



ARENA

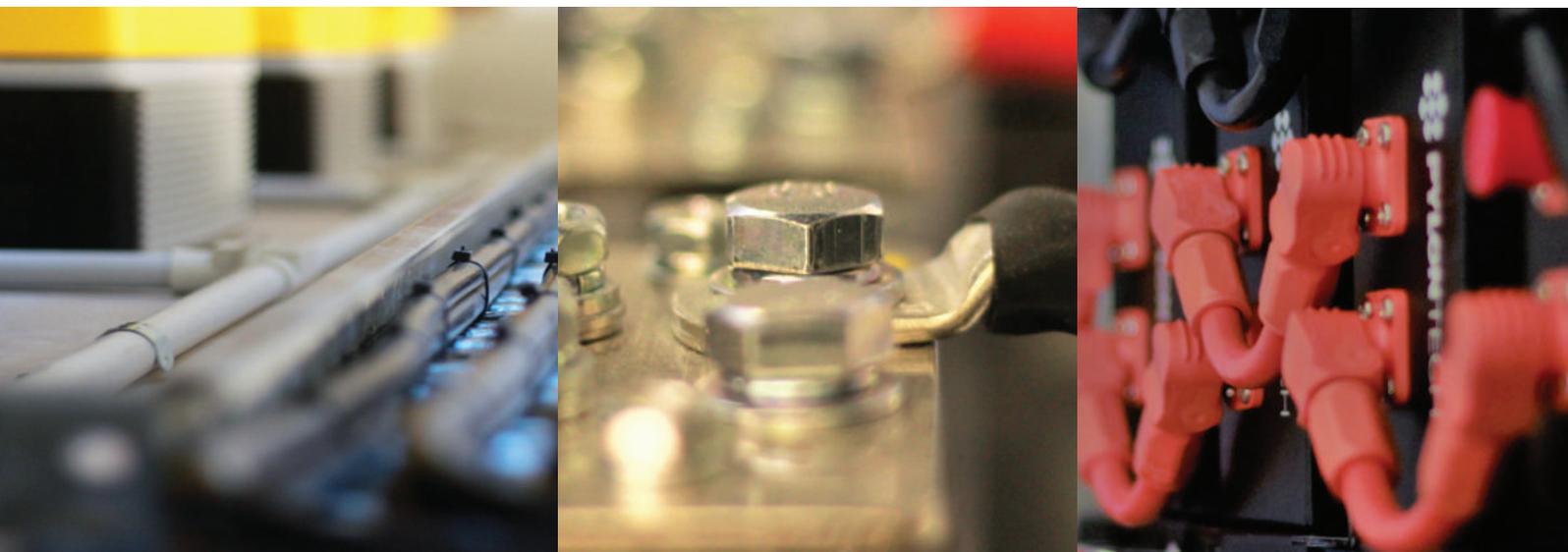


Australian Government

Australian Renewable
Energy Agency



BATTERY TEST CENTRE REPORT 3



November 2017



About ITP Renewables

ITP Renewables (ITP) is a global leader in energy engineering, consulting and project management, with expertise spanning the breadth of renewable energy, storage, efficiency, system design and policy.

We work with our clients at the local level to provide a unique combination of experienced energy engineers, specialist strategic advisors and experts in economics, financial analysis and policy. Our experts have professional backgrounds in industry, academia and government.

Since opening our Canberra office in 2003 we have expanded into New South Wales, South Australia and New Zealand.

ITP are proud to be part of the international ITP Energised Group—one of the world's largest, most respected and experienced specialist engineering consultancies focussed on renewable energy, energy efficiency and climate change.

Established in the United Kingdom in 1981, the Group was among the first dedicated renewable energy consultancies. In addition to the UK it maintains a presence in Spain, Portugal, India, China, Argentina and Kenya, as well as our ITP offices in Australia and New Zealand.

Globally, the Group employs experts in all aspects of renewable energy, including photovoltaics (PV), solar thermal, marine, wind, hydro (micro to medium scale), hybridisation and biofuels.

About this report

Supported by an \$870,000 grant from the Australian Renewable Energy Agency, the Lithium Ion Battery Test Centre program involves performance testing of conventional and emerging battery technologies. The aim of the testing is to independently verify battery performance (capacity fade and round-trip efficiency) against manufacturers' claims.

Six lithium-ion, one conventional lead-acid, and one advanced lead-acid battery packs were installed during Phase 1 of the trial. The trial was subsequently expanded to include an additional eight lithium-ion packs, a zinc bromide flow battery, and an Aquion 'saltwater' battery bank.

This report describes the process of procuring and installing the Phase 2 battery packs, and outlines preliminary testing results and general observations or issues encountered thus far with the Phase 1 batteries.

This and earlier reports, and live test results are published at www.batterytestcentre.com.au.



Report Control Record

Document prepared by:

ITP Renewables

Level 1, Suite 1,

19 -23 Moore St, Turner, ACT, 2612, Australia

PO Box 6127, O'Connor, ACT, 2602, Australia

Tel. +61 2 6257 3511

Fax. +61 2 6257 3611

E-mail : info@itpau.com.au

<http://www.itpau.com.au>

Document Control			
Report title	Lithium Ion Battery Test - Public Report 3		
Client Contract No.	n/a	ITP Project Number	AU
File path	n/a		
Client	Public	Client Contact	n/a

Disclaimer:

A person or organisation choosing to use documents prepared by IT Power (Australia) Pty Ltd accepts the following:

- Conclusions and figures presented in draft documents are subject to change. IT Power (Australia) Pty Ltd accepts no responsibility for their use outside of the original report.
- The document is only to be used for purposes explicitly agreed to by IT Power (Australia) Pty Ltd.
- All responsibility and risks associated with the use of this report lie with the person or organisation who chooses to use it.

LIST OF ABBREVIATIONS

AC	Alternating Current
AIO	All-in-one (referring to a battery unit which is combined with a battery inverter and PV inverter)
ARENA	Australian Renewable Energy Agency
AUD	Australian Dollar
BESS	Battery Energy Storage System
BMS	Battery Management System
BOS	Balance of System
C(number)	“C Rate” (charge rate), is a measure of the rate at which the battery is charged/discharged relative to its nominal capacity. Conversely, it can be thought of as the time over which the entire (nominal) battery capacity is charged/discharged (ie. a C10 rate indicates a charge/discharge rate at which a full charge/discharge takes 10 hours. A 2C rate indicates a charge/discharge rate at which a full charge/discharge takes only 0.5 hours)
CAN (bus)	Controller Area Network (a message-based communications protocol allowing microcontrollers and devices to communicate without a host computer)
DC	Direct Current
DOD	Depth of Discharge of a battery
ELV	Extra Low Voltage
IR	Infra-Red (region of the electromagnetic radiation spectrum used in thermal imaging)
ITP	IT Power (Australia) Pty Ltd, trading as ITP Renewables
kW	Kilowatt, unit of power
kWh	Kilowatt-hour, unit of energy (1 kW generated/used for 1 hour)
kWp	Kilowatt-peak, unit of power for PV panels tested at STC
LFP	Lithium Iron Phosphate (a common li-ion battery chemistry)
Li-ion	Lithium ion (referring to the variety of battery technologies which use and electrolyte composed of a lithium-salt dissolved in an organic solvent)
LMO	Lithium Manganese Oxide (a common li-ion battery chemistry)
MODBUS	A serial communication protocol for transmitting information between electronic devices
NMC	Nickel Manganese Cobalt (a common li-ion battery chemistry)
PbA	Lead Acid
PMAC	Permanent Magnet Alternating Current (a variety of Electric motor)
PV	Photovoltaic
RE	Renewable Energy
SOC	State of Charge of a battery
UPS	Uninterruptable Power Supply
VRB	Vanadium Redox Battery, a type of flow battery
VRLA	Valve Regulated Lead Acid



CONTENTS

EXECUTIVE SUMMARY	1
1. PROJECT BACKGROUND	2
Purpose of Testing	2
Project Summary	2
Batteries Being Tested	3
Testing Procedure	4
2. IMPLEMENTATION	7
I. Alpha ESS	7
II. Ampetus Super Lithium.....	8
III. Aquion Saltwater Battery	10
IV. BYD B-Box.....	12
V. GNB Lithium.....	13
VI. LG Chem RESU HV.....	15
VII. Pylontech	17
VIII. Redflow	18
IX. SimpliPhi.....	20
X. Tesla Powerwall 2.....	22
3. BATTERY PERFORMANCE	25
SOC Estimation.....	25
EcoUlt Cell Failure.....	26
GNB SOC Recalculation Issues	26
Capacity Fade Analysis	27
Efficiency Analysis.....	28
4. LESSONS LEARNED	30
Procurement.....	30
Installation and Commissioning.....	31
Performance.....	31
Inverter Technology.....	32





EXECUTIVE SUMMARY

ITP Renewables (ITP) are testing the performance of residential or small commercial-scale battery packs in a purpose-built climate-controlled enclosure at the Canberra Institute of Technology.

