CHAPTER 6

ENERGY STORAGE IN THE ANTIPODES

Building Australia's New Batteries

Max E. Easton and **Thomas Maschmeyer,** University of Sydney and Gelion Technologies Pty Ltd

Although renewable energy sources such as wind and solar have matured to become a proven component of national energy grids, in countries such as Australia they are still only minor contributors. The missing link in the transition from fossil-based to renewable energy is energy storage—a suite of technologies designed to act as an energy buffer for intermittent power sources, enabling grid stability. However, current energy storage technologies rely on technologies largely optimized for mobile devices or power applications rather than energy applications. There is a large gap between the need for energy storage batteries and the market's need for batteries designed to act as a low-cost, reliable buffer system. This is especially the case for solar photovoltaic installations, which need to bridge times when there is no sunlight to be used as a 24/7 energy solution. This gap between what is currently feasible and what is needed is creating an opportunity for disruptive energy storage technologies to enter the market and boost renewable energy adoption.

This chapter explores some of the opportunities and challenges involved in introducing disruptive energy technologies to the contemporary energy space and reflects on experiences introducing new technologies to Australia's innovation environment. The chapter then looks at some of the diverse requirements for energy storage technologies and the difficulties legacy technologies have in meeting those demands, before discussing an exciting innovative approach to basing new, innovative technologies on the principles of adaptability, affordability, and safety.

Storage: The main challenge for renewable power sources

The energy industry has been in a state of rapid evolution over recent decades. Although concerns around the negative environmental impacts of fossil fuel use are often cited as the force driving the industry towards renewable power sources, alternative energy sources such as solar and wind-derived power generation are making their own case financially. Rapidly falling costs and increasing efficiencies are creating a new regime wherein renewable energy is not just a 'green alternative' but a commercially highly competitive approach when compared with conventional fuel sources on a dollar-for-dollar basis.

A positive feedback loop appears to be materializing, making renewable energy impossible to ignore. Renewables, such as solar photovoltaic energy, have seen massive decreases in costs over the past several decades; these lower costs have combined with rapidly increasing energy efficiencies. Wind power now has greater generation capacity, with every doubling in turbine size approximately halving its manufacturing costs.[1] Technologies for previously fringe energy sources, such as tidal and geothermal power, are all entering the market as genuine players in the contemporary energy space.

Consequently, renewable power sources are moving from minor contributors to national energy supplies to noticeable

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contributors in many places around the world (e.g., Germany now gets 27% of its energy supply from renewable sources). Australia, with its renewables contribution of 5% wind and solar currently at only 3% of its total need, can see this as a substantial growth opportunity.[2] A key limitation to widespread adoption lies not in the wind and solar technologies themselves (which can be considered reasonably mature), but in the drawbacks of the natural source of energy of which they make use. The intermittency of solar (with its day/night cycles and its dependence on cloud conditions) and wind (which is determined by meteorological variations such as 'gusting' winds) has had these sources pigeonholed as secondary power sources that can be used only as grid support, not as baseload replacements. Clearly, a solution that brings renewable energy as a contender into (partial) baseload replacement is the world of electrochemical energy storage: batteries.

Batteries represent a well-known technology. They are used to power portable devices such as smartphones and laptops; they also have larger-scale applications in the transport arena, where the storage technologies present solutions that range from simple batteries to operate starter motors in internal combustion engines to those used in hybrid and fully electric vehicles. Batteries function by storing electric energy as chemical potential energy through carefully designed chemical reactions. Passing an electrical charge into the device creates a high-energy chemical state that can be reversed at will by drawing that charge out again. Different battery chemistries have different advantages, with some being more useful in high-power applications (these are able to discharge quickly, but need to avoid fully discharging to keep battery health); others are more useful in energy storage applications (these are 'slow and steady', and utilize deep or full discharge). Important, but often ignored, is the complication that using one battery type in the primary field of application of another battery type can lead to significant problems regarding longevity, efficiency, and safety.

