March 2020

CHARGED UP

The uptake of batteries in Australia and implications for NEM energy market policy

Engineroom
Infrastructure Consulting

This project was funded by Energy Consumers Australia (www.energyconsumersaustralia.com.au) as part of its grants process for consumer advocacy projects and research projects for the benefit of consumers of electricity and natural gas.

The views expressed in this document do not necessarily reflect the views of Energy Consumers Australia.

Contents

Table of figures and graphs

List of abbreviations

ACOLA: Australian Council of Learned Academics

AEMC: Australian Energy Market Commission

AEMO: Australian Energy Market Operator

ARENA: Australian Renewable Energy Agency

CALC: Consumer Action Law Centre

CPRC: Consumer Policy Research Centre

DEIP: Distributed Energy Integration Program

DER: Distributed energy resources

DNSP: Distribution Network Service Provider

ENA: Energy Networks Australia

ESB: Energy Security Board

EV: Electric vehicle

FCAS: Frequency Control Ancillary Services

FFR: Fast frequency response

IRENA: International Renewable Energy Agency

ISP: (AEMO's) Integrated Systems Plan

NEM: National Energy Market

PIAC: Public Interest Advocacy Centre

TEC: Total Environment Centre

TNSP: Transmission Network Service Provider

TOU: Time-of-use

VPP: Virtual Power Plant

Chapter One: The current landscape

1.1 Introduction

The purpose of this report is to inform consumer understanding about the likely timing of the uptake of batteries that allow users and market participants to store energy. This is important since, as AEMC noted recently:[1]

> *The prevalence of behind the meter residential batteries in the retail market is growing with the declining cost of battery technology and the introduction of government subsidy schemes. This is likely to disrupt the retail market and provides both an opportunity and a challenge similar to the rise of residential solar PV installations in the early 2000s.*

The emergence of batteries in significant numbers will have an impact on the national energy market (NEM), supporting more renewable generation, affecting demand for transmission and distribution services, and requiring rules around integration of customer generation within the NEM. This report explores the future of the NEM with a particular focus on the policy implications stemming from the uptake of batteries, including current NEM arrangements that may need to be revised to maximise consumer benefits.

Batteries form one part of a range of storage technologies that are emerging in energy markets around the world. They have the potential to disrupt existing methods of energy delivery by supporting intermittent renewal generation sources, and in particular, distributed generation sources. They can support voltage control, reduce transmission congestion, and enable users to rely on battery use at times when tariffs are high, and recharge when tariffs are low.

In fact, batteries provide so many potential services, that the policy question is constructing a market that enables each of these services to be valued. Doing so is important, as batteries are likely to require multiple revenue streams to justify their high upfront cost. Access to some of these revenue streams appears to be difficult under current National Electricity Rules.[2]

[1] AEMC 2019c, p. 148

[2] The National Electricity Rules are the rules that have been adopted uniformly across the States and Territories that are part of the NEM. They set out the arrangements for physical and financial operation of the NEM.

The policy focus for designing a market that optimises the value of batteries is identifying and assessing the suitability of the National Electricity Rules for the introduction of batteries.

1.2 Types of storage

Batteries are one of five types of storage technologies in energy markets, with a range of battery types used across contexts from reserve and response services, supporting the transmission and distribution grid, and providing bulk power management (See Figure 1, below). Other key types of storage include mechanical sources of storage such as pumped hydro. From Figure 1 it is noticeable that batteries offer the widest dimension of services compared to other forms of storage.

These different storage options fulfil different needs in the energy market. Batteries that deliver a few hours of energy storage are sufficient for the purposes of supporting the NEM in smoothing peaks and troughs and distributing renewable energy. Large scale deep storages, such as hydro power, however, provide longer-term power system security and resilience because they can continue to operate for a significant time (e.g. Snowy 2.0, a major pumped hydro project with a capacity of 2,000 MW, is forecast to store about one week of storage).[3] AEMO note that only deep storage can provide both daily and seasonal energy shifting while batteries typically exhaust after supplying power to cover daily peak loads.[4] For this reason, AEMO views it as ideal that there is a diversified portfolio of different types of storage to meet the varying needs of the market to meet daily peaks and to provide security and resilience to weather variability and climate change.[5]

Among batteries, there are many options (as illustrated in Figure 1) including lead acid, lithium-ion, zinc bromide flow, and sodium nickel chloride molten salt batteries (CSIR0, 2015). Having said that, the consensus in the academic literature (as well as in discussions with consumer groups) is that lithium batteries were likely to become the dominant chemistry for batteries.[6]

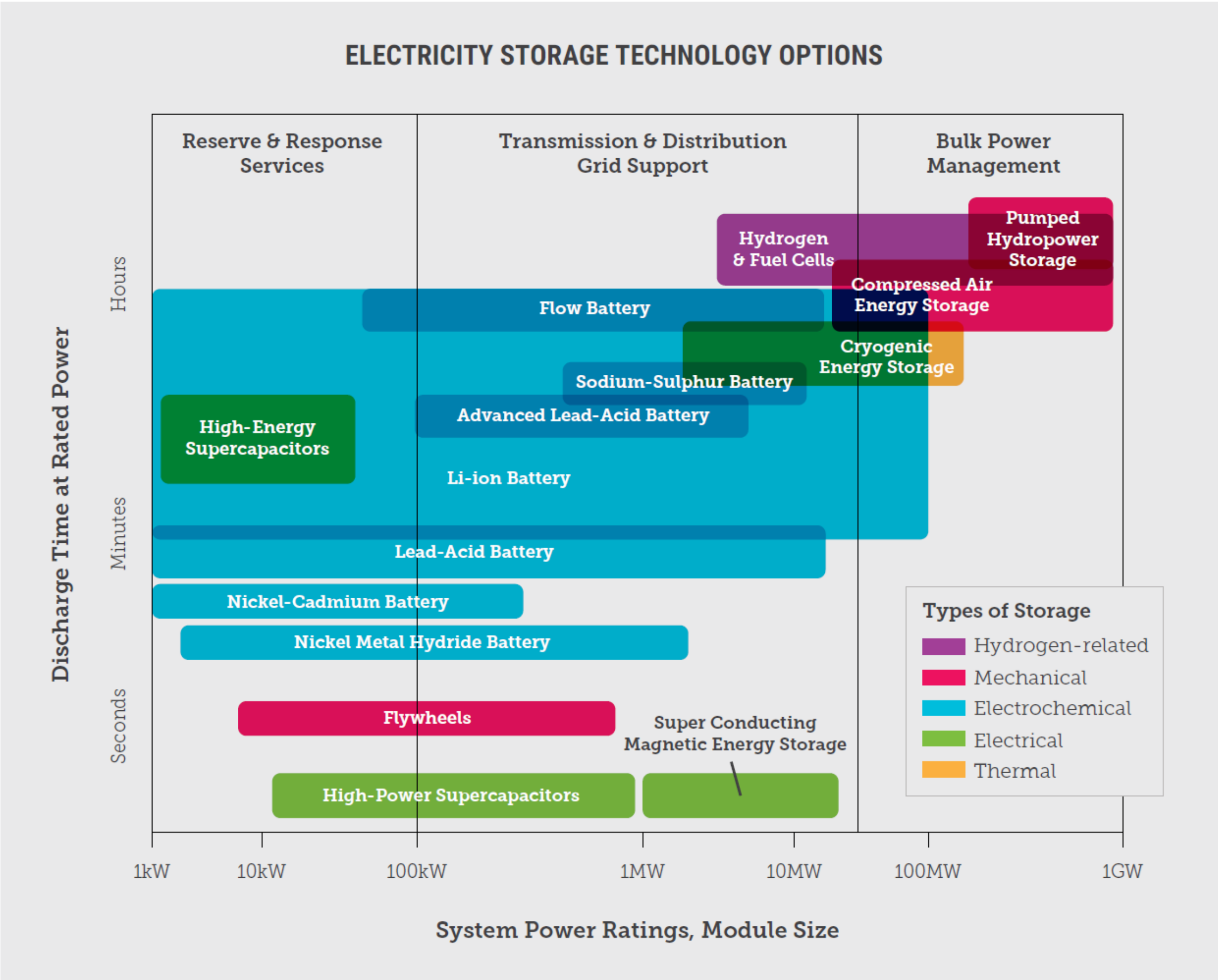
A battery's chemistry affects factors such as: [7]

- **Depth of discharge** – the amount of energy that is actually usable in a battery. While this is not a hard limit, after a battery is "beyond its depth of discharge, its performance tends to degrade." For example, lithium batteries can be discharged to near their full capacity while lead-acid batteries (e.g. car batteries) can only be discharged a few percent before their performance tends to degrade.
- **Cycle life** – the "number of cycles of complete discharge down to depth of discharge that a battery can go through before its performance degrades substantially".
- **Round-trip efficiency** – the percentage of energy a battery releases relative to the energy required to recharge it. For example, it is estimated that it takes about 15 kWh to charge a 13.5 kWh Tesla Powerwall 2 battery.
- **Rate of discharge** – the rate in kWh or MWh at which the battery can discharge.
- **Safety** – some battery chemistries are more unstable that others.

[3] AEMO 2019a, p. 6
[4] AEMO 2019a, pp. 7-8
[5] AEMO 2019a, p. 9
[6] E.g. Schmidt et al 2019, Renew 28 October 2019
[7] Generally, see CSIRO 2015, pp. 31 – 32 for both quotes and concepts in the following dot points. Also see https://batteryuniversity.com/learn/archive/whats_the_best_battery

Lithium ion batteries are expected to dominate over other chemistries as they have good performance across these factors, although they can be fragile and require a protection circuit board to assure safety.[8]

FIGURE 1: ENERGY STORAGE TECHNOLOGIES[9]



1.3 Services provided by storage

An important feature of batteries compared to other components in the electricity supply chain is the wide variety of services that they can provide compared to other energy market infrastructure. AECOM noted that batteries can provide services in time-of-use load shifting, back-up security, wholesale arbitrage, fuel saving, ancillary services, demand management incentives, network investment returns, power quality, and grid stabilisation.[10]

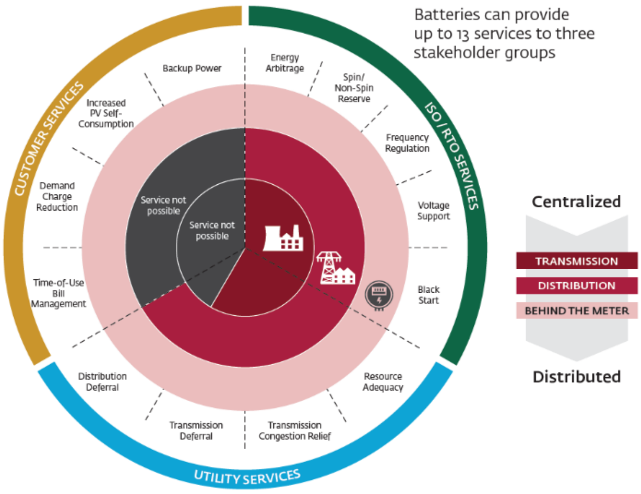
[8] See https://batteryuniversity.com/learn/archive/whats_the_best_battery

[9] Climate Council of Australia, 2018, p. 19

[10] AECOM 2015, pp. 18-21

In Figure 2 below, the International Finance Corporation illustrated the range of services provided by batteries.[11] These services lie across transmission and distribution investment deferral, ancillary services such as voltage control and black start, and customer services such as increased PV self-consumption and time-of-use bill management.

FIGURE 2: BATTERY ENERGY STORAGE VALUE CHAIN - UPSTREAM PORTION: UTILITY-SCALE AND BTM



(Source: Rocky Mountain Institute's The Economics of Battery Energy Storage)

Figure 3 below shows the wide range of applications for batteries and other storage behind-the-meter.

AEMC categorized battery services into four areas:[12]

- **Demand:** reduce their reliance on the grid, maximise the value of their solar PV system, provide back-up supply or arbitrage their retail tariff. These services are described as 'customer services'.
- **Network support services**: DNSPs or Transmission Network Service Providers (TNSPs) may procure the services provided by batteries to help them provide distribution or transmission services. For example, batteries are capable of reducing peak load in order to defer network augmentation, or to help manage the technical characteristics of their networks.
- **Wholesale market services**: Electricity retailers may use the electricity generated and/or consumed by distributed energy resources (DER) in aggregate to manage their risk of participating in the NEM, or for actual participation as a generator in the NEM.
- **Frequency Control Ancillary Services (FCAS) market services**: Other parties may use DER to provide ancillary services, such as frequency control, to AEMO. Frequency control or FCAS is the group of services that help maintain the power system at 50 cycles per second (50 hertz). It involves the fast injection or fast reduction of energy to manage supply and demand.[13]

---

[11] International Finance Corporation, (2016), pp. 13 and 18

[12] AEMC 2019c, p. 151

[13] See ARENA website at https://arena.gov.au/blog/what-is-frequency-control-ancillary-services/

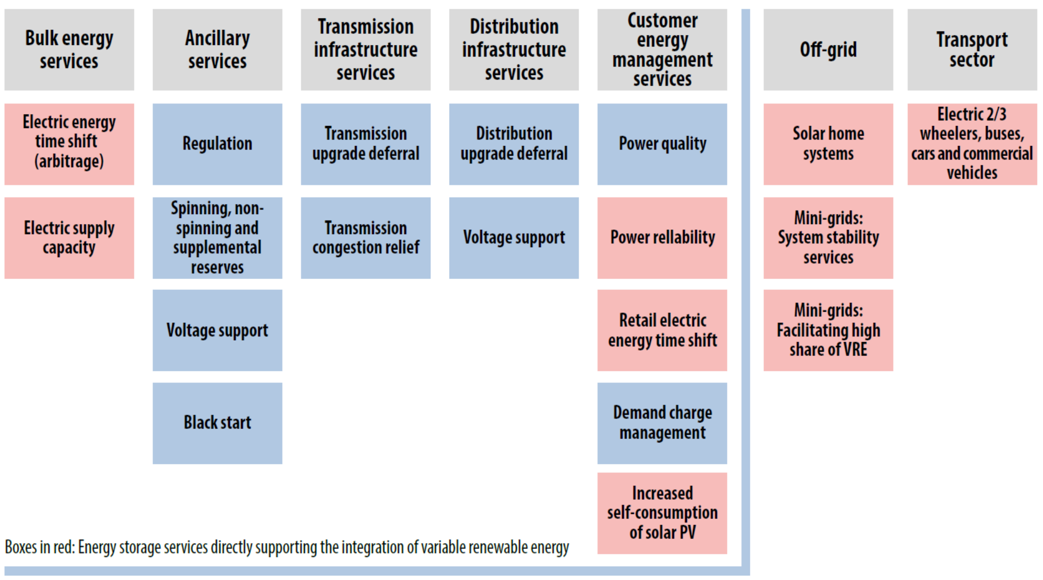
FIGURE 3: BEHIND-THE-METER ENERGY STORAGE APPLICATIONS[14]

Market Drivers	Customer Applications	Description/Benefit
Rising electricity rates, increasing electric vehicle (EV) use, increasing energy management system use	Demand charge reduction	Respond automatically to building load spikes—reduced electricity expenses
	Time-of-use (TOU) energy bill management	Manage charging and discharging based on retail electricity rates—reduced electricity expenses
Increasing solar PV installations	Onsite generation self-consumption	Maximize consumption of onsite generation, primarily solar PV—reduced electricity expenses
Need for resiliency/power quality	Backup power/improved power quality	Protect sensitive equipment from power quality fluctuations/outages—ensure operability during grid outage
Grid stability concerns and capacity needs	Ancillary services	Provide frequency regulation, voltage support, electric supply reserve capacity, etc.—improved efficiency of centralized generation, smoother integration of variable generation
	Demand response (DR)/	Manage charging and discharging based on retail electricity rates—reduced electricity expenses
New utility infrastructure needs	Transmission and distribution investment deferral	Limit investments in new infrastructure through reduced peak demand

IRENA, the International Renewable Energy Agency, identifies a range of services provided by energy storage, including batteries[15]. These are presented in Figure 4, below.

FIGURE 4: THE SERVICES PROVIDED BY ENERGY STORAGE INCLUDING BATTERIES

Figure ES1: The range of services that can be provided by electricity storage



Storage allows for greater flexibility in generation options by providing for the storage of excess generation for later use. In particular, storage allows for greater penetration of utility-scale

[14] Source: International Finance Corporation, (2016)
[15] IRENA 2017, p. 11

renewable generation and distributed energy generation. For example, storage can store generation from solar panels during the day for use at times of peak demand, which for residential users is typically around 6 pm to 9 pm.[16] While storage is not itself a generator, it can become a generator in effect through storing excess generation and then discharging that storage into the market.

Storage can also provide short-term voltage support to enable markets to ride through sudden changes in supply or demand that would otherwise result in a mismatching of supply and demand. Historically, this service was provided by spinning reserve in coal and gas turbines (the mechanical inertia of turbines), or by hydro power (which can react very quickly to dispatch instructions to increase or lower output in order to rematch supply and demand). As these forms of generation become a smaller part of the future generation portfolio, batteries and other forms of storage will assume increased importance in providing these services.

Battery systems can be the most cost-effective option to stabilise the grid, provided they have the appropriate power electronics to deliver the 'fast frequency response' (FFR) needed by the grid, and are ready for immediate discharge when required. By comparison, where geology and water availability permit, large-scale energy storage by pumped hydro is currently most cost effective for delivering energy reliability.[17]

Given the wide range of services provided by batteries, the key focus in removing barriers to entry of batteries into the NEM is providing value for all of these value streams for battery owners.[18] To borrow the terminology used in a number of publications, it is important to construct a market where all of the value streams provided by batteries can be 'stacked' on top of each other to provide a total revenue stream that justifies the upfront cost of the battery.[19]

1.4 Unique features of battery storage

There are many forms of storage to suit different applications, and storage can be installed at many places in the electricity supply system. Dr Lachlan Blackhall of the Battery Storage and Grid Integration Program nominated three main places where batteries might be installed: (i) behind the meter at a residential or business address; (ii) in front of the meter in a large scale utility connected to the transmission or subtransmission grid; and (iii) at a suburban level (such as at a distribution substation or in a community battery/energy park).[20] It was noted by Renew that community-scale batteries are significantly cheaper than behind-the-meter batteries in per kW terms due to their larger scale (perhaps 15 c/kWh compared with 35 c/kWh).[21]

Behind-the-meter energy storage will increase as more consumers choose to take control of their electricity needs. Those consumers already utilising solar energy will see the opportunity to maximise the yield from their solar installation, and there is an increasing possibility of microgrids being established. These types of deployment offer opportunities for aggregation of distributed storage assets to boost security and reliability, particularly at the local distribution level in electricity networks.

[16] ACOLA 2017, p. 81
[17] ACOLA 2017, p. 36
[18] AEMC 2019c, p. 149
[19] See e.g. Rocky Mountain 2015, p. 32, Clean Energy Council 2019a, p. 8-18
[20] Battery Storage and Grid Integration 25 November 2019, Renew 28 October 2019
[21] Renew 28 October 2019. See section 2.9 for further discussion about community-scale batteries

Another unique feature of batteries is that battery storage can be constructed very quickly compared to traditional generation,[22][23] and it can be moved after construction. This distinguishes batteries from other forms of generation, which tend to be fixed and take many years to receive the necessary planning and environmental approvals to be built. Moreover, other forms of generation (e.g. coal plant) cannot be moved once installed.

The ability of batteries to support a range of services means that they can see seen as a 'platform' technology, that is a technology that enables a range of other technologies. For example, batteries can facilitate additional types of generation (renewable), changes in the grid (reductions in capacity), and improvements in voltage quality.

1.5 Potential impact of batteries on the NEM

How might the NEM look after the widespread adoption of batteries?

In broad terms, the following developments are likely:

- There should be lower peaks and shallower troughs in demand over the day and over the year as batteries charge during times of peak solar and wind generation and discharge during times of peak demand. The impact of this is a reduced requirement for augmentation of distribution networks.
- Batteries will support more intermittent renewables in the generation portfolio by soaking up excess renewable generation at times of peak renewable generation (with additional transmission lines to connect areas rich in renewable assets).
- It could be expected that there might be more microgrids at the fringe of the distribution network as local generation options become more affordable than extension of the distribution grid.
- The grid should experience improved resilience to sudden changes in voltage or demand since batteries and other forms of storage can react almost instantaneously to signals to increase or decrease power into the market in order to match supply and demand.[24]
- There may be less need for export limits on the generation that can be exported from distributed energy resources such as solar panels since batteries soak up excess demand from other forms of DER.[25]

Overall, these developments should facilitate lower energy prices as renewables and batteries fall in price and begin to push out more expensive coal and gas, while also reducing the need for distribution augmentation.

1.6 Current regulatory and policy activity around batteries and storage

A large volume of regulatory work is being conducted by AEMC, AEMO, and other agencies around batteries and other forms of storage.

[22] Fully charged: Renewables and storage powering Australia Climate Council of Australia, 2018, p. 19
[23] For example, Hornsdale Power Reserve announced in November 2019 that it was building a 50 MW/64.5 expansion of its 100 MW/129 battery, and was forecasting the expansion would be completed in the first half of 2020: https://hornsdalepowerreserve.com.au/hornsdale-power-reserve-to-be-expanded/
[24] Total Environment Centre 29-30 October 2019. In the electricity market it is necessary to match supply and demand at all times for the market to function.
[25] At present, many distributors impose grid export limits on the amount of power that DER can export to the distribution grid in order to ensure the stability of the grid.

In 2015, AEMC conducted a review of energy storage and the regulatory implications of integration of energy storage into the NEM. It recommended that batteries should be a contestable service and that distributors should be banned from owning batteries behind the meter in the interests of a level playing field.[26] It also recommended that AEMO:[27]

- investigate any technical limits on small generation aggregators offering frequency control ancillary services by, for example, combining the capability of a number of storage devices behind the meter.
- Review registration categories for aggregators of small, behind-the-meter generators.
- Review technical standards for connection of behind-the-meter batteries.

AEMO's current work streams have picked up these recommendations and focus on measures to integrate DER including both generation and storage into a two-way market.

AEMO recently submitted a rule change request to AEMC seeking to change the NEM rules to accommodate more bi-directional flows by allowing for a registration category for storage devices as 'Bi-directional Resource Providers'.[28] The rule change would allow a new registration category for such devices and clarify the position under the NEM with respect to the types of services that such devices could provide.[29]

AEMO's other work program includes:[30]

- **DER visibility** – publishing a register of all DER from 1 December 2019 to provide it with much better visibility of DER installed across Australia.
- **DER capability** – AEMO has commenced a program of work called the DER Standards Stream, which aims to improve the performance and capability of DER in ways that are consistent across the energy system. For example, AEMO's Technical Integration of Distributed Energy Resources Report, published in April 2019, shared AEMO's preliminary findings to date on the behaviour of DER during disturbances and proposes the development of improved DER performance standards and DER dynamic models. AEMO wishes to ensure adequate tools are in place to manage a high DER world. This work ensures a sustainable, secure and reliable energy supply.
- **Connection framework and technical standards** – AEMO is working with Energy Networks Australia (ENA) to inform the development of a national framework for the connection of distributed resources.
- **Market access** – AEMO is working with the AEMC on changes to the regulatory regime to facilitate DER access to energy, ancillary, and reserve markets.
- **Pilot programs** – AEMO is establishing pilots focused on enabling virtual power plants (VPPs) and aggregated DER to offer energy and frequency services into the market, with these resources being dispatched alongside other resources. A later phase will progress the trialling of a distributed market model, and AEMO will work with distribution businesses to progress this. AEMO opened a VPP Demonstrations program for registration in July 2019.

