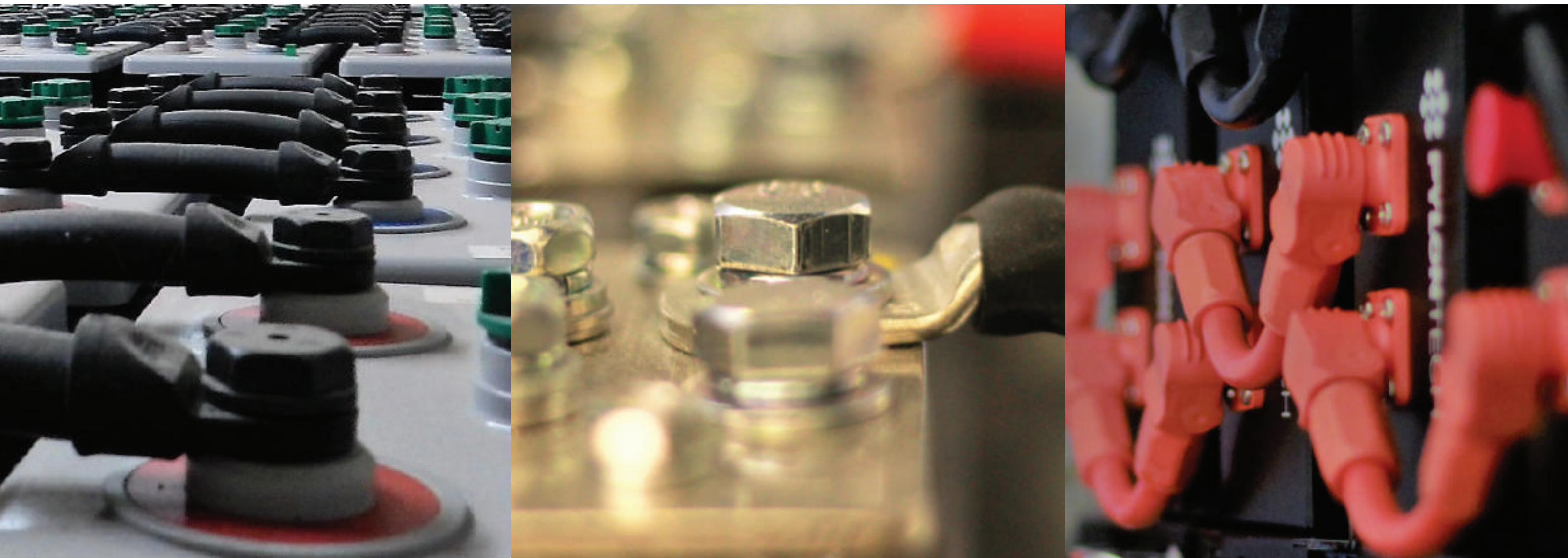
BATTERY TEST CENTRE
REPORT 5



An ARENA Funded Project

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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 testing results and general observations or issues encountered thus far with both the Phase 1 and 2 batteries.

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

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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 in which lithium ions are intercalated at the anode/cathode)
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

ITP Renewables (ITP) are testing the performance of small-scale residential/commercial battery packs in a purpose-built, climate-controlled enclosure at the Canberra Institute of Technology. Round-trip efficiency and capacity fade as a function of cycles completed are reported, alongside various qualitative observations regarding procurement, installation, integration, and reliability.

Capacity fade trends are well-established for both Phase 1 and Phase 2 battery packs, and significant variation in performance between packs is apparent. DC round-trip efficiency varies less between packs, with average values of 85-95% apparent.

Several batteries are performing well and meeting claims made by the manufacturer. Nonetheless, the trial continues to reveal performance and reliability issues with some battery packs. In most cases the issues can be attributed to inadequate product development and/or a lack of understanding on the part of local salespeople/technicians in regard to product integration (ie. with inverters or control systems).

In particular, this report describes the replacement of the Redflow ZCell and SimpliPhi PHI 3.4 packs, ongoing challenges controlling the Tesla Powerwall 2, the insolvency of Aquion and Ampetus, and some operational issues with the CALB, LG Chem, EcoUlt and GNB lead-acid battery packs.

The Battery Test Centre website continues to provide an effective means of knowledge sharing with total page views of 103,500, global reach, and good interaction with the content.

1. PROJECT BACKGROUND

ITP Renewables (ITP) is testing the performance of small-scale residential and commercial battery packs in a purpose-built, climate-controlled enclosure at the Canberra Institute of Technology. This is the fifth public report outlining the progress and results of the trial thus far. A summary of the three previous reports is provided below, but complete reports are accessible on the Battery Test Centre Website[1].