The aim of the testing is to independently verify battery performance against manufacturers' claims. Specifically, ITP is investigating capacity fade and round-trip efficiency of fourteen lithium-ion battery packs, one conventional lead-acid battery, one advanced lead-acid battery, one salt water battery and one zinc bromide flow battery.

Six lithium-ion, one conventional lead-acid, and one advanced lead-acid battery packs were installed during Phase 1 of the trial. The trial was subsequently expanded to include an additional eight lithium-ion packs, a zinc bromide flow battery, and a saltwater battery bank.

This report describes the process of procuring and installing the Phase 2 battery packs, and outlines preliminary testing results and general observations or issues encountered thus far with the Phase 1 batteries.

The key findings of the trial so far are predominantly related to the procurement, installation and technology performance as there is still limited conclusive evidence to detail battery capacity fade results.

Battery supply and installation issues continue to hamper the progress of the battery market as a whole. The battery market in Australia has been characterised by instability over the past year with a number of manufacturers either exiting the market or substantially changing their product offerings. This instability contributes to issues with supply as well as integration and commissioning problems. Technical support and system documentation has generally been poor with limited resources available in Australia for installers to troubleshoot problems. A number of products required firmware updates after deployment or a specialised service technician to attend site, which is unrealistic for large numbers of domestic or commercial installations, and generally indicative of a lack of product testing and development prior to release.

Integration of batteries with inverters continues to be problematic for battery products generally, with the communications interface being the most common challenge encountered. There is still no standardised approach to battery-inverter communications. ITP expects installation and commissioning issues to remain common until communications interface protocols are standardised.

Results from the Phase 1 testing indicate that capacity fade is continuing and that typically lithium ion batteries demonstrate both higher efficiency than the alternative technologies and (when they are correctly integrated with an inverter) more consistent performance.



1. PROJECT BACKGROUND

Purpose of Testing

Lead-acid battery technologies have been used in energy storage applications for decades. In recent years, however, new technologies have appeared on the market, and the range of options for the storage of renewable energy and/or the provision of back-up power has increased significantly.

Energy system designers and end users, however, have been reluctant to transition to new technologies, particularly in remote applications where reliability is critical. In part, this reluctance is due to a history of over-stated manufacturers' claims, which are often based on in-house lab testing that lacks independent verification.

The purpose of the battery performance testing is therefore to verify claims made by manufacturers about performance, integration, and installation of battery packs, and to disseminate the results to the public. To achieve this ITP is independently testing the performance of:

- Fourteen different Li-ion battery packs;
- A zinc-bromide flow battery;
- An 'advanced' PbA battery bank (lead acid with a carbon ultracapacitor); and
- A conventional gel VRLA (lead acid) battery bank

The batteries are tested side by side in hot daytime and cool overnight temperatures, similar to what they would be expected to face in real-world conditions. The desired outcome is to better inform energy storage system investors, to facilitate further uptake of renewable energy.

Project Summary

A battery testing laboratory has been built at the Sustainable Skills Training Hub at the Canberra Institute of Technology and performance testing has commenced. In brief this involves:

- Cycling the batteries three times a day for three years to simulate nine years' worth of 'normal' daily cycling of the batteries (noting that while accelerated, this cycle rate is within manufacturers' specifications);
- Mimicking 'real world' conditions by cycling the temperature of the facility where the batteries will be installed; and,
- Publishing performance data, including the batteries' decrease in storage capacity over the three years of the trial, and documenting any integration challenges or issues that arise.



Our Knowledge Sharing Plan aims to maximise the demonstration value of the trial by:

- Sharing the knowledge with the largest possible audience;
- Publishing trial data in an accessible and user-friendly manner; and
- Adding value to the raw data through expert analysis of the results.

If the trial successfully demonstrates that newer technologies are superior in performance, lifetime and cost-effectiveness compared to traditional lead-acid batteries, then the outcome will be that:

- Those interested in grid-connected energy storage systems will be in a position to make more informed investment decisions;
- The cost of integrating high levels of renewable energy into electricity networks (of all sizes) will decrease, and hence cheap but variable renewable energy generation (ie. solar PV and wind) will become more attractive.

Batteries Being Tested

The batteries have been installed in two Phases. Testing of Phase 1 batteries commenced in August 2016 and testing of most of the Phase 2 batteries commenced around July 2017.

Phase 1

Product	Country of Origin	Chemistry	Total Installed Capacity (kWh)
CALB	China	Lithium Iron Phosphate	10.24
Ecoult UltraFlex	USA	Lead acid carbon	14.8
Kokam Storaxe	Korea	Nickel Manganese Cobalt	8.3
LG Chem	Korea	Nickel Manganese Cobalt	9.6
Samsung	Korea	Nickel Manganese Cobalt	11.6
Sonnenschein	Germany	Lead acid	15.84
Sony Fortelion	Japan	Lithium Iron Phosphate	9.6
Tesla Powerwall	USA	Nickel Manganese Cobalt	6.4

Phase 2

Product	Country of Origin	Chemistry	Total Installed Capacity (kWh)
Alpha ESS	China	Lithium Iron Phosphate	9.6
Ampetus Super Lithium	China	Lithium Iron Phosphate	9.0
Aquion Aspen	USA	Aqueous Hybrid Ion	17.6
BYD B-Box	China	Lithium Iron Phosphate	10.24
GNB Lithium	Germany	Lithium Iron Phosphate	13.6
LG Chem RESU HV	Korea	Nickel Manganese Cobalt	9.8
Pylontech	China	Lithium Iron Phosphate	9.6
Redflow Zcell	USA	Zinc-Bromide Flow	10
SimpliPhi	USA	Lithium Iron Phosphate	10.2
Telsa Powerwall 2	USA	Nickel Manganese Cobalt	13.2

Testing Procedure

The key objective of the testing is to measure the batteries' decrease in storage capacity over time and with energy throughput. As the batteries are cycled they lose the ability to store as much energy as when they are new.

To investigate this *capacity fade*, the lithium-ion batteries are being discharged to a state of charge (SOC) between 5% and 20% (depending on the allowable limits of the BMS), while the lead-acid batteries are being discharged to a 50% SOC (i.e. 50% of the rated capacity used). The advanced lead battery is being be cycled between 30% and 80% SOC. These operating ranges are in line with manufacturers' recommendations for each technology.

Each battery pack is charged over several hours (mimicking daytime charging from the PV), followed by a short rest period, then discharged over a few hours (mimicking the late afternoon, early evening period) followed by another short rest period. In total, there are three charge/discharge cycles per day.

Temperature Profile

The ITP lithium-ion battery trial aims to test batteries in 'typical' Australian conditions. It is expected that most residential or small commercial battery systems will be sheltered from rain and direct sunlight, but still be exposed to outdoor temperatures; therefore, the ambient



temperature in the battery testing room is varied on a daily basis, and varies throughout the year. The high and low temperatures are given in Table 1.

ITP implements ‘summer’ and ‘winter’ temperature regimes for the three daily charge/discharge cycles. In the summer months the batteries undergo two cycles at the monthly high temperature and the third at the monthly low temperature, and in the winter months the batteries undergo two cycles at the monthly low temperature and the third at the monthly high temperature.

Table 1: Daily high and low ambient temperatures throughout the year

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Low	22	20	18	16	14	12	10	12	14	16	18	20
High	36	34	32	30	28	26	24	26	28	30	32	34
Regime	S	S	S	S	W	W	W	W	W	W	S	S

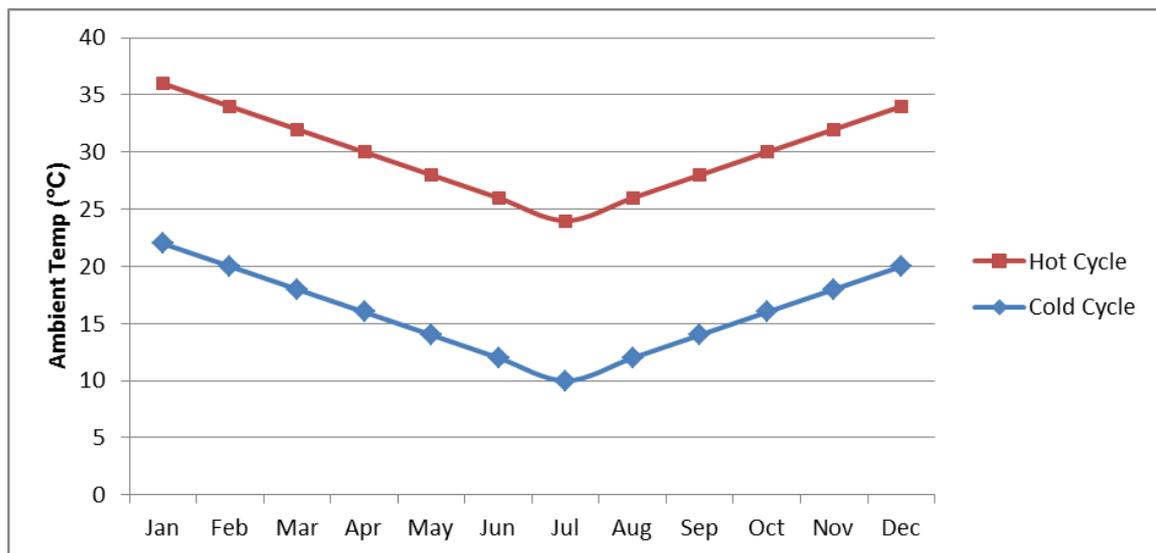


Figure 1: Daily hot and cold cycle temperatures throughout the year

Given the focus on energy efficiency and low energy consumption at the CIT Sustainable Skills Training Hub, the timing of the high and low temperature cycles is matched with the variations of outdoor temperatures, to allow transitions between high and low temperature set-points to be assisted by outdoor air. The schedule of charge and discharge cycles is show in Figures 2 and 3.

