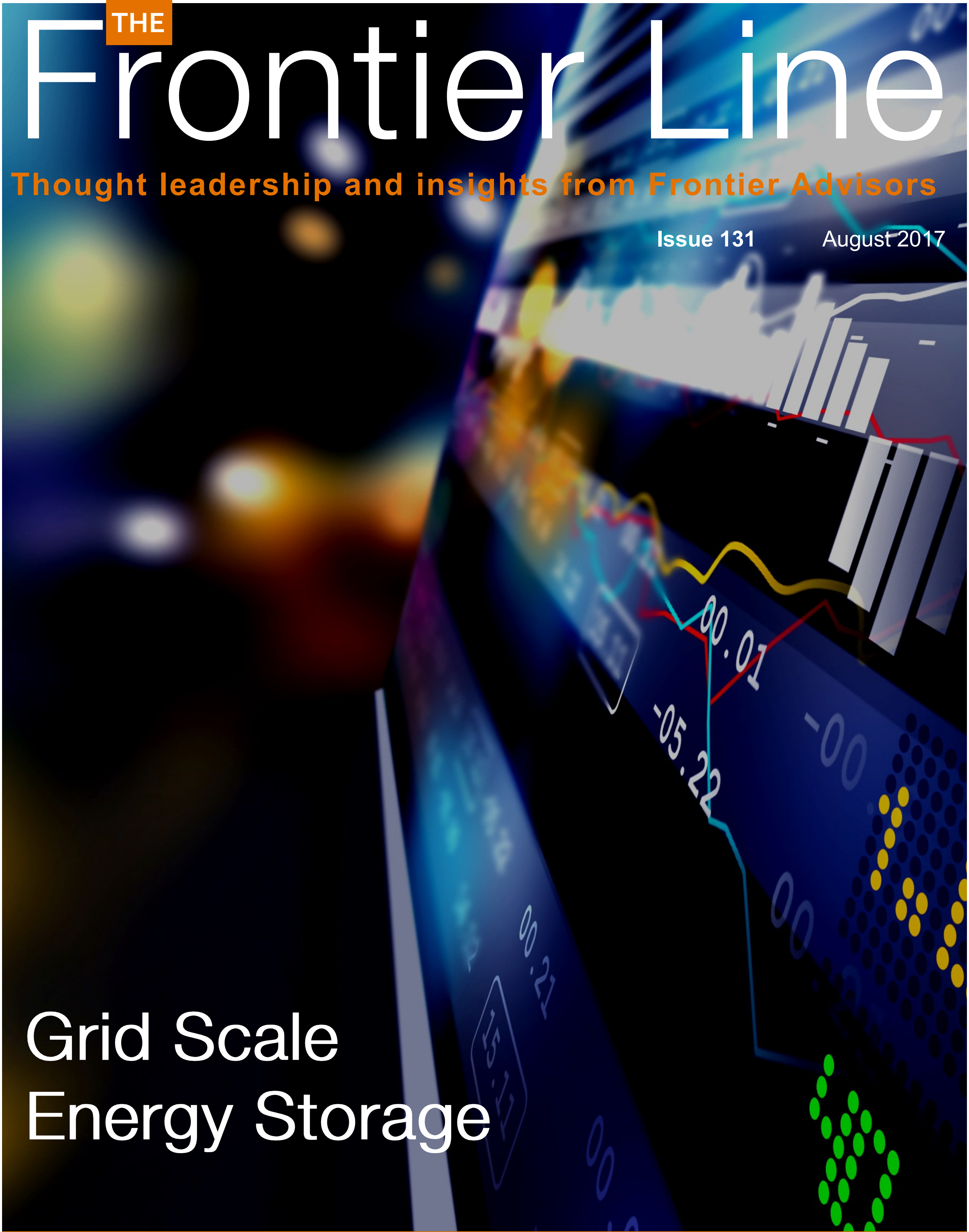

THE Frontier Line

Thought leadership and insights from Frontier Advisors

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Grid Scale Energy Storage

FRONTIER ADVISORS

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Grid Scale Energy Storage

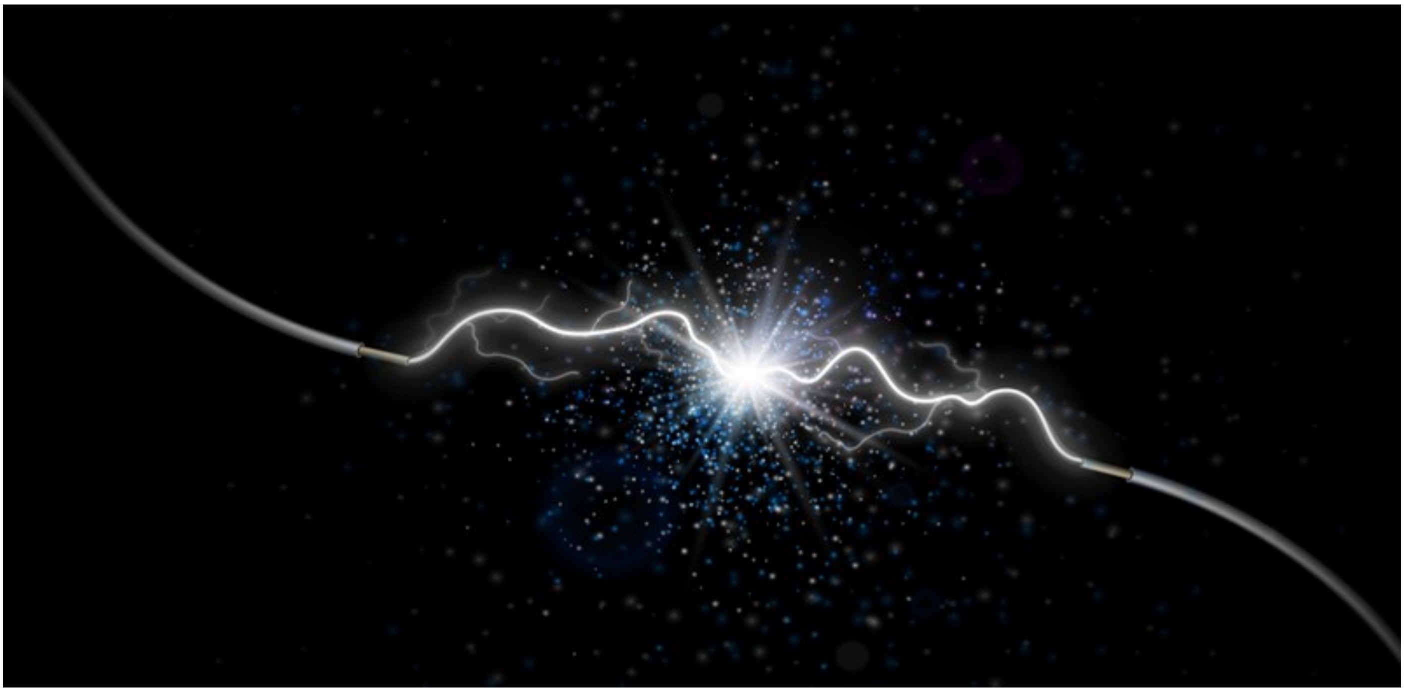
While grid scale energy storage is nothing new, as a topic it is moving into the spotlight for a number of reasons. A key driver is the increasing penetration of renewable generation assets into the energy generation mix in many jurisdictions, with this only expected to continue into the future. The peaky nature of renewable generation means storage technologies can have a role in storing and smoothing power delivery. However, as we will note later, there are a range of benefits energy storage can provide, other than just storing electricity.

Another reason for the attention is increasing viability of alternative technologies – particularly lithium-ion battery storage. Ongoing development and price decreases make options that previously were not viable closer to being cost effective. However, the storage sector is much broader than lithium-ion batteries – indeed pumped hydro storage makes of the vast majority of energy storage capacity around the world and technological developments will likely expand the range of viable storage types over time.

Regulatory changes in the US have also triggered a rapid uptake of new storage over the past few years, particularly for lithium-ion based storage. This was followed by an emergency roll-out of battery storage in California to stabilise its energy network in the second half of 2016, which was needed due to a massive gas leak from a key natural gas storage facility. These events have proven the broader benefits of battery storage.

This is only likely to increase the demand for new assets as other jurisdictions take notice. For example, both South Australia and Victoria have now tendered for battery storage, with grid stability a key objective of installing these facilities and rapid roll-out a key requirement.

Clearly, there is a lot of change happening at the current point in time in the energy storage space, and with such rapid change may come opportunity. It is an immature sector for non-hydro storage solutions, so it is worth monitoring as more comfort in the technologies are gained and contractual and regulatory structures evolve. This is also a sector that can only grow as renewable energy becomes increasingly integrated into the energy generation mix globally in order to meet carbon emission targets. The sector could become appropriate at some point for a well-positioned infrastructure investor, so is definitely worth understanding and monitoring.



