjunction with installed solar panels, helps the user avoid steep demand costs during short intervals of cloud cover.
5. **Rate Optimization**: allows the user to set peak power demand parameters to control demand and remain eligible for lower demand charge brackets.

[7] Green Charge Networks, "The Next Frontier: Power Efficiency" Whitepaper.

Running two or modules concurrently allows for increased savings through “value stacking.”

At present Green Charge Networks targets large commercial and industrial users, especially government facilities such as schools, government buildings, and universities who may be under governmental directives to increase building efficiency but are unable to invest the capital required for storage system ownership. The Power Efficiency Agreement circumvents this problem, with Green Charge Network as the owner of the system covering all system costs, and profit is shared.

Case B: Australia- City of Adelaide Residential Solar + Storage Schemes

The city of Adelaide located in South Australia, leads Australia in providing renewable energy with nearly 40% of the state’s power coming from renewable sources. With the goal of becoming a carbon-neutral city, Adelaide was the first in Australia to begin issuing subsidies for residential storage users in 2015. As part of the city’s “Sustainable City Incentive Schemes,” the city awarded a subsidy of 50% system installation costs of an energy storage system up to a maximum of AUD$5,000. In addition to this storage scheme, the government is also encouraging PV installations with a similar subsidy structure, with city subsidies up to AUD$5,000.

According to the Adelaide city government rules, a storage system must be set up to increase internal consumption efficiency, not only serve as a backup device. Additionally, if a storage system is part of a PPA, the applicant must be designated as an owner of the system by the end of the contracted term.

While the city’s subsidy program can certainly speed along adoption of storage systems in the city, SunWiz, an Australian solar consultancy calculated that a solar + storage system already has a payback period of 7 years before subsidies. Battery systems average lifetime is currently around 10 years, making this a cost-effective solution before subsidies. After subsidies, the payback time will be even shorter. According to their calculations, a residential user with 5 kW PV system accompanied by 13 kWH of storage can generate 88% of household energy needs, reduce solar exports by three-quarters, and reduce grid draw by 72%[8].

SunWiz also reports explosive growth in battery systems installed, with a total of 6750 battery systems installed across Australia in 2016, up from a total of 500 in 2015.

Island Use

Owing to the large number of APEC economies with significant island land mass, we have included this section devoted to energy storage systems in island applications. Electrification of small islands separated from larger grids poses several challenges, often requiring expensive and heavily-polluting diesel generation. In this section, we highlight two projects in the APEC region focused on island microgrid design with a focus on integration of renewable energy to decrease dependence on diesel generation and provide higher-quality, more reliable, and cheaper power supplies.

[8] SunWiz Solar, Battery Market Report 2017

Case A: Korea- Gapado Island Microgrid

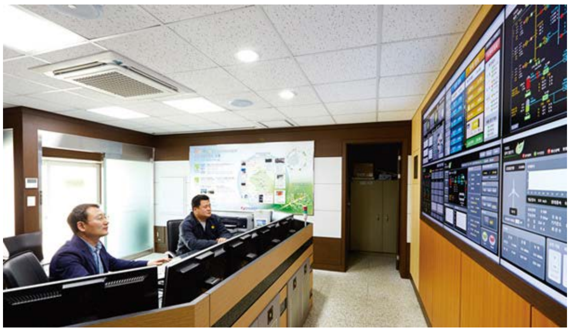


Figure 11 Gapado Microgrid Control Center. Image Source: Hyosung.

Korea southern coast, dotted by over 3,000 islands, has become the focus of the Korean government's heavy investments into island microgrids powered by renewable energy. Microgrid design and management poses unique challenges to system engineers and the smaller load profiles magnify voltage spikes, with renewable energy fluctuations further complicating things. Energy storage is a crucial resource to balance microgrid load. The Korea Electric Power Research Institute has been running a project on Gapado Island located off the southern tip of the larger Jeju Island to explore ways in which renewable energy sources and energy storage can be used to reduce the island's dependency on expensive diesel generators. This fits in with a government program instituted in 2009 to make Gapado and Jeju carbon free by 2030.

The island microgrid consists of two 250kW wind turbines which, in conjunction with rooftop solar, can currently provide 70% of island power, putting a large dent in the island's diesel generation requirements. A 1 MW/1 MWh Li-ion battery system by Samsung with system integration by Hyosung.

The island's 250 residents also received generous subsidies to install rooftop solar panels, with 90% of costs coming from the district office. Wind and solar have undercut the expensive diesel generation, residents have reported that energy bills have but cut by more than half.

Total investment costs nearing US$102 million came from Jeju Self-Governing Province, Korea Southern Power Co. (KOSPO), and the Korea Electric Power Corporation (KEPCO).