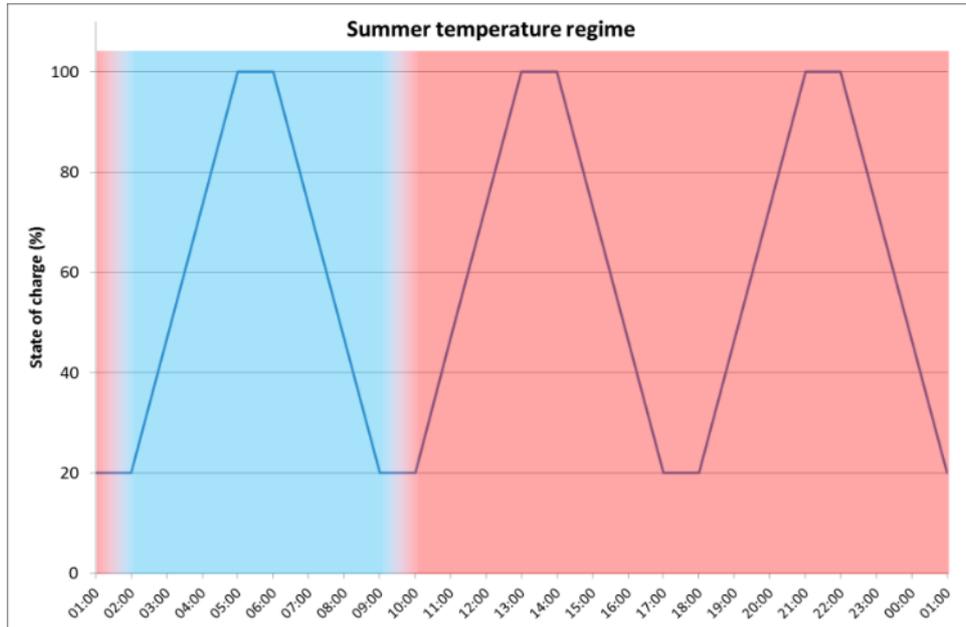


Figure 2: Summer temperature regime and charge regime

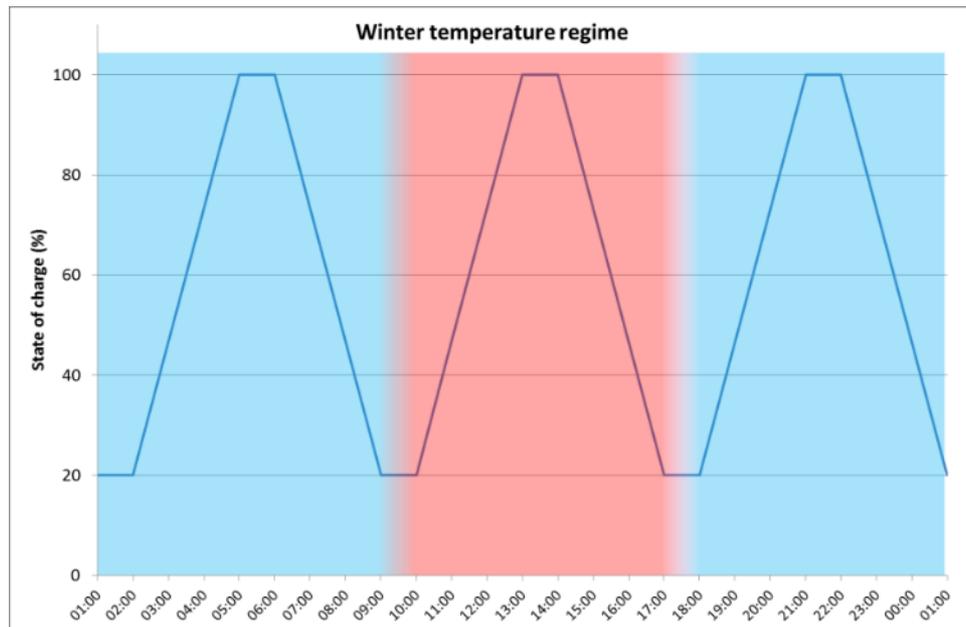


Figure 3: Winter temperature regime and charge regime

On the last day of each month, the batteries undergo a charge/discharge cycle at 25 °C as this is the reference temperature at which most manufacturers provide the capacity of their batteries. From this, an up-to-date capacity of the battery can be obtained and compared to previous results



to track capacity fade. Although the duration of a month varies between 28 and 31 days, ITP does not expect this to make a statistically relevant difference to the results.

2. IMPLEMENTATION

These observations come from procurement and installation of batteries as part of Phase 2 only. Commentary on battery packs installed in Phase 1 is provided in the 1st public report available on the battery test centre website (www.batterytestcentre.com.au).

I. Alpha ESS

The M48100 cell is one of a number of LFP cells available from Alpha, either stand-alone or included in one of their All-In-One systems. It is a modular-rack mounted unit with up to 6 able to be connected in parallel. The capacity of each battery is 4.8kWh nominal, with a recommended DoD of 90%. The batteries are indoor-rated (IP20).

The M48100 is manufactured by Chinese company EVE (Energy Very Endure), established in 2001. EVE manufactures a range of lithium-ion battery products for residential, off-grid, telecom and industry applications.

The Battery Test Centre installation consists of two M48100 batteries in parallel, connected to an SMA Sunny Island inverter.

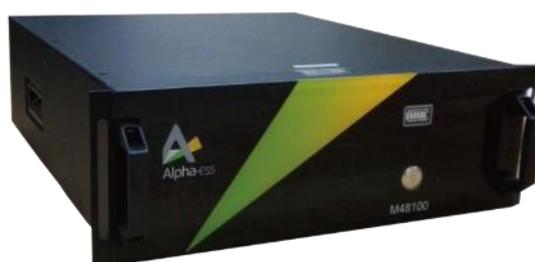


Figure 4. Alpha M48100 Module

Procurement

ITP originally attempted to include an Alpha battery pack in Phase 1 of testing. Following payment, however, the supplier cancelled the order citing that the product required further development. ITP was subsequently issued a refund.

For Phase 2, ITP initiated contact with Alpha directly. ITP spoke with multiple staff members during this time and found communication difficult. The batteries were received over 2 months after ITP originally submitted the Purchase Order. This delay was due to a lack of local stock, as

well as uncertainty about the ability of the battery to integrate with the Sunny Island inverter (software development for this feature was ongoing at the time of order).

Following installation of the battery pack, an Alpha technician came to site to perform a firmware update and supply a communications cable.

Installation

As rack-mounted batteries, the Alpha M48100 units were easy to install. At 158mm high, they are a little larger than many other rack-mounted batteries, and also heavier (at 63kg). Nevertheless, it was a simple procedure to slide the batteries into the racks.

Electrically, the batteries were simple to connect, with battery modules pre-fitted with Anderson connectors at the back. ITP installers made leads to run to the inverter. Inter-battery comms cable was supplied.

During a visit by technicians to update firmware, Alpha provided ITP with a communications cable specifically for use between the battery pack and the inverter. The pack did not come with this communications cable included.

The pack also did not come with sufficient documentation to carry out the installation, though Alpha's technicians were responsive and helpful.

Commissioning

The Alpha batteries were simple to commission. The Alpha technician verified that the DIP switch settings were correct, and once the inverter was turned on, the pack was able to operate immediately.

Alpha technicians again visited site a few months after installation to perform another firmware upgrade. The update was apparently to optimise performance, as ITP had not observed any issues with battery behaviour.

II. Ampetus Super Lithium

The Ampetus battery installed in the Battery Test Centre is the ASL100-60, manufactured by Sinlion in China. Sinlion Battery Tech is a Chinese manufacturer established in 2011. The LFP battery is promoted for its long lifetime, marketed at 10,000 cycles. Each battery module has a nominal capacity of 3kWh, and a recommended DoD of 90%. They are indoor-rated (IP21).

Ampetus offers the batteries individually or as part of the Ampetus Super Pod, which contains multiple Sinlion batteries and an inverter in an IP65-rated cabinet.

The Battery Test Centre installation consists of 3 Sinlion batteries connected in parallel (9kWh), paired with a SolaX X-Hybrid inverter.



Figure 5 Ampetus Super Lithium battery module

Procurement

At the time of installation, Ampetus Energy was the sole distributor of Sinlion batteries in Australia. Ampetus markets their battery pack as 'Super Lithium Batteries', selling them as part of the Super Pod offering, which includes the Sinlion batteries and a Mass Energy inverter in a cabinet. They also offer the batteries individually, which was ITP's chosen option.