[26] AEMC 2015, pp. ii-iii
[27] AEMC 2015, pp. iv-vii
[28] AEMO 2019e
[29] As well as whether such devices should pay distribution and transmission charges and market charges
[30] AEMO 2019d, pp. 91-92

- **Open Energy Networks** – AEMO and ENA have commenced a body of work, in consultation with industry, to look at models that enable DER integration and optimisation, considering both transmission and network constraints, and aimed at informing regulatory framework changes.

Energy Networks Australia through the Open Energy Networks program has observed that distributors face challenges in the two-way grid created by flows from solar and other localised DER. Currently, distributors tend to manage DER exports using static controls, such as limits on maximum export. In the future, as DER grows, this may be less feasible and distributors want to improve their ability to manage the grid dynamically, allowing maximum exports that do not breach prevailing constraint conditions. Accordingly, ENA is working to:[31]

- Define the distributor requirements for increased visibility of localised constraints on the network to ensure it can continue to maintain network operations
- Determining the communications requirements to manage these localised constraints; and
- Establishing guidelines for managing operating envelopes for export limits.

AEMC noted that there are a number of regulatory processes under way that would help battery owners to capture value from their batteries:[32]

- **Wholesale demand response mechanisms.** The AEMC is assessing rule change requests to place demand response providers on equal footing with generators in the wholesale market in order to allow them to more readily offer transparent wholesale demand response.
- **Multiple trading relationships**. The AEMC also recommended in the Reliability Frameworks Review that consumers be permitted to engage multiple retailers/aggregators at the same connection point.

Under AEMC's *Coordination of generation and transmission investment implementation – access and charging (CoGaTI) review*, AEMC has also moved to act on changes in the NEM in generation and transmission. AEMC has observed that the NEM is transforming over time from a small number of large and more centrally located generators to a large number of relatively small, flexible, asynchronous and geographically dispersed generators. At the same time networks are becoming more meshed and interconnected across States and Territories.[33] AEMC has postulated that this will require better coordination between transmission and generation to support supply. AEMC has released two position papers:

- A **proposed access reform model** to: (i) introduce dynamic regional (locational) pricing so that large-scale and storage receive signals about where to locate plant (with higher prices for transmission in locations that are more congested); and (ii) rights for generators to buy financial transmission rights to provide hedges against price differentials across zones to protect against changes in prices between zones.
- **Renewable energy zones** to provide clarity around the concept of zones of high renewable generation and how such zones can be better facilitated in the future.

[31] Open Energy Networks 2019, p. 4
[32] AEMC 2019c, pp. 153-154, wording adopted and shortened
[33] See AEMC's Coordination of generation and transmission investment implementation – access and charging review at https://www.aemc.gov.au/market-reviews-advice/coordination-generation-and-transmission-investment-implementation-access-and

Following this, in March 2020 AEMC released three papers:[34]

- A **transmission access reform** update paper providing an overview of the access model's features and how AEMC will develop and model the proposed access reform as part of Energy Security Board (ESB) market design work during 2020.
- A **technical specifications** report that provides a detailed blueprint of the current transmission access model.
- A **benchmarking study** conducted by NERA on the benefits and costs of transmission access reform based on lessons from other jurisdictions. The study estimates reform benefits considerably outweigh costs.

Under these reforms, AEMC proposes to introduce locational marginal pricing and financial transmission rights in the NEM. These arrangements would in effect increase the cost of generation for remote generation compared to generation near to customers. This would provide increased incentives to locate generation near to customers where possible. As batteries can be collocated with customers, the reforms would encourage the adoption of batteries.

AEMC also noted a number of recent regulatory changes in the past few years that will facilitate the efficient uptake of batteries as they are implemented. These include:[35]

- **Five minute settlement**, published 2017 with effect from July 2021. Previously, generators were dispatched in 5 minute periods but paid the average price in the market over six periods (30 minutes). From 2021, generators will be paid for each five minute periods. Since prices can vary widely over six periods, the rule rewards more nimble forms of generation, i.e. forms of generation that can rapidly enter and leave the market.[36] By reducing the financial settlement time interval from 30 minutes to 5 minutes, the rule change will provide more dynamic pricing, which will reward sources of generation such as batteries that are quicker to respond to changes in prices.
- **Distribution network pricing arrangements,** published 2014 and being rolled out by distributors, provides for distributors to move from flat or declining block tariffs[37] towards time-of-use tariffs.[38] As batteries can store power at times of low prices and discharge at times of high prices, they can benefit from this change.
- **Competition in metering,** published 2016 and being rolled out by distributors, provides that all new residential meters must be smart meters. Smart meters can measure the time during the day when customers are using electricity. By measuring the time of use, smart meters are a prerequisite for the introduction of time-of-use tariffs.

It is also noted that AEMC has recommended that distribution networks should be allowed to use stand-alone power systems to supply remote customers rather than being obliged to connect new

---

[34] See AEMC website at https://www.aemc.gov.au/market-reviews-advice/coordination-generation-and-transmission-investment-implementation-access-and

[35] AEMC 2019c, pp. 154, wording adopted and shortened

[36] Coal plant generally cannot increase or decrease generation output rapidly while batteries and hydro can do so almost instantaneously

[37] Otherwise known as consumption-based or volumetric tariffs

[38] Time-of-use tariffs charge higher prices at times of peak use and lower prices at times of off-peak use in order to encourage users to switch their consumption to off-peak times. Switching use from peak to off-peak times reduces the amount of money that transmission and distribution networks need to spend on expanding the network to meet demand at peak times.

customers to the grid even where the connection costs are very high.[39] This should encourage more local generation, batteries, and microgrids to supply remote customers.

The Clean Energy Council also noted the Distributed Energy Integration Program (DEIP) being facilitated by ARENA, which "consists of different workstreams to enhance the effectiveness of DER, customer, markets, frameworks and interoperability".[40] The DEIP aims to enable VPPs[41] and demand-response integration.[42] A summary of the work of the ESB and Arena in relation to DER is detailed in Box 1 below.

Box 1: Integrating DER into the grid

A major challenge will be integrating DER into the grid. DER includes batteries, solar generation, electric vehicles and controllable load such as controllable hot water and air-conditioning, into the grid.[43] The common feature of DER is that it is located in the grid at or near user premises, and can be challenging to manage because it creates a two-way flow of electricity, both to and from user premises. Historically, electricity was generated at large, remote power stations and flowed one way to users. The two-way flow of power from DER makes it more difficult to manage the grid but, if managed well, can create opportunities to save on transmission, distribution, and generation costs.

The Energy Security Board has developed a DER Integration Workplan to address technical, regulatory, and market integration issues around DER. The ESB is working collaboratively with bodies such as AEMO, the AEMC, and market participants on implementing the Workplan, including through the Distributed Energy Integration Program (DEIP). The DEIP is a program of work initiated by ARENA, involving the energy market institutions, industry, academic and consumer bodies. In addition, market integration of DER is part of the ESB's broader post-2025 review of energy markets.

The ESB reports quarterly on the implementation of its DER Workplan.[44] The February 2020 quarterly report is the second in the series, and discusses a range of issues including inverter compliance, standards, the economics and regulation of business models for distribution-level storage, and VPP trials.

As noted above, ARENA hosts the DEIP, which is aimed at "maximising the value of customers' DER for all energy users".[45] The DEIP is working on four work packages in 2020:[46]

[39] AEMC rule change - Review of the Regulatory Frameworks for Stand-Alone Power Systems at https://www.aemc.gov.au/market-reviews-advice/review-regulatory-frameworks-stand-alone-power-systems. Referenced in Clean Energy Council 2019, p. 13
[40] Clean Energy Council 2019, p. 12
[41] VPPs involve operating batteries or other DER in a coordinated way to supply power at particular times
[42] Clean Energy Council 2019, p. 12
[43] Demand-side response or DSR could be included in this list. DSR is the ability of certain users to switch off to alleviate strain on the grid at times of peak use. For example, some users may be willing to switch off their use if offered a sufficient reward.
[44] See ESB microsite at http://www.coagenergycouncil.gov.au/publications/distributed-energy-resources-der-integration-workplan
[45] See ARENA's website at https://arena.gov.au/knowledge-innovation/distributed-energy-integration-program/
[46] See ARENA's website at https://arena.gov.au/knowledge-innovation/distributed-energy-integration-program/

1) DER Access and Pricing – Building consensus and developing arrangements to support evolving regulatory frameworks to meet changing community expectations and higher penetration of DER

2) DER Interoperability – Coordinated industry wide support and implementation of DER interoperability platform, cyber security & device standards

3) DER Market Development – Testing the theory in practice for how DER marketplaces may deliver the most efficient outcome for consumers

4) Electric Vehicles – Facilitating the efficient integration of EVs into existing networks and markets

At the same time, the States and Territories have created financial incentives to encourage the uptake of batteries and solar panels. These are summarised in Table 1 below.

TABLE 1: FINANCIAL INCENTIVE ARRANGEMENTS FOR BATTERIES[47]

State/Territory	Policy/incentive
ACT	$25m fund to subsidise batteries for 5000 Canberra homes and businesses by 2020
NSW	$50m for up to 200 MW (home and business - $1000 incentive per home). $20m for up to 134 MW (gov buildings)
SA	100 MW/129 MWh Hornsdale Power reserve Proposed $100m grants program to facilitate batteries in 40,000 homes Solar and Batteries for up to 50,000 homes (mix of public housing and privately owned) Subsidy of $500-$600 per kWh reducing to $300-400 per kWh from 15 April 2020[48]
Vic	$40m for up to $5,000 off as many as 10,000 batteries on homes with pre-existing solar $1.34b for up to $2,225 off as many as 650,000 solar systems
Qld	Loans up to $4,500 for up to 3,500 home solar systems Loans up to $6,000 and grants up to $3,000 for as many as 500 battery systems Loans up to $10,000 and grants up to $3,000 for as many as 1000 solar and battery systems
NT	Home improvement Scheme previously offered up to $4,000 vouchers for purchases including solar and batteries. Participants required to fund at least 50 per cent
Tas	Battery of the Nation pumped hydro feasibility study Proposed $200,000 micro-grid pilot
WA	No specific policy

1.7 Creating a regulatory environment conducive to batteries

It is important to examine what steps the National Electricity Market needs to take to optimise the take-up of batteries.

In the first instance, this involves identifying and removing barriers to the uptake of batteries. More broadly this process involves designing the electricity market to enable people investing in batteries to capture the value that batteries create in the market.

[47] Adapted from Open Energy Networks 2019, Figure 24, p. 42
[48] South Australian Home Battery Scheme at https://homebatteryscheme.sa.gov.au/about-the-scheme

Batteries have high upfront costs and low operating costs.[49] Consequently, the upfront capital cost is often a significant hurdle. However, this is a *commercial* barrier rather than a regulatory barrier to the uptake of batteries. It is possible that new models will emerge where the upfront costs are paid by a third party such as a retailer and customers pay off this cost over time.[50] Such retailer-supported models have emerged to support the adoption of solar panels, as examined by multiple authors in previous reports.[51]

International research on typical regulatory barriers to batteries found that, globally, the main barriers to electricity energy storage are:[52]

- Inadequate definition and classification of [storage] in legislation;
- Lack of markets for some ancillary services;
- Inadequate market design that benefits traditional technologies; and
- The lack of need for [storage] in some jurisdictions.

More broadly, optimising the design of the market for batteries involves ensuring the rules allow battery owners to access the benefits offered by batteries. As Ruz and Pollitt (2016) note, batteries have potentially many different revenue streams and regulations may curtail some of these revenue streams.[53] This includes examining existing arrangements such as:

- Flat or declining block retail tariff arrangements, which fail to reward customers who use batteries to curtail demand at times of peak demand. The impact of current arrangements and time-of-use tariff arrangements with and without batteries is illustrated in Box 2 below. It shows that under a reasonable set of assumptions, batteries can work in with time-of-use tariffs to store energy including from a household's own solar panels and discharge it at peak times to save costs. The savings come from maximising self-consumption from the solar panels (which is typically more attractive than the feed-in tariff) and by reducing grid use during costlier times of the day;[54]
- Connection agreements are too rigid and need to allow for dynamic engagement of DER.[55]

The biggest barrier is likely to be continued use of flat or declining retail tariff arrangements, as these do not reward users for shifting their use away from times of peak use, such as through the use of batteries.

---

[49] CSIRO 2015, p. iii and iv, p21
[50] Suggested by PIAC during interview, 6 November 2019
[51] Including ARENA (2016) and Roberts et al (2018)
[52] Ruz and Pollitt, 2016
[53] Also, Rocky Mountain Institute 2015
[54] A major impediment to P2P is network tariffs, as revealed during the ARENA-funded P2P trial and the AGL solar credit trading scheme. Clean Energy Council 2019a, p. 17
[55] Clean Energy Council 2019a, p. 19

Box 2: How time-of-use tariffs improve the business case for batteries

Currently, retailers offer a range of flat tariff residential options in many states. If they moved to time-of-use tariffs this could, depending on the timing of energy use during the day, significantly increase the attractiveness of the household installing a battery.

Assume a household pays the 22.583 cents/kWh tariff, with a feed-in tariff of 8.6 cents/kWh (AGL Essential Saver tariff). The household uses 40 kWh per day and on a given day has solar panels that generate 20 kWh per day. Of this solar generation, 10 kWh is used at the house and 10 kWh is exported to the grid and earns the feed-in tariff. Assume the household uses 25 kWh at peak times (generally during the early evening when the sun has gone down and the solar panels are not generating much power) and 15 kWh at off-peak times, with only 3 kWh of its use at peak times is supplied by the solar panels.

Now assume that a time-of-use tariff is offered where prices are halved at non-peak times and increased to 1.5 times the standard rate at peak times (say 4-10 pm on weekdays).

Ignoring daily charges, then:

- Under the standard flat tariff arrangements, the household pays for use of 40 kWh less 10 kWh generated by its solar panels * 22.583 cents/kWh less 10 kWh paid at the feed-in tariff of 8.6 cents/kWh. This is 6.7-0.86 or **$5.91 per day**.
- Under the time-of-use tariff, the household would pay for 25 kWh less 3 kWh generated by its solar panels at the peak rate (22.583*1.5*22) and pay for 15 kWh less 7 kWh of generation from solar panels at off-peak times (8*22.583/2) and would receive the feed-in tariff on 10 kWh (10*8.6). This is 7.55+0.90 – 0.86 or **$7.60 per day.** This is higher than the standard rate because the household is a reasonably high user at peak times.

Now suppose the house installs batteries that mean it captures the full generation from the solar panels and uses this stored power at peak times. Now,

- Under the time-of-use tariff, the household uses 25 kWh at peak times less 20 kWh of power stored by the battery (22.583*1.5*5), and 15 kWh of power at off-peak times (15*22.583/2). It does not receive any income under the feed-in tariff because all the power from the solar panels is being used on-site during peak times. The cost per day is $1.72+1.69 or **$3.41 per day**.

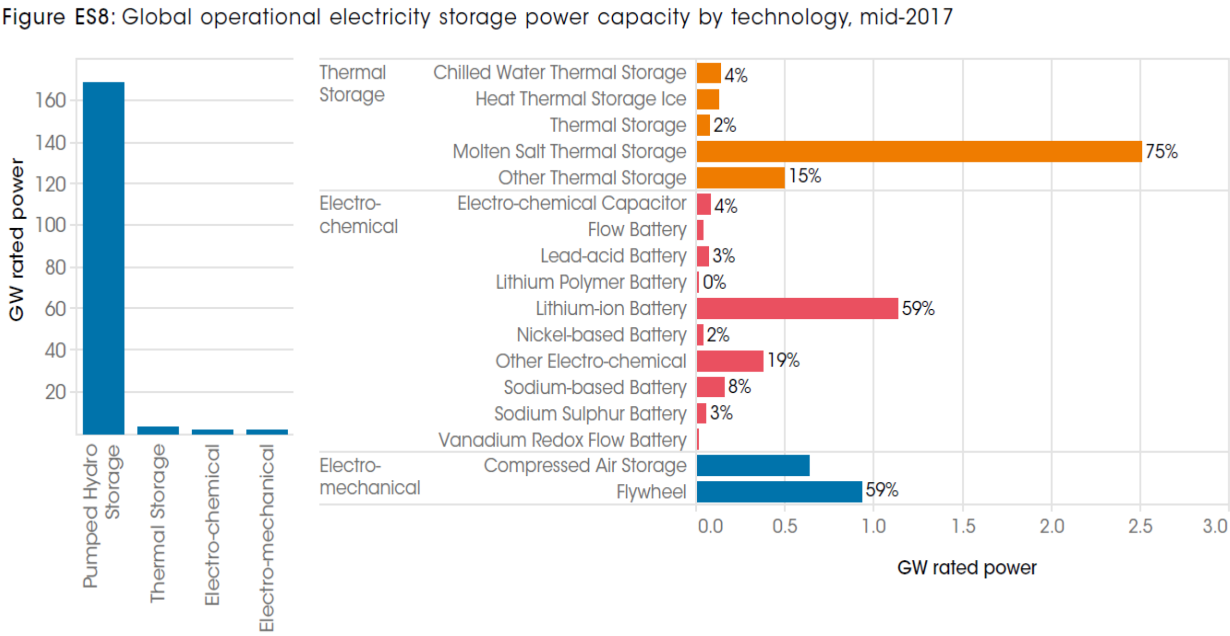
1.8 Current and emerging storage in NEM

Globally

Batteries are currently still only just starting to emerge nationally and internationally as a share of total storage capacity. The International Renewable Energy Agency (IRENA) has presented in Figure 5 below the capacities of different storage technologies globally in 2017.[56] At the time, hydro power dominated installed capacity, while among other technologies, molten salt thermal storage was the most significant, with lithium-ion batteries second.

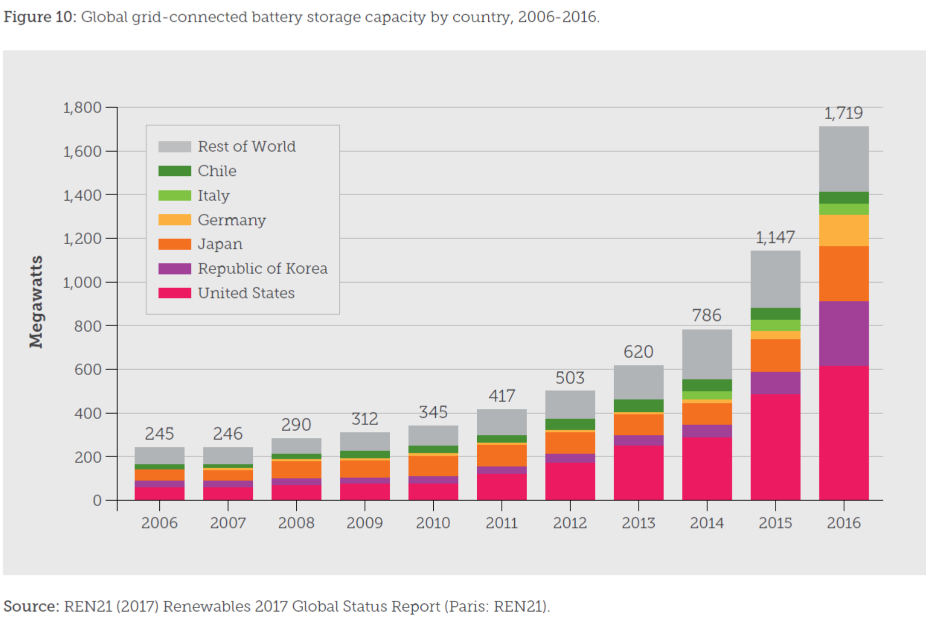
[56] IRENA 2017, p22

FIGURE 5: GLOBAL OPERATIONAL ELECTRICITY STORAGE CAPACITY, 2017



However, internationally, installed battery storage capacity is starting to rise strongly from this low base, as illustrated in Figure 6 below.[57] Battery storage is growing quickly, particularly in the U.S., Germany, Japan, and Korea.

FIGURE 6: INTERNATIONAL GROWTH IN STORAGE



In the Australian market, there are a number of new storage initiatives. The Australian Financial Review noted in September 2019 that energy storage projects in 2019 have overtaken solar and wind.[58]

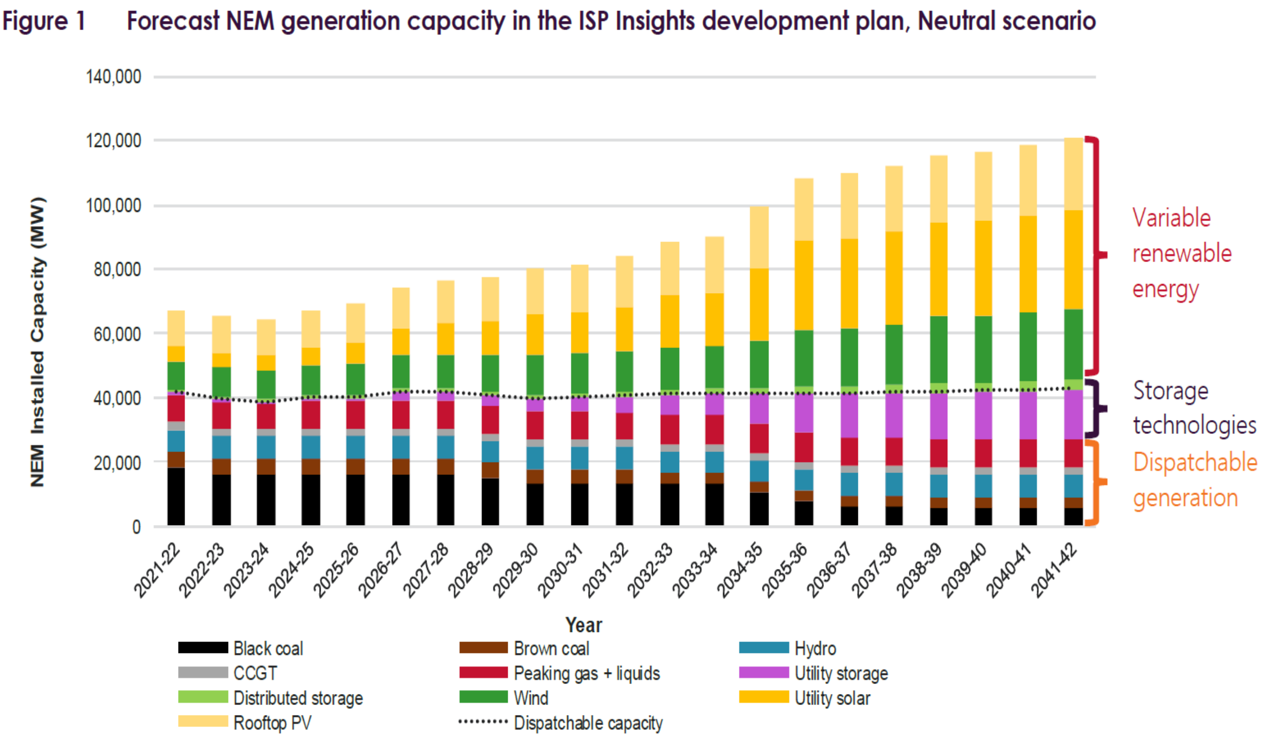
[57] Climate Council of Australia, 2018, p.30
[58] Australian Financial Review, *Project line-up defies market risks*, 13 Sept 2019, p. 24

The Climate Council note that SolarReserve are building Australia's largest solar thermal plant in South Australia for a levelised cost of no more than $78/MWh – significantly cheaper than a new coal power station. Solar thermal plants can both generate and store electricity.[59] When the Queensland Government called for new renewables projects under the Renewables 400 scheme, a number of the bidders included batteries as part of their bids.[60]

AEMO reports on installed and planned projects throughout Australia, as well as forecasting further ahead in its Integrated Power System (ISP) report and in its Electricity Statement of Opportunity (ESOO) report.