Case B: China- Dongao Island Microgrid

There are 6,961 islands with areas larger than 500m^2 across China, among these are 433 islands with populations exceeding 4.5 million. Due to the high costs of constructing submarine power cables, these islands rely on diesel generators. The Chinese government, like Korea, has identified island microgrid research as a key research interest. Dongao Island is one such microgrid project integrating energy storage and renewables in an island context.

Diesel power generation results in high electricity prices, frequent outages, and environment impact on the island. The residential electricity retail tariff is CNY2.9/kWh even after a CNY1.0/kWh subsidy provided by local government, meaning Dongao island electricity is six times more expensive than on the mainland. Tourism, the main economy on the island also causes power shortages during peak seasons. The local government has reported frequent complaints from tourists due to frequent outages, noise, and the pollution caused by the diesel generators.

In 2010, supported by the local government, State Grid Zhejiang Electric Power Research Center installed 354.4kWp rooftop PV, and 650kW PV arrays, 45kW wind turbines and 2000kWh lead-acid battery system to form a micro grid with existing 1220kW diesel power.

Figure 12 Dongao Island microgrid configuration. Source: State Grid Zhejiang EPRI.

After commissioning the microgrid the Zhejiang Electric Power Grid reported that increased grid stability from smart controls and energy storage system increased the diesel generator power efficiency, decreasing from 317g/kWh generated to 220g/kWh generated. Retail costs for electricity decreased from CNY3.9/kWh to 1.9/kWh. Diesel fuel, which once provided 100% of the island's power, decreased to providing 28%, meaning 72% of the island's power came from the energy storage system.

Part III: Existing Storage-Related Policies and Recommendations

In this section, we have highlighted key energy storage related policies across five APEC economies which have already begun implementing energy storage related policies: the United States, Japan, China, Korea, and Australia. The results are summarized in Table 2, with Germany added for reference as a non-APEC economy with a strong energy storage industry growth.

Table 2 Energy storage policy comparisons across APEC economies with Germany for reference. Source: CNESA.

Energy Storage Policy Category	US	Japan	Germany	China	Korea	Australia
Energy storage development/installation target	✓	✓	×	×	×	×
Energy storage procurement program	✓	×	×	×	✓	×
Policies supporting R&D, demonstration projects	✓	✓	✓	No system	✓	✓
Installation subsidies/tax breaks	✓	✓	✓	×	✓	✓
Pay by performance in ancillary services	✓	×	×	✓	×	In progress
Peak/off-peak pricing mechanisms	✓	✓	✓	In progress	✓	✓

United States

The US currently leads APEC economies, in addition to the rest of the world, in terms of total installed energy storage projects. As we analyze below, the rapid growth and innovation stems from a well-rounded effort from coordinated support for R&D efforts, to power system reform, along with several mandates and subsidy measures explored by various US states. For example, the opening of ancillary services markets to energy storage resources in the eastern US lead to the first growth spurt in installed energy storage capacity. The state of California next followed by issuing a 1.3 GW energy storage mandate to state utilities to balance large amounts of renewable resources flooding the state's power grid.

R&D Efforts

The United States currently funds several R&D focused national level funding projects. Here, we discuss two representative programs.

ARPA-E

ARPA-E short for, Advanced Research Projects Agency-Energy, is a federal program founded in 2007 to accelerate the development of high-impact projects considered too early-stage and risky for traditional investment. In 2009 the program received its first batch of funding of US$400 million as part of the American Reinvestment and Recovery Act following the US economic recession of 2008. Since its funding, has awarded grants totaling US$1.3 billion to over 475 projects on average US$2-3 million to be awarded over several years. As of 2016, 45 of the ARPA-E projects have gone on to attract over US$1.25 billion in private investments, while 36 project teams have created companies.

Of ARPA-E's funding tracks, there are two active programs focusing on energy storage technology including Cycling Hardware to Analyze and Ready Grid-Scale Electricity Storage (CHARGES) and Reliable Electricity Based on Electrochemical Systems (REBELS) along with a third program focused on applied science Innovative Development in Energy-Related Applied Science (IDEAS).

DOE Sunshot Initiative

The US Department of Energy's (DOE) Sunshot Initiative was launched in 2011 to spur development of affordable solar energy for all Americans. One of their founding goals was setting cost targets of US$0.09/kWh for residential PV, $0.07/kWh for commercial PV, and $0.06/kWh for utility-scale PV by 2020 without subsidies. In May of 2016, Sunshot reported 70% progress towards these goals 5 years into the program. [9]

Of Sunshot's funding structure, several sub-programs such as the Concentrating Solar Power sub-program and Systems Integration fund research into energy storage technologies that enable solar energy adoption. In 2017 the Systems Integration sub-program awarded a total US$30 million to projects as part of the funding program called ENERGISE including projects employing energy storage technology in coordination with solar PV systems.