Ampetus informed ITP of a lead time before the order was made. However, the batteries missed their intended shipment, resulting in a delay of about four weeks. Once the batteries arrived in the country, the supplier experienced freight issues and had to reschedule collection. Arrival of the batteries to site was approximately a month past the original indication.

Despite these issues, Ampetus kept ITP well informed throughout the process, providing updates, documentation and information on preparing the inverter for integration with the batteries once they arrived.

Installation

The Ampetus batteries, as rack-mounted modules, were reasonably easy to mount. Each unit is 47kg, 131mm high, and has handles at the front to assist with lifting and manoeuvring.

Inter-battery communications cables were included. However, when the system experienced communications issues, Ampetus recommended that these be replaced with cables of shorter length. Ampetus also recommended a termination plug, which was not supplied with the batteries.

A communications cable between the batteries and the inverter was not supplied with the batteries, although Ampetus provided the necessary information to make what was required. Ampetus also provided all the required cables and termination plugs when the installation was experiencing communications issues.

The batteries did not come with any documentation, although Ampetus provided ITP with information required for installation, and documentation as it was being developed.



The DIP switches on the front of the unit are only accessible by removing the plate which covers them. This can be quite difficult to do, although after installation ITP was informed (and found) that a magnet makes this much simpler. The DIP switches themselves are very small and require a small screwdriver. Care must be taken not to damage them.

Commissioning

Commissioning of the Ampetus batteries was initially unsuccessful, apparently due to communications issues. An Ampetus technician came to site to update firmware, and provided replacement communications cabling and termination plugs which appeared to solve the issues. However, ITP has since observed that the maximum charge current is limited below the specifications of the pack and, at the time of writing, is still working with Ampetus to resolve the issue.

Despite the documentation being rudimentary and under continual development, Ampetus has been able to provide good support generally. Support has been provided by Ampetus, rather than manufacturer Sinlion (which ITP has no contact with).

III. Aquion Saltwater Battery

Aquion batteries use a saltwater electrolyte, a carbon-titanium-phosphate composite anode, and a manganese oxide cathode. The Aspen 48S battery module has a nominal capacity of 2.2kWh (at a 20-hour discharge rate). Multiple Aspen 48S stacks can be added together to scale system size.

The battery modules have an IP22 rating. Aquion promoted the safety and environmental aspects of their batteries and marketed them as the only ones in the world to be Cradle to Cradle Certified.

Aquion started commercial production in 2014 but filed for voluntary bankruptcy in March 2017. It has since been acquired by Juline-Titans LLC.

The Battery Test Centre installation consists of eight Aquion batteries, paired with a Victron MultiGrid inverter.



Figure 6: Aquion Aspen 48S battery module

Procurement

ITP procured the batteries from Fusion Power Systems, which was the only importer of Aquion batteries in Australia, although they also supplied other resellers. Other stockists included Ampetus Energy, Ecoelectric, and Blitzability Battery Storage Solutions. The Aspen 48S was a new model at the time of ordering, and so ITP was informed of when the first shipment was expected into Australia. ITP received the batteries approximately 2 weeks after this date. The supplier was responsive and provided ITP with all required documentation upon request.

Fusion Power Systems also put ITP in touch with Aquion directly to discuss the technology and optimal configuration given the testing regime. Aquion was able to provide detailed information on the preferred battery quantity as well as SOC calculation methods. Importantly, information received by ITP on compatible inverters differed between Aquion and the supplier.

ITP was unable to procure the SOC calculator developed by Aquion and offered by the supplier (the DataTap) as Aquion entered insolvency shortly after the batteries arrived to site.

Installation

With each stack weighing 118kg, the Aquion batteries are very difficult to physically manoeuvre. Given this, it would be very difficult to install them in a location that did not have perfectly flat access. Their tall, skinny shape combined with this weight means that a great deal of care has to be taken in transport and handling.

The batteries have MC4 plugs at the top (under the top cover), to which the cables are to be connected. Cables to the inverter were not supplied, and ITP installer made these up on site. In addition, no documentation came with the batteries which would have assisted with the installation process (although the documentation was available online).

The Aquion batteries do not require any communications wiring to the inverter.

Commissioning

Aquion filed for bankruptcy in early March 2017, before ITP was able to complete commissioning of the battery pack. Without support from Aquion, ITP has found it difficult to successfully commission the batteries with the installed Victron inverter. Victron was approached but was unable to supply any further assistance other than existing Aquion documentation. ITP has set all parameters detailed in existing documentation but is still unable to complete commissioning the battery, at the time of writing.

Although Aquion was bought out in July 2017, it is not supporting existing products in any way, and all existing warranties are void.

IV. BYD B-Box

The BYD B-Box contains 1-4 x 2.56kWh indoor-rated (IP20) LFP modules with a DOD of 95.7%.

BYD is a leading Chinese manufacturer of LFP cells and packs for electrical vehicles and communications industries, and the B-Box is their product for the residential and commercial energy storage market.

There are four BYD modules installed at the Battery Test Centre, connected to an SMA Sunny Island inverter.



Figure 7. BYD B-Box battery module

Procurement

At the time of purchase, BYD batteries were not yet available from distributors within Australia. ITP contacted BYD directly, who organised delivery of ITP's batteries through their service and logistics partner, Alps Power. Arrival of the batteries in Australia was according to the timeframe



originally discussed by BYD and Alps Power. Alps Power had not realised that delivery to our site was necessary, but dispatch was quick and straightforward once this was clarified.

BYD's Australian product launch event was held shortly before the batteries arrived to site. BYD batteries are now available through a large range of distributors, including RFI Solar, 360Storage, Solar Australia, and Sol Distribution.

Installation

At the time of procurement, BYD batteries were only available in pre-wired cabinets. As a result, installers had to remove the batteries from the supplied cabinet before putting them in the ITP racks. This required also removing all cabling, the BMS, and the positive/negative busbars from the cabinet as well. This was somewhat time-consuming; however, ITP notes that the batteries are now available for individual purchase and so this process would no longer be required. Once the batteries were removed, however, they were very easy to then mount in ITP's own racks. Due to the system also having been pre-wired, installers only had to re-assemble this wiring (including already lugged cables) rather than make up their own.

The BYD batteries came with both an installation and user manual. The instruction in the user manual was detailed and easy to understand, so that the installers did not require any external support from BYD. The only issue was that both manuals were provided only in black and white; in particular, the photos are very dark and difficult to make out.

Commissioning

Commissioning for the BYD batteries is quick and simple. Once the DIP switches were set, ITP was able to set the required settings in the Sunny Island inverter. The battery functioned without issue once turned on.

V. GNB Lithium

The Sonnenschein@home product is GNB's lithium offering for the residential energy storage market with up to 6 modules able to be connected in parallel. The Sonnenschein brand is known for their lead-acid batteries and is the market leader in RAPS applications. Their parent company, Exide Technologies, has been in the battery business for over 120 years.

The Sonnenschein@home battery packs are manufactured by BMZ. Each battery has a nominal capacity of 6.8kWh, with a recommended DoD of 80%. They are indoor-rated (IP21).

The Battery Test Centre installation consists of two Sonnenschein@home batteries paired with an SMA Sunny Island inverter.



Figure 8: GNB Sonnenschein@home

Procurement

GNB has well established distribution networks for supplying a variety of batteries to its markets. The Sonnenschein line of batteries (specifically developed for renewable energy storage applications) is available from a variety of solar distributors.

The batteries tested in the battery trial were procured directly from GNB. At the time of order, ITP was unaware of any lead time, but was informed that the products would be in stock in just over a month. There was one short additional delay (four days) from this anticipated date for the batteries to arrive to the supplier. Subsequent delivery from the supplier was less than a week.

The batteries are installed with a protection box which includes circuit breakers. These parts did not arrive with the batteries and delivery took a further three weeks. ITP actually received multiple breaker boxes in the eventual delivery and was obliged to return the extra components.

The supplier was always readily responsive and kept ITP informed with the status of the order.

Installation

The batteries are large (940mm x 640mm x 465mm) and heavy (95kg), and are therefore somewhat cumbersome to manoeuvre. They have small footpads which do make them relatively sturdy. The batteries can be stacked on top of each other (only three batteries permitted per stack) which reduces the amount of floor space required. However, the right-hand side of the batteries, which is where the fuses are located, must be accessible. The cables exit at the rear of the battery. These points, along with the spacing requirements as specified by GNB, mean that the batteries must be spaced at least 20cm out from each wall. This not only increases the amount of space the batteries require, but also impacts aesthetics.

The batteries came with a protection box with circuit breakers (called the BAT BREAKER), to be installed between the batteries and the inverter. This is actually an Enwitic (not GNB/Exide) product. Despite taking some extra time, the installation of this component was not difficult. An



installation manual was provided with the breaker box, although the storage system referenced is not the Sonnenschein@home battery.

The batteries themselves were not delivered with any documentation.