Coupling renewables with batteries is sometimes posited as a revolutionary new idea for future energy grids, but it is noteworthy that this was, in fact, proposed alongside some of the first solar panels ever designed. As far back as 1885, American engineer Charles Fritts stated, in reference to his selenium-based solar cell:

> The current, if not wanted immediately, can either be 'stored' where produced, in storage batteries [...] or transmitted over suitable conductors to a distance, and there used, or stored as usual till required.[3]

Clearly, the worlds of renewable power generation and energy storage have been intertwined from the very beginning. Energy storage has long been seen among the scientific and engineering community as a foundational aspect of renewable power supply.

Energy storage might contribute to energy networks in many ways. The obvious example, and the one Fritts suggested in 1885, is what is referred to as 'load levelling'—that is, excess solar power that has been stored in a battery during the day can be returned for use in the evening. Alternatively, excess (thus cheap) power at any time of the day can be stored and released when the price is more attractive (energy arbitraging). Such load-levelling schemes can be very sophisticated and powerful and can interact positively with the overall grid, increasing resilience and efficiency. Other applications include improvement to power quality; that is, batteries can also modulate voltaic and harmonic distortions between the generator and the end user, thus improving the quality and reliability of the power.

Innovations in storage technologies

Although significant progress in energy storage technologies has been made over recent decades, activities have been primarily focused on the optimization of small-scale applications (primarily in personal devices and electric vehicles). Clearly, however, coupling batteries with energy generation using solar photovoltaic and wind sources will form the backbone of renewable baseload power.

An innovative approach is that of Tesla, which uses batteries designed for power applications and deploys them for grid support and, to a certain extent, for energy storage. Tesla's 100 megawatt (MW) lithium-ion battery installation in South Australia has shown that it is indeed possible for large-scale energy storage to operate in tandem with the energy grid. So far, the battery array has provided 2.42 gigawatt-hours (GWh) of energy back to the grid with a round-trip efficiency of 80% over one month's operation.[4] This performance is creating optimism for energy storage in Australia with the perception that other significant storage projects are being buoyed by this success. However, it is important to use power batteries in a peak-modulation mode, using them to provide fast responses intermittently because that suits the battery chemistry employed. Daily, deep full-cycling of such batteries will reduce their lifetimes dramatically, since it will accelerate the effects of internal failure mechanisms inherent in their chemistry.

Other chemistries and modes of operation, such vanadium redox flow (Ronke Power) and zinc bromine flow (Redflow), have advantages in that they can be cycled at full discharge and are designed as true energy batteries. Flow batteries operate by cycling a liquid electrolyte, stored in tanks, through a battery electrode system, which is thought to increase longevity and robustness. Gelion's technology is able to capitalize on the attractive chemistry of zinc-bromine in a novel non-flow system based on ionogels with a more convenient and conventional battery footprint.

Furthermore, in the case of lithium-ion batteries, the availability of their primary electroactive components—particularly lithium and cobalt—is expected to face bottlenecks. Currently exploited lithium reserves are largely isolated in Argentina, Bolivia, and Chile, a region referred to as 'the lithium triangle.' New mining capacity elsewhere in regard to lithium might overcome this obstacle. Australia is well placed to benefit from this trend, since it is estimated to hold up to a third of the world's reserves. However, access to cobalt—the other essential chemical in lithium-ion batteries—remains a primary concern for the most commonly employed (and least expensive) types of lithium-ion batteries, given the limitation in international mining capacity and geopolitical concerns, with more than 70% of known reserves located in the Democratic Republic of the Congo. The expected pressures that come with rapidly increasing demand are creating possible long-term challenges in lithium and cobalt supply. This pressure is already starting to be felt—for example, the price of cobalt has gone from US$21,750 per metric tonne in February 2016 to US$92,250 in March 2018.[5]

Indeed, recent modelling by Australia's Office of the Chief Scientist has shown that using the total world's battery production capacity in 2014 (including all commonly produced battery chemistries, such as lithium-ion, lead-acid, etc.), would translate into only 11 minutes and 27 seconds of global electricity consumption stored. The scale is such that the production capacity of Tesla's gigafactory, which began operation in 2017, would need to improve its output by 184 times to provide just one day of back-up power supply.[6] It is clear, then, that new, accelerated thinking is required for this evolving energy paradigm.