Technologies

A lot of current focus is on lithium-ion battery storage, due to high profile companies such as Tesla entering the market as well as rapid cost decreases. However, there are actually a large range of storage technologies, each with specific characteristics and benefits. Technology continues to develop, which not only means completely new technologies, but also improved characteristics from existing technologies, or even improved characteristics from existing assets. For reference, power output is typically measured in megawatts (MW), while energy storage capacity is measured in megawatt hours (MWh). More detail on storage technology characteristics on page 6.

The variety of technologies includes the following.

Pumped hydro storage (PHS) – This is the grand-daddy of storage technologies, being one of the first technologies utilised, with the first installations occurring in the 1890s. These assets can be as simple as introducing the capability to pump water back into the reservoir at a traditional hydroelectric power station, through to purpose built facilities. The vast majority of utility scale energy storage globally is in the form of pumped hydro. These tend to be large facilities due to the economies of scale involved. A key limitation is the number of suitable locations for such facilities, as there needs to be an upper and lower reservoir separated by a suitable height. Proposed or existing variants of the technology include using the ocean as the lower reservoir, or using abandoned mines as the lower reservoir. An example is the Bath County Pumped Storage Station in Virginia, US, which is a purpose built pumped storage facility with two reservoirs separated by 380 meters and a generation capacity of 3,003 MW.

Static battery energy storage – This uses a wide range of different chemistries to store electrical energy, including lithium-ion, sodium-sulphur and lead-acid chemistries. Developments in mobile technologies and electric vehicles (EVs) has resulted in the cost of production of lithium-ion based storage to drop rapidly, which means this is the chemistry with the most potential at the current point in time. Notably though, some of the characteristics that makes lithium-ion a suitable chemistry in EVs, namely high energy density, is unnecessary for a static storage installation. As a direct current device, battery storage also needs other components, such as inverters and rectifiers to connect to the alternating current network. The largest installed lithium-ion battery to date is a 30 MW, 120 MWh facility in Escondido, California, but this will be eclipsed by a planned facility in South Australia.

Flow battery energy storage – This is a variant of battery storage where the electrolyte is stored externally and is pumped into a reaction cell to extract or store energy. A key benefit of flow cells relative to more conventional batteries is that their maximum power output and storage capacity are independent of one another. There are a number of different potential chemistries, but Vanadium Redox Flow Batteries (VRB) are currently the most common in terms of installations. The largest installed VRB to date is a 15 MW, 60 MWh facility in Hokkaido, Japan.

Compressed air energy storage (CAES) – This fits into a similar niche as pumped hydro in terms of application, output and storage capacity, but instead of pumping and recovering water, it pumps compressed air into underground caverns. In terms of utility scale CAES, only three facilities exist globally, with the largest in terms of power output being Huntorf, Germany at 290 MW. More plants are planned and there is ongoing development of the technology underpinning these facilities.

Molten salt heat storage – This is a form of thermal energy storage used to extend the operating hours of a thermal solar plant. The salt itself is stored in insulated tanks and is pumped to where it is heated by the solar plant, or to where the heat is extracted to generate steam to drive a conventional turbine generator. The benefit is that the energy can be extracted when needed, rather than when the sun is shining. As an example, the Crescent Dunes Facility in Nevada can generate 110 MW and has 1,100 MWh of storage. This operates as both a solar power station and as energy storage.

Flywheel energy storage systems (FESS) – These store energy as kinetic energy in rapidly rotating masses. A key advantage of flywheel systems is the ability to store and discharge rapidly, with very rapid ramp rates.

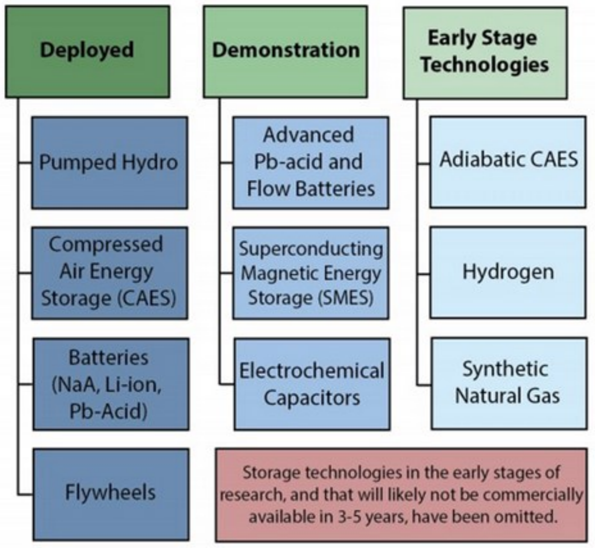
This means they are more suitable for transient grid support functions, such as frequency control, rather than bulk storage of energy. At smaller scales, flywheel systems are used in a number of roles, including in uninterruptable power supplies. Some utility scale facilities, using multiple flywheels, have been constructed, but these still tend to be small in terms of storage capacity. An example is a 20 MW, 5 MWh facility in Stephentown, New York.