Commissioning

GNB provided ITP (via email) with all documentation for installation of the batteries, prior to their delivery to site. This documentation indicated that the Sonnenschein@home batteries require commissioning with the Sonnenschein@home Lithium Service Tool, which includes an executable file. ITP was required to specifically request the necessary files from GNB. The files turned out to be significant in size and were therefore sent to ITP on a USB.

The software must be run on a computer while one of the batteries is connected, and the process repeated for each battery. The firmware for the battery is updated through the program, and the cell voltages are captured as well. The documentation states that the cell voltages of the batteries in their initial condition should be sent to the supplier, although the supplier did not mention or request this information from ITP. The software is also used to set the configuration of each battery as a master or slave.

The documentation for the Service Tool was clearly laid out and easy to use.

When the batteries are first switched on, the slave batteries are automatically in standby mode and remain so unless their voltage differs from the master battery voltage by less than 100mV. When this is not the case, the master battery must be charged or discharged until the voltage of both batteries are the same, at which point the main relay of the slave battery is switched on and its status changes to active.

However, the batteries switch off if there is no communication between the battery storage system and the inverter for 20 minutes. ITP therefore had to activate charging and discharging of the batteries via inverter control before the time-out. The slave battery then became active as anticipated without issue.

Each battery is switched on and off with small buttons under the service flat on the side of the unit. These, along with the LED status lights in the same location, are somewhat difficult to access. However, operation and commissioning instructions are clearly detailed and easy to follow in the Sonnenschein@home Installation and Operating Manual.

VI. LG Chem RESU HV

The RESU system is a lithium-ion battery pack & BMS, manufactured by LG Chem in South Korea. The battery is NMC chemistry, and the HV range includes a 7.0kWh and a 9.8kWh model. The batteries are outdoor-rated (IP55) with a recommended DoD of 95%.

LG Chem is one of the largest lithium-ion battery manufacturers globally, and the RESU is an early market leader for lithium-ion batteries in grid-connected systems.

The Battery Test Centre installation is a 9.8kWh model, paired with an SMA Sunny Boy Storage inverter.



Figure 9. LG Chem RESU HV

Procurement

LG Chem's RESU battery range are some of the most commonly available lithium-ion batteries for sale in Australia, and LG Chem has well established distribution networks throughout the country. The RESU battery is available from a number of solar distributors. Distributors generally have LG Chem batteries in stock and are able to ship to most locations across Australia within days. ITP procured its battery from Solar Juice, which was received without any delays.

LG Chem previously provided technical and battery service support in Australia through Solar Hub, a solar retailer based in the ACT, but have since established their own support base in Melbourne, and provide a service support line.

Installation

Being a high voltage battery, the cables required are much smaller when compared to low voltage installations. This makes installation much easier, and allows for standard PV isolators to be used for cable protection and switching.

The battery is wall-mounted on a bracket. The bracket took some extra effort to get onto the wall, and the battery, at 97kg, took some manoeuvring to get onto the bracket. However, the shape of the battery made this reasonably manageable.



The battery came with clear installation documentation.

Commissioning

The LG Chem RESU battery itself does not require any detailed commissioning. It is able to be simply switched on for operation, including the internal switches under the cover at the bottom right of the unit.

Most of the commissioning for this system was related to the SMA Sunny Boy Storage inverter, which had to be correctly configured.

VII. Pylontech

Pylontech's US2000B battery module is the Chinese manufacturer's home energy storage solution. Pylontech was founded in 2009 and manufactures LFP batteries for ESS and electric vehicles. The US2000B modules are rack-mounted and each have a nominal capacity of 2.4kWh with a recommended DoD of 80%. Multiple modules can be connected in parallel to form a larger system.

The Battery Test Centre installation consists of four Pylontech batteries connected to a SolaX X-Hybrid inverter.



Figure 10. Pylontech US2000B battery module

Procurement

Pylontech batteries are available from multiple distributors within Australia. ITP procured its batteries for the Battery Test Centre from Prosun Solar. At the time, the US2000B model was only recently released in Australia and not easily available from all distributors.

It was not clear before ordering that the interconnecting battery cables would need to be purchased as a separate component. Once this was clarified, the process was straightforward and delivery was timely. Prosun Solar was responsive in communications.

Installation

The Pylontech batteries were very easy to install. They are rack-mounted, and also not overly heavy, with each module only weighing 24kg.

The power cables use Amphenol connectors, and therefore require minimal time (no screwing required) to connect to each battery.

A copy of the installation manual was provided with every battery. The only information not available was the addressing of the DIP switches. SolaX was able to provide this information. Given there is no local Pylontech support in Australia, presumably the supplier would also have been able to supply this.

The batteries are clearly indoor-rated, although there is not actually any IP rating specified in Pylontech's documentation.

Commissioning

The Pylontech batteries were very simple to commission. Once the DIP switches were correctly addressed, the batteries worked as soon as they were turned on. As each battery has both a POWER and a SW button, it is not immediately clear by observation alone how to turn the batteries on, but this is detailed in the Pylontech manual which was included with the batteries.

VIII. Redflow

The ZCell is a zinc-bromide flow battery designed by Australian company Redflow. Redflow is based in Brisbane and was founded in 2005. The battery modules are manufactured in North America by FLEX. The ZCell is Redflow's ZBM2 (Zinc Bromide Module) battery enclosed in an outdoor-rated casing.

Redflow promotes the battery's low fire risk compared to other battery technologies, and its ability to discharge to 100% DOD with no degradation.

The Battery Test Centre installation consists of a Redflow ZCell battery connected to a Victron MultiGrid inverter.



Figure 11. Redflow ZCell



Procurement

ITP contacted Redflow directly about procuring a battery for the Battery Test Centre. Generally Redflow does not sell units directly to customers, but rather through their registered installers. ITP was able to obtain the battery directly from Redflow. Included with the battery purchase was provision for on-site installation support by a Redflow technician, which Redflow stipulated as a requirement in order for ITP to install the battery at its Test Centre.

Upon ordering ITP was informed of a 4 week ETA for the next shipment of ZCells into the country, contributing a total 6-7 weeks estimated lead time. The eventual lead time from the date of purchase to delivery of the battery was only 4 ½ weeks.

Redflow recommended installation with a new model of Victron inverter. When ITP experienced issues in procuring this inverter within the required timeframe, Redflow assisted with supply of this inverter to ITP directly.

The Redflow battery that was originally installed in the Battery Test Centre was replaced by Redflow due to suspected contamination in manufacturing, and therefore possible shorter lifetime. Redflow contacted ITP and arranged dispatch of a replacement battery, and pick-up of the original contaminated battery. The replacement battery was dispatched approximately one week after ITP was first contacted about the issue and took another week to arrive on site.

Installation

The Redflow is by far the heaviest single battery unit installed in the Battery Test Centre. With the enclosure, the ZCell weighs approximately 290kg (of which the ZBM2 battery module weighs 240kg). It is also very large, measuring 1020mm (L) x 520mm (D) x 1150mm (H). As a result, the ZCell is extremely difficult to manoeuvre. A lifting device, such as a forklift or pallet jack is absolutely necessary, which could make installs in residences with more restricted access impossible.

Once in place, ITP installers wired up the battery. This part of the installation was relatively straightforward. The battery terminals on the bottom of the battery were delicate and care had to be taken not to apply too much torque to avoid damage.

Redflow sent one of their own technicians to site to assist with installation of the battery. The technician supervised ITP's installation of the ZCell, and the installers worked together on installation of the Redflow BMS. The technician was experienced and this part of the installation was completed without issue, including commissioning of the battery settings through the BMS interface.

The Redflow technician also configured the settings of the Victron MultiGrid inverter to work with the ZCell. This was an involved process and required a special adaptor cable from Victron, which ITP did not possess.



The ZCell came with a Quick Start Guide for installation, although this documentation is technically for the ZBM2 (rather than the ZCell).

The initial ZCell that was provided to ITP was recalled by Redflow after around two months of cycling as the electrolyte was found to have contaminants in it. Redflow provided ITP with a replacement ZCell. The replacement ZCell was installed by ITP installers. This process was straightforward, and no assistance was required from Redflow. Again, the most difficult part of this replacement was the physical manoeuvring of the unit. ITP was requested to pack the original unit in the replacement packaging (pallet crate), which was only possible due to the equipment available for ITP's use at the Battery Test Centre. Presumably Redflow would offer more assistance were the replacement for a residential installation.

Commissioning

The Redflow technician set up most of the required settings. Some of the settings were in the Redflow BMS, and some were in the Redflow inverter. ITP only had to change settings to allow the battery and inverter to work with the Battery Test Centre cycling methodology and control regime.

ITP was not informed of the BMS control parameters originally, but Redflow was supportive in providing ITP with access to the online portal.

The Redflow battery frequently runs a maintenance cycle where the BMS autonomously discharges the battery down to 0% SOC and takes the pack offline for a few hours. This interrupts ITP's cycling regime. In future, efforts will be made to program this maintenance cycle so as to minimise downtime.

IX. SimpliPhi

The SimpliPhi PHI 3.4 battery is an LFP battery with a nominal capacity of 3.44kWh and a DoD of up to 100%. SimpliPhi cells are designed and manufactured in the US. SimpliPhi promotes the safety of the LFP technology and its reduced risk of thermal runaway.