Under its base case or neutral scenario as part of its 2018 ISP, AEMO is forecasting a significant rise in renewables and supporting storage over the period to 2040, as illustrated in Figure 7 below. The figure shows storage technologies in purple steadily rising over the twenty-year period to 2040 (particularly from 2030), with variable renewable energy rising strongly. Dispatchable generation, making up coal and gas and liquids, decreases over this period even though overall installed capacity almost doubles from 65,000 MW to around 120,000 MW.

FIGURE 7: AEMO FORECASTS GROWTH IN RENEWABLES AND SUPPORTING STORAGE[61]



AEMO is forecasting 30 MW of new battery capacity in the NEM in 2019 (against about 7,000 capacity instalments mainly across wind, solar, and water).[62] Beyond 2019, AEMO expects the

[59] Climate Council of Australia, 2018, p. ii

[60] See https://www.business.qld.gov.au/industries/mining-energy-water/energy/renewable/projects-queensland/renewables-400. The Renewables 400 scheme is a Queensland Government scheme for a 'reverse auction for up to 400 megawatts of renewable energy capacity including up to 100 megawatts of energy storage'

[61] Source: AEMO 2019a, p. 7

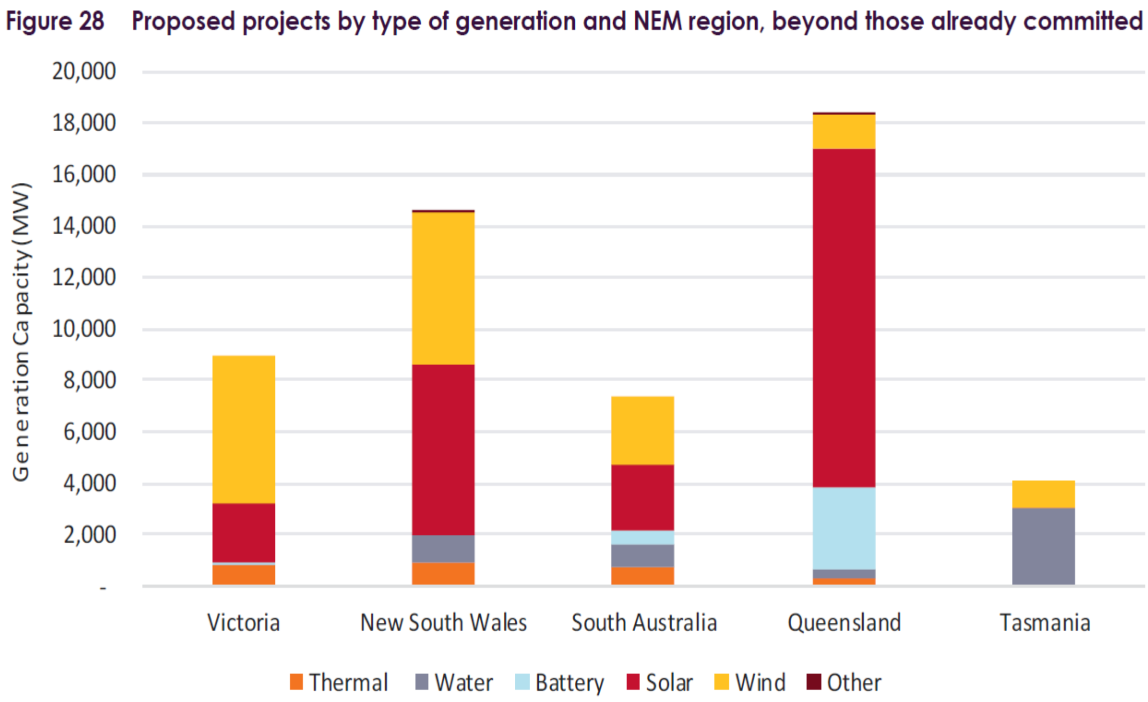
[62] AEMO 2019d. p. 66

projects it is tracking to comprise 5 per cent will be battery storage, while more than 75 per cent will be solar and wind.[63]

AEMO forecast in its 2018 Integrated System Plan that "Battery systems [will] provide up to approximately 10 per cent of operational maximum demand by 2030".[64] Australia will see a steady rise in behind-the-meter (customer) batteries over the period to 2040, with a central case of a rise in batteries from around 300 MW of installed capacity to about 3,000 MW of installed capacity, AEMO forecasts.[65] In its draft 2020 Integrated System Plan, AEMO considered that small -scale DER including batteries and solar is expected to double or even triple by 2040[66] and added that "AEMO modelling projects DER [including batteries and solar] could provide 13% to 22% of total underlying annual NEM energy consumption12 by 2040".[67]

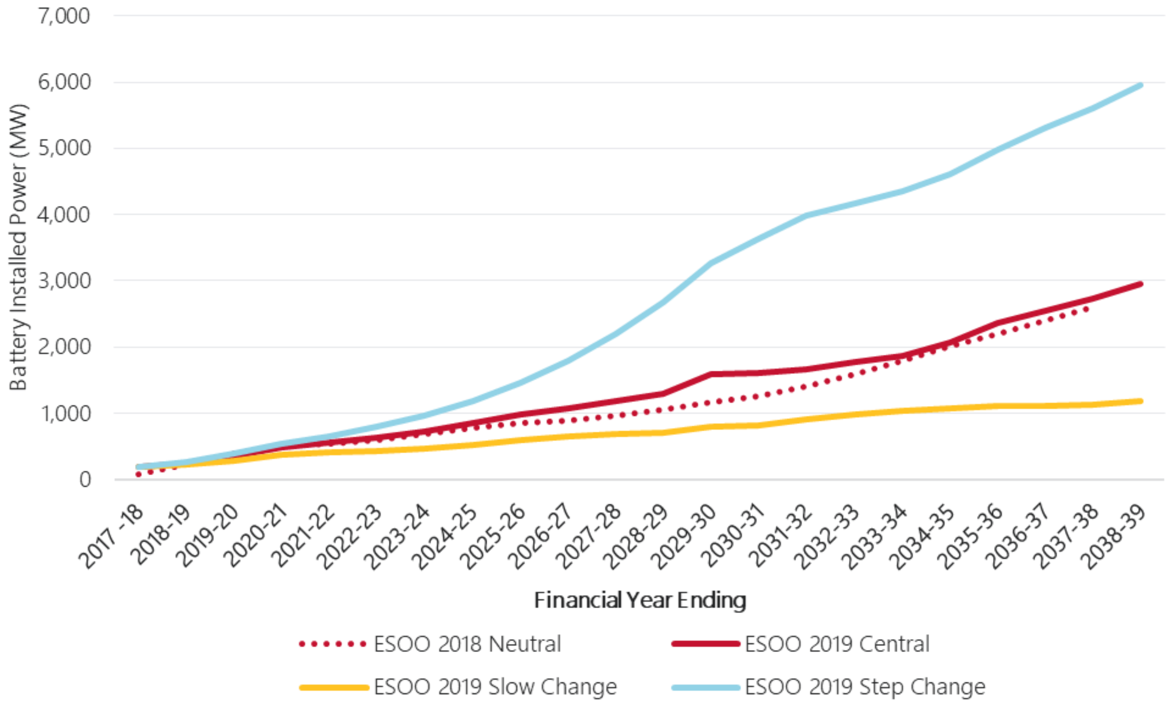
Figure 8 illustrates AEMO's pipeline of future projects as forecast in the 2019 Electricity Statement of Opportunities, showcasing the growth of solar and wind projects. The role to be played by behind-the-meter battery storage highlighted by Figure 9.

FIGURE 8: THE RISE OF SOLAR AND WIND



[63] AEMO 2019d, p. 70
[64] AEMO 2018, p. 27
[65] AEMO 2019d, p. 38
[66] AEMO 2019f, p. 34
[67] AEMO 2019f, p. 10

FIGURE 9: THE PREDICTED RISE OF BEHIND-THE-METER BATTERIES

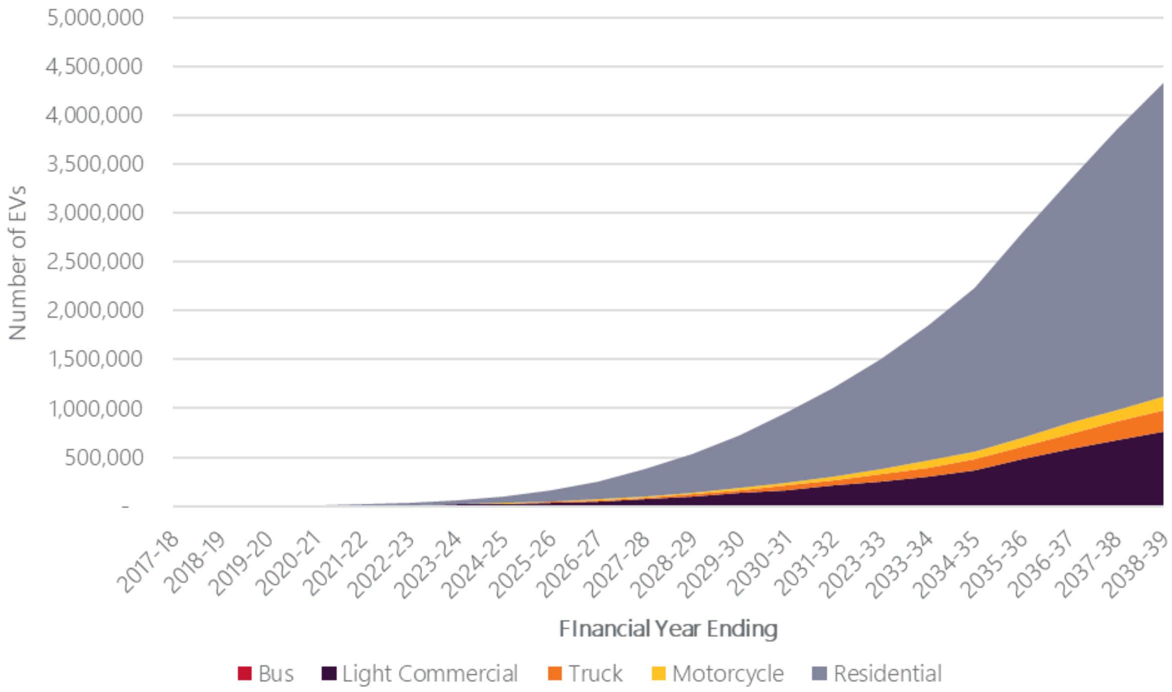


Also of significance is the steep rise in electric vehicles (EV) forecast to impact the market from the mid-2020s (see Figure 10 below).[68] EVs have large batteries (perhaps 50-70 kWh if the current Tesla car is a guide) and if this can be integrated into the NEM through appropriate technical arrangements, the amount of battery capacity available in the NEM would soar from the mid-2020s assuming EVs are adopted in the vehicle market in large numbers.[69] AEMO's draft 2020 ISP noted that EVs and behind-the-meter batteries would add significant extra controllable demand across the NEM – controllable in the sense that the time when they charge or discharge is discretionary compared to most demand. This would increase the amount of battery capacity in the market significantly.

[68] AEMO 2019d, p. 39. Compare Renew 28 October 2019 that electric vehicles would be a significant presence in the market from around 2024

[69] The impact of EVs on battery uptake is discussed further in section 3.2.7

FIGURE 10: EXPECTED GROWTH OF ELECTRIC VEHICLES TO 2039



1.9 Cost trends

New technologies are generally subject to a learning curve, where a new technology initially starts with a high cost, which then falls rapidly each year as manufacturing techniques improve until a point of inflection where the rate of fall in costs per year slows as knowledge of the lowest cost way of making the technology matures.

As a relatively new technology, batteries are postulated to be a learning curve at present on a downward trend. There are differing views about whether the curve has reached the point of inflection such that future falls will start to become smaller and the overall price falls lower each year.[70] Accordingly, a review has been undertaken of various literature on the point on the learning curve that batteries are likely to present, with a focus on lithium-ion batteries as the leading battery technology. In 2015, CSIRO projected battery costs would fall some 53 to 79 per cent by 2025, depending on technology[71].

Global utility scale storage cost trends as mapped for the IFC's Energy Storage Trends and Opportunities in Emerging Markets are illustrated in Figure 11[72]. Lithium-ion battery costs are projected to fall from about $800/MWh to about $350/MWh of installed capacity over the ten years from 2014 to 2024.

[70] Parkinson 2019 and 2017, Bellini 2017
[71] CSIRO (2015), p. ii
[72] IFC 2017

FIGURE 11: TRENDS IN STORAGE SYSTEMS GLOBALLY[73]

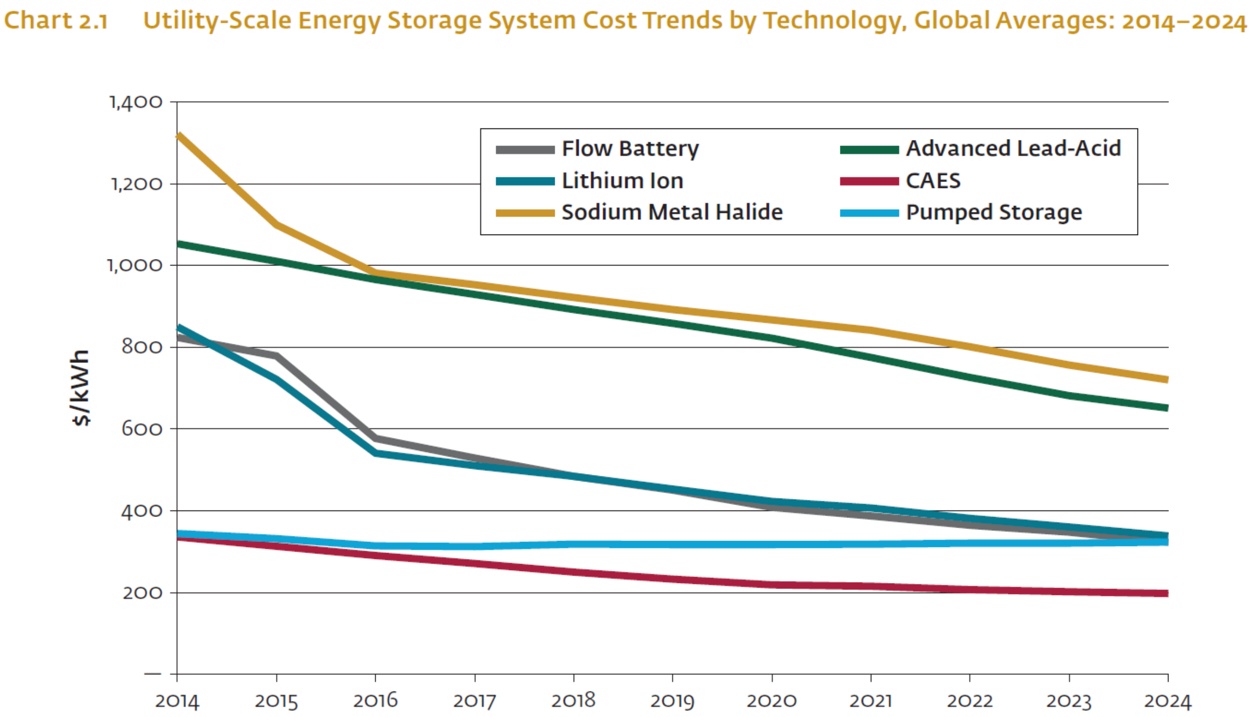
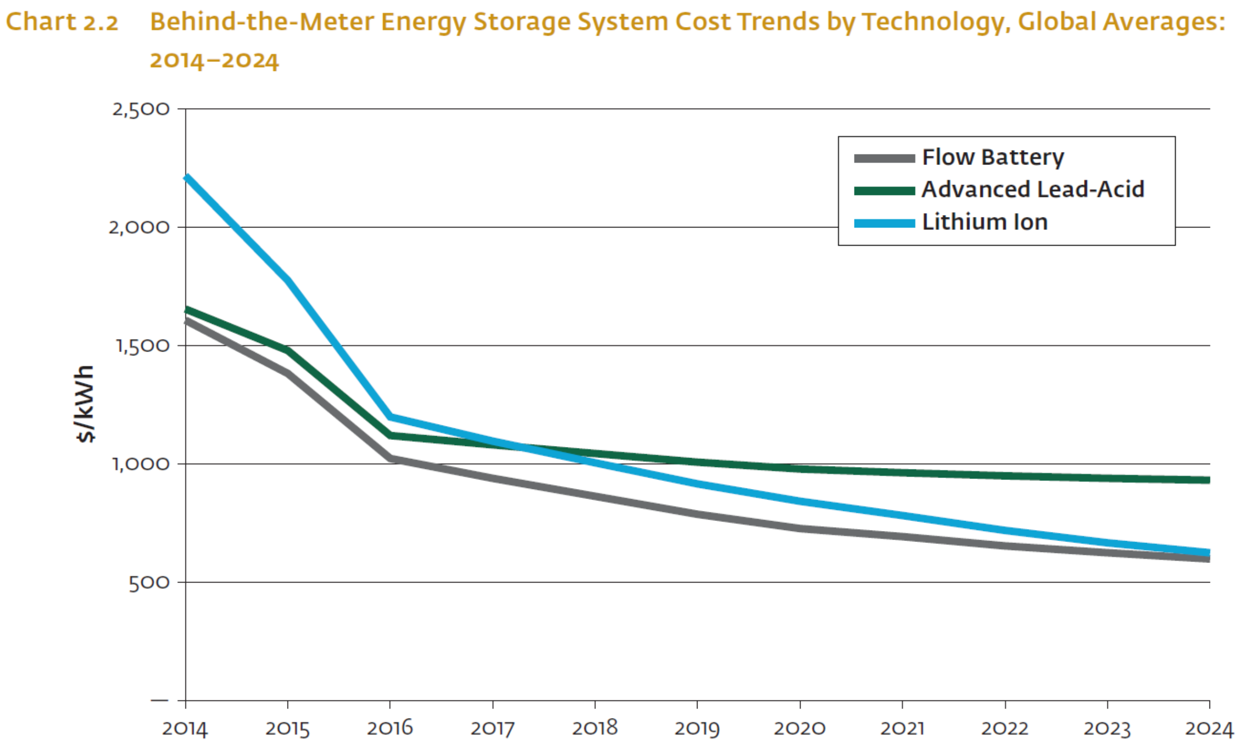


FIGURE 12: BEHIND-THE-METER ENERGY STORAGE COST TRENDS[74]

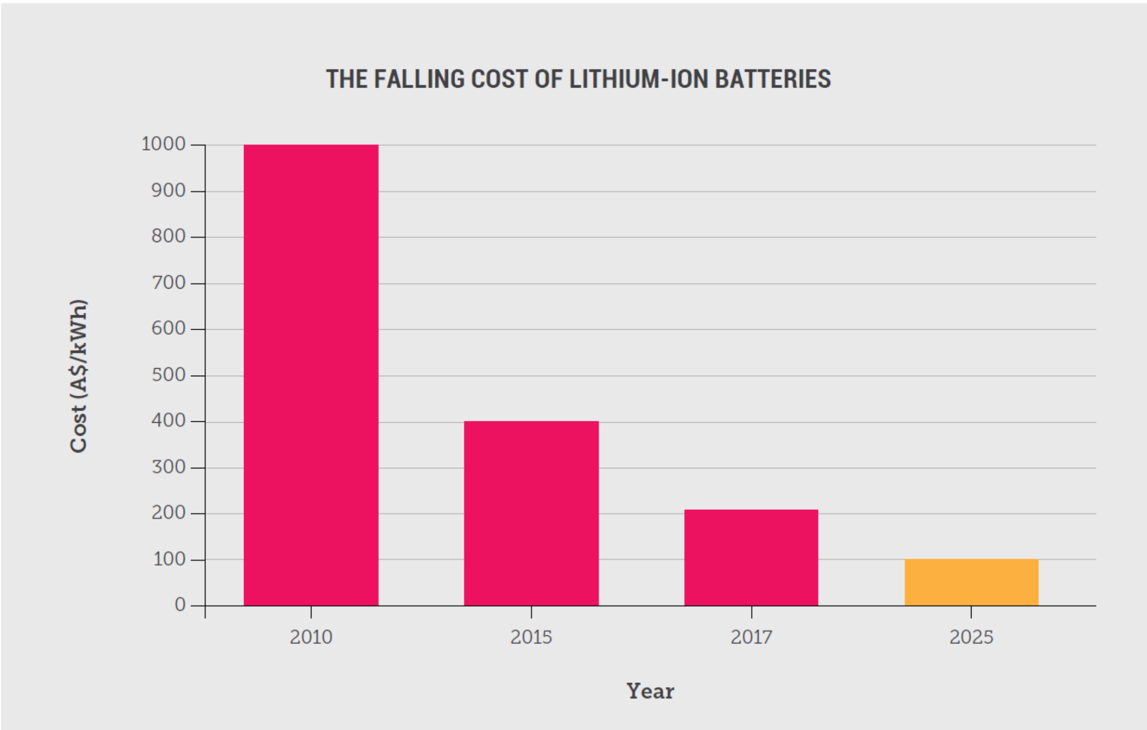


[73] Source: IFC 2017, p. 10
[74] Source: IFC 2017, p. 11

Behind-the-meter storage cost trends are illustrated in Figure 12. Most notably, this chart shows that lithium-ion batteries have come from a position of highest price per unit of installed capacity to roughly equal cheapest, with all three battery types falling substantially in price between 2014 and 2024[75]. Lithium ion batteries are forecast to fall from around $2200/MWh to around $600/MWh, or about 67 per cent in the ten-year period from 2014 to 2024.

Bloomberg New Energy Finance predict "a further halving of lithium-ion battery costs per kilowatt-hour by 2030… on top of an 85 per cent reduction from 2010-2018".[76] Drawing on the BNEF's research, Australia's Climate Council forecasts that lithium ion battery costs will fall by a factor of 10 over the period from 2010 to 2025, as illustrated in Figure 13.[77]

FIGURE 13: COST REDUCTIONS PREDICTED FOR LITHIUM-ION BATTERIES



Source: Bloomberg New Energy Finance 2017b; SunWiz 2017.

In terms of the impact of these forecast price falls on demand for batteries and resulting installed capacity, the Bloomberg New Energy Futures predicts that:

> *PV and batteries behind the meter will make up 38 per cent of all capacity by 2050, driven by competition in PV installation and relatively high retail tariffs. It expects the levelized cost of storage to fall 64 per cent to $67/MWh by 2040 (from $187/MWh today)*[78]

[75] IFC 2017 p11
[76] Australian Financial Review, *Project line-up defies market risks*, 13 Sept 2019, p. 24
[77] The Australian Climate Council 2018, p. 34
[78] BNEF (2019a) Bloomberg New Energy Outlook, slide 4

Batteries will become the most cost-effective form of peaking generation by the mid-2020s, Bloomberg forecasts, and by 2030 will start dispatching coal and gas generation in dispatchable generation [baseload], making coal and gas more marginal.