Capacitors and supercapacitors – Capacitors and supercapacitors store energy in an electrostatic field, or in a stored static charge between two electrodes. Their main benefit is their very rapid response time, but they have limited storage ability. There are a number of operational facilities, but these are small scale, such as the "Hybrid Energy Storage System" in Gaston County, North Carolina. This combines supercapacitors with battery storage and is connected to a solar generation facility.

Others – This list is far from exhaustive and there are a range of other technologies that have been used in storage applications, or have potential to be used in storage applications. These include technologies such as superconducting magnetic energy storage, which has been used commercially, through to "Stored Energy in the Sea" (StEnSEA), which is an experimental technology that involves pumping water out of hollow spheres in deep water.

Probably the key takeaway here is that there are a wide range of very different storage technologies that can potentially be utilised at a grid scale. However, the specific purpose of the storage technology determines which one is appropriate. Each technology is also at a different stage of maturity, with Chart 1 outlining the various technologies by maturity.

Chart 1: Maturity of Energy Storage Technologies



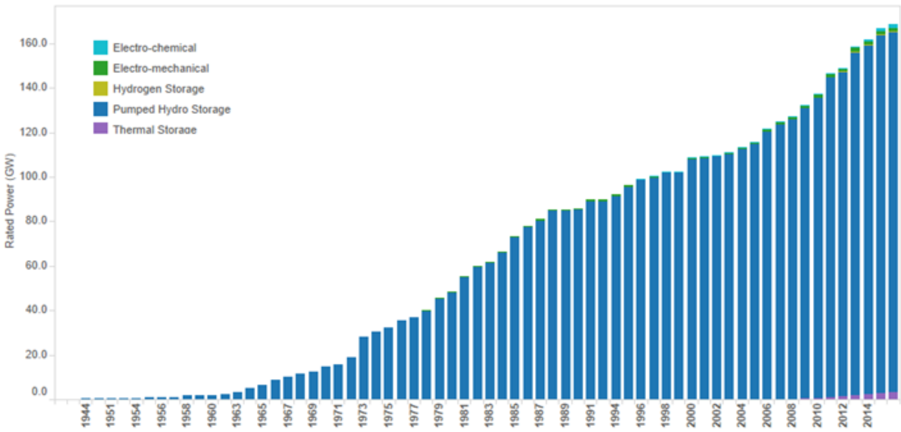
Source: Center for Sustainable Systems, University of Michigan

Chart 2 gives an idea of just how dominant pumped hydro is in the storage space (noting that this measures power, not capacity). However, there are almost three times the number of projects in batteries (electro-chemical) than pumped hydro. Hence, the average hydro project is around 500 MW, whereas the average battery project is around 3 MW.

Much current focus is on energy storage being used to manage the variable output that result from renewable energy sources, which means the ability to store large amounts of energy (bulk storage) tends to be one of the more valuable characteristics. Other characteristics, like energy density, are less important in these applications.