SimpliPhi started as LibertyPak in 2002. Its products have largely focused on off-grid remote and military applications and the film industry.

The Battery Test Centre installation constitutes three SimpliPhi 3.4 batteries connected to a SolaX X-Hybrid inverter.



Figure 12. SimpliPhi battery module

Procurement

SimpliPhi batteries are available in Australia through two distributors, DPA Solar and Enirgi Power Storage. Although ITP originally contacted SimpliPhi directly (in the US), and was able to obtain a quote for direct order and delivery from the US, ITP eventually procured the batteries through local distributor DPA Solar.

There was a lead time of approximately one and a half months as DPA Solar was waiting on a battery shipment, which ITP was informed of. The shipment arrived on time; however, there was a delay in delivery to site as the supplier was unaware that payment had been made. Once this was confirmed, dispatch was relatively quick.

The batteries are easy to transport as they are physically quite small (343mm x 356mm x 203mm).

Installation

The SimpliPhi batteries at the Battery Test Centre are installed on a shelf in a cabinet. The batteries are 34.8 kg each, and were easy to lift onto the shelf.

The SimpliPhi batteries did not come with any leads, so ITP installers were required to make their own, which took a little time. In screwing the lugs onto the terminals, the installers noted that the bolts (on top of the batteries) are somewhat delicate. Care had to be taken not to risk damaging the bolts by applying too much torque. However the wiring itself was very straightforward.

There was no communications wiring required, and there are no DIP switches or other settings on the batteries which require configuration.

Commissioning

SimpliPhi provided ITP with some draft parameters for setting up the SolaX inverter. ITP put SimpliPhi and SolaX in touch to finalise the parameter list, which ITP subsequently used to commission the battery pack. The battery cycled as per commands once these parameters were set.

There is no comms between the SimpliPhi battery and the inverter – the inverter only sees the voltage at its terminals. SOC is not communicated by the SimpliPhi BMS. While this does not impact on functionality, ITP required SOC for visualisation purposes. To that end, ITP was provided with a map to estimate SOC from pack voltage. However, SOC results obtained using this map never appeared realistic.

X. Tesla Powerwall 2

The Tesla Powerwall 2 is the successor to Tesla's first Powerwall. It includes an NMC lithium-ion battery pack with 13.5kWh usable capacity, and an inbuilt inverter. The cells were designed by Tesla and Panasonic and are manufactured in the USA. The Powerwall 2 incorporates a liquid thermal regulation system to cool and balance battery cell temperature.



Figure 13 Tesla Powerwall 2

Procurement

Originally, the Tesla Powerwall 2 was to be sold through a network of solar distributors within Australia, as had been the case for the original Powerwall battery. However, early in the year Tesla shared that it would offer the Tesla Powerwall 2 directly to all interested purchasers, including directly to homeowners. Homeowners would even be able to organise installation through Tesla.

Formerly, the Powerwall 2 was to be available in two variants, with and without the internal inverter (AC and DC versions). The DC version was to be compatible with a range of inverters, including Fronius, SMA and SolarEdge models. In early March Tesla announced that it would no



longer be offering the DC version, even though customers had already been able to place deposits. ITP was originally planning to test the DC version.

ITP procured its Powerwall 2 from Tesla directly. To do this, ITP had to be approved by Tesla as a Certified Installer. Although ITP had been an Authorised Reseller with Certified Installers under the previous system (for the original Powerwall batteries), this was a new agreement and Tesla established new procedures for procurement.

According to Tesla Energy's website earlier in the year, the Tesla Powerwall 2 was to be available in February 2017. This was pushed back to March, then April and then later. ITP was assigned one of the first available units, which arrived at the end of May. Up until the time of delivery it was not clear when ITP's unit would be available.

Tesla had indicated that they would send their own technician to assist with the install; however, this did not eventuate and Tesla provided remote support over the phone during installation instead.

Installation

ITP installers found installation of the Powerwall 2 unit far easier and quicker than for the Powerwall 1 battery. All wiring enters the unit at a single point on the side, which is normally covered by a side-plate, and the wiring is all AC which is more familiar to electricians than the DC wiring of other batteries.

As per Tesla's recommendations, the battery was mounted on the wall just above the ground. This very low height (and the restricted surrounding area) resulted in some difficulty in manoeuvring the unit to the exact position required to fit on the wall mount.

The Tesla Powerwall includes a Gateway, which is a metal enclosure (similar to a meter box) with switchgear and communications. The Gateway is responsible for the monitoring and control of the Powerwall 2. It is designed for the US market, and has different dimensions to Australian meter boxes, which it is installed alongside. The Gateway was easy to install. It is not possible to install the Powerwall 2 in isolation without this Gateway, a fact not clearly advertised by Tesla.

Tesla technical support was available via phone during the installation and for the commissioning process. The Powerwall 2 came with Safety Instructions and Owner's Manual documentation, but the Installation Manual had to be accessed online by ITP.

Commissioning

The battery was able to be energised and charged following installation. While no issues were observed during this charge, a burnt out terminal block, shown in Figure 14 below, was discovered following installation. The termination appeared to be correctly installed and so it is still unclear what caused this issue. The terminal block was replaced and has not been an issue since.



Figure 14 Burnt out Tesla Powerwall 2 terminal block

The Tesla battery is still not cycling because the unit is unable to execute charge/discharge commands as required for testing without time of use functionality. This functionality was originally expected to be released with the product, but Tesla pushed this back to November, 2017. ITP understands that it may not be available until 2018, and presumably has become a lower priority as Powerwall 2's are currently not available to consumers or installers.



3. BATTERY PERFORMANCE

SOC Estimation

Accurate SOC estimation is crucial for operation of both lead-acid and lithium-ion batteries. In the latter case, over- or under-estimation of SOC can lead to battery failure as both over voltage and under voltage conditions can destroy battery cells.

When conducting capacity tests on lithium-ion battery packs, the capacity available is determined by the electrochemistry of the cells, but interpreted by the algorithms of the BMS. The BMS estimates SOC based on any combination of voltage, temperature, current, nominal capacity, historical capacity, coulomb counting, etc. Nevertheless, because the reported SOC is only an estimate, on any given capacity test the capacity available can vary, distorting the results.

Generally, efficiency data shows greater variance than capacity results due to the compounding effect of SOC estimation inaccuracy on both the charge and discharge cycle.

ITP has observed SOC estimation issues for Phase I battery packs as described below.

Tesla Powerwall

The Tesla Powerwall shows relatively low SOC resolution (ie. $\pm 3\%$) and, moreover, the SOC tends to drop significantly when the battery is loaded. It is normal for the voltage of a battery cell/pack to fall when it is put under load, but the BMS will in most cases allow for this in their SOC estimation. From the data collected, it is unclear that the Powerwall is doing so. In any case, capacity and efficiency results are very consistent between cycles and ITP is confident that the Tesla data collected is representative.

CALB + REC BMS

The CALB capacity test cycles show it is regularly cutting off charge/discharge cycles before the maximum and minimum SOC setpoints are reached. In addition, charge delivery/acceptance (the ability of the battery to discharge or charge at a certain current) in the final third of both the discharge and charge cycles fluctuate significantly. It is expected that this is the result of either a weak/faulty cell, or poor cell management by the REC BMS managing the CALB pack.

The BMS is manufactured by REC in Slovenia, and communications to ensure that parameters have been set correctly has proven difficult. Documentation provided with the BMS was insufficient for this purpose, and subsequent communications between REC and ITP were unclear. The issues generally highlight the difficulty and risk of integrating components outside of the factory.

The CALB pack currently still operates acceptably, but the issues described above impact the variability and reliability of the test cycle data collected.

EcoUlt Cell Failure

Throughout the cycle testing, EcoUlt would periodically contact ITP and request that external command was disabled. As EcoUlt have direct access to the BMS, they are able to initiate “refresh” charges as required. Though the EcoUlt pack cycles between 30% and 80% SOC, the refresh charge takes the SOC up to 100%, and is required to maximise battery lifetime.

Following one such refresh charge, ITP was unable to initiate cycling. Upon contacting EcoUlt, ITP were advised that three of the eight cells appeared to be faulty. The suspected faulty cells were subsequently removed from site and sent to manufacturer in the US for diagnostics.

GNB SOC Recalculation Issues

Over the last three months of cycle testing the GNB lead acid battery pack has exhibited a voltage sag during discharge that has caused the SMA inverter to dramatically recalculate the battery SOC. Figure 15 below demonstrates the SOC (orange line) recalculation when the battery pack is being discharged. This rapid voltage drop is characteristic of a lead acid battery that has a significantly reduced capacity due to sulfation. Sulfation is the process by which large sulphate crystals develop on the lead plate of the battery reducing the active material available, reducing the energy storage capacity of the battery.