As at 2018, Bloomberg noted that:[79]

> *…battery prices are down 84 per cent since 2010. We expect the build-out of battery manufacturing for electric vehicles to continue to drive down the price of batteries for stationary applications. These fall to $62/kWh by 2030, down some 64 per cent from today [$172/MWh].*

Bloomberg predicts that by 2050, 40 per cent of all battery deployment will be behind-the-meter. They predict customers will start adding battery storage along solar PV by 2025 as the value overshadows the upfront cost. They expect the payback period to halve over the next twenty years from 13 years today to 6 years by 2040.[80]

Some three-quarters of the behind-the-meter battery capacity can be expected to be used to minimise system peaks by 2030.[81] Further, Bloomberg point to the emergence of EVs as likely to assist in battery uptake.[82] This could occur through improvements in scale economies and through greater consumer acceptance.

Schmidt et al 2019 expressed the view that Li-ion batteries would become comparatively the cheapest form of storage after 2030.[83]

AEMC predict that:[84]

> *residential solar PV with storage systems are forecast to achieve 'socket parity' — when the average LCOE of grid-connected residential solar PV with a storage system is equal to that of the price a consumer can purchase energy from the grid — for most Australian states around 2019-2020. … with battery costs falling, the average payback period of residential solar PV with battery storage is expected to decline to under 10 years by 2022.*

AEMO predict in its 2018 ISP that large scale batteries would fall by 11 per cent in 2019, then 8 per cent in 2020, and thereafter by 2 or 3 per cent each year until the end of the forecasting period in 2040.[85] This would suggest that, in their view, the learning rate will be steep until around 2020 or 2021 and then inflect and moderate. The 2018 ISP was endorsed by the Battery Storage and Grid Integration Program as the most reliable view in the market.[86]

[79] Bloomberg NEF 2019a, Executive Summary, Technology and Materials, p. 1
[80] Bloomberg NEF 2017, Beyond the Tipping Point, p. 1
[81] Bloomberg NEF (2019b). Blog comments relating to Energy Storage Outlook 2019
[82] Bloomberg NEF (2019b)
[83] Schmidt et al (2019), page 81
[84] AEMC press release
[85] AEMO 2018, 2018 Integrated System Plan Modelling Assumptions, build cost tab, information for large scale battery storage (2hrs storage)
[86] Interview 25 November 2019

1.10 Current drivers for uptake of storage

It is important to understand the drivers for the uptake of storage, and, in particular, batteries, to understand the drivers for installation of batteries.

The main arguments advanced for the uptake of batteries are:

- To support increased penetration of intermittent renewables into the generation mix, particularly in areas of the grid with high levels of renewables;
- To support voltage control;
- As a low(er) cost form of generation; and
- Behind the meter as part of a strategy of self-consumption by users with excess solar generation during the day, especially in conjunction with time-of-use tariff arrangements.

Overall, the penetration of renewables is not expected to require the uptake of solar in the period to 2030. The CSIRO indicates significant new battery storage is not required in Australia until wind and solar supply exceeds 30 per cent of electricity supply.[87] The Australian Council of Learned Academics has found that Australia could reach 50 per cent renewables without a significant requirement for energy storage.[88] The Battery Storage and Grid Integration Program at ANU supported this view. They indicated during interview that with the large area of the NEM and the significant diversity of wind and solar over that space, there was less need for storage than might be imagined.[89]

ACOLA 2015 modelled uptake of storage in the NEM under low (35 per cent), middle (50 per cent), and high (75 per cent) renewable generation scenarios, that is where renewables supply 35, 50, and 75 per cent of total generation at a given time. They found that:[90]

> *Energy storage is both a technically feasible and an economically viable approach to responding to Australia's energy security and reliability needs to 2030, even with a high renewables generation scenario.*

Only under the high renewable energy scenario is storage required to support the increased share of renewables, and it is required for the purpose of reliability[91] rather than security (as illustrated in ACOLA's scenarios in Figure 14, below).[92] In other words, under the high renewables scenario, storage would be required in order to ensure sufficient supply to provide users with power, but not for the purposes of supporting voltage control and other measures to ensure power is supplied within technical parameters.

---

[87] CSIRO and Energy Networks 2017, page 97
[88] ACOLA 2017, p. 10
[89] Interview 25 November 2019
[90] ACOLA 2017, p. 6
[91] AEMO defines reliability as "the probability that the installed capacity to produce and transport electricity (including generation and demand response), will be sufficient to meet the actual or anticipated demand for electricity". See https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability
[92] AEMO defines security as "the ability of the power system to continue operating within defined technical limits (satisfactory), even in the event of the unexpected disconnection of a major power system element such as an interconnector or large generator (secure)." See https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability

The ACOLA report notes that the high renewables scenario assumes that some States, such as South Australia and Tasmania, would be powered by close to 100 per cent renewables under the high renewable energy scenario.[93]

FIGURE 14: ACOLA MODELS STORAGE CAPACITY REQUIREMENTS ACROSS THREE SCENARIOS

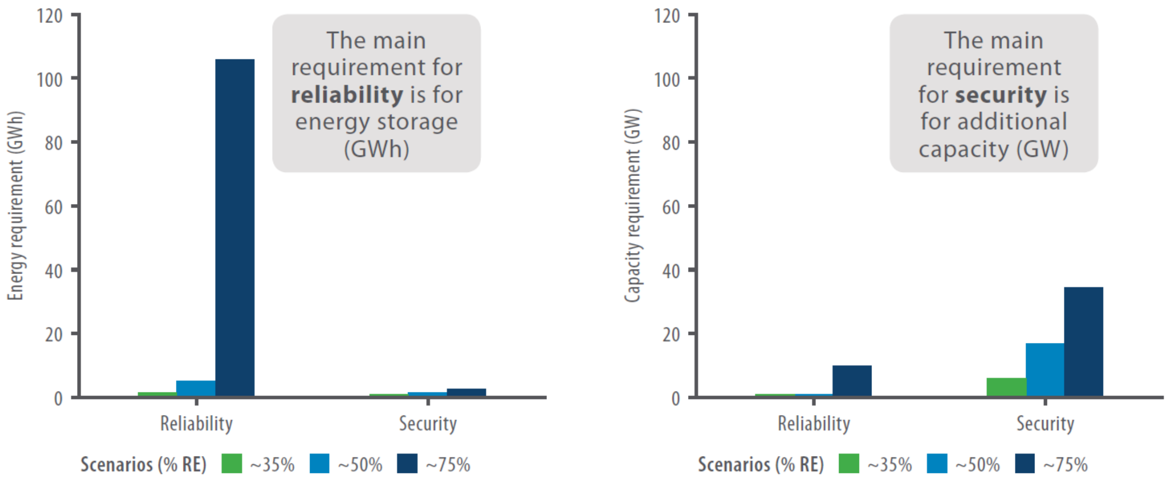


Figure 1: Reliability (GWh) and security (GW) requirements at 2030 across the three scenarios

Capacity (GW) Requirement	LOW RE	MID RE	HIGH RE
Reliability	0.5 per cent	2.4 per cent	9.8 per cent
Security	7.3 per cent	19.8 per cent	34.5 per cent

Table 1: Storage capacity requirements under the three scenarios

The CSIRO and ACOLA analysis would suggest that neither the increasing penetration of renewables nor power system security are an immediate and driving factor in the uptake of batteries.

Storage can be a lower-cost form of generation than traditional fossil fuels. AEMO found that large scale storage is increasingly cheaper than other forms of generation. Its 2018 ISP found that in 2017-18, large scale battery storage was already among the lowest cost forms of generation (as set out in Figure 15).[94] It was second cheapest form of generation among the nine forms of generation at $1480 per kWh of installed capacity, only more expensive than open cycle gas turbines (lowest) and pumped hydro (second lowest).

At the same time, batteries have the attraction that they can be moved, can be built much more rapidly due to less environmental and planning approvals, and are continuing to come down in price.

[93] ACOLA 2017, p. 5
[94] AEMO 2018, 2018 Integrated System Plan Modelling Assumptions, build cost tab

FIGURE 15: FORECAST GENERATION COSTS IN THE NEM

Cost of generation $/kWh (real 2017 dollars)	2017-18	2018-19	2019-20
Biomass	$ 3,779.15	$ 3,770.82	$ 3,757.65
Closed Cycle Gas Turbine	$ 1,500.68	$ 1,500.66	$ 1,500.66
Open Cycle Gas Turbine	$ 1,019.61	$ 1,014.51	$ 1,009.44
Single-axis Tracking Solar PV2	$ 1,952.05	$ 1,733.25	$ 1,634.67
Solar Thermal Central Receiver (6 hours storage)	$ 4,434.41	$ 3,677.62	$ 3,299.20
Wind	$ 1,945.06	$ 1,940.42	$ 1,933.93
Pumped Hydro (6 hours storage)	$ 1,386.11	$ 1,379.18	$ 1,372.29
Large Scale Battery Storage (2 hours storage)	$ 1,480.18	$ 1,313.14	$ 1,208.39
Black Coal (HELE)	$ 3,268.42	$ 3,263.89	$ 3,249.43

Thus, the low cost of batteries as a form of generation is a prime driver of their uptake, and the argument that they support renewable forms of generation is just an additional benefit that they can provide.

Behind-the-meter demand for batteries is growing even though demand is tempered by the high upfront cost of installation. AECOM saw behind-the-meter batteries as having a strong business case and identified that the main revenue streams for new battery installation as tariff avoidance and TOU load shifting.[95]

Tariff avoidance comes from self-consuming DER, typically generation from solar panels, instead of from the grid. Time-of-use load shifting involves charging the battery from rooftop solar or the grid at times of low tariffs and then discharging at times of high (peak) tariffs. IRENA forecast that behind-the-meter battery growth to be largest driver of battery storage growth, especially when teamed with PV.[96] Their reason was that users would install meters, "to increase self-consumption or avoid peak demand charges in the residential and commercial sectors".[97]

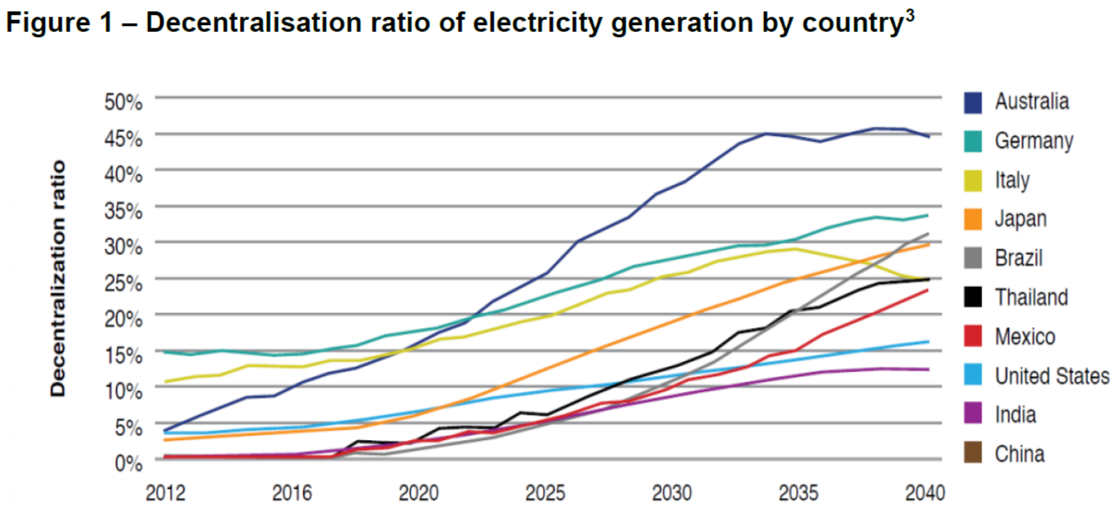
Two factors make and will continue to make behind-the-meter batteries attractive:

- The high rates of solar installation behind-the-meter. At present, Australia has the highest solar penetration rates in the world.[98] Moreover, the rate of installation of small-scale solar is continuing to increase off an already high base.[99] Solar installation increases the attractiveness of battery installation as batteries allow for self-consumption of solar generation, which is higher value than the return from export of excess solar generation to the grid.
- The high decentralization of the electricity supply grid in Australia. Australia has the most decentralized grid among the countries listed in the Figure 16 below, meaning that users are

[95] AECOM 2015, p. 81
[96] IRENA 2017, p. 17
[97] IRENA 2017, p. 17
[98] Open Energy Networks 2019, p. 3: "Australia now has more rooftop solar installed per capita than anywhere else in the world"
[99] Clean Energy Council 2019a, p. 7

more widely spread that in other countries.[100] Reliability and security could be increased by either augmentation of the distribution grid or by additional behind-the-meter batteries. Under the stand-alone power systems review being conducted by the AEMC, distribution networks will be able to choose to supply their customers with stand-alone systems rather than connecting them to the gird where that is cheaper.[101] This should maintain the decentralization of the Australian energy supply system.

FIGURE 16: DECENTRALIZATION OF ENERGY SUPPLY



The issue of long payback periods for batteries behind-the-meter has been highlighted by some commentators, but this argument is complicated by both prevailing trends and context. AEMC has forecast that with falls in the costs of lithium ion batteries, the payback period for behind-the-meter batteries is expected to fall below 10 years by 2022 (noting that this is before users gain access to revenue from all possible value streams).[102] However, in an environment of low interest rates, a payback period of 10 years can appear attractive compared to alternatives as it equates to a compounding return on investment over 7 per cent. A non-taxed, low risk return of over 7 per cent would seem compelling in the current (2020) interest rate environment.

Additionally, as noted above, there are a wide range of financial incentives being offered by State and Territory governments. In the case of South Australia, for example, these incentives can significantly reduce the upfront costs of battery installation for eligible users.

IFC set out the drivers for installation of behind-the-meter batteries in Figure 17 below.[103]

[100] Clean Energy Council 2019a, p. 6
[101] AEMC program 'Updating the regulatory frameworks for distributor-led stand-alone power systems', at AEMC website https://www.aemc.gov.au/market-reviews-advice/updating-regulatory-frameworks-distributor-led-stand-alone-power-systems
[102] AEMC 2019c, p. 149
[103] IFC 2017, p. 18

FIGURE 17: THE BUSINESS MODEL FOR BEHIND-THE-METER BATTERIES

Table 3.2 BTM Energy Storage Applications

Market Drivers	Customer Applications	Description/Benefit
Rising electricity rates, increasing electric vehicle (EV) use, increasing energy management system use	Demand charge reduction	Respond automatically to building load spikes—reduced electricity expenses
	Time-of-use (TOU) energy bill management	Manage charging and discharging based on retail electricity rates—reduced electricity expenses
Increasing solar PV installations	Onsite generation self-consumption	Maximize consumption of onsite generation, primarily solar PV—reduced electricity expenses
Need for resiliency/power quality	Backup power/improved power quality	Protect sensitive equipment from power quality fluctuations/outages—ensure operability during grid outage
Grid stability concerns and capacity needs	Ancillary services	Provide frequency regulation, voltage support, electric supply reserve capacity, etc.—improved efficiency of centralized generation, smoother integration of variable generation
	Demand response (DR)/	Manage charging and discharging based on retail electricity rates—reduced electricity expenses
New utility infrastructure needs	Transmission and distribution investment deferral	Limit investments in new infrastructure through reduced peak demand

From Figure 17, it is evident that batteries generate a wide variety of possible value streams. The Rocky Mountain Institute found that, "customer-sited, behind-the-meter energy storage can technically provide the largest number of services to the electricity grid at large - even if storage deployed behind the meter is not always the least-cost option.[104] Rocky Mountain Institute argued that, "Energy storage can generate much more value when multiple, stacked services are provided by the same device or fleet of devices".[105]

These arguments (namely that behind-the-meter batteries can provide multiple services in energy markets) highlight that the key focus in optimising the value of behind-the-meter batteries is unlocking the multiple sources of potential value. Some of these benefits may only be accessible via changes in regulatory arrangements, that is the rules that govern the operation of the NEM.

[104] Rocky Mountain Institute 2015, p. 6
[105] Rocky Mountain Institute 2015, p. 7

Chapter Two: Towards Adoption

Chapter One postulated that storage was likely to be driven at utility scale by low cost, and at user scale by falling prices and increasing access to the multiple benefits that may be unlocked by regulatory changes. This chapter focusses on the likely timeframe for significant adoption of batteries.

2.1 Motivations to buy a battery

Predicting the uptake of batteries depends on the motivations of potential battery buyers.

At a residential level, there are a number of potential motivations to buy a battery including both economic and environmental concerns.

Energy Consumers Australia recently surveyed residential users on why they might intend to purchase a battery across the following set of reasons:[106]

- To save money
- To become less dependent on mains electricity
- To make more efficient use of energy
- To protect the environment
- Other reasons.

The survey classified users into nine socio-economic groups. The survey found that across seven of the nine groups, saving money was the primary driver of purchasing intent, while 'becoming less dependent on mains electricity' was the second driver. For the two remaining groups, becoming less dependent on mains electricity' was the primary driver, while saving money was the second driver.[107]

Based on the survey results, it is assumed that residential users will be motivated to a large degree when considering the purchase of a battery by the desire to save money.

At a business level, it is expected that the desire to save money will be the primary driver of purchasing decisions.

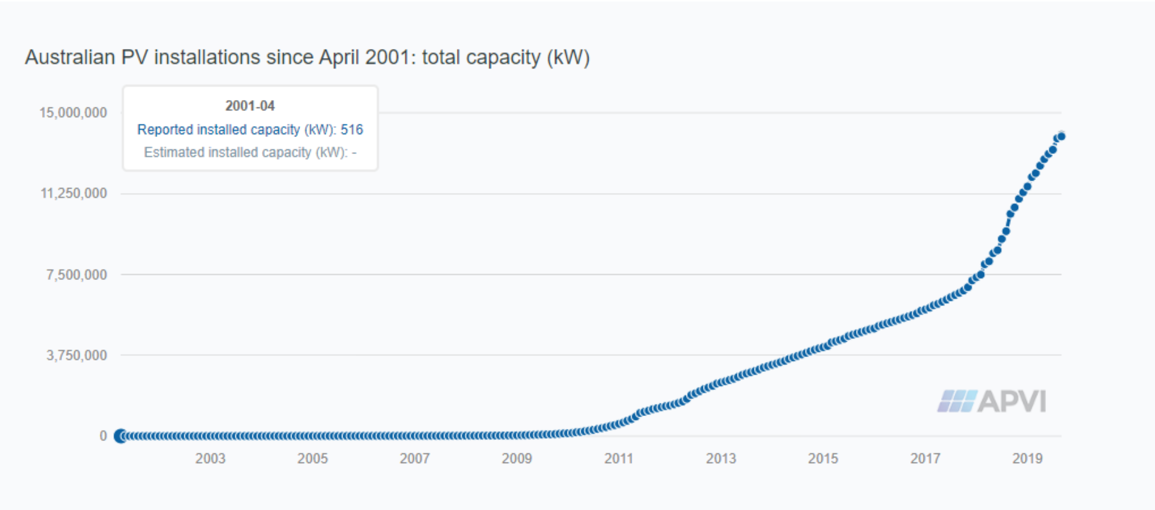
[106] Energy Consumers Australia (2019a), p.30
[107] Energy Consumers Australia (2019a), p.30

2.2 Point of significant adoption

The point of significant adoption of batteries is a key consideration in estimating when battery installation is likely to impact the policy context around the NEM. 'Significant' in this sense is difficult to define with precision. A reasonable approach would be to say that it means the point at which the installed capacity of batteries significantly impacts the physical or financial operation of the market. This is a better approach than focussing on the point where batteries are installed at a threshold percentage of user premises or reach a threshold percentage of total installed capacity.

Analogies can be drawn here with the point at which solar panels started to affect the NEM. Below is a graph of the uptake of solar panels since 2001.

FIGURE 18: AUSTRALIAN PV INSTALLATIONS SINCE 2001[108]



It can be seen that solar panel installations started to increase around 2010. From this point, solar panel installations rapidly affected the operation of the market in a number of ways. Just some of these issues were:

- Policies designed to encourage the adoption of batteries such as feed-in tariff arrangements rapidly become expensive, and these costs were borne by other users or governments;
- The grid became more difficult to manage because of the two-way flow of energy from users with batteries. Power quality become more difficult to manage with spikes in solar output in some parts of the grid;
- Equity issues opened up between customers with panels and those without panels. Users with solar panels on volume-based tariffs paid little for grid power even though they benefitted from grid connection. These costs were effectively transferred to parties without solar panels.[109]

It can be seen that solar PV installation became significant in policy and operational terms from around 2014 when solar panel installation was well under than 5 per cent of the installed capacity of

[108] See https://pv-map.apvi.org.au/analyses

[109] For example, Simshauser, Paul, *Distribution network prices and solar PV: Resolving rate instability and wealth transfers through demand tariffs*, Energy Economics, volume 54, February 2016, pages 108-122

the NEM. Even today, solar PV represents 6.1 per cent of installed generation capacity and 3.2 per cent of output.[110]

By analogy, a 'significant' level of battery installation might be perhaps 2 or 3 per cent of total installed capacity (around 1000 or 1500 MW), or at 2-3 per cent of user premises. Batteries currently stand at 0.4 per cent of capacity and 0.1 per cent of output.[111]

2.3 Qualitative research on the emergence of batteries at a user level

At the user level, there is a popular expectation that batteries will emerge soon in the market. A survey by Ausgrid for its 2019-24 regulatory proposal found 30 per cent of customers were considering home battery storage.[112] Nationwide, the Climate Council of Australia found that 74 per cent of people polled expect household batteries to be commonplace in homes in the next decade.[113]

Consumer groups interviewed for this report had mixed views. One group felt that while uptake to date had been slow, the decision to buy was not entirely based on the expected monetary savings, and could be enhanced by subsidies or third party finance of the upfront costs.[114] Another group expressed surprise that an expected surge in battery uptake had not occurred in the past few years, and attributed this to the fact that since 2016 or 2017 battery prices had not continued to come down in price as expected.[115]

Energy Consumers Australia polls residential and small business users for the Energy Consumer Sentiment Survey, covering, inter alia, expectations about the emergence of batteries. The December 2018 survey found that between 3 and 7 per cent of surveyed users said that they already had a battery storage system, and that between 24 and 39 per cent of consumers in each market are considering purchasing a battery storage system (see Figure 19 below).[116] Where parties already had rooftop solar panels, 53 per cent were considering purchasing a battery storage system, 6 per cent in the next 12 months and 47 per cent in the longer term.[117] This continues a consistent and increasing trend of consumer interest in battery storage systems since the first survey in March 2016.

