Grid Energy Storage

The grid energy storage market is buzzing, and many new technologies are being thrust from the research and development realm into the commercial space. The question of which technology is going to be the big winner for the energy storage revolution is a discussion mired in speculation and clouded with preconceptions. However, it may just be possible to make some educated guesses if we read the market road signs and consider each technology independently.

This article discusses storage technologies that are being developed and their applications, explains why momentum is building for storage technologies in the market, and attempts to make some predictions about which of these technologies might affect the residential and commercial energy markets in the short term.

Grid Energy Storage Technologies

The technologies presented below are some of the more prevalent grid energy storage products that are currently commercially available in one form or another.

Valve-regulated Lead-acid Batteries

Unlike flooded lead-acid batteries, valve-regulated lead-acid (VRLA) batteries generally do not need to have their electrolyte refilled as it is suspended in a medium and the batteries themselves are sealed. Absorbed Glass Matt (AGM), Gel and new types of lead-based batteries, such as the Ultrabattery by Ecoult, are examples of VRLA batteries. VRLA batteries are a mature technology, having been used in the telecommunications industry and rural stand-alone systems for decades. Their well-established position and low maintenance costs have made them the preferred choice for grid energy storage at all levels.

“VRLA batteries are a mature technology ... the preferred choice for grid energy storage at all levels.”

Lithium-ion and Lithium-ion Polymer Batteries

Lithium-ion batteries have been commercially available for over 20 years. Rapid improvements in battery chemistry and production quality have led to the universal acceptance of lithium-ion batteries for mobile applications. Lithium-ion and lithium-ion polymer (also known as just lithium-polymer) batteries have very similar chemistries and virtually the same structure, except that lithium-polymer batteries have a porous gelled electrolyte instead of a porous separator. The polymer offers slightly higher energy densities but is more expensive to produce. Some lithium-ion chemistries are:

- Lithium iron phosphate
- Lithium nickel cobalt aluminium
- Lithium cobalt oxide
- Lithium manganese oxide
- Lithium nickel manganese cobalt oxide
- Lithium titanate.

These chemistries have different attributes relating to safety, cost, energy, power and cycle life. Owing to their safety attributes, the two most commonly used chemistries are lithium iron phosphate and lithium nickel cobalt aluminium.

Nickel-based Batteries

Nickel-based batteries are stable, robust and generally have some of the lowest costs per cycle of any battery type available. Nickel–cadmium was the most popular nickel-based chemistry from the 1950s, but more recently it has been widely displaced by nickel metal hydride due to the toxicity of cadmium. Nickel metal hydride batteries are extensively available for use in consumer products and have been used in many hybrid electric vehicle (HEV) applications. Nickel-based batteries are safer and cheaper than other types of batteries with higher specific energies, such as lithium-ion batteries, but the research and development focus given to technologies such as lithium-ion may quickly change this. As well as having a lower specific energy than other technologies, nickel-based batteries have a high self-discharge rate and a tendency to 'remember' cycle depth unless fully discharged at regular intervals.

Flow (Hybrid or Redox) Batteries

Flow batteries are being used increasingly in the grid energy storage market. The two most popular types of flow batteries are the vanadium redox battery (also known as the vanadium redox fuel cell) and the zinc bromide battery. Unlike a traditional battery, a flow battery has a decoupled energy–power relationship. Energy is proportional to the amount of electrolyte available, whereas power is proportional to the surface area of the electrode. Flow batteries also have a very long cycle life and, if charge capacity is reduced, the battery's electrolyte can be replaced, which eliminates the need to replace the battery structure (containment, electrode, pumps, etc.). Despite their advantages, flow batteries generally have a very low specific energy and their complexity and maintenance requirements are considerable compared to those of other battery technologies.