Related Electricity System Reforms

Legal framework enabling energy storage began with a series of orders from the Federal Energy Regulatory Committee (FERC) the authoritative body that regulates the US wholesale energy markets. While on the state level, several states have begun issuing storage procurement mandates, requiring utilities to procure set amounts of storage resources by set target dates.

FERC Order 745

FERC Order 745 was first issued in 2011, paving the way for implementation of demand response programs administered by regional transmission organizations (RTOs) and independent system operations (ISOs) in wholesale energy markets. The order gives the RTO and ISO authority to "balance supply and demand as an alternative to a generation resource" when it determined to be cost-effective, and required demand response resources to be compensated for the services they provide at competitive and fair rates, with further guidelines provided by FERC. While energy storage is not particularly targeted in this ruling, the order was a significant step in setting precedent that allowed non-traditional assets to be dispatched in the place of generating assets to meet grid supply and be compensated for their services.

FERC Order 755

Later in 2011, FERC issued Order 755, arguably one of the most monumental storage-related policies to come from the agency. FERC determined that the previous rate structures in place by RTOs and ISOs failed to adequately reward fast-ramping resources as a frequency response service. Fast-ramping resources, like battery and flywheel storage, they argue, by definition, can respond more quickly and accurately to a dispatch signal than a traditional frequency regulation assets. To achieve fair and competitive rates, Order 755 rules that RTOs and ISOs must implement a two-part payment mechanism with a capacity payment including the unit's opportunity costs and a payment-by-performance mechanism to reward resources that accurately follow the dispatch signal. The capacity payment is based on the unit's opportunity cost, i.e. storage capacity that stands "on-call" to participate in frequency regulation markets loses revenue through not providing other storage services. The performance payment is "mileage based" meaning as a dispatch signal fluctuates, a

[9] US DOE, "On the Path to Sunshot" Report <https://energy.gov/eere/sunshot/path-sunshot>

fast-ramping frequency regulation unit will travel more mileage to match the signal than a slower-ramping one.

Energy Storage Subsidies and Mandates

For energy storage targets, several states in the United States have set energy storage mandates, including New York City, the first municipality to also issue a mandate.

Table 3 US energy storage state and municipal mandates.

State/Municipality	Storage Mandate	Date
California	1.3 GW	2020
Massachusetts	200 MWh	2020
Oregon	5 MWh	2020
New York City	100 MWh	2020

California's state mandate, the first in the US, was born in the state legislature with Assembly Bill (AB) 2514, which required the state utility regulator, the California Public Utilities Commission (CPUC) to issue a mandate for the state's leading utilities by 2013. The bill reasoned that in order to satisfy the state's previous goals for renewable energy consumption, environmental improvement, and requirement to provide reliable electric power, energy storage would be a necessary technology that utilities must incorporate. Leading up to the announcement the CPUC held several rounds of hearings gathering input from stakeholders including utilities and industry groups, ultimately setting targets to be met every two years from 2014-2020 by three of the state's leading utilities. California's procurement targets, along with the state-run subsidy program known as the Self-Generation Incentive Program (SGIP), have propelled California's grid to the be the US' leading grid region in terms of installed energy storage capacity, a title once held by the PJM grid whose ancillary services market (covered in the case studies section of this report) also helped spur on growth.

Japan

Owing to a lack of fossil fuel resources, Japan's renewable energy and energy storage sector began developing relatively early, especially in the wake of the 2011 earthquake and tsunami as public support for nuclear energy faded. This left the government with the imperative to decrease the ratio of nuclear energy mix, causing a large shift towards renewable energy, distributed generation and energy efficiency schemes. Energy storage thus has a large space for development in Japan as a key technology to enable these renewable energy goals. Below are representative policy measures that have been enacted in Japan relating to the economy's adoption of energy storage technology.

R&D Efforts

Following the energy crisis of the 1970s, Japan launched the "Sunshine Project" in 1974 to promote new energy technology. In 1978, Japan also launched the "Moonlight Project" to research energy saving and highly energy efficient technology. Under these two programs, solar power generation and energy storage technology developed rapidly, and storage became widely acknowledged as a crucial technology to ensure uninterrupted power supply. Government funds were directed towards research into lead acid, Na-S, and flow batteries. In 1993 the Sunshine and Moonlight Projects were combined to create the "New Sunshine Project" or NSS, which before formally ending in 2000, invested over US$11 billion in commercial applications for photovoltaics along with energy storage grid integration projects. Despite the discontinuation of NSS, the government still continues to invest heavily in energy related R&D.