1.1. Report 1 – September 2016

Report 1 was published September 2016 and outlined the background of the project. The intended audience of the trial included the Australian public, research organisations, commercial entities, and government organisations who are considering investment in battery energy storage.

The report described conventional lead-acid and lithium-ion technologies, the process of battery selection, and the testing procedure. The implementation process from procurement through installation to commissioning was also described for the eight “Phase 1” batteries listed in Table 1 below.

Table 1. Phase 1 battery packs

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

At the completion of this first report testing had been underway for roughly three months. At that early stage testing data did not provide meaningful insight into long-term battery performance. As such, the report focussed on the lessons learned during the procurement, installation and commissioning phases and set out the structure in which results would be released in future reports. Refer to the complete report for details.

[1] http://batterytestcentre.com.au/reports/

1.2. Report 2 – March 2017

By the publication of Report 2 in March 2017, Phase 1 battery cycling had been ongoing since August 2016. Capacity and efficiency tests were conducted in each of the six months between September 2016 and February 2017.

It was reported that the Kokam Storaxe battery pack had suffered irreversible damage during that time, due to improper low-voltage protection provided by the built-in Battery Management System (BMS). It was also reported that the CALB pack required a replacement cell and thereafter was functional, but still showing evidence of either a weak cell or poor battery management by the external BMS.

The main lessons learned included that capacity fade was evident for some of the battery packs under test, as expected. However, for others, long-term trends were not yet discernible owing to the inherent variability in individual capacity test results. In particular, this variability was attributed to inherent imprecision in SOC estimation.

In terms of round-trip efficiency, despite the limited data, already it could be observed that lithium-ion out-performs the conventional lead-acid battery pack, despite lead-acid efficiency appearing higher than general expectations. Refer to the complete report for details.

1.3. Report 3 – November 2017

Report 3 was published in November 2017. It described the process of procuring and installing the 10 x Phase 2 battery packs listed in Table 2 below, and outlined preliminary testing results and general observations or issues encountered with the Phase 1 batteries.

Table 2. Phase 2 battery packs

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	13.5

In particular, Report 3 described how battery supply and installation issues continued to hamper the progress of the battery market as a whole, which had been characterised by instability with a number of manufacturers either exiting the market or substantially changing their product offerings. Market leaders Tesla and LG Chem had aggressively cut wholesale pricing, and introduced second generation battery packs.

In terms of Phase 1 pack performance, one EcoUlt Cell failure and general SOC recalibration issues with the GNB lead-acid battery were reported.

Integration of battery packs with inverters continued to be problematic for battery products generally, with the communications interface being the most common challenge encountered. There was still no standardised approach to battery-inverter communications and the report described the expectation that installation and commissioning issues would remain common until communications interface protocols were standardised.

Results from Phase 1 battery pack testing indicated that capacity fade was continuing and that lithium-ion batteries continued to demonstrate higher efficiency.

1.4. Report 4 – March 2018

Report 4 was published in March 2018. It outlined the preliminary testing results and general issues encountered with both Phase 1 and Phase 2 batteries. This report provided particular detail on the ongoing commissioning challenges with the Tesla Powerwall 2 and Aquion saltwater battery packs, the replacement of the Redflow and Ecoult packs, and upgrades to the Ampetus pack.

Ongoing erratic behaviour of the CALB lithium-ion and GNB lead-acid battery packs were observed, but generally higher round-trip efficiency for lithium-ion technology over conventional lead-acid and zinc-bromide technologies continued to be demonstrated.

Capacity test results show characteristic capacity fade for all Phase 1 battery packs (1,000+ cycles completed) still in operation. There is significant variability between packs, and the potential role of temperature effects in contributing to these results is discussed. Phase 2 battery packs (500+ cycles completed) show similar initial trends and variability in capacity fade.

Refer to the complete report for details.

2. BATTERY PACK PERFORMANCE

This section describes the operational challenges and performance of both Phase 1 and Phase 2 batteries over the last 6 months.

2.1. Operational Challenges

While most battery packs continue to perform without any specific issues, some have demonstrated challenges that affect operation, capacity fade testing, and efficiency testing. These issues are described below.

CALB

The CALB capacity test cycles continue to show that the BMS is regularly cutting off charge/discharge cycles before the maximum and minimum SOC setpoints are reached. It is likely that the maximum and minimum voltage setpoints are instead ending the charge and discharge cycles respectively, meaning SOC estimation by the external BMS is unreliable.