Molten-salt Batteries

Molten-salt batteries come in various forms, such as sodium sulphur, sodium metal halide and sodium aluminium chloride. In all forms, molten-salt batteries use a high-temperature salt (typically sodium based) as a highly conductive electrolyte. Molten-salt batteries have a very high specific energy and a long cycle life at high depth of discharge, are non-toxic and operate efficiently in most environments. Their key disadvantage is that, for the battery to operate, the sodium-based electrolyte must be fluid or molten. As such, the operating temperature of most molten-salt batteries is above 200°C.

Flywheels

Flywheels have been used for centuries to store energy. The energy stored is proportional to the flywheel's moment of inertia and rotational velocity. As flywheels have been used extensively for intermittent generators (such as the internal combustion engine), it is natural that they be considered for grid energy storage, for which intermittent generation and inconsistent demand are issues. Although flywheels are a simple form of storage, they have low specific energies (about half that of a lead-acid battery) and cannot store energy for long periods of time because of rotational friction losses.

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Hydrogen Fuel Cells

Hydrogen fuel cells combine hydrogen and oxygen to yield water and electrical energy. The hydrogen fuel cell was looked at for some time as the saving grace of the energy storage problem; however, some of the obstacles related to the hydrogen fuel cell are proving difficult to overcome. Hydrogen must be generated through the electrolysis of water and, to be used efficiently as an energy-storage medium, it should be generated using renewables. As renewables have seen a significant uptake only in the past 5–10 years, this has typically not been cost-effective. Additionally, hydrogen must be compressed and stored, which requires significant amounts of materials and energy and has safety issues and high costs.

Pumped Hydro

Pumped hydropower has been used for years and is easily the most pervasive form of grid energy storage. Pumped hydropower, also known as pumped-storage hydroelectricity, is typically used for demand smoothing, which means that water is pumped to a higher elevation during periods of low electricity demand so that it can be reused in a hydropower plant during periods of high electricity demand. Although there are losses associated with pumping and evaporation, pumped hydro is a simple and efficient method for storing energy. Despite its advantages, it is limited by location and scale. Pumped hydro needs a storage location at significant elevation and must be done on a large scale owing to equipment and maintenance costs.

Compressed Air

Compressed-air energy storage has been used in the manufacturing and transportation industry for many years and is a robust and proven technology. In theory, a compressed-air storage unit with perfect isothermal energy transfer has over twice the specific energy of most lead-acid batteries. However, in practice, this is much harder to achieve and the specific energy is typically half that of a lead-acid battery. Compressed-air storage, like flywheel storage, is a simple and long-life mechanism for storing energy, but this storage medium is challenged by its low specific energy and high maintenance costs.

Grid Energy Storage Applications

Grid energy storage can be used for grid forming, grid support, peak-demand management and load shifting, and self-consumption of renewables.

Grid Forming

Grid-forming inverters are used to create micro-grids, supplement areas of the national grid and to regulate the grid's voltage and frequency. Energy storage can be a critical part of how a grid-forming power converter or multimode inverter functions. Traditional micro-grids use a generator to form the grid but, as fossil fuel prices increase, especially in remote parts of the world, it is becoming more common to power villages and communities with renewable energy power systems. To create a stable grid waveform, the power conversion unit (typically a multimode inverter) must draw from a stable and reliable source. The energy storage unit can then be used as a power sink to store energy in times of peak renewable generation and supply energy when the renewable energy systems are not generating.

Grid Support

Increasingly, network providers are choosing grid energy storage in preference to infrastructure development and the associated maintenance and the costs imposed. In many cases, aging grid infrastructure can be maintained simply by adding energy storage and power-conditioning systems. A good example is the single wire earth return (SWER) lines that are part of Ergon's network in Queensland (among others). As infrastructure ages or demand increases, grid quality is potentially reduced. The addition of an energy storage unit can help maintain grid voltage, frequency, power factor, etc. Some of the units are also set up to create islanded grids such that, if the main grid goes down, the portion connected through the energy storage unit stays up.