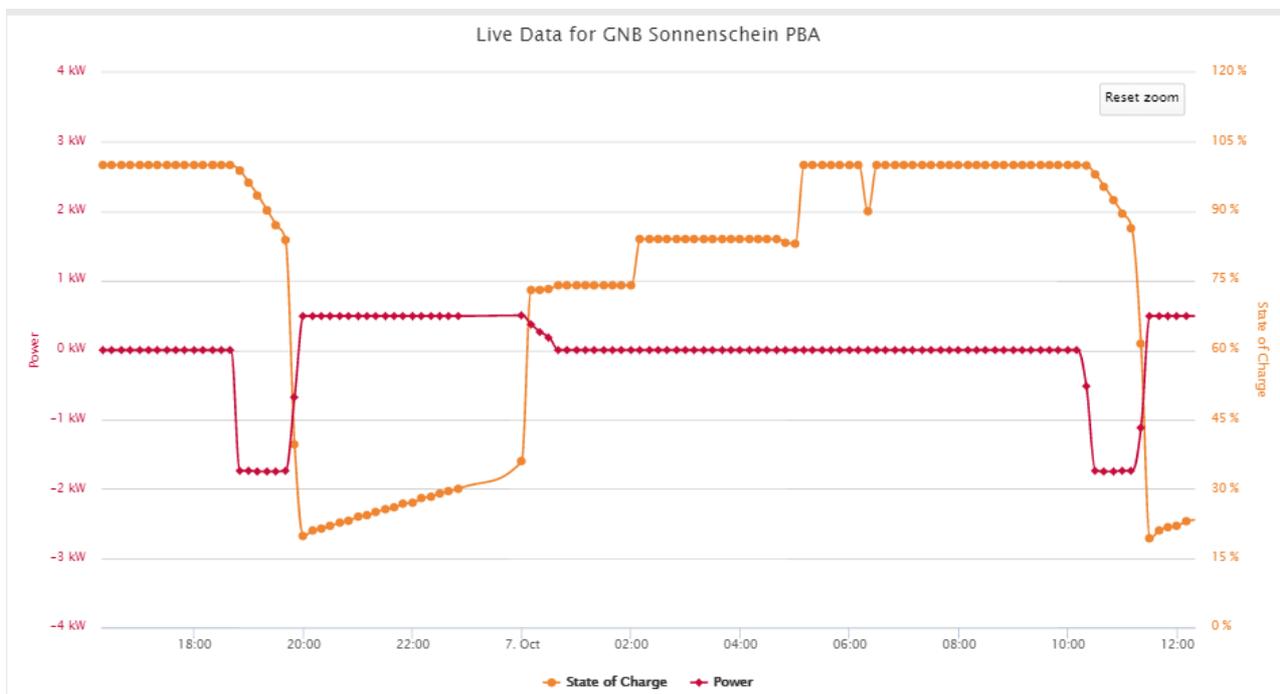


Figure 15 GNB Lead Acid battery SOC Recalculation under load



In this case the sulfation may be caused by the frequent short cycles that the battery is required to do under the battery testing methodology. The duration of the charge cycles in particular may not be adequate for the battery to fully charge each cycle. The low charge acceptance of the lead acid battery at high states of charge makes it difficult to ensure that the battery is fully charged at every cycle. The batteries undergo frequent equalisation charges to achieve a full state of charge, however, it may be the case that these charges are inadequate for this battery pack.

This battery pack is currently undergoing a series of equalisation charges to restore it to a serviceable condition. The pack will then re-enter commission under the test, potentially under a revised cycle regime to accommodate its specific needs. This characteristic of lead acid batteries, demonstrated through this trial, impacts their reliability in real world conditions and limits the viability of this battery chemistry in a range of applications such as stationary storage for solar applications.

Capacity Fade Analysis

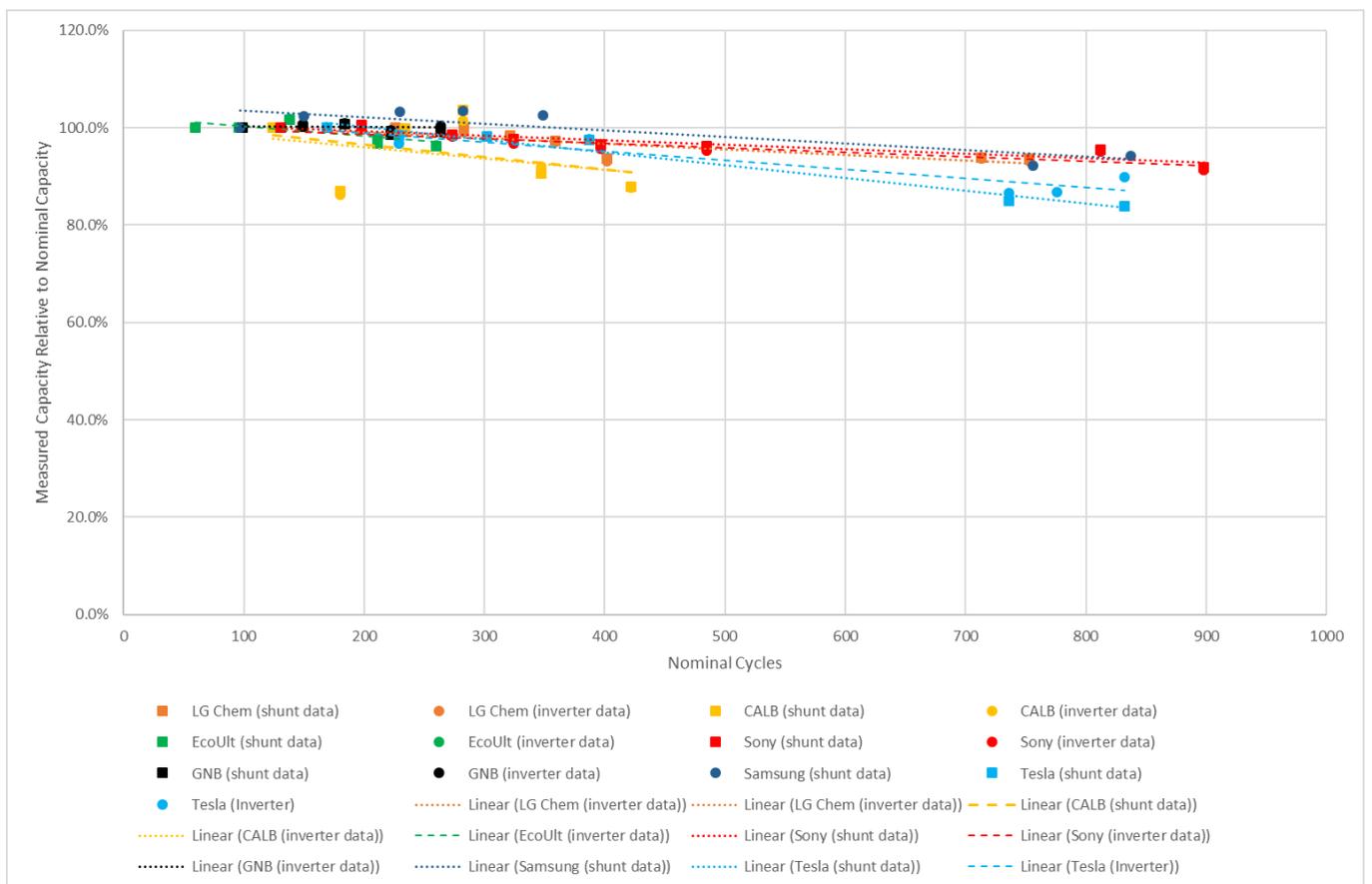


Figure 16 time series capacity fade for the phase one batteries

The above chart shows capacity fade for each of the phase one batteries over the life of the trial. Several batteries have achieved approximately 900 nominal cycles of the expected 3000 over the course of this trial (a nominal cycle being defined as the cumulative energy discharged from a battery divided by its nominal capacity). From the data that is available here it is apparent that it is still too early to ascertain definitive results with respect to capacity fade, however, the following observations can be made:

- The capacity fade of the lead acid batteries (prior to the issues outlined above arising) was similar to the Lithium ion batteries, noting that the lead acid battery has been subjected to fewer nominal cycles than the lithium batteries (due to the lower depth of discharge).
- The issues associated with state of charge estimation for the CALB battery make capacity fade analysis difficult.
- At this stage the rate of capacity fade appears to be generally faster than typically described in manufacturers product descriptions, noting that manufacturers usually cite results based on testing in laboratory conditions at 25C. It is expected that the elevated 'real-world' temperatures used in this trial contribute to this faster rate of capacity fade.

Efficiency Analysis

Efficiency data shows greater variance than capacity results (likely due to SOC estimation inaccuracy), but nevertheless it is possible to observe higher lithium-ion efficiency than lead-acid efficiency, as expected.