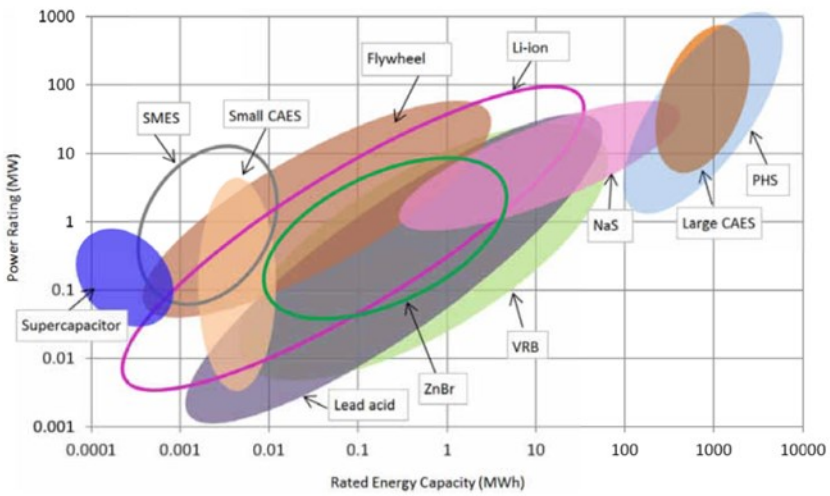
In this kind of role, the various battery technologies, CAES and pumped hydro tend to be more appropriate, at least at present. Technologies such as supercapacitors and flywheels tend to have a role more in applications where a high power output is required for a short period of time, or where very fast response times are required. From an infrastructure investor's standpoint, the bulk storage applications make more sense as well, due to scale and more potential to structure these as infrastructure style investments. Chart 3 shows the various technologies by storage capacity and power output, which highlights some of the relative differences.

Chart 2: Global Installed Capacity by Technology



Source: DOE Global Energy Storage Database

Chart 3: Comparison of Power Rating and Storage Capacity of Different Technologies



Source: ARENA (ESCRI-SA project)

Reasons for need/ benefits

While the obvious use of energy storage is simply storing energy for when it is needed, it can actually have a range of other benefits to the network in which it is installed. How many of these benefits can be monetised will depend on the regulatory framework within which it operates, and will ultimately impact on the financial viability of a storage device.

Some of the potential benefits include the following.

Energy storage – The most obvious role is storing electricity when it is plentiful (and importantly, cheap) and supplying when it is in demand (and more expensive). The return from this function is typically generated by the difference between purchase and sale prices (altered by the efficiency of the overall cycle).

Peaking capabilities – Supplying electricity to the network when demand is high.

Frequency control – The frequency of an electricity network changes when there is a mismatch between demand and supply. Many storage technologies can rapidly supply energy to the network, or reduce demand if it is withdrawing energy, which can be used to support the network's frequency. This has been a key driver behind the uptake of lithium-ion batteries in the US in recent years.

Voltage support – This refers to keeping the network's voltage stable. This requires a characteristic called reactive power.

Grid stability/islanding – Islanding is where a part of the electrical grid disconnects from the broader grid, but continues to be powered by local power supplies. Where islanding is desired, a storage device that can operate independently as a local power supply could be valuable.

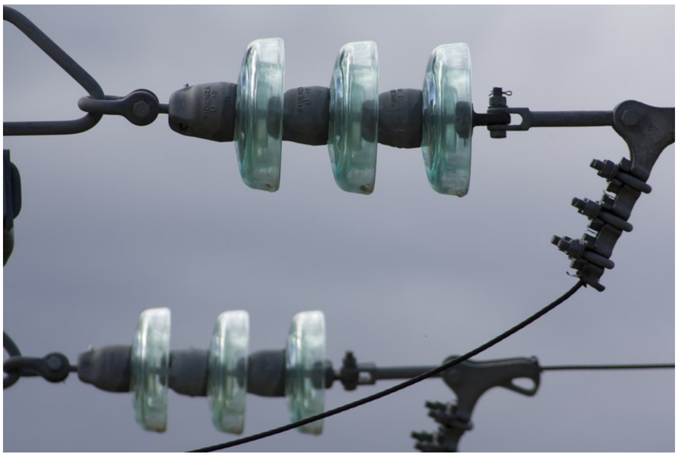
Marginal loss factor modification – This is the alteration of the network's transmission losses due to shifting the location of energy supply and demand in a network.

Load smoothing/peak shaving – This can be a "behind the meter" function. In some regulatory regimes, energy users are charged a fee based on their peak power demand over a specified period of time. This is a way to pass network costs to users that place the greatest demands on the network. Reducing this peak power demand by use of a storage device at peak demand times will reduce this fee.

Alternative to network augmentation – Rather than increase the capacity of a capacity constrained link within an electricity network (a "bottleneck"), an energy storage device on the electricity demand side of the bottleneck can be installed. This device can store electricity in low demand periods and supply electricity in high demand periods, reducing peak demand on the constrained part of the network.

Black start support – On the rare occasion where there is a grid-wide outage, restarting the grid requires a careful sequence of steps, with many generating plants not necessarily suitable for black-start capability. For example, many power stations require an energised grid in order to begin their own starting procedure. The characteristics of storage devices means they can potentially provide support for restarting an electrical grid.