Peak-demand Management and Load Shifting

Peak-demand management is practised most commonly by utilities and commercial energy consumers. In times of very low consumption, a utility may choose to store energy, typically through pumped hydro, so that it can be used during periods of high consumption. This practice may become increasingly important to commercial customers because a significant portion of their energy bill is based on peak power demand. Demand charges vary, but are typically between $10/kVA and $20/kVA in Australia.

If an energy storage unit is installed, the period of peak demand can be flattened by charging the batteries from the grid (or a renewable energy source) during low periods of demand and using that power to displace the typically high periods of demand (Figure 1).

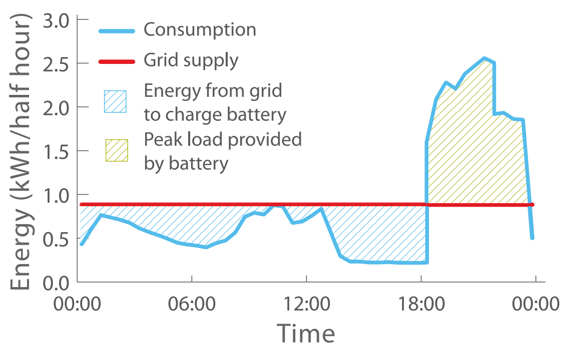

Figure 1: *Flattening peak demand with energy storage.*

In residential applications, peak demand charges typically do not apply; however, a time-of-use meter will often be installed when a solar photovoltaic (PV) system is installed (if the residence does not have such a meter already). To avoid high peak or shoulder tariff rates, an energy storage system can be added. In this way, the storage system can be charged during a low-tariff period and used during a high-tariff period (Figure 2).

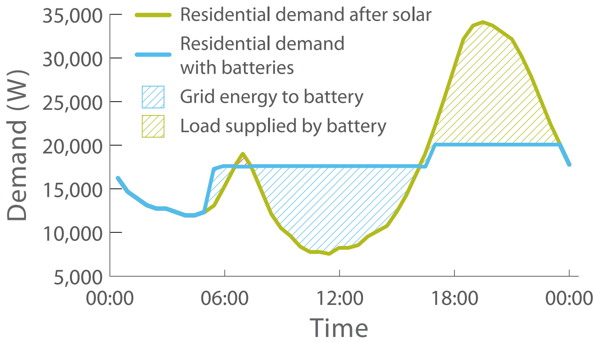

Figure 2: *Charging batteries during low-tariff periods to reduce high-tariff period grid use.*

Self-consumption of Renewables

To offset and protect against the rising costs of grid-supplied energy, it has become increasingly common for residential consumers to install solar PV systems or other renewable energy systems. Often the generation of the PV system occurs at times of low demand, such as during the day when home owners are at work. Instead of exporting that energy to the grid for low or potentially no benefit, many residential consumers choose to store that excess energy to be used during higher periods of demand such as the evening. Figure 3 illustrates how storage can shift generation into periods of higher demand.

Grid Energy Storage Key Market Movers

The critical caveat to this section is that there is the possibility of a market niche for every battery technology described in this article. However, when specifically targeting the residential and commercial building market, some predictions can be made.

Compressed-air storage has attracted a lot of interest. Companies such as LightSail Energy have devised a method of heat transfer to improve round-trip efficiency and cost-competitiveness.

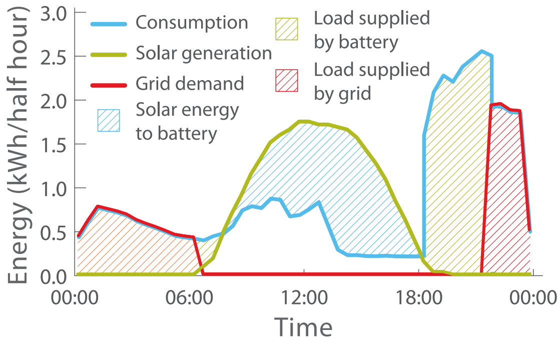

Figure 3: *Using storage to shift self-generated power use to peak periods and decrease grid use.*

Although these systems may have a bright future for utility-scale power, they do not fit well to the residential or commercial space.