The 2018 Queensland Household energy survey conducted by the Queensland networks, Powerlink, Energex and Ergon, found that:

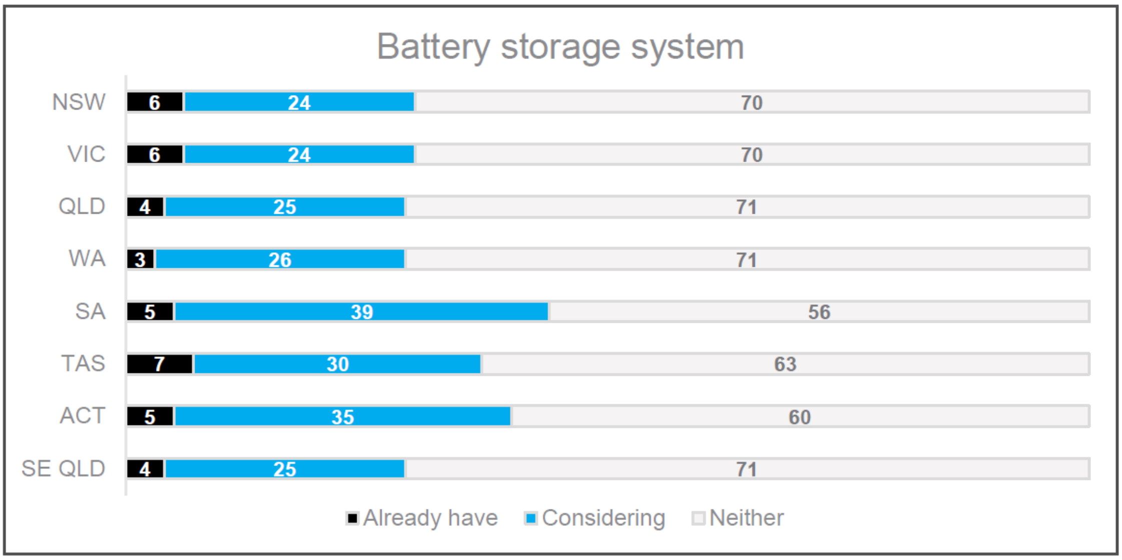
- 30 per cent of Queensland households have the intention of installing battery storage over the next 10 years;[118]
- Regional Queensland households are the most likely to install new solar PV and battery storage systems – in particular, those in the Outback (22 per cent intend to install solar PV; 15 per cent intend to install battery storage) and Fitzroy (24 per cent intend to install solar

[110] See AER website at https://www.aer.gov.au/wholesale-markets/wholesale-statistics/generation-capacity-and-output-by-fuel-source-nem. Figures are for 2019-20 as of 1 January 2020.
[111] See AER website at https://www.aer.gov.au/wholesale-markets/wholesale-statistics/generation-capacity-and-output-by-fuel-source-nem. Figures are for 2019-20 as of 1 January 2020.
[112] Ausgrid regulatory proposal 2019-2024, p. 44
[113] Climate Council of Australia, 2018, p. 6
[114] PIAC 6 November 2019
[115] Renew 28 October 2019
[116] Energy Consumers Australia 2018, p. 29
[117] Energy Consumers Australia 2018, p. 29
[118] Queensland Household Energy Survey 2018, slide 34

PV; 13 per cent intend to install battery storage) regions (possible to provide backup power during blackouts)[119]

- Mainstream uptake of battery storage is expected to begin when prices reach approximately $10,000 (58 per cent would be willing to spend this amount). Assuming the typical user requires a system with a usable capacity of 12 kWh or more, some systems are nearing the acceptable $10,000 price point.[120]

FIGURE 19: What investments are residents considering[121]



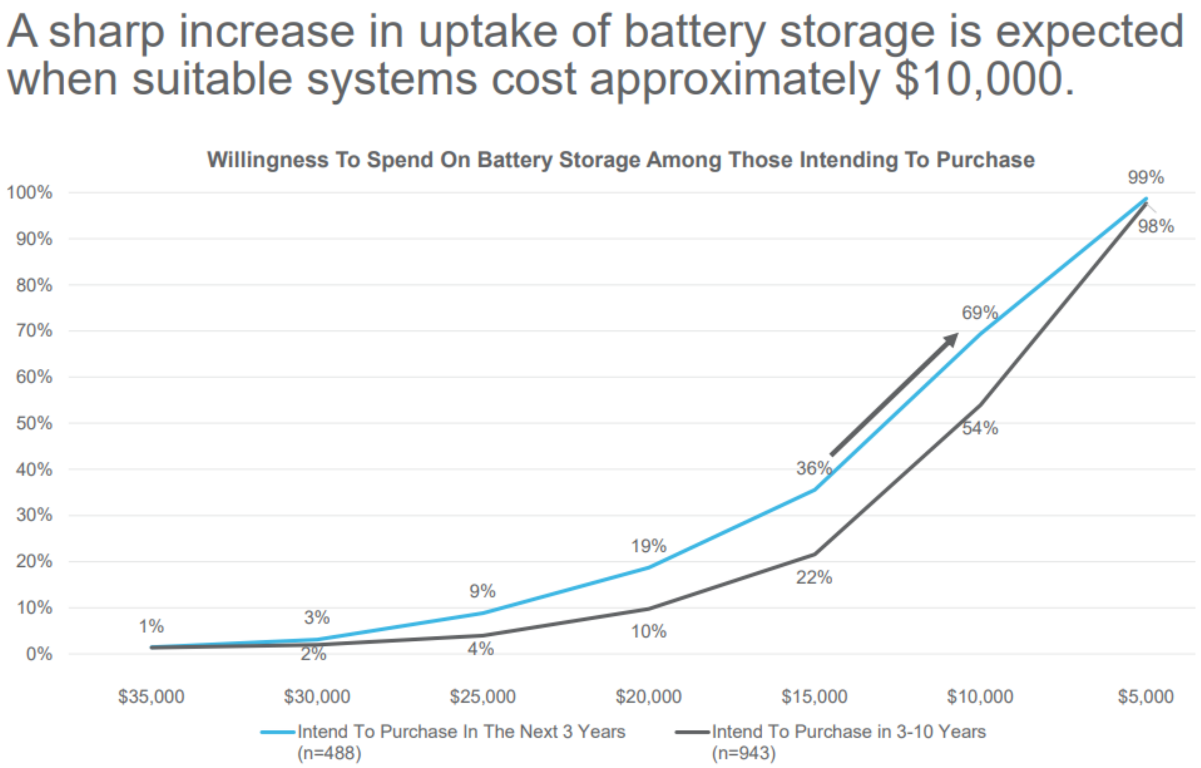
A chart of the intention to buy battery storage mapped against the price of such systems found that intention to buy increased markedly with falls in price. Almost 100 per cent of those who intended to buy a battery system in the next 10 years would do so if the price fell to $5,000 (as illustrated by Figure 20 below).[122]

This data provides a point of reference for assessing the emergence of batteries, since it suggests that battery uptake behind the meter would become significant at price points below $10,000.

It is noted that subsidies in South Australia have driven the price point for Tesla 2 Powerwalls to below $9,000 installed without major uptake as yet. On the other hand, the head of the Energy Security Board, Dr Schott noted that about one in eight newer PV installations at houses included storage batteries as part of the system.[123]

[119] Queensland Household Energy Survey 2018, slide 35
[120] Queensland Household Energy Survey 2018, slide 38
[121] Energy Consumers Australia 2018, p. 33
[122] Queensland Household Energy Survey 2018, slide 38
[123] Simon Evans, *Household batteries too much like holiday homes*, Australian Financial Review, Oct 9 2019, at https://www.afr.com/companies/energy/household-batteries-too-much-like-holiday-homes-20191009-p52ywl

FIGURE 20: WHEN IS STORAGE CONSIDERED AFFORDABLE?

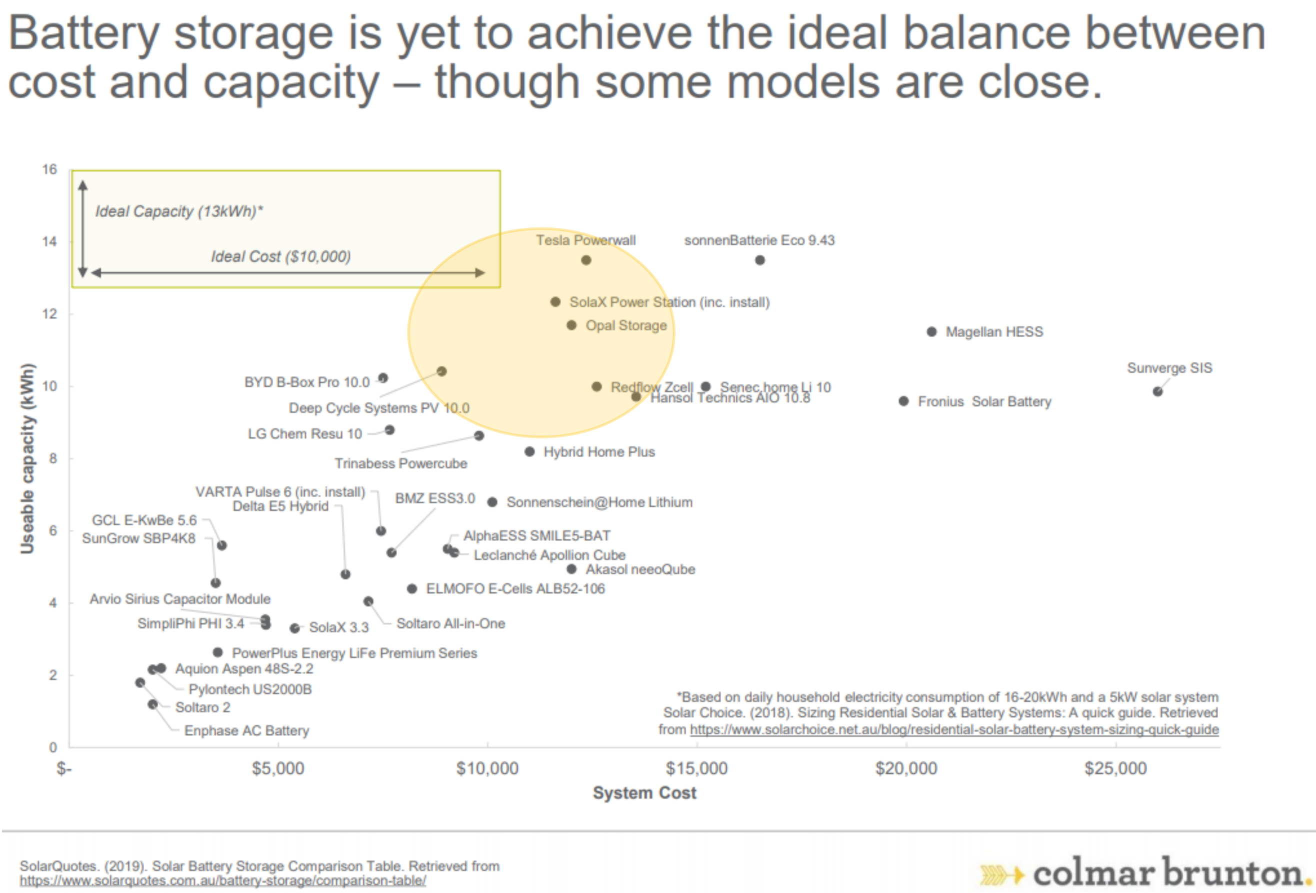


The 2018 Queensland Household energy survey noted that a number of battery systems on the market are close to this point of willingness to buy (particularly if the buyers can get access to government financial incentives), as illustrated in the following graph of battery storage prices mapped against capacity.[124] Based on the view that the ideal balance was a 13 kWh system for $10,000, Figure 21 below shows the systems that come closest to meeting consumer preferences – those in the orange circle marked on the graph.

The qualitative analysis would suggest that there is likely to be a significant pickup in behind-the-meter battery installation by some point during the 2020-2030 decade.

[124] Queensland Household Energy Survey 2018, slide 39

FIGURE 21: THE IDEAL BALANCE BETWEEN COST AND CAPACITY



2.4 Quantitative model

The quantitative modelling work looked at the upfront costs of batteries with a primary focus on residential-scale batteries.

It then examined data on the learning curve from a range of sources and the assumed shape and inflection point of the curve to develop an assumed learning rate for battery costs for 2019, 2020, 2021, 2025, 2030, 2035, and 2040. This is displayed, with starting prices, in Figure 22 below. The starting price for batteries was selected as $14,100. This was based on an estimate of the installed price of a Tesla Powerwall 2. The Tesla Powerwall 2 was selected because it is the leading battery in the home market. The installed price was based on a blend of information including a standard quote from Origin to retrofit a Tesla Powerwall 2 for $12,749 in 2019 in urban areas (since increased by Origin to $14,995 in 2020)[125] and information from interviewees.[126]

FIGURE 22: ASSUMED LEARNING RATE AND STARTING PRICES FOR RESIDENTIAL BATTERIES

Year	2019	2020	2021	2025	2030	2035	2040
Installation price and saving per year	14,100	9%	5%	4%	3%	2%	2%
		12,831	12,189	10,119	8,507	7,622	6,829

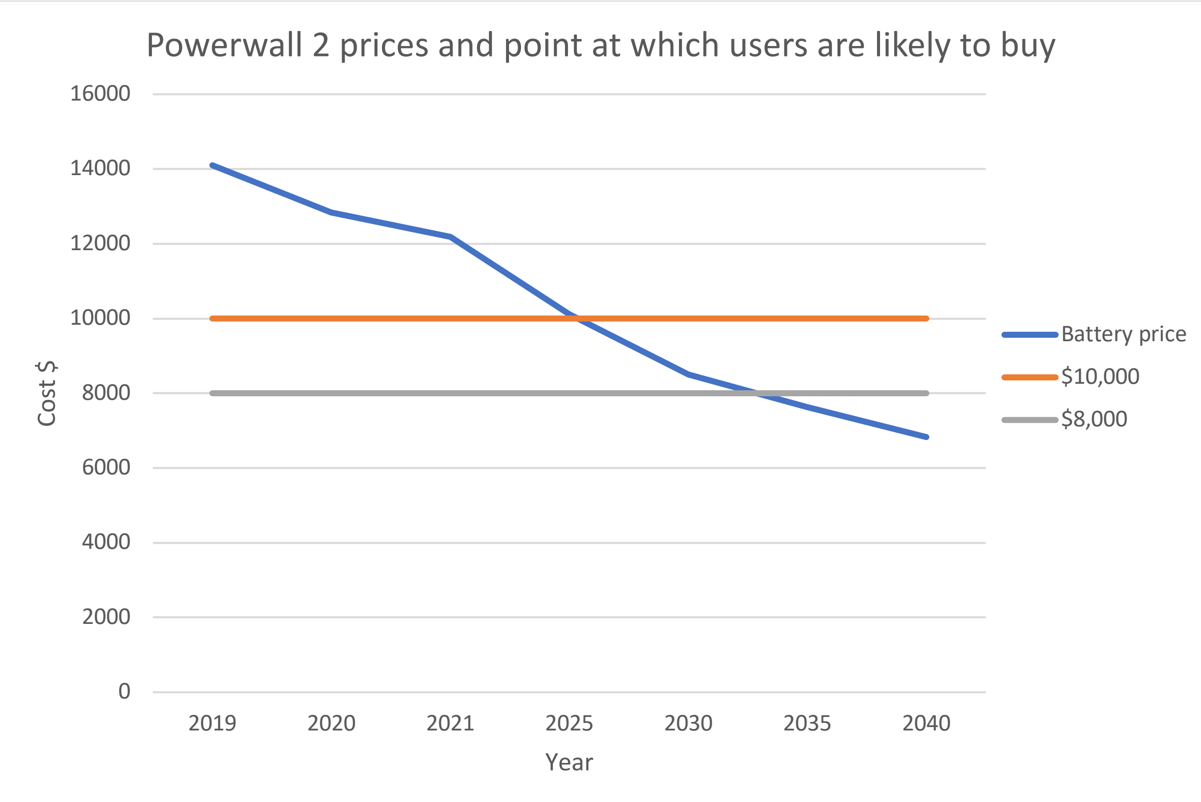
[125] Origin website at https://www.originenergy.com.au/solar/batteries/tesla-powerwall.html. Retrieved in 2019 and 2020
[126] Renew

The modelling examined data on the threshold price point at which residential customers were willing to buy a Powerwall 2 system (13.5 kWh) capacity and adjusted this forward compared with the falling price of batteries based on the applied learning rate.

It was assumed that people would start to buy if they could buy a 13-kWh system below $10,000 installed. A second grey line represents a purchase once the installed price falls below $8,000.

The analysis was graphed in Figure 23 below to show that consumers would begin buying residential batteries in significant numbers from around 2025 on the assumed $10,000 price point for a 13 kWh battery.

FIGURE 23: ATTRACTIVE PRICE-POINTS FOR TESLA POWERWALL 2 INSTALLATION



This analysis was supplemented by an examination of the payback period. The analysis started with a base case, represented by a residential home with 5 kW of solar panels and a specified pattern of peak and non-peak use. The analysis examined the payback with and without time-of-use tariffs. Figure 24 illustrates the calculations for the assumed pattern of use to achieve payback.

The base case was based on a generalized view of typical household use in terms of total use and peak and off-peak use. In practice different households vary significantly in terms of both total use and use at peak and off-peak times.

FIGURE 24: ASSUMED PATTERN OF USE FOR PAYBACK

Use	Units	Value
Non-peak - day use	kWh/day	5
Non-peak – night use	kWh/day	5
Peak use	kWh/day	20
Generation by panels	kWh/day	16.1
Peak use covered by solar generation (in absence of battery)	kWh	3
Generation to charge 13.5 kWh battery	kWh	15
Tariff – flat	c/kWh	26.0267
Feed-in tariff	c/kWh	7.8
Tariff – TOU peak	c/kWh (150 per cent flat)	39.04
Tariff – TOU non-peak	c/kWh (50 per cent flat)	13.01
Discount factor	per cent per year	5

Figure 25 (below) presents the results of the analysis across two scenarios, flat tariffs and time-of-use tariffs.

FIGURE 25: PAYBACK PERIODS

Payback period (at 5 per cent discount rate	**2019**	**2020**	**2021**	**2025**	**2030**	**2035**	**2040**
Capital cost ($)	14,100	12,831	12,189	10,119	8,507	7,622	6,829
Flat tariff scenario (years to nearest half-year)	> 40	> 40	> 40	> 40	> 40	> 40	34.5
Time-of-use scenario (years to nearest half-year)	20.5	16.5	16	12	10	8.5	7.5

The results show that residential battery users on a time-of-use tariff could expect a payback period under 10 years only in 2030. By contrast, payback periods on the flat tariff scenario were much longer. This analysis does not include any subsidies on the upfront cost or any additional revenue (e.g. from frequency control) except the revenue earned by increased self-consumption from the solar panels. Green cells show acceptable payback periods.

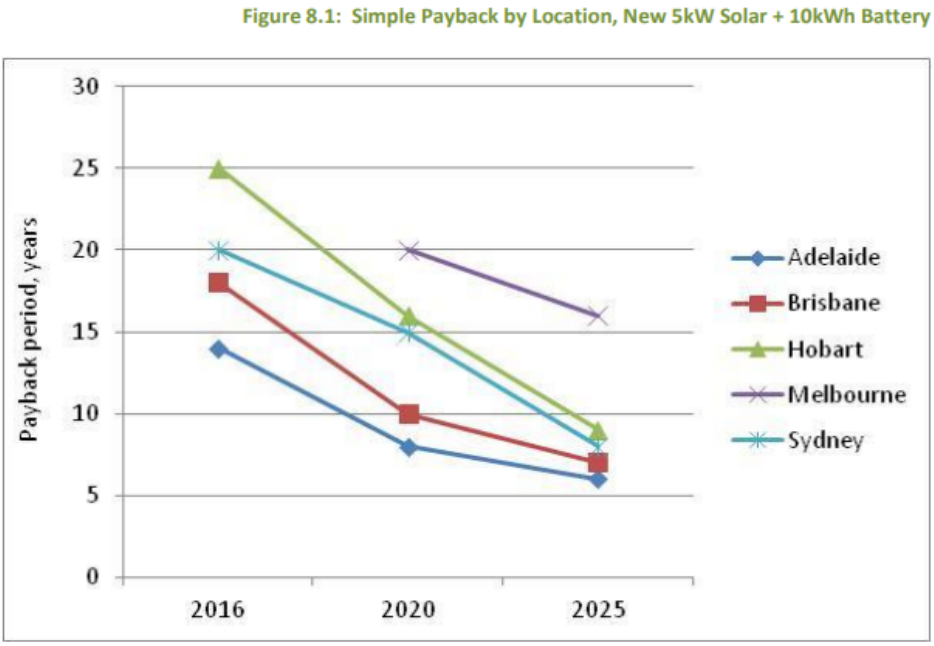
Based on the payback period analysis, batteries would become attractive to time-of-use customers (particularly those with high peak use) from around 2030, although perhaps as early as 2025 in an environment of low interest rates[127] and/or where investors preferred certainty of returns.[128] This is based on the view that a payback period under 10 years is reasonably attractive to users at present due to prevailing low interest rates. However, based on a payback period of 10 years, batteries would become attractive around 2030.

The full modelling and assumptions can be found in the attached excel spreadsheet.

[127] Compared with the selected discount rate in the model of 5 per cent
[128] Also compare Clean Energy Council 2019, p. 4

These findings can be compared with the findings of the ATA when it undertook an analysis in 2016-17 of the payback period on a package of a new 5 kW solar PV panel and a 10kWh battery.[129] The ATA report was based on a granular analysis of household use over half-hour blocks over a year in Sydney, Melbourne, Hobart, Adelaide, and Brisbane. The analysis found that by 2020, the payback period in 2020 would be 10 or below in Brisbane and Adelaide, and by 2025 would be 10 or below in Brisbane, Adelaide, Sydney, and Hobart, as shown in Figure 26 below.

FIGURE 26: SIMPLE PAYBACK BY LOCATION IN FIVE CAPITAL CITIES IN THE NEM



While the ATA analysis is from an earlier period (2016-17), it shows that payback periods under 10 years should be available for a significant portion of the market from 2020 and for most of the capital city markets by 2025.

2.5 Sensitivity analysis

A range of factors could affect the attractiveness of buying batteries. The model was adjusted for potential changes in a range of the inputs to see how this would affect the payback period.

There are a wide range of factors that would affect residential consumer interest in buying a battery. This would include:

- Subsidies provided by governments to buy batteries. To model this effect, a subsidised battery price was selected based on the current subsidy in South Australia. The South Australian government pays a subsidy of $500 per kWh of battery capacity ($600 for energy concession holders). This reduces on 15 April 2020 to $300 per kWh ($400 for concession holders).[130] The subsidy was modelled to reduce from post April 2020 levels by 25 per cent

[129] See ATA (2017). *Storage Advice: Final Report for Energy Consumers Australia*, January at p. 74

[130] See South Australian Government website at https://homebatteryscheme.sa.gov.au/home-battery-scheme-subsidy-changes

in 2021, another 25 per cent of the post-April 2020 levels by 2025, and then to cease after 2025.

- A 10 per cent improvement in solar panel efficiency. This might occur if panels became more efficient in the future, generating more power and thus increasing the amount of power available for charging the battery;
- A change in feed-in tariffs paid for solar panel generation into the grid. A rise in the feed-in tariff would reduce the relative attractiveness of batteries as it would improve the attractiveness of the alternative of selling this output into the grid through the feed-in tariff;
- Electricity prices up or down 10 per cent. Increases in electricity prices would make batteries more worthwhile, as batteries would then displace higher priced electricity from the grid. Lower electricity prices would make the high upfront cost of batteries less worthwhile;
- More use by the consumer at peak times and less at off-peak times, and the opposite scenario. More use at peak times under time-of-use tariffs would make batteries more worthwhile, because batteries offset higher-priced peak use;
- A lower discount rate (3 per cent instead of 5 per cent). The discount rate is the rate at which future costs are savings are discounted compared to current (upfront) costs or savings. A discount rate of 3 per cent would generally be considered low. However, interest rates worldwide have been low since the global financial crisis in 2008 and are expected to stay low, suggesting that a rate of 3 per cent might be appropriate;
- Peak tariffs at 200 per cent of flat tariffs and off-peak tariffs at 40 per cent of flat tariffs (compared with the base case of peak tariffs at 150 per cent and off-peak tariffs at 50 per cent of flat tariffs). Alternatively, a second scenario was modelling where peak tariffs were only 130 per cent of flat tariffs while off-peak tariffs were 70 per cent of flat tariffs. Higher peak tariffs create more value for batteries because batteries are a mechanism for storing power at off-peak times for use during peak times.

As batteries are not typically economic under flat tariffs for many years, the results have only been modelled for a scenario where time-of-use tariffs apply. The results are displayed below in Figure 27 below. Green cells show acceptable payback periods.