From both a materials and a technological perspective, alternatives are needed to supplement current market offerings. Not all energy consumers have the same needs, and not all battery chemistries can meet all the demands placed on them. The requirements of power generators, end users, and every intermediary point are incredibly varied. Existing technologies may not be able to provide the versatility and scalability required without the availability of new technologies. These new technologies, able to adapt and meet the manifold demands made on them, are urgently needed.

The evolving energy space requires innovative new storage technologies based on three main tenets:

- **adaptability** to varied energy battery demands based on modular designs;
- **affordability** based on low up-front cost coupled with a long lifetime, translating to a very low levelized cost of energy storage; and
- **safety** inherent to the chemistry used.

In this context, non-flow batteries are more flexible and cost-competitive than flow batteries for anything other than the very large scale of hundreds of megawatt-hours (MWh), where the utility of flow batteries are yet to be proven.

Modular designs eliminate much of the engineering overhead associated with specific solutions for differently sized applications—for example, when using a simple standard battery cell, different applications are easily accessible by changing the battery cell's connectivity.

Zinc-based batteries are significantly cheaper in terms of materials cost and safer than lithium-based ones. They are also less toxic than lead-acid batteries and do not present a fire hazard.

Design tenets within the Australian context

In the 1980s the University of New South Wales began to develop the vanadium redox flow battery, with a series of commercialization efforts just falling short in the ensuing decades (a reflection of the coal-first energy paradigm of the 1980s and 1990s). However, development of this battery continues optimistically today, and two utility-scale units are being built in China: one with a capacity of 100 MW and 500 MWh in Hubei,[7] and one with a capacity of 200 MW and 800 MWh in Dalian for US$500 million.[8]

In the early 2000s, Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) developed a hybrid supercapacitor, which has now been commercialized by Cap-XX,[9] and a lead-acid battery termed the UltraBattery that is in early production today.[10] Similarly, Brisbane-based Redflow is successfully manufacturing zinc-bromine flow battery systems.[11]

Most recently, in 2016, Gelion Technologies reported a non-flow variation of the zinc-bromine chemistry.[12] These batteries are in the early stage of commercialization, and beta versions are expected to be sold for evaluation purposes in 2019; initial mass production is scheduled for 2020.

When paired with solar power, the non-flow zinc bromine battery's ability to combine deep discharge resilience with a low price, even at capacities as small as 2 kilowatt-hours (kWh), as well as safety and a high degree of recyclability is a compelling proposition. Gelion's aim is to produce battery cells that cost less than US$100/kWh to manufacture. The objective is to supply a range of different solar photovoltaic applications, including street lighting, solar pumps, micro-grid support, and, eventually, fully scalable solutions in stackable shipping containers (e.g., Tesla's batteries in South Australia).

The expected market growth, in combination with some of the inherent limitations of the established energy storage technologies, means that the time has come for disruptive energy technology in Australia and throughout the world.

The changing regulatory environment favours energy storage as a necessary buffer that will allow the introduction of renewables while retaining grid stability. There is a clear mandate both from business (e.g., Australia's AGL Energy) and consumers to enable a greater portion of renewables in the Australian energy mix. Indeed, the Australian government's 2017 *Independent Review into the Future Security of the National Electricity Market* officially acknowledged energy storage as being a vital contributor to future energy systems.[13] The report contains a range of recommendations, including a key one about price settlement periods that pertain to the adoption of battery and pumped hydropower storage to enable renewable energy adoption. These recommendations immediately led the Australian Energy Market Commission (AEMC), which regulates the market, to draft an essential rule change for the adoption of energy storage that substantially alters Australia's National Energy Market (NEM).[14]