Pumped hydro has much the same issue as compressed air. It is extremely successful in the utility energy storage market but is not being developed for the commercial or residential markets.

Hydrogen fuel cells have long been the hope for the clean energy future. Companies like AREVA have developed turnkey solutions for networks that combine an electrolyser, fuel cell and storage system. Although these systems may at some point suit networks, the safety concerns are still too great for wide-scale use in commercial and residential systems.

Flywheels have been used for centuries for energy storage and are currently being investigated for use as grid energy storage. Companies like Velkess Energy Storage and Power Conversion are developing new types of flywheels for use in the residential and commercial markets; however, the flywheel is still largely untested in this arena and has the inherent issues of low specific energy and retention.

Molten-salt batteries are being developed by some of the major players in the energy industry, such as GE with its Durathon battery. There are enticing benefits available from molten-salt batteries and they represent a great solution for many utility-level and telecommunications applications. However, for commercial and residential usage, the safety and maintenance risks may be too great a hurdle to overcome.

Like molten-salt batteries, flow batteries also have some very enticing benefits. They are generally a lot safer than molten-salt batteries and, as such, they have been used in some commercial and residential applications already (for example, the Redflow battery used in Ausgrid's Smart-Cities campaign and the ZBB battery used in the new UTS Broadway building). However, the complexity of these batteries and their high maintenance costs still do not make this an attractive option beyond the few pilot projects that have gone forward.

> *“Lithium-ion batteries are the major contenders in the residential and commercial market for grid storage.”*

Nickel-based batteries have had a resurgence of attention recently because of their safety and stability. Companies like BASF are pushing the limits of nickel metal hydride technology to increase specific energy and cycle life. Nevertheless, with the strong market focus on the potential of other technologies like lithium-ion, nickel-based batteries may find it hard to compete in the market.

Lithium-ion batteries are the major contenders in the residential and commercial market for grid storage. Major companies like Tesla, Bosch, Samsung and Exide have strongly committed to this technology. As manufacturing costs come down and safety is increased, there may be no stopping this new and exciting technology.

The only thing that could be more attractive than a new energy storage technology is a significant advancement to an existing one. Companies like Ecoult, which developed the CSIRO Ultrabattery, have managed to take the tried and tested VRLA battery and increase its depth of discharge and cycle life substantially.

Energy Market Disruption Timeline

It is difficult to predict when grid energy storage will gain market hold across various sectors, but focussing on a small sample set may provide a guide to when this may happen. Retail energy rates of small commercial and residential energy consumers in New South Wales were reviewed against the levelised cost of energy (LCOE) of solar, solar with lead-acid batteries and solar with lithium-ion batteries. Focus was given to lead-acid and lithium-ion because these two technologies seem to be the front runners in the storage race, as discussed above. As can be seen in Figure 4, solar alone is significantly cheaper than retail energy (and has been for some time). Solar with lead-acid batteries will become cost-competitive with retail energy in about 2017 and solar with lithium-ion batteries will achieve parity with retail energy in approximately 2019. If these two sectors are indicators for what will happen globally and are forbearers of the utility and industrial markets, we could see ubiquitous grid energy storage before the end of the decade.

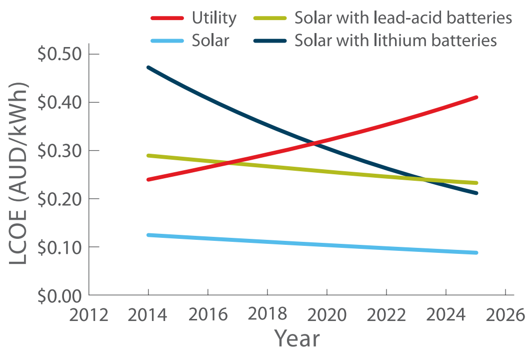

Figure 4: *Utility LCOE against solar and solar with battery storage.*

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