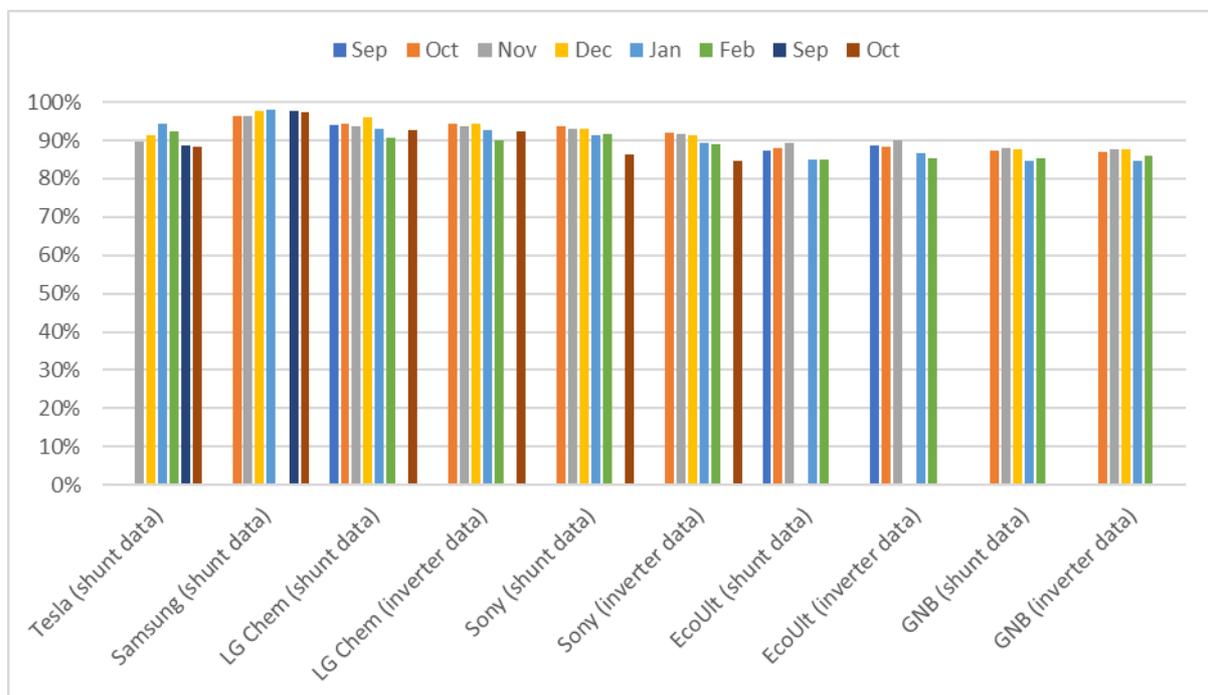


Figure 17 Measured capacity as a percentage of energy input



From the data available to date, it is apparent that on average the Li-ion batteries are slightly more efficient than both the GNB and EcoUlt batteries typically achieving approximately 90% cycle efficiency compared to approximately 85% cycle efficiency for the PbA batteries.



4. LESSONS LEARNED

Many of the lessons learned from the first phase of the battery trial remain relevant for this second phase of the trial. Procurement and commissioning of batteries remain the most challenging aspects of installing these products.

Procurement

The Australian battery market continues to develop in a fluid manner with a number of new products entering the market from existing and new manufacturers as well as a number of products exiting the market in the last six months. There have also been a number of ongoing procurement and technical support problems that suppliers and manufacturers continue to be dealing with.

Lead times on battery products are often not met. Most products are shipped in to Australia from international manufacturers on an as needed basis. This has led to an often-sporadic supply of battery products in Australia and is a key consideration for any project that relies on this supply of batteries.

Many of the batteries require specific Balance of System (BOS) components for either DC protection or battery communications. Suppliers that don't have an in depth understanding of how these products work as well as a lack of detailed installation and commissioning documentation has led to situations where critical BOS components were not shipped with the battery. It is important that manufacturers either provide the critical BOS components with the batteries or ensure that they use common BOS components that any installer could reasonably be expected to provide themselves along with clear instructions on how to install them.

Tesla Powerwall 2 batteries launched in Australia at the end of May. ITP were fortunate to receive one of the first of these batteries to arrive in Australia and install it in our testing facility. However, along with limited installation documentation and support Tesla are yet to provide the full functionality of this battery product as it requires a firmware upgrade to perform time of use functions etc. A range of other lithium batteries including Alpha and Ampetus have required technicians to visit the testing facility to physically upgrade the firmware on the batteries once they were installed. This may be an indicator of products being released before they're fully field tested and ready for market.

Additionally, Tesla have had no stock of the Powerwall 2 product in Australia for the past five months (since the initial batch were released in May) as they have decided to focus their efforts on larger scale projects like the system under construction at the Hornsdale Wind Farm in South Australia. Redflow have also decided to remove their residential scale product, the Z Cell, from the market instead focusing on the larger scale energy storage market. This is indicative of how



dynamic the battery market remains in Australia with manufacturers changing product offerings with little or no notice.

LG Chem have been experiencing issues with their HV RESU battery in Australia as many of these units have been arriving to installers with inadequate charge in the batteries for commissioning to occur. LG have attributed this to the batteries self-discharging during the longer than expected transit to Australia from Korea. LG have now addressed these issues at the manufacturing plants and their technical support in Australia has been quick to provide solutions to the installers in the field who are contending with these issues.

Installation and Commissioning

The installation and commissioning documentation that accompanies most battery products continues to be inadequate with minimal information on how to integrate the products with inverters or troubleshoot installation issues. In many cases the documentation is incomplete or poorly written which, when coupled with weak technical support, suggests that some of these products may still be under development and not yet ready for release into the market.

Acquiring engineering support during the both the project development and construction phases continues to be challenging. The sales representatives of many manufacturers lacked technical knowledge, particularly in relation to how to configure their battery management systems to be compatible with the battery inverters. Acquiring this advice required communicating directly with manufacturers (often overseas) and it is apparent that many still do not yet have processes in place to directly assist end-users with technical problems.

Performance

Despite the limited data, already it can be seen that lithium-ion out-performs both the advanced and traditional lead-acid battery packs in terms of round-trip efficiency, despite lead-acid efficiency appearing higher than general expectations. The initial data suggests that efficiency of >90% can be expected for either Li-ion NMC or Li-ion LFP chemistries, and it is possible that a difference in efficiency will be apparent between the different Li-ion chemistries by the conclusion of the trial.

The advanced lead-acid battery pack (EcoUlt) outperforms the conventional lead-acid (GNB) in terms of round-trip efficiency in the data collected thus far. The ability of the advanced lead-acid to avoid the majority of the conventional lead-acid's absorption charge phase is likely to be largely responsible for this result.

The SOC calculation issues stated above do not impact on the performance of the batteries themselves, however where the SOC is used as a measure of the battery performance this inaccuracy is problematic.



The issues experienced by the lead acid battery (described above) highlight the shortcomings of the technology in high charge rate applications. These shortcomings have typically been overcome by installing larger than required battery banks which contributes to project costs for transport and installation on top of the cost of additional batteries. This trial demonstrates that lithium batteries are more suited to the high charge rate applications and have a higher efficiency leading to smaller battery banks being required.

BMS integration with lithium battery banks is crucial for the battery operation. The CALB battery pack is paired with an external REC BMS which is limited in its ability to balance the cell voltages. The cells in this pack appear not to be particularly well matched in terms of internal resistance which means that some cells will charge or discharge faster and require intervention from the BMS to prevent overcharge/over-discharge. This leads to battery charge inefficiency and reduces the effective capacity of the battery pack. It is important that manufacturers integrate the BMS into their battery packs to ensure that the battery cells are properly managed and the battery utility is maximised.

Inverter Technology

Incompatibility between inverter and battery technologies continues to be a major limiting factor. The rapid developments in the battery market have made it difficult for inverter manufacturers to continue to produce products that integrate with new battery products and meet the needs of consumers. Inverter manufacturers are responding by producing new products to cater to new batteries, but there is a lag while the new inverter products are developed, tested and implemented.

These shortcomings in inverter and battery compatibility could be solved through standardisation of battery and inverter communications and integrations standards. Alternatively, inverter and battery manufacturers may collaborate to develop products in concert to provide fully integrated systems. In the case of Tesla and Enphase the manufacturer has moved to a fully vertically integrated approach which provides end-users with an “AC battery”. These fully integrated products appear to provide a cost-effective option for the customers for whom it is designed, however, for applications such as off-grid systems there are still limited options. A standardised approach to battery and inverter integration would mean that any battery could be used with a wide range of inverter products providing greater competition and versatility of the products.

ITP has found that the Victron multigrad inverter used in this trial for the Redflow and Aquion batteries has been particularly complex to program and has a relatively low and asymmetrical charge/discharge power rating. ITP noted that when the cover is off this particular model of inverter there are exposed terminal screws (230 V AC) which pose an electrical safety hazard. The SMA sunny island inverter is no longer suitable for on-grid installations as it is no longer accredited to the AS4777 Standard governing the grid connection of inverters. There is a limited range of grid connected battery inverters available on the market and the changeable landscape



of the battery market makes it difficult for new products to be developed by inverter manufacturers. A standardised communications interface between batteries and inverters would address this issue and give consumers confidence that products they buy now will be compatible with new system components into the future.



IT Power Renewable Energy Consulting

Southern Cross House, 6/9 McKay St, Turner, ACT
PO Box 6127 O'Connor, ACT 2602
info@itpau.com.au

abn 42 107 351 673
p +61 (0) 2 6257 3511
f +61 (0) 2 6257 3611

itpau.com.au