FIGURE 27: SENSITIVITY ANALYSIS - ASSUMES TOU SCENARIO IN ALL CASES

Payback period	2019	2020	2021	2025	2030	2035	2040	Sensitivity
Base case	20.5	16.5	16	12.5	10	8.5	7.5	---
Subsidised battery price (or higher falls in battery prices)	9	10	11	10	10	8.5	7.5	very high
10% improvement in solar panel efficiency	19.5	17	15.5	12	9.5	8	7	low
Feed-in tariff at 10c/kWh	23	19	18	13.5	10.5	9	8	moderate
Electricity prices up 10%	17	15	13.5	10.5	8.5	7.5	6.5	moderate
Electricity prices down 10%	26.5	22	20	15	12	10	8.5	low
More use during peak and less during off-peak	21	18	16.5	12.5	10	8.5	7.5	low
More use off-peak during day and less during peak	16.5	14.5	13.5	10.5	8.5	7	6.5	high
Discount rate at 3% (rather than 5%)	16.5	14.5	13.5	11	9	8	7	high early, trending lower over time
Peak pricing higher than off-peak prices (200% of base tariff and 40% of base tariff)	11	10	9	7.5	6	5	4.5	high
Peak pricing not much higher than off-peak prices (130% of base tariff and 70% of base tariff)	40	31	27.5	19.5	14.5	12.5	11	high

2.6 Seasonal impacts

In addition to the above factors, seasonal impacts might affect the payback period on batteries. Solar panels generate less during the winter months and more during the summer months. This means that batteries capture more charge from solar panels in summer months and less in winter months than the average 16.1 kWh assumed in the base case. If time-of-use tariffs are oriented to charge more in a particular season, this could affect the results.

Generally, electricity use peaks in summer with higher use of air-conditioning.[131] Thus, time-of-use tariffs which are based on peak use could be expected to be higher during the summer. This would increase the value of batteries, as they capture more output from solar panels during the summer.

The return from installing a battery in the base case was modelled against expected solar panel generation across the year. The results are shown in Figure 28 below.

FIGURE 28: SEASONAL VARIATION IN THE SAVINGS PROVIDED BY BATTERIES

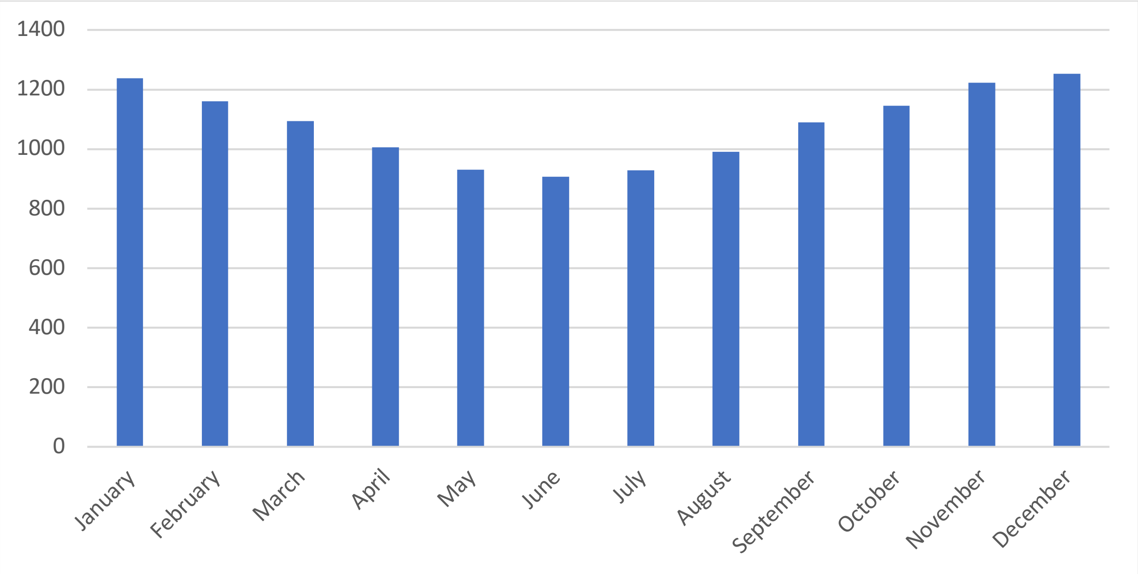


Figure 28 shows that, as expected, batteries generate more savings in summer and less in winter. Thus, the use of a seasonal time-of-use tariffs with a summer peak might be expected to somewhat encourage the uptake of batteries. However, the overall effect of these seasonal variations is probably not large to be influential on purchasing decisions. The spread from June (the lowest month of savings) to December (the highest month of savings) is only 28 per cent. This makes intuitive sense since the first units of generation from panels that are stored in batteries are the most valuable. Under time-of-use pricing, the first units of generation go towards displacing high-priced peak units of use while the latter units of generation go towards displacing the need to purchase power from the grid at off-peak times.[132] Thus the first units of generation from batteries are more valuable than the subsequent units of generation.

[131] This may not be true in the colder States, such as Tasmania.

[132] For example, if peak use is charged at 39c/kWh and off-peak use is charged at 13 c/kWh, then the battery will first be used to displace the peak priced units, saving 39c/kWh. Only in the middle of summer do the solar panels generate sufficient energy to fully charge the battery and then have left over generation to displace lower priced use at off-peak times.

2.7 Finding

Based on the quantitative analysis above, the finding of this report is that batteries will become a significant presence in the NEM somewhere between 2025 and 2030 based on existing policy settings and resulting revenues, and assuming residential customers had access to time-of-use tariffs.[133] Current policy efforts that unlock additional value for batteries (especially in demand response and frequency control markets) might advance this date.

2.8 Caveats on finding

There are a number of caveats on the findings:

- Without access to time-of-use tariffs, the business case to install a home battery is weak. This in turn depends on retailers offering time-of-use tariffs (particularly with a significant difference between peak and off-peak tariffs) and on installation of smart meters that can detect the time of use during the day. Some retailers have been reluctant to offer time-of-use tariffs.
- The sensitivity analysis shows that a change in a wide range of input factors (e.g. installed price of batteries, discount rate), could bring earlier or later adoption.
- Batteries installed at the home require significant clearance on both sides (600mm) as well as above and below. There will be a number of dwellings that do not have sufficient clearance for installation of a home battery.

2.9 Emergence of batteries at a community or utility level

As discussed in section 1.4 above, batteries may emerge at the community or utility level in addition to at the user level.

At utility scale, batteries are forecast to become the second cheapest form of generation in the NEM by 2020.[134]

The first utility scale battery was the Neoen Hornsdale battery with 100MW/129 MWh of capacity. This battery has reported revenue equal to one third of its construction cost in the first year, from the SA Government to provide reserve capacity, from trading in the frequency control market, and from sale of stored generation.[135] The revenue from frequency control is noted to be highly volatile as "it only takes a few more batteries to really crush or put a lot of downward pressure on that market".[136] The battery has also earned revenue from charging when NEM pool prices are negative.[137] The Hornsdale battery has been commercially successful enough that in November 2019, the owners announced a 50MW/64.5 MWh expansion of the battery, with the battery forecast to be completed in the first half of 2020.[138]

---

[133] This in turn assumes that time-of-use tariffs have been reasonably widespread and accepted by customers and smart meters have been installed at a significant number of residential addresses.
[134] Refer to the table of Forecast generation costs in the NEM above.
[135] Australian Financial Review, Project line-up defies market risks, 13 September 2019, p. 24
[136] Australian Financial Review, Project line-up defies market risks, 13 September 2019, p. 24
[137] Australian Financial Review, 6 September 2019. Wholesale prices in the NEM can turn negative when demand is low, but generators want to continue generating to avoid the disruption from shutting down and then starting back up.
[138] See Hornsdale Power Reserve website at https://hornsdalepowerreserve.com.au/expansion/

In January 2020, AGL announced a 100 MW/150 MWh battery at Wandoan in Queensland and noted that in 2019 it had built a 30 MW battery on the Yorke Peninsula in SA and a deal to buy capacity from four 50 MW/100 MWh batteries in NSW.[139]

These developments suggest there is scope for utility scale batteries to be economic in some locations.

The electricity distributor Ausgrid is currently conducting research into a community battery. [140] Ausgrid is calling for registrations of interest for interest in a community battery. Its stated goal is to offer customers a community battery at no upfront or maintenance cost. Outside the NEM in Western Australia, Western Power and Synergy are working together to offer a community-scale battery where users can pay a daily charge to have their excess solar power stored. The arrangement is summarised in Box 3 below.

Box 3: PowerBank community battery storage

Western Power, which operating the operates the grid in south-west Western Australia, is collaborating with Synergy, the largest electricity retailer in WA, to install and trial three community-scale batteries:[141]

1) **Meadow Springs, Mandurah**: launched in October 2018 with a 105kW (420kWh) battery.

2) **Falcon, Mandurah**: an extension of the Meadow Springs trial with a 116kW (464kWh) battery.

3) **Ellenbrook**: a PowerBank 2 trial launched in February 2020 with a 116kW (464kWh) battery.

The projects offer up to 192 households between 6-8 kWh of virtual storage in the PowerBank at a cost of $1 to $1.90 per day to store excess solar generation. Western Power and Synergy will own and maintain the battery and support the grid during peak demand.

The WA and Ausgrid examples show the possibilities for community-scale batteries as an alternative to batteries located behind-the-meter at user premises.

In 2018, AEMO forecast 215 MW of large-scale batteries by 2021-22.[142] Their more recent analysis in their draft 2020 ISP suggested that as renewable energy replaced coal-fired generation, there would need to be more dispatchable resources (including batteries, hydro, and demand-side response) to back up the renewables. They forecast up to 21 GW of dispatchable resources and forecast 5.6 GW of battery storage installation by 2036-37, up from a capacity close to zero today.[143]

Large scale batteries could grow faster than behind-the-meter batteries due to:

- Their lower cost on a per MW or MWH basis than behind-the-meter batteries;
- Easier financeability due to their larger size;
- Ease of coordination by grids or market operators.

[139] See AGL press release at https://www.agl.com.au/about-agl/media-centre/asx-and-media-releases/2020/january/new-giant-battery-to-support-agls-renewable-energy-drive-in-queensland
[140] See Ausgrid website at https://www.ausgrid.com.au/In-your-community/Community-Batteries
[141] See Western Power website at https://westernpower.com.au/energy-solutions/projects-and-trials/powerbank-community-battery-storage/
[142] AEMO, 2018 ISP, Appendix 3, central storage tab
[143] AEMO 2020

Large scale batteries were estimated to cost about 15 c/kWh compared with 35 c/kWh per kWh of installed capacity.[144] Ausgrid has stated that community batteries are more cost-effective than behind-the-meter batteries.[145]

Community batteries should be easier to finance as banks generally prefer to finance large assets to small assets. They should be easier to coordinate because coordination only requires agreement with one party, compared to VPP arrangements where an aggregator might need to enter coordination agreements with hundreds of small behind-the-meter battery owners.

This could see community-scale batteries emerge earlier than behind-the-meter batteries.

[144] Renew estimate

[145] Simon Evans, *Household batteries too much like holiday homes*, Australian Financial Review, Oct 9 2019, at https://www.afr.com/companies/energy/household-batteries-too-much-like-holiday-homes-20191009-p52ywl

Chapter Three: Policy Implications

3.1 What are the implications of battery uptake for the NEM?

This chapter discusses the implications of the uptake of batteries in the NEM. A number of themes emerged from the literature and consumer group interviews:

- In a technology-neutral market like the NEM,[146] the value of batteries must be unlocked by reviewing any features of the market that prevent to realizing their multiple value streams.[147]
- Batteries must be operated by market operators in a coordinated way to unlock their full value.[148] This can be achieved through the offering of incentives to battery owners.
- It will be important to build trust and confidence before battery owners will permit third parties to control their behind-the-meter batteries.
- Issues around ownership and operation of batteries need to be resolved, specifically whether networks should be able to own or operate batteries.[149]

AEMC and AEMO have been working on these issues, as noted in section 1.6.

Currently a hurdle to integration of batteries in the NEM is the fact that battery owners cannot participate in providing wholesale market services, that is buying or selling electricity in the NEM.[150] This requires battery aggregators wishing to provide this service to work through or with a retailer.

To respond to this, in August 2019 AEMO submitted a rule change to create a new registration category in the NEM for battery aggregators.[151] The rule change calls for a new registration category within the NEM, namely a bi-directional service provider. This would recognise the bi-directional generation and consumption role of storage and allow registered participants in this category to

[146] The AEMC has a commitment to maintaining a technology-neutral NEM, that is a NEM in which the market does not favour one type of technology over another. See, e.g. AEMC 2015, p. ii
[147] For example, Rocky Mountain Institute 2015 p. 37
[148] E.g. Consumer Action Law Centre, Renew
[149] Views varied on whether networks should own batteries, from the view that networks might favour their own batteries over batteries installed by users or generators (Renew) compared with the view that networks would generally welcome batteries due to the benefits that batteries provided for networks and batteries were most economically installed at the suburb level (Battery Storage and Grid Integration Program, ANU).
[150] AEMC 2019c, pp. 152-153
[151] AEMO 2019e

aggregate batteries behind the meter and offer them into the market without needing to have a relationship with a retailer.[152]

AEMC also recognised that there might be technical issues hindering batteries from offering frequency control services, which AEMO was working through with participants.[153]

Additionally, AEMO is assessing through VPP trials whether there are any issues arising from integrating batteries into the NEM. AEMO started the VPP in April 2019.[154] In AEMO's words, the demonstrations are planned and underway to:[155]

- *develop the systems and frameworks required to effectively and securely integrate VPPs into the existing electricity grid and market,*
- *craft a FCAS Assessment tool for VPPs to deliver multiple services across energy markets, and potential network support services,*
- *provide systems to allow AEMO access to real-time data from DER,*
- *operationalise VPP on-boarding of the FCAS system,*
- *assess current regulatory arrangements affecting participation of VPPs in energy and FCAS markets, and inform new or amended arrangements where appropriate,*
- *provide insights on how to improve consumers' experience with VPPs in future, and,*
- *understand and inform the necessary cyber security capabilities of VPPs to safely 'plug' into the electricity grid.*

Other key issues identified by AEMC are orchestration of DER and optimisation of DER.[156]

Orchestration means the aggregation of many (smaller) batteries by a third party to realise a value such as FCAS.[157] In some ways, this orchestration or coordination may run counter to on-premises use of the battery.

Optimisation means maximising the value of the battery across all its potential value streams by choosing the highest value stream to pursue at a given time.

While residential users might be expected to be hesitant to permit a third party to control their battery, Ausgrid found that, "A recent survey found 41 per cent of customers with battery storage would consider allowing Ausgrid to operate their battery system in return for a financial incentive".[158] It will be necessary to build trust for battery owners to permit orchestration.

3.2 Issues identified in the literature and from consumer group interviews

During the development of the draft report, discussions were held with a number of consumer and other groups that had previously worked on issues related to batteries and storage, including AEMO,

[152] As at the start of April 2020, the AEMC advises that it "has not yet initiated this rule change request" and that when "the AEMC initiates this process, the AEMC will publish a Consultation Paper to facilitate stakeholder consultation on the request": See AEMC website at https://www.aemc.gov.au/rule-changes/integrating-energy-storage-systems-nem. The AEMC may be waiting to consider this rule change request in the context of other developments.
[153] AEMC 2019c, p. 153
[154] AEMO website at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/DER-program/Pilots-and-Trials
[155] AEMO website at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/DER-program/Pilots-and-Trials
[156] AEMC 2019c, p. 153
[157] Compare AEMC 2019c, p. 153
[158] Ausgrid regulatory proposal 2019-2024, p. 43

ANU Battery Storage and Grid Integration program, Renew (ATA), PIAC, CALC, CPRC, and TEC. Relevant literature was also reviewed, as listed in the bibliography.

Key issues identified included:

1. Stacking of multiple revenue streams through participation in demand response and FCAS markets;
2. Coordination (orchestration) of batteries and VPP trials;
3. Network ownership or operation of batteries;
4. Registration of battery aggregators/providers;
5. Tariff reform, particularly the extent of price signals in retail tariffs;
6. Battery price trends;
7. Impact of electric vehicles on energy markets;
8. Connection;
9. Safety;
10. Consumer protection;
11. Battery reliability; and
12. Equity issues in access to batteries and resulting tariffs for users with batteries and users without batteries.

These issues are discussed in turn below.

3.2.1 Stacking

Stacking occurs where battery owners or controllers are able to earn revenue from multiple sources for provision of services from batteries, e.g. greater self-consumption, ancillary market services, and energy market services. Chapter one explored the many benefits that batteries provide to the electricity market.

One community group highlighted that stacking of residential-scale batteries required the presence of an aggregator as the costs would be too high for individual battery owners to themselves sell their battery's output into the market.[159]

The battery vendor Reposit conducted stacking trials in Canberra where customers earned revenue from battery/solar panel combinations through:[160]

- Solar generation;
- solar charging of the battery;
- smart charging of the battery at off peak times;
- market operations; and
- behavioural change.

The trial found that "customers were able to make significant savings on electricity bills".[161]

[159] Renew 28 October 2019
[160] Clean Energy Council 2019, p. 8
[161] Clean Energy Council 2019, p. 8

VPP trials need to fully investigate potential for stacking. It is noted that sometimes revenue streams will conflict with one another, for example, self-consumption of solar generation compared with using that generation to provide energy to the market.[162]

One benefit that batteries provide to the market is backing up or firming up renewables. Batteries (and other forms of storage such as pumped hydro) do this by storing power from renewables as they generate and then generating this power into the market as it is needed. At present, under the structure of the wholesale market in the NEM, there is no payment for standing ready or available to inject power into the market as and when required. Instead, all generation is paid the prevailing price in the market and there are no payments for standing ready to generate. This penalizes so-called 'dispatchable' generation which can step in to generate when other generators such as renewable generators cannot.[163] This raises the question of whether there needs to be a payment in the NEM for availability or dispatchability. It is noted that the SA Government agreed to pay the Hornsdale battery for providing reserve power for the SA region of the NEM.[164] The value of dispatchability and the value of batteries in providing this service needs to be further investigated by the AEMC.

3.2.2 Coordination (orchestration) of batteries and Virtual Power Plant trials

To maximise the value of batteries in the market, they must be available to generate power at times of peak demand. In practice this involves third parties remotely controlling behind-the-meter batteries owned by residential users. In exchange behind-the-meter battery owners should expect to be paid for the service provided by their battery. As noted earlier, the SA Government has required battery owner permission for orchestration of behind-the-meter batteries as a condition of the subsidy it is providing for home batteries under its Home Battery Scheme.[165]

AEMO and other parties are investigating the technical challenges in orchestration of multiple batteries simultaneously.

One aspect of these technical challenges is controlling the amount of power flowing from households with solar panels and batteries, and the ability of localised areas of the grid to cope with these power flows. Following the installation of significant rooftop solar panels from 2010 onwards, some localised areas of the grid faced the risk of excess outflow of power from households into the grid, particularly around midday, when solar panel generation is at its peak. Distributors in some cases responded by imposing export control limits that prevented more than a set amount of power being exported by these households.

Theoretically, exporting from batteries could increase flows into the grid at localised levels, making it more important to have control over and visibility of flows and localised network limitations. IN this regard, the Clean Energy Council notes that most residential solar panel inverters (including 96 per cent of inverters installed in 2019) have the ability to sense grid conditions and provide more or less power (including reactive power) when the grid needs it.[166] Community energy models could be supported by the work that distributors are doing under the Open Energy Networks program to improve the visibility of constraints in their network at a street level. The Open Energy Networks

[162] Compare AEMC discussion of the need for tools for optimisation: AEMC 2019c, p .153
[163] Contrast Rai and Nunn (2020) which identified the value of dispatchable generation in the NEM
[164] Australian Financial Review, Project line-up defies market risks, 13 September 2019, p. 24
[165] See SA Government website at https://homebatteryscheme.sa.gov.au/about-the-scheme
[166] Clean Energy Council 2019, p. 9

work on visibility would also help in the move to dynamic control of export limits. There is also a need to ensure that smart meters have the technical features to support these arrangements.

A second technical challenge is coordinating all the batteries reliably as and when required. It may be difficult to send signals to some batteries and get them to respond, while in other cases, the batteries may not be able to respond because they are depleted.

There have been a number of trials, with some currently taking place, to see how well batteries can operate in concert with the network to manage issues such as discharging at times of peak demand., for example AEMO's VPP trial

The AEMC noted a successful 2017 trial in South Australia by AGL where AGL installed and operated 1,000 behind-the-meter batteries with 12 kWh capacity. The battery was programmed to maximise solar self-consumption. The trial worked as planned in maximising self-consumption of solar. AEMC notes that early results indicate batteries may be able to participate in the six-second contingency market (subject to confirmation). The trial also showed that batteries can provide grid support as well as, through aggregation, a physical hedge and arbitrage opportunity in the wholesale market.[167]

However, further trials need to be conducted to establish whether residential-level batteries can, for example: (i) be bid into energy markets in concert with each other while obeying AEMO dispatch rules; or (ii) participate effectively in ancillary services markets. It has been noted that most of the trials to date have only been on a small scale, and only the trial in the ACT was at a scale greater than 5 MW.[168]

A broader issue is whether battery owners will agree to let third parties such as aggregators or retailers 'orchestrate' or dispatch their batteries. This will depend on factors such as whether battery owners are properly rewarded for permitting third party control, the battery owner's concerns about needing the battery themselves at a time when the third party wants to dispatch it, and the level of trust of the battery owner for the aggregator or retailer. Concerns about the battery being needed by the owner could be dealt with to some extent by setting a limit on the degree of third party dispatch e.g. so that the battery be left with a minimum reserve charge after third party dispatch.

Whether the battery owner will permit third party orchestration may depend on the original motivation of the battery owner in buying the battery. If battery owner bought the battery in order to ensure continuity of supply, they may be reluctant to permit third party dispatch. On the other hand, if the battery owners bought the battery to reduce power costs, they may be more cost-focussed and therefore interested in permitting third party dispatch for what they see as a reasonable reward. VPP trials could usefully focus, among other matters, on assessing battery owner experience with third party orchestration with a view to judging how to develop the right social conditions that encourage battery owners to permit orchestration.

3.2.3 Network ownership or operation of batteries

Under current NER provisions, distributors are prohibited from owning batteries. The rationale is that batteries are a contestable electricity service and should be separated from non-contestable or

[167] AEMC 2019c, pp. 157-158

[168] Battery Storage and Grid Integration Program, 25 November 2019

monopoly electricity services such as electricity distribution or transmission services.[169] Electricity distributors can, however, obtain access to the benefit of batteries by setting a ring-fenced entity which owns batteries and operates them at arm's length.[170]

Distribution networks have skills in asset management, making them suitable to maintain and manage batteries located on the network.[171] The argument is that they should be able to place batteries on the network at places such as substations in order to avoid expanding the substations as demand increases (the batteries would discharge when demand was greater than the substation's capacity).

Based on this view, ring-fencing arrangements might stifle networks in respect of network batteries by over-complicating the development of business cases, which is a precondition of the capital planning process for distributors in selecting the lowest cost solution to build out a network constraint.[172]

If the battery provided other services, such as ancillary market services, then the associated costs and revenues would need to be ring-fenced.[173]

Some consumer groups felt ring-fencing was unlikely to prevent network from providing network battery solutions as networks have scope to seek exemptions from the AER and, as noted above, can set up a ring-fenced entity to own the batteries.[174]

An alternative (or complement) to distributors owning the batteries located on the network, would be community ownership of storage. Distributors could access this service through a contracted fee. This would be clearer and avoid any concerns about conflicts or complications around what revenues and costs should be allocated to distributor regulated revenues. At the same time, it would be easier to operate these batteries for non-network services, e.g. energy trading.[175] As noted in section 2.9, box 3, Western Power and Synergy are trialling community batteries on the Western Power network in south-west Western Australia.