Storage Related Electricity System Reforms

Beginning in 2015, Japan's House of Representatives and House of Chancellors enacted several measures to break up power sector monopolies, lower electricity prices and rapidly develop renewable energy. This round of power reforms is divided into three stages, the first stage established the Organization of Cross-regional Coordination of Transmission Operators (OCCTO), an organization that joined regional power grids to allow for inter-regional responses to dispatch signals, especially designed to prevent future accidents like the Fukushima reactor meltdown cause by disrupted power supply to the reactors in the wake of the 2011 tsunami.

The second stage of power reforms, begun in April 2016, liberalized the electricity retail market. The third stage to take place from 2018-2020 is set to undertake the final stages of legal unbundling to ensure complete independence between retailers and the transmission and distribution bodies.

Market liberalization creates enormous space for the adoption of energy storage resources in the power sector, and Japan's recent market reforms are likely to create growth both in front and behind the meter as market forces encourage energy efficiency and demand low prices and reliable electricity.

Energy Storage Subsidies

Japan's Ministry of Economy, Trade, and Industry (METI) began a subsidy program in 2014 for Li-ion energy storage systems greater to or equal to 1kWh, in total setting aside nearly US$100 million in funds. Li-ion battery system buyers can obtain up to 2/3 of the cost in subsidies. Among these, household user subsidies upper limit is US$10,000 and the commercial user subsidy capped at US$1 million. The Japanese government hopes to increase the proportion of renewable energy consumption, effectively manage peak loads, and increase grid stability through subsidies such as these. In addition, this can help the government measure the impact of mass-scale production on battery costs.

Korea

Korea, in addition to housing battery manufacturing giants LG and Samsung, has also identified energy storage as a key industry to develop and support in order to stabilize Korea's fast-growing power demands along with ensuring the economy's technological innovation and competitiveness. Korea has instituted a series of subsidy programs to encourage energy storage adoption along with announcing the world's largest frequency regulation procurement program.

R&D Efforts

Beginning in 2011, Korea began planning for strategic development of the economy's industry storage development. Korea's Ministry of Trade, Industry and Energy (MOTIE) published the report, "K-ESS 2020" in May 2011 announcing plans for Korea to hold 30% of global market share by 2020 and a development target of 1,700 MW of installed energy storage systems. In February of 2013 MOTIE also published "The Sixth Electricity Supply Plan (2013-2027)" revising the previous storage target to instead reach 2,000 MW by 2020.

In January 2014, MOTIE published the "2nd Energy Master Plan," laying out plans for Korea's energy growth by 2035, also acknowledging the inseparable relationship between energy storage the strategic energy sector goals. In particular, the report promotes the use of energy storage in demand side management, renewable energy sectors, along with incentive mechanisms to bring about mass marketization of storage technology, along with increasing efforts into R&D and model demonstrations to increase Korea's international competitiveness. The report also touches upon energy storage's role in efforts to promote smart grids, virtual power plants, vehicle-to-grid (V2G) networks, energy efficient architecture and design.

In terms of targets, the "2nd Energy Master Plan" calls for reduction of energy storage system costs by one half by 2020 through expanding efforts into R&D. The R&D focus also includes plans to develop alternative technologies, other than Li-ion, redox flow, and Na-S batteries. Demonstration studies are focused on medium to large sized projects between 50-100 MW storage systems including a 1,00MW compressed air system, and 50 MW Li-ion battery system connected to wind power.

Storage Related Electricity System Reforms

Beginning in 2017 power from large scale energy storage systems greater than 1MW energy storage power can be traded on power markets. The national utility, KEPCO has also modified its rate design to give preferential rates to energy storage users in both their demand charge and electricity charges. Not only does the rate structure incentivize installing a storage system, but also further discounts are added to preferentially reward "good battery behavior" i.e. battery discharge during peak hours and installing a sufficient battery capacity relative to the total contract power. The rate discounts are summarized below:

Table 4 KEPCO electricity rate design for energy storage systems. Source: KEPCO < https://cyber.kepco.co.kr/ckepco/front/jsp/CY/D/C/CYDCHP00212.jsp>.