A point to note is that many of the various benefits are closely related to one another, and essentially describe ways to monetise the various characteristics and uses of the device. A storage device can potentially generate revenue from multiple functions, depending on the characteristics of the device as well as the regulatory regime. In practice, however, market trading (peaking and storage) is likely to generate most of the revenue for large scale energy storage devices, especially in a market with volatile electricity prices, although this will depend on the regulatory regime.



Characteristics of storage devices

As we have alluded to in previous sections, there are a range of different characteristics of a storage device that determine what functions it can perform within an electricity network, and the level of involvement. Many of these characteristics are shared with both generation sources and loads in a network (given storage devices operate as either at different times). As different forms of storage have different characteristics, this makes them more or less suitable for the various tasks outlined in the previous section.

The various characteristics include the following.

Storage capacity – This is simply the amount of energy that a device can store, typically measured in megawatt hours. This, combined with the power output/charge rate, will determine how long the device takes to fully discharge or charge. Some types of storage only make sense at large scale (such as pumped hydro), whereas others can operate at smaller scale (such as batteries). Other types of storage are relatively small (such as flywheels), but may have other beneficial characteristics that don't require a high storage capacity.

Power output – This is the level of power the device can discharge into the network, equivalent to the power rating of a conventional generator and is typically measured in megawatts.

Storage rate – This is essentially how quickly the device can store energy, which is not necessarily the same as the power output.

Physical location – The location of the asset determines how beneficial its capabilities can be. For example, some storage devices are relatively unrestricted in where they can be located (such as battery storage), hence can be placed in optimal locations, whereas others require particular characteristics in their location (such as particular hydrology and geology for pumped storage).

Efficiency – In any charge/discharge cycle, there are losses, which determines the overall efficiency of the process. For example, pumped hydro is about 80% efficient, which means 80% of the energy that goes into the device can be re-extracted. The point in the process where energy is lost will vary by technology as well.

Ramp rate – This is how rapidly a device can start delivering energy into the network. Many storage technologies have a very rapid ramp rate, which means they have value in such functions as frequency control.

Reactive power – Maintenance of an electrical grid's voltage requires the management of a characteristic called reactance. This has traditionally been provided by generation sources that can generate a characteristic called reactive power, which offsets this reactance. Storage devices can provide reactive power.

Inertia – Traditional energy generation sources have inertia – literally large rotating masses within turbines in power stations that have a tendency to keep rotating, even with changes in load. This smooths out frequency fluctuations, which is a valuable characteristic. However, some storage devices have actual inertia, or can supply "synthetic" inertia, which also helps slow frequency fluctuations.

Cost – The cost of a device depends on both the technology and scale. For example, pumped hydro is relatively inexpensive per unit of storage, but has to be installed in large scale in specific locations. Battery technologies tend to be much more expensive, but can be made smaller and the cost of newer technologies, such as lithium-ion batteries, are decreasing rapidly, which means the playing field is constantly changing.

We note that this is not an exhaustive list of all the important characteristics relating to storage. Many others are also important, depending on the application, such as energy density, self-discharge, allowable depth of discharge and durability.

Alternatives to using energy storage

Storage technologies are used to achieve particular characteristics in an electricity grid, with a number of alternative, and more conventional, methods capable of achieving these same characteristics. The viability of storage technologies will depend on the cost and viability of these alternatives, as well as conservatism, that may mean established methods are used in preference to newer storage technologies.

Examples of alternatives include reducing the level of renewables in the network, increasing capacity on capacity constrained transmission links, introducing more peaking capability, improving network interconnections, using more distributed generation, and using other approaches to moving and storing energy, such as gas storage. Hence, while energy storage may be one solution to a particular problem, there may be others.

Challenges and opportunities

While in theory storage technologies have a range of benefits, there are still a number of challenges to their widespread adoption in large scale. Pumped hydro is the most viable technology in large scale, which explains why it makes up the vast bulk of energy storage capacity globally. However, it is constrained by limits in where it can be located.

Lithium-ion based battery technology is developing rapidly and has a range of advantages, including rapidly decreasing cost. However, this and most other non-hydro technologies are still very expensive, which limits their viability in many situations. However, this will likely change, particularly for lithium-ion batteries, as costs of production continue to decline. Additional technical development, and mass adoption of other technologies, also has the potential to make these cost effective, but this is a longer term proposition.