The Total Environment Centre is currently working on a project around different community battery ownership models.[176]

The new standards being developed under the Open Energy Networks initiative around connection of batteries could address concerns about networks using connection standards and processes as a way of favouring their network batteries over community and third party batteries either in front of or behind the meter.[177]

There does not seem to be a reason to vary from rules that prohibit networks from owning batteries behind the meter except through ring-fenced arrangements. The arguments that storage services

---

169 AER 2017
170 For example, Yurika works in the virtual power plant and microgrid space, and is owned by Energy Queensland, which operates the Energex and Ergon distribution networks: https://www.yurika.com.au/#about-us
171 Battery Storage and Grid Integration Program, 25 November 2019
172 PIAC 6 November 2019
173 Battery Storage and Grid Integration Program, 25 November 2019
174 Renew 28 October 2019
175 Total Environment Centre 29-30 October 2019
176 Total Environment Centre 29-30 October 2019
177 This was a particular concern of AEMC in AEMC 2015

should be contestable services and therefore separated from non-contestable services such as distribution services appear to remain as valid as they were in 2015.

Since the 2015 AEMC review the AER has examined ring-fencing guidelines on one occasion but has not specifically canvassed this issue.[178] A further review of ring-fencing guidelines by the AER commenced in August 2019 and is currently underway.[179]

3.2.4 Registration of battery aggregators/providers

A number of parties see it as important that a new registration category is created in the NEM for third parties that wish to aggregate and control batteries.[180] One consumer group saw it as essential for there to be a separate registration category for parties controlling DER to separate such services from retailers.[181] Another saw that the current arrangements gave retailers an effective monopoly over battery services offered into the NEM.[182] AEMC supported this view more recently, and in August 2019 AEMO submitted a rule change request to add a new category of participant, being a 'Bi-directional Resource Provider'.

Creating this new category would help separate such providers from retailers and allow them to deal directly with a range of other parties in the electricity market.

The category proposed by AEMO is broader than previously conceived by AEMC, since it extends beyond the ability to provide battery coordination services to all two-way services that batteries can provide.

3.2.5 Tariff reform, particularly the extent of price signals in retail tariffs

Tariff reform could unlock a lot of the value in batteries. One of the key value streams offered by batteries is the ability to divert consumption from peak times to off-peak times. Batteries can do this by charging from solar panels or the grid at off-peak times and discharging this power at peak times.

The workings presented in Section 1.7 and in Chapter Two point to the significant benefits that batteries could unlock in a scenario where time-of-use tariffs are applied,[183] particularly where users used a high proportion of their total use during peak times. In the example modelled in Chapter Two, the payback period fell by a factor of around 4, so in 2025, the payback period was >40 years on a flat tariff and 12 years on a time-of-use tariff. The scale of the fall in the payback period is transformative of demand for (and the value of) batteries. This area of value capture for batteries is more significant than other factors.

Flat residential tariffs do not encourage users to switch discretionary use (e.g. washing machines, pool pumps, refrigeration, air-conditioning) from peak times to off-peak times.

Electricity use is typically highest between 6 pm and 9 pm on weeknights on residential areas of the distribution grid. Significant distribution network is built to cater to this peak. Battery use, if it can

---

[178] Compare AER 2017
[179] AER 2019
[180] For example, Clean Energy Council 2019a, Tesla 2018, Total Environment Centre 29-30 October 2019
[181] Total Environment Centre 29-30 October 2019
[182] Renew 28 October 2019
[183] In the example in Chapter 2, peak prices were one and a half times prevailing tariffs, and off-peak tariffs were half prevailing tariffs.

be relied upon to dispatch as ordered, could postpone significant capital expenditure to meet this peak.

AEMC, as noted in section 1.6 above, published a rule in 2014 to require distributors to reshape their distribution tariffs to reflect the higher costs at peak times. This process is still progressively rolling out as distributors enter new regulatory periods. AEMC has also required that all new residential meters be smart meters.

However, it has been noted that changes in distribution tariffs do not necessarily have to be passed on by retailers, and in practice retailers appear to be reluctant to offer time-of-use tariffs.[184] For example, a review on 1 December 2019 of AGL's three offered retail energy contracts for NSW, Victoria, and Queensland all featured flat tariffs (plus one or two controlled load options).[185] Tariffs are made up of generation, transmission, distribution, and retail elements, so reshaping the distribution element (typically around 35 to 40 per cent) of the total tariff, may not impact the final retail tariff sufficiently to drive changes in behaviour, or the uptake of batteries. Moreover, retailers can elect not to reshape retail tariffs at all. Although failing to reflect changes in distribution tariffs in retail tariffs exposes retailers to risk, in practice alternative tariffs like time-of-use tariffs depend on installation of smart meters that can measure power on the half-hour, and currently only Victoria has high levels of smart meters.[186]

3.2.6 Battery price trends

The leading battery in the market is the Tesla Powerwall. It tends to lead the market in terms of prices per kWh of installed capacity.

The Powerwall 1 was released in 2015, with 7 kWh of capacity.[187] The Powerwall 2 was first released in October 2016. It was about the same price as the Powerwall 1 but twice the capacity, effectively halving the price of the battery.

However, the price of the Powerwall 2 (and related equipment) rose in October 2018 by about 20 per cent, partly related to the battery and partly related to additional required equipment.[188] The price then fell by around $650 or 5 per cent in July 2019.[189]

Overall, the expected fall in residential battery prices has not eventuated in the period since October 2016. One view is that subsidy arrangements were influencing users to buy batteries, and Tesla did not need to drop prices in order to obtain sales.[190] Additionally, as the price leader, Tesla has not experienced strong competition from competing brands. This lack of competition, especially in batteries with a capacity above 10 kWh, may be leading to suboptimal outcomes for users.

---

[184] Battery Storage and Grid Integration Program, 25 November 2019
[185] AGL website at https://www.agl.com.au/get-connected/electricity-gas-plans#/
[186] See Energy Consumers Australia (2018), p. 34
[187] A proposed 10 kW option of the Powerwall 1 was never pursued: https://en.wikipedia.org/wiki/Tesla_Powerwall
[188] https://onestepoffthegrid.com.au/tesla-confirms-price-hike-powerwall-2-battery-storage-reflect-better-value/
[189] https://www.solarquotes.com.au/blog/tesla-powerwall-price-drop/
[190] Renew 28 October 2019

3.2.7 Impact of electric vehicles on energy markets

The view was expressed during interviews that the emergence of electric vehicles could significantly reconfigure the NEM. If EVs were able to connect to the grid as behind-the-meter batteries, then they could reduce the need to purchase separate behind-the-meter batteries, and provide a battery for those users who did not wish to invest in a battery.[191] Electric vehicles could be a significant presence in the market by around 2024.[192]

There are differences of views currently between suppliers over whether EV batteries can or should be integrated into supply to houses. AGL for example was supportive of the idea.[193] On the other hand, there have been mixed views from Tesla whether using EVs to power houses would compromise EV battery health by over-stressing the battery.[194] Nissan notes that its Leaf vehicle has vehicle to grid ((or home) capability, which is in use in Japan and is on its way to Australia.[195]

It is understood that connecting EVs to the house would require a DC to AC converter and could raise warranty issues, which would need to be worked through.[196]

EV batteries can be significantly larger than existing residential batteries on the market. For example, the Nissan Lead is 30 kWh, the Ford Focus is 23 kWh, and the Tesla S is 70 or 90 kWh.[197] These compare with residential batteries generally being less than 10 kWh with the Tesla Powerwall 2 the largest residential battery at 13.5 kWh (see Figure 21 in section 2.3 above).

It may be that battery makers are switching their focus from residential batteries to EV batteries, perhaps with a view to developing an integrated EV battery that can also be plugged in and used at night at home.

There may be cultural issues for residents to overcome in using EV batteries at home as residents may be concerned using the car battery to power the house might prevent them using the car at night, if the car battery charge fell too low. These concerns are likely to abate with deeper experience, and with arrangements such as programming the car battery to stop discharging for home use once it has fallen below a specified threshold chosen by the homeowner.

3.2.8 Connection

Connection agreements cover the rights and obligations on parties connecting to the grid. Distributed energy resources such as batteries and solar panels require a connection agreement. For small users such as residential and small business users, distributors generally have standard connection agreements.

---

[191] E.g. Renew 28 October 2019
[192] Renew 28 October 2019
[193] https://thedriven.io/2019/11/29/the-driven-podcast-why-your-ev-will-also-be-a-virtual-power-plant/
[194] Compare https://www.greentechmedia.com/articles/read/why-is-vehicle-to-grid-taking-so-long-to-happen (may over-stress the EV battery) with https://electrek.co/2018/07/05/tesla-vehicle-to-grid-technology-v2g-elon-musk/ (worth revisiting the issue, noting that early on car batteries could input power to the grid).
[195] https://insideevs.com/news/363304/nissan-teases-v2g-criticizes-tesla/, https://thedriven.io/2019/07/11/nissan-sees-leaf-as-home-energy-source-says-tesla-big-battery-waste-of-resources/; https://www.caradvice.com.au/775866/qa-with-nissan-ev-boss-nic-thomas/
[196] Renew 28 October 2019
[197]See https://batteryuniversity.com/learn/article/electric_vehicle_ev

Connection agreements vary considerably by distributor (particularly around issues such as installed capacity limits and export limits) and many connection agreements contain provisions with hard limits on export of DER rather than dynamic limits.[198] The ENA is working to standardize connection agreements but has yet to make significant progress. It will be important to streamline connection processes as far as possible to facilitate battery connection.

3.2.9 Safety

Some battery types can be fragile and can catch fire if they overheat or are punctured.[199]

In July 2019, a new standard for residential battery electrical safety was agreed.[200] The standard is for lithium-ion batteries with a rated capacity of equal to or greater than 1 kWh and up to and including 200 kWh of energy storage capacity and can be found at: http://www.batterysafetyguide.com.au

It is worth noting that the standard covers electrical safety, *not* installation safety risks. AS/NZS 3000 and AS/NZS 5139, when published, are likely to address installation risks.[201]

There was some criticism from consumer groups that the new safety standard imposed a one-size-fits-all approach on batteries, even though some batteries have chemistries that are much lower risk.[202] However, on balance, it seemed the view was that it was important that the issue of safety had been addressed, and was now not likely to prevent batteries from entering the market.

A point to note is that the considerable clearances required around batteries under the safety standards will mean that some households cannot install a battery because there is no suitable point on the house with the required clearances.

3.2.10 Consumer Protection

As the battery market expands there is scope for poor quality installers to enter the market.[203] With solar panel systems, the Clean Energy Council has leverage to manage installer quality through the renewable energy certificates offered in the market, as only accredited installers have access to these rebates. There is currently no such leverage with battery installers.[204]

One consumer group noted that there had been some reports of door-to-door, high pressure sales approaches for battery systems, and some reports of battery systems offered without an assessment of customer need.[205] Other concerns included inappropriate finance and overstated claims about performance, bill savings, or the ability to go off-grid following installation of a battery.[206]

It will be important to ensure appropriate consumer protections are in place around the sale of residential batteries, in particular around representations of battery capability and potential savings.

---

[198] Clean Energy Council 2019, p.19, Renew 28 October 2019
[199] E.g. https://batteryuniversity.com/learn/archive/is_lithium_ion_the_ideal_battery
[200] CEC press release 25 July 2019
[201] Battery Best Practice Guide, http://www.batterysafetyguide.com.au
[202] Renew 28 October 2019
[203] Renew 28 October 2019
[204] Renew 28 October 2019
[205] Consumer Action Law Centre 23 October 2019
[206] Consumer Action Law Centre 23 October 2019

3.2.11 Battery reliability

Residential-level batteries are still relatively new. As such there is potential that they will fail at a high rate, or that some brands may fail.

Even if batteries do not fail entirely, they may not fully meet promised performance specifications. For example, they may fail to fully recharge with each recharging cycle. While a degree of loss of charge with each cycle could be anticipated, the uncertainty would be around how quickly this occurs. Batteries could also require more power to charge up. This would significantly increase their payback period.[207]

Some battery providers or retailers may fail, leaving users with little scope for redress if their batteries do not perform to standard.

It will be important for consumers to have confidence in battery products and installers.

3.2.12 Equity issues

Battery have a high upfront cost to buy. This creates potential equity issue as some households will not be able to afford to buy batteries. The equity issue could arise in a number of ways. For example, if governments provide significant subsidies for batteries, these subsidies will benefit the users that can afford the buy a battery. Also, renters may not be able to access the benefits of subsidies. If some users cannot afford the subsidised price, they will be locked out of the direct benefit of the subsidy.[208]

Over time the price of batteries is likely to come down, and battery vendors or third parties are likely to provide financing arrangements to reduce the upfront cost of batteries (e.g. by paying the upfront cost of a battery at a user's premises and then recovering this cost over time from the user). This is likely to allow greater access to batteries and reduce inequalities. Governments could also target subsidies to less well-off users in order to provide equity of access to batteries. The SA Government is doing this under its Home Battery Scheme, where it provides greater subsidies to energy concession holders and also provided batteries for public housing tenants.[209] Another point is that batteries provide benefits to the market beyond the user installing them (e.g. through improved voltage support and frequency control), meaning that users without a battery may benefit to some extent from an investment in batteries even if they cannot afford to buy a battery themselves.

[207] The key performance measures will be around depth of discharge, cycle life, and round-trip efficiency. Section 1.2 above discussed these aspects of battery performance.

[208] Such users may, however, obtain some indirect benefits of the subsidy if the batteries provide benefits to the NEM that are broader than the benefits earned directly by the investing user. This could be the case, for example, where a battery permits voltage control which is of benefit to all users in the network.

[209] See SA Government website at https://homebatteryscheme.sa.gov.au/about-the-scheme

Chapter Four: Advocacy

This chapter examines possible areas of consumer advocacy that arise from battery uptake.

4.1 Getting access to all the benefits provided by storage

As noted in section 1.4 above, batteries can be seen as a platform technology, which enable and support a range of other technologies and benefits.

In order to access the full benefits of batteries changes will need to be made to the NER. Some of these changes are underway, and consumers need to participate in these changes to see them to fruition.

The benefits provided by batteries and the changes to the NER that will allow consumers to access those benefits are listed in Figure 29 below.

FIGURE 29: CHANGES TO THE NATIONAL ELECTRICITY RULES REQUIRED TO ACCESS THE BENEFITS OF BATTERIES

Benefit	Change needed to access that benefit
Deferral of network augmentation	1. Substation batteries/Community batteries 2. Close scrutiny of augex against storage alternatives and additional safeguards in the NER against over-expenditure on capex, particularly sub-station expansion 3. Time-of-use retail tariff arrangements (at least on an opt-in basis)[210]
Ancillary services, including frequency control	Resolve technical issues around access (on-going AEMO work in this area)
Energy services	Resolve technical issues around confidence in bidding batteries in to the wholesale market (AEMO VPP trials in this area)

In addition, there are prerequisite changes that are needed to support entry of batteries into the market, as listed in Figure 30 below.

[210] Noting the concern of CALC 23 October about the impact on users remaining on flat tariffs where most users migrated to time-of-use tariffs

FIGURE 30: CHANGES TO SUPPORT THE ENTRY OF BATTERIES TO THE MARKET

Prerequisite issue	Comment
Connection	Standardisation of network connection processes at minimum acceptable levels
Installation safety	Installation safety standards
Smart metering	Advance the program for installation of smart meters. At a minimum provide standing offers in the marketplace for installation of smart meters that any customer can easily access. Ensure that smart meter data is available to DER aggregators.
Consumer protection	Clear and fit-for-purpose consumer protection legislation
Battery economics	Consider mandating greater offering of time-of-use tariffs

In the medium term (say from the mid-2020s), EV batteries are likely to be a candidate to participate in electricity markets, especially given their large size relative to typical home batteries (perhaps 70 kWh compared to a typical home battery around 10 kWh).

The cost of EVs is likely to come down on a learning curve similar to batteries. A tipping point may be reached quite soon (perhaps 2022) where EVs are much cheaper to run on a whole-of-life basis than petrol/diesel vehicles. Additionally, climate factors could increase the adoption of EVs. This could result in a major uptake of EVs much soon than is currently expected.

There may be technical issues to participation of EV batteries in electricity markets. Accordingly, work should start soon to investigate and remove any technical barriers to the entry of EV batteries.

4.2 Future market design considerations

Some broader market design considerations have been raised by commentators. These arise in view of the platform or enabling nature of battery technology:

1. **Availability markets**. Should a value be placed on the availability of batteries to stand ready to inject power into the NEM? As discussed in section 3.2.1, this availability service has significant value. The Australian Financial Review reported that:[211]

   David Green, chairman of Lyon Group, which is seeking to develop a fully integrated solar and storage projects in Australia and Asia, said the Australian market needs to reward the dispatchability of power rather than incentivizing wind and solar projects to have the lowest possible cost and thereby passing the costs of managing that power to the networks sector.

   At present, the NEM is an energy-only market. Other markets, such as the PJM market in the US) offer availability payments.[212] Introducing an availability payment to the NEM would increase the complexity of the NEM but is becoming more important as renewables emerge as a greater share of generation in the NEM.

2. **Allow multiple players to connect batteries to the network in-front-of-the-meter**. IFC recommended considering energy storage "as a unique and agnostic asset on the grid, [and

[211] Australian Financial review, Project line-up defies market risks, 13 Sept 2019, p. 24

[212] E.g. Chattopadhyay D., T. Alpcan, *Capacity and energy-only markets under high renewable penetration*, *IEEE Trans. Power Syst.*, vol. 31, no. 3, pp. 1692-1702, May 2016

to] recognize the highly flexible nature of the technology and allow multiple players on the grid system to install, own, and operate the system".[213]

This could potentially be combined with a rule forbidding networks from connecting batteries to the grid, such that they do not face a conflict to prefer their own batteries to those connected by third parties.

3. **Reform network capex rules to ensure close scrutiny of augmentation capex** so that augmentation expenditure is not favoured over battery alternatives.[214] One consumer group felt that while reviews into capex had found that distributors did not have a material bias towards augex over alternatives, other reviews had found otherwise. Returns on augex can look more attractive than on alternatives, particularly when considering that returns on alternatives can be risky and can fluctuate compared to the return on assets in the regulated asset base.[215] On the other hand, a view was expressed that distributors are quite keen on batteries (both in front of and behind the meter) as batteries moderate peak consumption, and will be a source of demand when they are charging.[216]
4. **Enable users to get ready access to time-of-use tariffs.** As the analysis in chapter 2 showed, batteries are only likely to become economic to install in the next five years where users have access to time-of-use tariffs, and in particular where peak use is priced significantly above off-peak use. However, time-of-use tariffs require smart metering, and many retailers have been reluctant to offer time-of-use tariffs. It is understandable that some users may be reluctant to try time-of-use tariffs as there is a risk that if they use a lot of power at peak times, they may experience bill shock compared to the situation where they stay on consumption tariffs. However, it will be important for retailers to offer time-of-use tariffs and for users to have access to time-of-use tariffs if they want them for the value of batteries to be unlocked.
5. **Adopt network revenue models and tariff structures that support peer-to-peer trading, network service provision by DER, and VPPs.[217]** Peer-to-peer trading involves one party on the distribution grid selling to another party on the grid, bypassing the centralised market. The focus here is to determine whether this form of service should be enabled as an alternative to trading through the centralised market (assuming that is possible under the market rules), and how distribution charges for use of the network are accounted for.
6. **Develop a method to maximise the overall value of batteries rather than the value to a particular segment of the electricity supply chain.** Batteries can be operated to optimise grid stability, reduce the need for grid augmentation, reduce tariffs, permit greater renewable generation, and so forth. There may be occasions where one of these goals conflicts with another. One example is where a user installs a battery and uses it as a time of peak usage of the grid to charge the battery. This would put pressure on the grid to expand. The user may be indifferent to this outcome as the user is on a volume-based tariff which does not send a price signal to move use from peak to off-peak times. Another example

[213] IFC 2017, p. 41
[214] IFC 2017, p. 41
[215] PIAC 6 November 2019
[216] Total Environment Centre 29-30 October 2019
[217] Clean Energy Council 2019, p. 17

might be where a distribution grid captures a benefit from batteries, such as increased grid stability, without paying a fair price for that benefits to the party that installed the battery.

One way to address these problems may be to appoint an independent market operator that is separate from the participants in the market to operate batteries installed on the grid. Another way would be to set the NER with proper incentives to send signals to the battery operator to operate the battery in a way that maximised its market benefits. This might involve making it obligatory for users with batteries to be on a tariff, such as a time-of-use tariff, that sent signals to charge the battery at off-peak times.

4.3 Technical considerations

At present, many distributors manage exports to the grid by imposing hard limits on exports, particularly in areas where there is significant rooftop solar. Hard limits are specific limits on the size of solar systems that can be installed and/or on the amount of electricity that can be exported. These limits are designed to prevent generation in localised areas of the network that is excess to demand. The limits can also affect batteries to the extent that batteries are discharging into the grid, perhaps while participating in the future in energy or ancillary services markets.

The Clean Energy Council made some technical recommendations to support DER:[218]

- Inverters should have volt-watt and volt-var response capability (that is, the ability to sense dynamically whether export limits are being reached)
- Volt-Watt and Volt-var response should be a mandatory requirement in the Australian standard for inverters (AS 4777.2).
- There should be common standards for communications between DER and application programming interfaces (APIs)
- The AER should approve expenditure by DNSPs on dynamic network intelligence.

This would allow distributors to "move toward dynamic export limits (from hard limits/ export controls or grid strengthening) and this should be incorporated into connection agreements".[219] A review by SA Power Networks, the SA electricity distributor, found that the benefits of this approach exceeded the costs for all customers.[220]

A number of these initiatives are part of the Open Energy Networks program, particularly the recommendation towards increasing the visibility of the grid. The Open Energy Networks program proposes to install sensors at a circuit level to improve distributor visibility of the grid and develop an operating envelope for managing exports.

4.4 Cultural issues

The cultural issues in the change in the grid also need to be considered. Historically, the grid was centrally planned in a monopoly environment in which consumers were not involved or consulted. This process has not lent itself to considering consumer requirements and involving customers as a prerequisite to supply planning.[221]

[218] Clean Energy Council 2019, p. 4 and p. 9
[219] Clean Energy Council 2019, p. 11
[220] SA Power Networks 2019
[221] PIAC 6 November 2019

However, in a decentralised grid with multiple DER options, consumer preferences should be the key focus. As the Energy Consumers Australia submission to the AEMO VPP project highlighted, it is critical for consumers to be front and centre in the VPP demonstration project in a range of ways, especially around dispatch of behind-the-meter batteries:[222]

> "Any sense that central control is being exercised without appropriate engagement and reward for consumers will undermine trust and confidence and slow the development of these new services." … especially as VPP remote control of DER in residential households could affect residents' safety and lifestyle.

The ECA submission also noted that:[223]

> *The focus on the wholesale market also masks some considerations of the role of consumers. For example, the VPP needs to present an ability to dispatch to the market operator, but the ability to do so depends on the agreements the VPP has with its customers and the competing values from DNSPs. Meaningful trialling of VPP market participation needs to be grounded in meaningful and scalable consumer participation.*

The ECA submission pointed out two significant research projects (funded by ARENA), in which Energy Consumers Australia is participating as demonstrations that consumers are interested in and can participate in an informed way to the debate and policy outcomes:[224]

- The Community Energy Models project, being run by ANU's Battery Storage and Grid Integration Program.
- The ARENA Distributed Energy Resources Pricing project, being run by Oakley Greenwood.