<table>
<tr><td>Discount</td><td colspan="2">Details</td></tr>
<tr><td>Demand Charge Reduction
Effective 2017-2026
*From 2017-2020 the effective discount will be worth 300% the calculated value</td><td colspan="2">Calculated over the monthly billing period
(kw) = (A-B) / (C*3 hours)
A: Total energy discharged from battery system during weekday grid peak times
B: Total energy charged to battery system during weekday grid peak times
C: Total number of weekdays in monthly billing period</td></tr>
<tr><td>Electricity Charge Reduction
Effective 2017-2020</td><td colspan="2">50% discount of off-peak electricity used to charge the energy storage system</td></tr>
<tr><td rowspan="4">Additional Power Rating Discount
Applied to demand and electricity discounts</td><td>Storage system power to contract power ratio</td><td>Eligible % of combined demand and electricity charge discounts</td></tr>
<tr><td><5%</td><td>80%</td></tr>
<tr><td>5%-10%</td><td>100%</td></tr>
<tr><td>>10%</td><td>120%</td></tr>
</table>

Energy Storage Subsidies & Mandates

In Korea it is mandatory to install an energy storages system with a rated power that is 5% of contract power in public buildings with contract power over 1,000 kW.

KEPCO Frequency Regulation Procurement Program

Korea's frequency regulation market is scaled at over 1.1 GW. To satisfy the regulation capacity needs the Korean Utility, KEPCO, had to reserve nearly 5% of thermal energy generation capacity, resulting in annual costs of US$583 million. In order to mitigate the need for large amounts of generating capacity to be used for frequency regulation, KEPCO in 2014 began the world's largest frequency regulation energy storage procurement to date, acquiring 500 MW of energy storage by

2017, roughly equal to 40% of the total frequency regulation requirement. The total project investment costs are estimated to be US$503 million, resulting in an annual savings of US$283 million.

KEPCO predicts that the results of the frequency regulation market will have the following effects on the power system. First, select thermal power plants can be relieved of the need to reserve the 5% operating capacity for frequency reserves, or alternatively power plants can now operate on a 2.5% requirement. This will help bring about lower prices for electricity generation along with maintaining low wholesale prices necessary to Korea's economic development. Secondly, while the energy storage systems 500MW represents roughly 40% of the market, this figure can be considered to be closer to 50% in practice owing to fast-ramping energy storage resource's ability to more accurately track a dispatch signal.

Energy Storage in Korea's Renewable Energy Credits System

Korea's Renewable Energy Credit (REC) System is designed to encourage renewable energy development and increase the penetration of renewable resources into the energy mix. By 2020, Korea has scheduled to shut down 10 super coal-fired power plants, along with meet a target of 6% renewables. The Korean government plans to invest nearly US$27 billion to achieve these goals.

In 2012 the Korean government instituted a Renewables Portfolio Standard (RPS) to replace the previously intact Feed-in-Tariff (FIT). The RPS system, setting fixed quotas for renewable energy penetration by specific dates, allows renewable energy resources to enter the market on a competitive basis, albeit with prices still affected by government-set targets.

One of the defining features of the RPS system is in establishing a REC trading mechanism. Beginning in 2012, renewable energy power generators were awarded a set number of REC credits. Power generators could through investing in and constructing renewable energy generating plants be awarded REC credits. They could also buy RECs on the trading platform, allowing the REC credits to be counted towards the RPS standard. In this way, renewable power generators could directly sell their power to KEPCO or on the Korean Power Exchange (KPX) or generate profit through selling their REC credits directly to power generators that had failed to meet their own RPS standards.

Beginning in 2015, MOETI implemented plans to encourage the use of energy storage systems by awarding additional REC credits. In the 2015 plan, MOETI awarded REC credits during peak power periods when a power user discharged stored energy, with the credit award based on the amount of energy discharged by the storage system. Then in 2017, MOETI instituted a new program incentivizing energy storage co-localization at wind and solar power plant sites by rewarding REC for users who avoided battery discharge, instead charging batteries during high sunlight hours between 10:00-16:00. This policy, in addition to encouraging installation of storage equipment with solar PV, also ensured higher quality and more stable power output.

MOETI estimates solar + storage REC credits will bring about 800 MWh of newly installed storage capacity by 2020, resulting in US$392 of value output.

Australia

Australia's climate provides vast solar energy potential, and Australians have shown they are ready to use it, with a recent study demonstrating nearly 25% of all Australian households have residential installed solar panels.[10] To this end Australia has focused its energy storage development strategy especially towards solar + storage coordination both on large-scale solar farms and for residential users. In addition to ongoing power sector reforms in Australia, several cities have experimented with residential storage subsidies to accompany existing solar subsidies that allow users to self-consume their own energy.

R&D Efforts

The Australian government's key agency supporting the R&D into energy storage technology is the Australian Renewable Energy Agency (ARENA).