From an infrastructure investor's standpoint, there are a number of considerations. Scale is one, as in infrastructure terms, energy storage assets tend to be small, with the exception of some pumped hydro assets. However, we would expect grid scale lithium-ion battery storage to increase in size over time, which may make them more attractive to a typical mid-market infrastructure investor.

Another consideration is the contractual structure and regulatory regime surrounding the storage device. An asset that primarily generates its return through energy market trading activities would be unattractive to an infrastructure investor due to the volatility of return and risk associated future electricity prices.

However, the same asset with a contractual structure or regulatory regime that allows a more certain return stream (such as a regulated rate of return or an availability payment structure) could be attractive to an infrastructure investor. As a developing sector, this is one area where issues like these will continue to evolve.

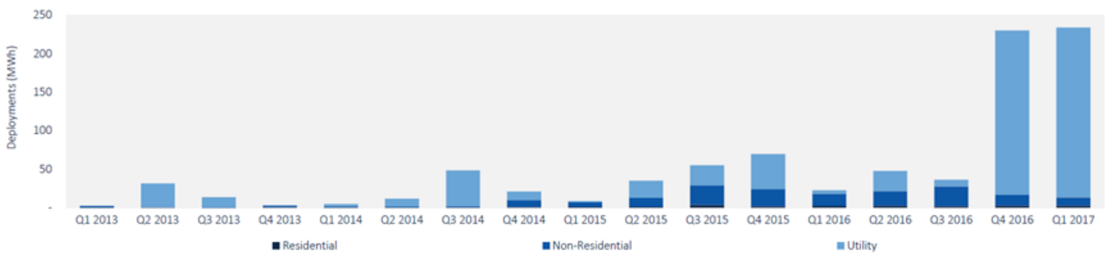
As an undeveloped sector, there may also be scope to earn a solid return premium from investing at the greenfield stage relative to brownfield in assets such as lithium-ion battery storage. This is because market participants will initially be wary of taking on construction risk until the technologies and construction techniques are solidly proven. This may create a window where an educated investor can be comfortable with the construction and technology risk, but is still receiving an outsized greenfield premium. Once more investors become comfortable with the construction and technology risk, this premium will narrow. Similar dynamics have been observed as various renewable energy technologies have been rolled out at grid scale. The maturity of lithium-ion battery technology in other applications, and its reasonably straightforward installation, could mean this greenfield premium narrows quite quickly, so the window of opportunity could be short.

Market developments

Globally there has been considerable activity in rolling out energy storage solutions, particularly lithium-ion battery storage, though the US is by far the most active jurisdiction. Activity started picking up around 2014 and ramped up dramatically over 2016, with the vast majority of installations using lithium-ion batteries.

Charts 4 and 5 show new deployments by quarter.

Chart 4: US Quarterly Energy Storage Deployments (MWh)



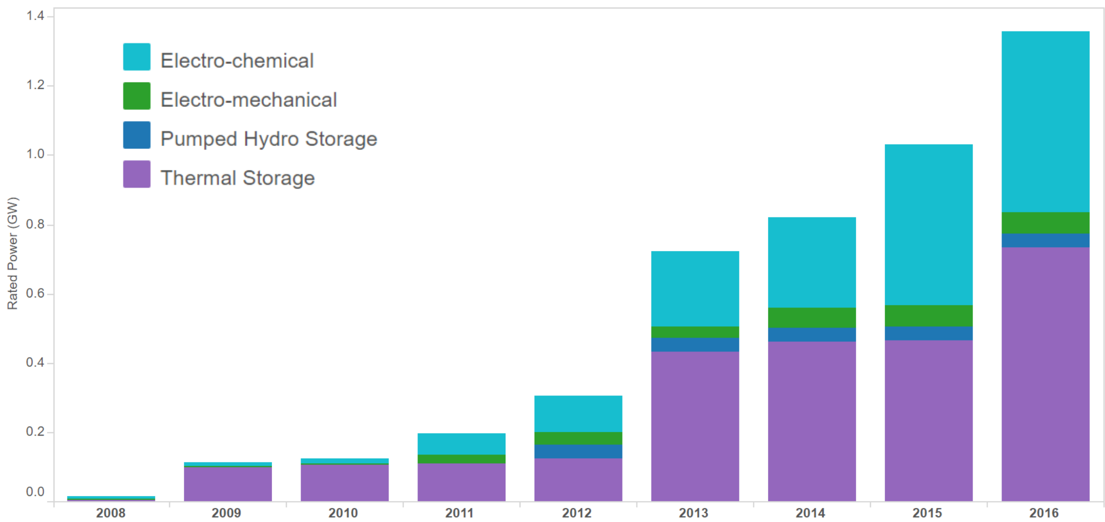
Source: GTM Research

Chart 5: US Quarterly Energy Storage Deployments (MW)

Source: GTM Research

Chart 6: Cumulative US Installed Capacity (MW)

Chart 6 shows the cumulative capacity over time by technology (noting that this only includes capacity installed over the covered period).