There are concerns among a number of consumer groups that the Open Networks process around integrating renewables, batteries, and controlled load into the grid did not involve consumers from the start of the process but rather consulted only on options after they had been developed by networks and AEMO.[225] This meant that customers were not involved in initial discussions about the broad design principles and objectives of the process, and may have led to the process being too focussed on achieving benefits from batteries for networks.[226]

4.5 Trust issues

Many of the benefits of batteries require that the owners of the batteries permit them to be operated ('orchestrated') by a third party, for example, to inject power into the market at peak times. Generally, if batteries are operated in this way, it will be by aggregators rather than

It is noted that it is a condition of the South Australian Government Home Battery Scheme that to obtain access to the subsidies offered under the scheme that the battery owner consents to the battery being orchestrated.[227]

This raises issues of trust in a number of ways:

- Do battery owners trust third parties to orchestrate their batteries?

---

[222] Energy Consumers Australia 2019, p. 1
[223] Energy Consumers Australia 2019, p. 3
[224] Energy Consumers Australia 2019, p 3
[225] For example, PIAC 6 November 2019, Renew 29-30 October 2019
[226] PIAC 6 November 2019
[227] See South Australian Home Battery Scheme at https://homebatteryscheme.sa.gov.au/about-the-scheme

- Are battery owners concerned that they may want the power from the battery at the same time as the third party?
- Do battery owners trust third parties to fairly compensate them for the value they provide in permitting orchestration of their batteries?

There is no reason why battery owners could not learn to trust third party orchestrators or aggregators. For example, In Queensland, residential users have for many years been able to sign up to off-peak tariffs which are priced at a significant discount to standard tariffs.[228] In exchange for the discount, the user permits the retailer to control circuits within the house wired to the off-peak tariff, typically hot water load or air-conditioning. The retailer can then switch off these circuits at times of peak use to reduce pressure on the grid. These off-peak tariffs are in reasonably widespread use throughout Queensland, showing that users have been able to trust third parties to orchestrate use of certain wired appliances in their house without becoming overly concerned about being left without hot water or sufficient air-conditioning.

One key to engendering trust will be for third party orchestrators to adequately compensate battery owners for the benefits that they provide by permitting orchestration. Another will be through establishing a strong reputation and acting consistently in their dealings with consumers.

[228]The standard tariff (tariff 11) is 26.027 c/kWh while the two off-peak tariffs (tariff 31 and tariff 33) are 19.704 c/kWh and 21.195 c/kWh respectively: see Ergon Energy website at https://www.ergon.com.au/retail/residential/tariffs-and-prices/general-supply-tariffs and https://www.ergon.com.au/retail/residential/tariffs-and-prices/economy-tariffs

Chapter Five: Conclusions and Recommendations

Consumer groups will need to participate in the rule-making process to ensure that a number of the processes underway are carried through to a landing point that supports efficient battery uptake.

To this end, consumer groups should consider -

1. Engaging in the DEIP, ESB DER Integration Work Program, and VPP programs to ensure that they are being conducted in a timely way to:
   - Are consumer-centered in the sense that they fully account for user's behaviour and preferences, including the need to engender user trust in the market mechanisms;
   - Resolve technical issues for DER to participate fully in energy and ancillary services markets;
   - Address roadblocks to fully participation in such markets are evaluated and tested fully and transparently and then are addressed, where possible, through appropriate changes to equipment, e.g. through changes in specifications to metering or sensing equipment.
   - Ensure the networks move as soon as possible to dynamic network control in order to optimise export limits for DER
   - Aim as far as possible for connection of DER be standardized across networks at any appropriate level to minimise costs of connection for DER as soon as possible and monitored to ensure it remains appropriate as technology changes. The Clean Energy Council noted that while Energy Networks Australia has bene working on this for several years, they have made little progress.[1]
   - Ensure that VPP trials evaluate issues around consumer behaviour and trust by battery owners for third party orchestrators of batteries.

2. Ensuring that:
   - The August 2019 registration changes to support battery aggregation are enacted in a suitable format as soon as possible.
   - Time-of-use tariffs are introduced at a retail level as soon as possible, even if they are non-compulsory for users, as this is a key value driver for batteries. TOU tariffs support the value that batteries generate in deferring network augmentation. Retailer resistance to offering time-of-use tariffs needs to be addressed, for example by requiring them to offer a minimum number of time-of-use tariffs as part of their retail offerings.

- The policy position that networks are not permitted to own batteries behind the meter is maintained.
- Demand response rule changes are enacted as soon as possible, including access by residential level storage.

Community-scale batteries may well be significantly cheaper than behind-the-meter batteries. As such, it will be important for consumers to encourage market participants including distributors, retailers, and independent third parties, to offer community-scale batteries as an option for consumers.

List of parties interviewed for this report

Renew, 28 October 2019

Total Environment Centre, 29-30 October 2019

Consumer Action Law Centre, 23 October 2019

PIAC, 6 November 2019

Battery Storage and Grid Integration Program, ANU, 25 November 2019

In addition, AEMO provided information on its current processes

Workshop attended by Energy Consumers Australia, Renew, Total Environment Centre, Battery Storage and Grid Integration Program, ANU, and PIAC, 3 February 2020

Bibliography

ACOLA (2017) (Godfrey, B., Dowling, R., Forsyth, M., Grafton, R.Q. and Wyld, I.). *The role of Energy Storage in Australia's Future Energy Supply Mix*. Report for the Australian Council of Learned Academies, www.acola.org.au. Retrieved from: https://acola.org.au/wp/wp-content/uploads/ENRG-final.pdf

AECOM. (2015). *Energy Storage Study: Funding and Knowledge Sharing Priorities*. Prepared for the Australian Renewable Energy Agency. Retrieved from: https://arena.gov.au/assets/2015/07/AECOM-Energy-Storage-Study.pdf.

AEMC (2015). *Integration of Storage: Regulatory Implications*, Retrieved at https://www.aemc.gov.au/sites/default/files/content/2da0d859-782d-46fb-a6c2-20d6469861dc/AEMC-Integration-of-Energy-Storage-Final-report.pdf

AEMC (2017). *Distribution Market Model*. Final Report, 22 August 2017, Sydney. Retrieved from: https://www.aemc.gov.au/sites/default/files/content/fcde7ff0-bf70-4d3f-bb09-610ecb59556b/Final-distribution-market-model-report-v2.PDF

AEMC (2019a). *Wholesale Demand Response*. Public Workshop, 05 March 2019. Retrieved from: https://www.aemc.gov.au/sites/default/files/2019-03/Workshopper cent20slidesper cent20-per cent205per cent20Marchper cent202019.pdf

AEMC (2019b). *AEMC moves to allow greater access to new innovation as solar and batteries approach 'socket parity'*. Media release, 28 June 2019. Retrieved from: https://www.aemc.gov.au/news-centre/media-releases/aemc-moves-allow-greater-access-new-innovation-solar-and-batteries

AEMC, (2019c). *2019 Retail Energy Competition Review Final Report*. Retrieved from: https://www.aemc.gov.au/sites/default/files/2019-06/2019per cent20AEMCper cent20Retailper cent20energyper cent20competitionper cent20reviewper cent20-per cent20Finalper cent20report.PDF

AEMO (2018). *Integrated System Plan*. Retrieved from https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan/2018-Integrated-System-Plan

AEMO (2019a). *Building power system resilience with pumped hydro energy storage*. Retrieved from: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2019/ISP-Insights---Building-power-system-resilience-with-pumped-hydro-energy-storage.pdf

AEMO (2019b). *Battery Energy Storage System Requirements for Contingency FCAS Registration*. Retrieved from: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Ancillary_Services/Battery-Energy-Storage-System-requirements-for-contingency-FCAS-registration.pdf

AEMO (2019c). *Integrating Distributed Energy Resources (DER) into the power system*. (blog post). Retrieved from: http://energylive.aemo.com.au/Editors-Picks/Integrating-DER-into-the-power-system

AEMO (2019d). *2019 Electricity Statement of Opportunities*. Retrieved from https://aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NEM_ESOO/2019/2019-Electricity-Statement-of-Opportunities.pdf

AEMO (2019e). *Electricity Rule Change Proposal: Integrating Energy Storage Systems into the NEM*, Retrieved at https://aemo.com.au/-/media/Files/Electricity/NEM/Initiatives/Emerging-Generation/23-August-2019--Integrating-ESS-rule-change-proposal-final.pdf

AEMO (2019f). *Draft 2020 Integrated System Plan*, December, Retrieved at https://www.aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp/2020-integrated-system-plan-isp#Draft%202020%20ISP

AEMO 2020, *Battery storage: charged and ready to go?*, (press release) Retrieved from: https://aemo.com.au/en/news/battery-storage

AEMO & Energy Networks Australia, (2018). *Open Energy Networks*, consultation paper. Retrieved from: https://www.energynetworks.com.au/sites/default/files/open_energy_networks_consultation_paper.pdf

AEMO/ENA cooperation on DER. No date. Retrieved from: http://energylive.aemo.com.au/Energy-Explained/Distributed-Energy-Resources-explained.

AER (2017). *Ring-fencing guideline: Electricity Distribution Version 2 Explanatory Statement*. Retrieved at https://www.aer.gov.au/networks-pipelines/guidelines-schemes-models-reviews/electricity-ring-fencing-guideline-october-2017

AER (2019). Electricity ring-fencing guideline review - August 2019. Retrieved at https://www.aer.gov.au/networks-pipelines/guidelines-schemes-models-reviews/electricity-ring-fencing-guideline-review-august-2019

ARENA (2016). *Advancing solar in Australia through RD&D investment*, Final Report, November 2016. Retrieved from: https://arena.gov.au/assets/2017/05/Final-report_SOLAR-RDD-REVIEW_For-Web_LowRes-2.pdf

ATA (2015). (Andrew Reddaway, Damien Moyse), *Household Battery Analysis*. November, Retrieved from https://renew.org.au/wp-content/uploads/2018/11/ATA-Household-Battery-Study.pdf

ATA (2017). *Storage Advice: Final Report for Energy Consumers Australia*, January

Bellini, E. (2017). *Study finds storage prices falling faster than PV and wind technologies*. Renew Economy, 1 August 2017. Retrieved from: https://reneweconomy.com.au/study-finds-storage-prices-falling-faster-pv-wind-technologies-74360/

Bloomberg NEF, (2019a). *New Energy Outlook 2019*, Executive Summary. Retrieved from https://about.bnef.com/new-energy-outlook/.

Bloomberg NEF, (2019b). *Energy Storage Investments Boom as Battery Costs Halve in the Next Decade*, blog post, July 31, 2019. Retrieved from: https://about.bnef.com/blog/energy-storage-investments-boom-battery-costs-halve-next-decade/

Bloomberg NEF, (2017). *Beyond the Tipping Point*, Executive Summary. Retrieved from: https://www.ceer.eu/documents/104400/-/-/13dcea6a-2575-a525-8c99-07e0d3988ff3

Brakels, Ronald (2019). *Good News! Tesla Drops Price Of Powerwall 2 By $650 — Less Than One-Quarter Previous Price Hike*, July 23, 2019 by , retrieved at https://www.solarquotes.com.au/blog/tesla-powerwall-price-drop/

Bungard, M. (2019). *'Half the cost': Entrepreneur says 'Sunny 1' is better than 'Snowy 2.0'. The Sydney Morning Herald*, July 28, 2019. Retrieved from: https://www.smh.com.au/environment/sustainability/half-the-cost-entrepreneur-says-sunny-1-is-better-than-snowy-2-0-20190626-p521i2.html

Castellano Ruz, F, and Pollitt, M.G., (2016). *Overcoming barriers to electrical energy storage: comparing California and Europe*. Working Papers EPRG 1614, Energy Policy Research Group, Cambridge Judge Business School, University of Cambridge. Retrieved from: https://www.eprg.group.cam.ac.uk/wp-content/uploads/2016/05/1614-PDF.pdf

Chattopadhyay D., T. Alpcan, *Capacity and energy-only markets under high renewable penetration,* IEEE Trans. Power Syst., vol. 31, no. 3, pp. 1692-1702, May 2016, https://arena.gov.au/assets/2017/06/Chattopadhyay-and-Alpcan_3.pdf

Clean Energy Council, (2019a). *The Distributed Energy Resources Revolution*. Retrieved from: https://assets.cleanenergycouncil.org.au/documents/advocacy-initiatives/the-distributed-energy-resources-revolution-paper.pdf

Clean Energy Council, (2019b). *Renewable energy investment slows as policy uncertainty and regulatory challenges mount*, media release, 11 September 2019. Retrieved from: https://www.cleanenergycouncil.org.au/news/renewable-energy-investment-slows-as-policy-uncertainty-and-regulatory-challenges-mount

Climate Council of Australia, (2017). *Energy Storage: Poll of Australians*. 21 September 2017. Retrieved from: https://apo.org.au/sites/default/files/resource-files/2017/09/apo-nid107966-1216126.pdf

Climate Council of Australia, (2018). (Stock, A., Bourne, G., Brailsford., L, and Stock P.). *Fully charged: Renewables and storage powering Australia*. Retrieved from: https://www.climatecouncil.org.au/resources/battery-storage-2018/

CO2CRC, (2015). *Australian Power Generation Technology Report*. Retrieved from: http://www.co2crc.com.au/wp-content/uploads/2016/04/LCOE_Report_final_web.pdf

Comello, S, and Reichelstein, S. (2019). *The emergence of cost effective battery storage*. *Nature Communications*, 10:2038. Retrieved from https://doi.org/10.1038/s41467-019-09988-z

CSIRO (2015). (Brinsmead, T.S. Graham, P. Hayward, J., Ratnam, E.L. and Reedman, L.). *Future energy storage trends: An assessment of the economic viability, potential uptake and impacts of electrical energy storage on the NEM 2015-2035.* CSIRO, Australia. Report No EP155039.

CSIRO and Energy Networks Australia (2017). *Electricity Network Transformation Roadmap*, Final Report. Retrieved from: https://www.energynetworks.com.au/resources/reports/electricity-network-transformation-roadmap-final-report/

Elliot, J., (2019). *Is home solar battery storage worth it?* Blog, solarchoice.net.au, 2 September 2019. Retrieved from: https://www.solarchoice.net.au/blog/is-home-solar-battery-storage-worth-it-april-2019-update/

Energy Queensland, (2018). *Submission to the Emerging Generation and Energy Storage in the NEM Stakeholder Paper*. Retrieved from: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Initiatives/Emerging-Generation/Submissions/Energy-Queensland_20181205.pdf

Energy Consumers Australia, (2018). *Energy Consumer Sentiment Survey – December 2018*. Retrieved at https://energyconsumersaustralia.com.au/publications/energy-consumer-sentiment-survey-findings-december-2018

Energy Consumers Australia, (2019). *Submission to AEMO: "NEM Virtual Power Plant Demonstrations Program"*. 8 January 2019. Retrieved from: https://energyconsumersaustralia.com.au/wp-content/uploads/NEM-Virtual-Power-Plant-VPP-Demonstrations-Program-Submission.pdf

Energy Consumers Australia, (2019a), *Consumer Sentiment and Behaviour, version 1.1*, July, retrieved at

Energy Networks Australia, (2016). Insights on consumer behavior and battery storage intentions. 9 June 2016. Retrieved from: https://www.energynetworks.com.au/news/energy-insider/insights-on-consumer-behaviour-and-battery-storage-intentions/

Energy Networks Australia, (2019a). *Energy Transformation Plan Welcome*, media release, 06 March 2019. Retrieved from: https://www.energynetworks.com.au/news/media-releases/energy-transformation-plan-welcome/

Energy Networks Australia, (2019b). *Energy Network Annual Award Winners Announced*, media release, 08 September 2019. Retrieved from: https://www.energynetworks.com.au/news/media-releases/energy-network-annual-award-winners-announced/

Energy Storage Association, (2017). State *Policies to Fully Charge Advanced Energy Storage: The Menu of Options*. Retrieved from: https://energystorage.org/thought-leadership/state-policy-menu-for-storage/

Energy Storage Association, (2018). *Enabling Energy Storage to Reduce Greenhouse Gas Emissions.* The ESA Blog, August 15, 2018. Retrieved from: https://energystorage.org/enabling-energy-storage-to-reduce-greenhouse-gas-emissions/

Evans, Simon. *Household batteries too much like holiday homes*, Australian Financial Review, October 9, 2019 at https://www.afr.com/companies/energy/household-batteries-too-much-like-holiday-homes-20191009-p52ywl

IFC (2017). *Developments and Opportunities for Energy Storage in Emerging Markets*. Retrieved from: https://www.esmap.org/sites/default/files/esmap-files/7151-IFC-EnergyStorage-report.pdf

IRENA, (2017). *Electricity Storage and Renewables: Costs and Markets to 2030*. International Renewable Energy Agency, Abu Dhabi. Retrieved from: https://www.irena.org/publications/2017/Oct/Electricity-storage-and-renewables-costs-and-markets

Johnson, J. and DeCarolis J. (2019). *In US, utilities are investing in big batteries instead of building new power plants.* RenewEconomy, 18 March 2019. Retrieved from: https://reneweconomy.com.au/in-us-utilities-are-investing-in-big-batteries-instead-of-building-new-power-plants-62274/

Lewis, M. (2019). *Making Solar Fair for All,* blog post, 21 February 2019. Retrieved from: https://www.energynetworks.com.au/news/energy-insider/making-solar-fair-for-all/.

Macdonald-Smith, A. (2019a). The winners from negative electricity prices. *Australian Financial Review*, Sep 6, 2019. Retrieved from: https://www.afr.com/companies/energy/the-winners-from-negative-electricity-prices-20190905-p52o7r

Macdonald-Smith, A. (2019b). *Battery project line-up defies lingering market risks*. Australian Financial Review, Sep 13, 2019. Retrieved from: https://www.afr.com/companies/energy/battery-project-line-up-defies-lingering-market-risks-20190912-p52qk9

Morris, G. (2015). *Will a Tesla battery enable me to leave the grid? One Step off the Grid*, July 9, 2015. Retrieved from: https://onestepoffthegrid.com.au/will-a-tesla-battery-enable-me-to-leave-the-grid/

NC State Energy Storage Team, (2018). Energy Storage Options for North Carolina. NC State University. Retrieved from: https://energy.ncsu.edu/storage/wp-content/uploads/sites/2/2019/02/NC-Storage-Study-FINAL.pdf

Open Energy Networks (2019). *Interim Report: Required Capabilities and Recommended Actions*, (A joint AEMO and Energy Networks Australia initiative. Retrieved from: https://www.energynetworks.com.au/projects/open-energy-networks/#open-reports-and-publications

Parkinson, G, (2017). *Why solar towers and storage plants will reshape energy markets*. RenewEconomy, 21 August 2017. Retrieved from: https://reneweconomy.com.au/why-solar-towers-and-storage-plants-will-reshape-energy-markets-73278/

Parkinson, G, (2019). *More stunning falls in solar and battery storage costs put fossil fuels on notice*. RenewEconomy, 27 March 2019. Retrieved from: https://reneweconomy.com.au/more-stunning-falls-in-solar-and-battery-storage-costs-put-fossil-fuels-on-notice-31119/

Queensland Household Energy Survey (2018). Retrieved at https://www.powerlink.com.au/sites/default/files/2019-04/Queenslandper cent20Householdper cent20Energyper cent20Surveyper cent20Reportper cent202018.pdf

Queensland Electricity Users Network, (2019). *Consumers should ask: Is more renewable energy affordable and reliable?*, media release, 15 May 2019. Retrieved from: http://www.qeun.com.au/pdf/QEUNper cent20Mediaper cent20-per cent2015per cent20Mayper cent202019per cent20-per cent20Consumersper cent20shouldper cent20askper cent20-per cent20Isper cent20moreper cent20renewableper cent20energyper cent20affordableper cent20andper cent20reliable.pdf

Rai, A., Nunn O. (2020), *Is there a value for "dispatchability" in the NEM? Yes*, The Electricity Journal, Vol 33, Issue 3, April, Retrieved at https://www.sciencedirect.com/science/article/pii/S104061902030004X

Roberts, M., Copper J., Bruce A, Barton T, Haghdadi, N., and Hu, R. (2018). *Solar trends report for solar citizens*. Final Report. University of New South Wales for the Australian PV Institute and Solar Citizens. Retrieved from: http://apvi.org.au/wp-content/uploads/2018/12/Solar-Trends-Report-for-Solar-Citizens-FINAL_11-12-18_2_logos.pdf

Rocky Mountain Institute (Fitzgerald, G., Mandel, J, Morris, J, Touati, H), (2015). *The Economics of Battery Energy Storage: How multi-use, customer-sited batteries deliver the most services and value to customers and the grid*. Rocky Mountain Institute. Retrieved from: http://www.rmi.org/electricity_battery_value

Ruz, F. C., & Pollitt, M. G. (2016). *Overcoming Barriers to Electrical Energy Storage: Comparing California and Europe*. Competition and Regulation in Network Industries, 17(2), 123–149. https://doi.org/10.1177/178359171601700202

Schmidt, O., Hawkes, A., Gambhir, A., et al (2017). *The future cost of electrical energy storage based on experience rates*. Nature Energy 2, 17110. Retrieved from: doi:10.1038/nenergy.2017.110

Schmidt, O, Melchior, S., Hawkes, A., and Staffell I. (2019). *Projecting the Future Levelized Cost of Electricity Storage Technologies*. Joule 3, 81-100, Elsevier. Retrieved from: https://doi.org/10.1016/j.joule.2018.12.008

SA Power Networks (2019) Maximising customer value from the network in a high-DER future AEMC / ARENA Regulatory DEIP dive, 6th June 2019. Retrieved at https://www.aemc.gov.au/sites/default/files/2019-06/ARENAper cent20AEMCper cent20DEIPper cent20Dive-per cent206per cent20Juneper cent202019per cent20-per cent20SAPNper cent20Presentation.pdf

Simshauser, Paul, Distribution network prices and solar PV: Resolving rate instability and wealth transfers through demand tariffs, Energy Economics, volume 54, February 2016, pages 108-122, retrieved at https://www.sciencedirect.com/science/article/pii/S0140988315003060

Tesla Motors Australia, (2018). *Submission to AEMO Emerging Generation and Energy Storage Stakeholder Consultation Paper*. 04 December 2018. Retrieved from: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Initiatives/Emerging-Generation/Submissions/Tesla_20181204.pdf

Total Environment Centre (on behalf of Total Environment Centre, Ethnic Communities Council of NSW, Consumer Utilities Advocacy Centre, Consumer Action Law Centre, and Public Interest Advocacy Centre Ltd, (2016). Small consumer groups submission to AER Electricity Ring-Fencing Guideline Preliminary Positions Paper, 30 May 2016. Retrieved from: https://www.eccnsw.org.au/Documents/AER-Ring-fencing-guideline-sub-final-31-May-2016.aspx

Vorrath, S. (2019). *Redflow says on track to cut flow battery production costs by one-third*. Renew Economy, 28 February 2019. Retrieved from: https://reneweconomy.com.au/redflow-says-on-track-to-cut-flow-battery-production-costs-by-one-third-79099/

Wahlquist, C, (2018). *South Australia's Tesla battery on track to make back a third of cost in a year*. *The Guardian*, 27 September 2018. Retrieved from: https://www.theguardian.com/technology/2018/sep/27/south-australias-tesla-battery-on-track-to-make-back-a-third-of-cost-in-a-year