ARENA holds three goals towards technology and project development: 1) identify long term obstacles in the way of long-term renewable energy development, 2) help renewable energy technology to satisfy energy user's needs, and 3) promote the commercialization of renewable energy and new technologies. ARENA views energy storage as a crucial technology to achieving these goals.

By the end of 2016, ARENA had issued more than US$98 million in support for energy storage projects, adding in third party matching support, the total figure exceeds US$197 million. This includes support over 27 projects including battery technology development and testing, home-use battery systems, as well as utility scale battery systems.

The Australian Research Council (ARC) is another organization supporting energy storage technology development. ARC is the administrator of the National Competitive Grants Programme, which has provided over US$318 million towards fundamental science research among them including 8 projects geared towards solar and energy storage technology.

Storage Related Electricity System Reforms

Australia's energy regulations were largely designed with Australia's fossil fuel energy sources in mind, as such many obstacles stand in the way of energy storage development. The Australian Energy Market Commission (AEMC) has begun work to identify these challenges and propose solutions. For example, in May 2016, AEMC revised the definition of grid-serving entities allowing for applications for virtual power plants. Later in November 2016, AEMC published the "National Electricity Amendment (Demand Response Mechanism and Ancillary Services Unbundling) Rule 2016" unbundling ancillary services from demand response resources. Additionally, the AEMC is also considering how to shorten the wholesale energy market 30-minute clearing mechanism to a 5-minute mechanism, thereby allowing fast-response resources like batteries to more effectively compete in power markets.

Demand Response and Ancillary Service Unbundling

AEMC's rule revisions in the "National Electricity Amendment (Demand Response Mechanism and Ancillary Services Unbundling) Rule 2016" allow the separation of ancillary service providers from energy providers, thereby opening ancillary services markets to more third-party participants. Previous rules required ancillary services providers to purchase from wholesale markets on behalf of customers in order to provide demand response services.

Following the rule amendments, demand response market participants can bundle together loads in different locations to provide a response creating a large market space for small business and small-scale power users. Demand-side management service companies and software control companies have already entered the market with support from ARENA to demonstrate the effectiveness of their

[10] Roy Morgan Research, Solar Electric Panels and Home Energy Battery Data

business model and effect on overall load. These companies include Reposit Power, GreenSync, EnerNOC, Geli and Sunverge.

Australia also plans to open an ancillary services market in July 2017, most likely signifying yet again an enormous potential for energy storage resources. The Australian Energy Market Operator (AEMO) is finalizing rules for the upcoming market launch after an open comment period on the draft rules.

Five-Minute Wholesale Market Clearing Mechanism Revisions

The current 30-minute market mechanism is, in essence, an average of six consecutive five-minute clearing prices. The reason for a 30-minute clearing period is simply a result of most time-sharing meters being configured to 30-minute intervals. However, under the current 30-minute market mechanism, fast-response resources who can provide competitive costs on a 5-minute scale are lost to a 30-minute scale.

Furthermore, in Australia's current market conditions, flexibility is only measured on a kW scale rather than based on the actual results of a signal response. Entering a five-minute clearing window would bring the Australian ancillary services market one step closer to the PJM's "pay-by-performance" mechanism currently in place in the US. The benefits increased flexibility bring is best illustrated by considering the widespread blackouts across Southern Australia in late 2016. These blackouts resulted in part due to a typhoon suddenly blowing down three critical transmission lines. In a market five-minute intervals, batteries would have been able to provide an immediate response and avoid grid shutdown.

According to analysis by the Melbourne Energy Institute, a five-minute market structure could increase earnings for batteries by up to five times, reaching a value of nearly US$472/kWh.

AEMC is expected to announce the decision on altering market clearing rules by July 2017.

Simplifying Grid Integration Procedures

Market rule and regulation alterations on the national level are just the first step in ensuring resilient grid networks that allow energy storage to effectively provide services. Australia's Grid Operator, Ausgrid is in the process of streamlining grid-entry procedures for energy storage, including simplifying application procedures and lowering application fees. All solar + storage systems under 30 kW are eligible for fast-track application procedure.

Energy Storage Subsidies

In addition to the Adelaide city scheme covered in the case studies section of our report, several other cities and states have implemented subsidy programs.

Canberra Next Generation Renewables Program

Australia's capital city of Canberra as part of the Next Generation Renewables Energy Storage program helped provide energy storage subsidies for homes and businesses in Canberra as part of efforts to help the city reach 100% renewables by 2020. In all the program invested over AUD$25 million, supporting installations of over 36 MW of solar + storage, residential users installing accompanying storage could gain up to AUD$825/kWp. At present the project has implemented two rounds, the first round called PilotNext Grants supported 200 homes and businesses with Tesla, Panasonic, and LG Chem winning bids to be the three storage providers. In May 2016 the city continued with the second round of subsidies, helping provide 600 homes and businesses with storage subsidies, and with 8 companies winning bids: ActewAGL Retail, Energy Matters, EPC Solar, Evergen, ITP Renewables, Origin Energy, Power Saving Centre, and Solarhub. The latest round of auction includes 200 MW grants for windfarms, who in addition to supplying renewable electricity to Canberra will also finance a new round of a total 36 MW of distributed battery storages in over 5,000 homes and business in Canberra.