Source: DOE Global Energy

An initial driver of this trend were regulatory incentives in the PJM frequency regulation market, with frequency regulation being one of the main stated purposes of storage installed over this period (PJM is a large regional energy market on the east coast of the US). Other purposes for these installations tend to be renewables related, such as renewables capacity firming and energy time shifting.

Over time, the scale of individual installations has continued to increase in size and power output, reflecting the overall development of the market and increasing comfort with the technology. The markets within which most activity is occurring has also shifted over time, with PJM the most active initially, and California now taking over. These shifts tend to be driven by regulation, with the PJM frequency regulation market driving much of the earlier activity. California took the lead in 2016 as an emergency roll out of battery storage took place in response to gas shortages that threatened to create mass blackouts (this gas shortage was due to a leak in the Aliso Canyon gas storage facility). This highlighted just how quickly the technology can be rolled out, with battery storage projects only taking six months from start to finish. California also has a mandated target of 1,325 MW of new storage by 2020, which is driving activity. As a comparison by size, the largest power station in Victoria, Loy Yang A, has a nameplate capacity of 2,200 MW. No doubt the overall US energy storage market will continue to evolve and some market participants are suggesting the sector could grow by many multiples over the next 10 years, although this will depend on regulation, costs and further technology developments.

In Australia, the most notable recent development is South Australia tendering for 100 MW of battery storage, with this awarded to Tesla and Neoen. The proposed facility will have a power output of 100 MW and a storage capacity of 129 MWh. Tesla has claimed it can have it installed within 100 days, and expectations are it will be completed by 1 December 2017.

Cost estimates vary widely from $66 million to $240 million. In terms of power output, it has been claimed to be three times more powerful than any other battery system ever installed, though it will be only marginally larger in terms of storage capacity.

Additionally, the Victorian government has tendered for a minimum of 100 MWh of storage to be deployed in western Victoria, which can be in up to two projects of a minimum of 20 MW each. Deployment is targeted for prior to January 2018.

There are also a number of other proposed projects across Australia that will include battery storage, including the Kingfisher Project near Roxby Downs in South Australia, which pairs a 100 MW solar farm with a 100 MW of battery storage. The company behind this project (Lyon Group) claims to have a number of other solar farms and battery storage projects in its pipeline across Australia.

The Australian Federal Government has also announced plans to expand the Snowy Mountains Scheme to expand its generation capacity by 50% (2000 MW) and to increase the pumped hydro capacity of the scheme. However, this project is early in the planning phase and construction of hydro projects is considerably slower than battery projects.

Beyond this, a large amount of storage capacity has been added globally over time, with China being particularly active in the storage space over the past decade. However, this additional capacity is almost entirely pumped hydro and will typically be combined with conventional hydro, rather than standalone storage facilities. What makes the US market relatively unique is how quickly it has switched to embracing battery technology, though there has been activity in battery storage in other markets, such as Korea, Japan and Europe.

The final words…

Clearly the energy storage sector is undergoing considerable change at the current point in time, particularly due to the widespread adoption of lithium-ion battery based storage. With such change comes opportunity. It is still early days with regards to the adoption of non-hydro storage solutions, but it is a sector worth monitoring as more comfort in the technology is gained and contractual and regulatory structures evolve. This is also a sector that can only grow as renewable energy becomes increasingly integrated into the energy generation mix globally in order to meet carbon emission targets. Additionally, as the price of the various technologies decreases (particularly lithium-ion), more projects will become viable from a risk-return standpoint, which should increase the potential investment opportunity set.

In many respects the characteristics of energy storage, particularly lithium-ion battery storage, look similar to utility scale solar PV, and may exhibit similar characteristics over time.

In our view, the energy storage sector could be appropriate, at some point, for a well-positioned infrastructure investor. Investment in this space also has the benefit of being strongly ESG positive, due to its enabling role in integrating renewable energy. We would consider the inclusion of energy storage assets into a renewable energy strategy as appropriate.