NEM operates on complicated operative rules, a core issue of which revolves around the 'consumer-first market approach' where the price point is averaged over a 30-minute settlement period to determine the cheapest energy supplier. Designed in the absence of renewables and substantial energy storage, this 30-minute rule aimed at protecting the consumer resulted in unintended favouritism towards mature fossil fuel–based power sources. One of the key advantages of batteries lies in their near instantaneous supply of power, meaning that the fossil-fuel advantage is diluted when normalized to the other sources over a 30-minute settling period because it negates much of the disadvantage of coal-fired power plants' lag time in energy provision. The AEMC's rule change has confirmed a reduction of the settlement period from 30 to 5 minutes, starting in 2021. This change will enable agile, fast-responding technologies to compete and open the door to electrochemical energy storage becoming highly cost competitive in Australia's utility sector. However, even this rule may be insufficient: Tesla reports being underpaid as a result of their very fast (200 milliseconds) response times, and further fine-tuning of market rules can be expected as more players and greater capacity come onto the market.

Australia: An environment where energy storage innovation can thrive

With a focus on adaptability, affordability, and safety, new market entrants are an attractive prospect for future energy storage systems. The expected market growth, in combination with some of the inherent limitations of the established energy storage technologies, means that the time has come for disruptive energy technology in Australia and throughout the world.

The combination of Australia's highly suitable weather conditions for renewables, a history of innovative thinking, an interest in adopting energy storage technologies, and a positively evolving regulatory environment make Australia an ideal place for the rapid penetration of batteries into its national energy landscape. Increasing investor confidence that is providing Australian companies with the capital to explore such disruptive technology is creating rapid growth in the development of renewables and batteries.[15] This enables Australian technology to play a significant part in the future of energy supply.

Notes

1 Clark, 2018.

2 Department of the Environment and Energy, 2017a.

3 Fritts, 1885.

4 McConnell, 208.

5 See www.lme.com/en-GB/Metals/Minor-metals/Cobalt.

6 Cuthbertson and Howard, 2016.

7 Information about Pu Neng, the site of this battery, is available at www.punengenergy.com.

8 Further information about the unit in Dalian is available at www.rongkepower.com (in Chinese).

9 Further information about CAP XX is available at www.cap-xx.com.

10 Further information about UltraBattery® is available at www.ultrabattery.com.

11 Further information about Redflow's storage systems is available at www.redflow.com.

12 Further information about Gelion is available at www.gelion.com.

13 Department of the Environment and Energy, 2017b.

14 Information about Australia's Energy Market Operator (AEMO) is available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM.

15 An example of investor confidence is the partnership that created the Powering Australian Renewables Fund; information about this fund is available at https://www.agl.com.au/about-agl/what-we-stand-for/sustainability/powering-australian-renewables-fund.

References

AEMC (Australian Energy Market Commission). 2017. 'Five Minute Settlement – Rule Change: Completed, Overview', 28 November. Available at https://www.aemc.gov.au/rule-changes/five-minute-settlement.

Clark, P. 2018. 'Bigger, Higher and Floating: Advances That Make Wind a Better Power Source'. *Financial Times,* 8 January. Available at https://www.ft.com/content/b7b7f8a0-cb06-11e7-8536-d321d0d897a3.

Cuthbertson, B. and W. Howard. 2016. 'Backing Up the Planet: World Battery Storage'. Office of the Chief Scientist of Australia. Available at http://www.chiefscientist.gov.au/2016/10/backing-up-the-planet-world-battery-storage/.

Department of the Environment and Energy, Australia. 2017a. *Australian Energy Update 2017.* Canberra. Available at https://www.energy.gov.au/publications/australian-energy-update-2017.

——. 2017b. *Independent Review into the Future Security of the National Electricity Market: Blueprint for the Future.* Available at https://www.energy.gov.au/government-priorities/energy-markets/independent-review-future-security-national-electricity-market.

Fritts, C. E. 1885. 'On the Fritts Selenium Cells and Batteries'. *Journal of the Franklin Institute* 119 (3): 221–32.

McConnell, D. 2018. 'A Month In, Tesla's SA Battery Is Surpassing Expectations'. ReNeweconomy, 16 January. Available at http://reneweconomy.com.au/month-teslas-sa-battery-surpassing-expectations-41248/.