Distribution Network Operator Provides Solar + Storage Subsidy

In 2016 Australia's fifth largest electricity transmitter SA Power Networks volunteered in the Adelaide suburb of Salisbury to launch 100 solar + storage demonstration projects, forecasting a total battery capacity of 6.4 MWh. Tesla and Samsung were selected to provide the user storage technology.

SA Power Networks provided the users with two solar + storage installation plans. One of this was the purchasing plan, with SA Power Networks provided a 3 kW rooftop solar and 6.4 kWh storage set for AUD$6,150. For users who had already installed solar, there was also an option to separately purchase the storage system for AUD$3600 (current retail prices for storage systems usually fall between AUD$10,000-AUD$20,000).

The second option was the leasing plan. Users could purchase the solar rooftop system for AUD$2,550, then by paying a AUD$500 deposit they could elect to rent the battery system for AUD$18.50 paid every two weeks. All battery rights would belong with SA Power Networks, and the leasing period had to last at least three years.

By December 2016 SA Power Networks had already completed 100 solar + storage installations. With a portion of the support coming from ARENA, one goal of the project was to satisfy the city's growing electricity demands. Another goal was to assess the cost savings of using energy storage resources to defer upgrades to T&D networks.

China

Despite China's ever-increasing energy storage manufacturing, currently producing 55% of all Li-ion batteries in the world, and with an annual Li-ion manufacturing capacity expected to reach over 120 GWh by 2021[11], the number of energy storage projects operating in China remains underdeveloped. This mostly stems from a lack of policy support and lack of power system reforms that prevent energy storage from becoming cost effective. In this section, we discuss the current hurdles facing Chinese adoption of storage technology.

R&D Efforts

While many research teams in China are devoted to basic research underlying energy storage technology, at present there is no coordinated government-backed program dedicated to allocating R&D funds into storage-related research.

Storage Related Electricity System Reforms

China, one of APEC's fastest growing economies has experienced tremendous growth in its power sector as well as in demand for power. In this section, we provide an overview of the development status of China's power sector reforms and explore the ways in which they create potential for energy storage.

Power Reforms Background

On 15 March 2015, the Chinese Communist Party Central Committee with the State Council together published "Opinions on Strengthening Power System Reforms" hereafter referred to as "Opinions."

[11] Data from Bloomberg New Energy Finance

The “Opinions” document laid out plans for the deregulation of T&D networks and electricity retail, allowing for free market power trading and market-determined electricity prices. In all, these reforms can help achieve better power system efficiency, lower emissions, and encourage the adoption of renewable energy resources. To aid in the implementation of “Opinions” the government released a series of six accompanying documents: “Implementation Opinions on Promoting Transmission and Distribution Electricity Price Reform;” “Implementation Opinions on Establishing Power Markets;” “Implementation Opinions Organizing Power Trading Mechanisms and Regulated Operations;” “Implementation Opinions on Opening Up of Power Plans;” “Implementation Opinions on Electricity Retail Reform;” and “Guiding Opinions on Strengthening and Standardizing Self-Contained Coal-Fired Power Plants Inspection Management.”

The latest rounds of reforms show plans to break up power system monopolies and announce intentions for clean energy, T&D system reform, power market establishment, power trading mechanisms, and power retail reforms.

Energy Storage in the “Three Norths” Ancillary Services Compensation Mechanism

In 2015, China’s “Three Norths” region became the first region to announce plans laying the groundwork for an ancillary services market. While energy storage was permitted to participate, there was little clarification about how this would be accomplished. The National Energy Administration in June 2016 clarified by issuing the subsequent policy document: “Notice Announcing Pilot Demonstration Work to Promote Electrical Storage Participation in the ‘Three Norths’ Regional Ancillary Services Market” (hereafter referred to as “Notice”.) This is China’s first policy document clarifying the value of energy storage participation in the ancillary services markets.

The “Notice” allows each province in the “Three Norths” region (consisting of three sub-regions the Northwest, North, and Northeast, in total approximately 12 provinces) to select no more than five energy storage facilities to participate in the region’s newly created ancillary services market. Generation-sited storage can either provide peak shaving, frequency regulation to the electricity generator at the location site, or participate as an independent body in the regional ancillary services market. User-sited storage facilities can program equipment to charge when electricity prices are low. Discharged electricity can be consumed by the storage equipment owners themselves, or can be sold as a distributed energy resource to nearby users. Additionally, user-sited facilities that achieve a set capacity (to be later defined by each province) can also be allowed to participate as an independent resource in the ancillary services market.

The “Notice” is the first such Chinese policy document clarifying energy storage as an independent body able to participate in the markets. The “Notice” also clarifies compensation mechanisms, grid connections, and grid dispatch requirements. Before the “Notice,” energy storage was not clearly defined as an entity able to participate in the markets, as such the compensation mechanism was unclear and complications arose with dispatching storage resources.

At present, of the three regions comprising the “Three Norths,” the Northeast Region is the first to begin implementation of the ancillary services market. The following are some problems encountered in the implementation.

Existing Challenges:

1. **Peak-Shifting Is Too Heavily Emphasized**
   Work on the ancillary services market in the Northeast region has just begun, and according to implementation documents released, peak-shifting work is the central focus. However, this proposes only one narrow application at the expense of other ancillary services such as

frequency regulation. Rule makers should study from other economy's experiences to better design ancillary services markets.

2. **Market Transaction Operations Have Yet to Begin**
In 2016 the Northeast region launched trial demonstration for peak-shifting ancillary services, followed by the release of several rounds of supporting documentation. However, no storage project has completed agreements to enter the market due to a lack of clarity surrounding the peak-shifting process. A lack of clarity has done little to encourage energy storage manufacturers and integrators to enter the market, thereby calling for more project demonstrations to show the feasibility of energy storage peak-shifting applications and increase confidence.
3. **Electrical Storage's Value Has Yet to be Verified**
Insufficient work has been done to verify the methods by which energy storage resources can calculate and receive earnings. Compared to the traditional storage application of price arbitrage, energy storage is even better suited to provide ancillary services, however this has yet to be demonstrated on a project level.

Energy Storage Subsidies

China currently does not provide subsidy programs geared towards energy storage.

Best Practices and Recommendations

While energy storage subsidies can help bring about large-scale adoption of energy storage resources in short periods of time, it is not always necessary to achieve cost-effectiveness. Rather, through intelligent rate design and market mechanisms, energy storage can be cost effective even today, and more so in the future as technology prices fall. While the APEC region covers economies at different stages of economic development with vastly different geographies and power systems, our report presents the following research findings as key recommendations from lessons learned from several APEC economies who have begun to implement energy storage technology.

1. **Promote renewable energy development**
Considering today's global environmental concerns, economies across the APEC region have worked to promote the development of resilient, low carbon, and sustainable energy systems. In line with these development goals, energy storage progresses hand-in-hand with development of renewable energy sources. Energy storage has a myriad of functions beyond acting as a source of backup power, and is the key technology to enable high renewable concentrations on electric grids from large concentrated wind and solar farms, or in small-scale distributed energy generation.

2. **Solidify policy support and liberalize electricity markets**
APEC economies like the United States, Korea, Japan, and Australia have all implemented generous technology subsidies have enabled energy storage applications across a variety of sectors, allowing a new technology to be tested and verified. However, policy support is much more than a subsidy, these economies have also provided several best-practices which can be studied and replicated in other policy areas including formulating development plans, transaction policies, and technology standards. Moreover, to ensure energy storage's future viability, it is important to evolve beyond subsidy-dependence—allowing free market principles to determine the optimum configurations for storage technology in liberalized power markets.

3. **Clarify market compensation methods**
   Wide-spread commercialization and adoption of energy storage technology hinges on two factors: 1) falling technology costs; and 2) market conditions allowing storage to generate revenue. Market liberalization is a first step, but without clear cost-recovery and compensation mechanisms set in place by appropriate government policy, investors will not have the confidence to install energy storage systems in a given power system. The PJM ancillary services market in the US has accomplished this through a high degree of transparency, making publicly accessible all market rules and payment determination formulas in addition to providing focused training sessions. Especially in the case of China, unclear payment mechanisms continue to pose a major challenge to energy storage adoption with investors wary of installing battery systems without a clear understanding of how they recover costs.

4. **Push demonstration projects towards commercialization**
   Energy storage has already become cost effective in select grid-side, T&D, and behind-the meter applications across APEC economies. However, more work can be done to open new applications for storage while APEC economies can learn from each other to implement strategic deployment of storage technology. Project demonstrations are a key first step to develop experience and collect data, but also necessitate effective transitional policies to help demonstrations become self-sufficient and operational.