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 charge and discharge cycles fluctuates significantly. It is expected that this is the result of a weak cell.

The CALB pack currently still operates acceptably, but the issues create significant variability between discharge cycles, which somewhat compromises the reliability of any conclusions that might be drawn about residual capacity.

LG Chem RESU

Throughout the trial the LG Chem RESU battery has experienced ongoing issues with temperature de-rating in hotter conditions. This is attributed to the high charge and discharge rates used in the trial, coupled with the battery pack’s high density and lack of active cooling mechanisms (ie. fans, coolant loops etc.).

The battery continued to exhibit this behaviour throughout the summer temperature regime of 2017/18. In early 2018 the temperature de-rating escalated to a full battery shut down with an error message indicating high temperature fault. This protection mechanism is activated by the BMS when the battery is outside it’s normal operating conditions.

The battery pack also periodically shuts down at low SOC with error messages reporting a cell imbalance. This cell imbalance reduces the capacity available. While the pack still cycles acceptably, the issues slow cycle accumulation and create significant variability between discharge cycles, which somewhat compromises the reliability of any conclusions that might be drawn about residual capacity.

SimpliPhi

Following the publication of the Battery Test Centre Report 4 – March 2018, SimpliPhi requested a review of the inverter setpoints that were being used for the SimpliPhi battery pack. When the system was commissioned in mid-2017 SimpliPhi technicians provided ITP with inverter setpoints and SOC conversion charts for the integration of the battery with the SolaX SKSU inverter.

At the conclusion of the review, SimpliPhi advised ITP that the inverter setpoints were no longer consistent with their operating guidelines. Consequently, the SimpliPhi pack had been cycled beyond what SimpliPhi now consider to be 100% depth of discharge. SimpliPhi attribute the rapid capacity fade depicted in the previous report to this over-discharging.

SimpliPhi have indicated that they will replace the existing batteries with a new set, and provide an updated installation manual and integration guide for the battery and inverter.

Data on the existing SimpliPhi battery pack is not provided below.

EcoUlt UltraFlex

In September 2017 EcoUlt removed some underperforming battery units from the Test Centre for analysis and identified that the BMS was allowing some cells to stray beyond their minimum SOC limits for extended periods, accelerating capacity fade. EcoUlt updated their SOC algorithm and replaced all batteries under warranty. Cycling of the new batteries commenced in January 2018.

From May onwards, the new pack has been unexpectedly low on capacity, failing to cycle down to 30% SOC due to low voltage cut-off. EcoUlt attributed this loss of capacity to over-discharging caused by incorrect SOC estimation. EcoUlt believe this issue is isolated to the Test Centre, and is that the effect is exacerbated the unusual cycling regime employed. EcoUlt have subsequently updated the algorithm and are conducting maintenance cycles in an effort to restore as much lost capacity as possible.

Data on the existing EcoUlt battery pack is not provided below.

GNB Sonnenschein Lead Acid

The previous report identified reduced capacity and ongoing SOC estimation issues, despite a series of equalisation charges attempting to restore the lead-acid pack. SOC estimation (conducted by the SMA inverter) frequently adjusts downwards (to ~20%) during discharge, triggering low-voltage protection modes in the inverter that prevent further discharge. The opposite is true during charging, where the SOC rapidly adjusts upwards.

It is expected that these issues are the result of sulfation. To avoid sulfation, lead-acid batteries should be fully charged regularly. However, owing to their poor charge acceptance at high SOC, this typically requires long charging times that are not possible during accelerated testing. In solar-storage applications, these limitations are typically managed by over-sizing the battery bank (to ensure shallow cycles only), but this adds capital cost and increases the fraction of solar energy that must be curtailed or exported.

Ampetus Super Lithium

During commissioning of the Ampetus Super Lithium in early October 2017, ITP observed that the Ampetus pack was constraining the charge rate below the rate requested by the test centre's control system. The manufacturer attributed this behaviour to communication issues between the BMS and the inverter. The battery pack was sent to a technician for Ampetus in Queensland for assessment and the issues were reportedly resolved with a firmware upgrade. The pack was subsequently returned to the test centre mid-November and re-entered cycling soon after. However, the pack continued to demonstrate issues with reliability as the battery pack would frequently shut down and require cell re-balancing.

ITP understands that these issues are not isolated to ITP's battery pack, and that Sinlion were not willing to honour their product warranty with regards to this fault. Ampetus were forced to bear this liability with their Australian customers and subsequently went into receivership in May.

Aquion Saltwater Battery

Aquion's bankruptcy in early March 2017 continues to leave ITP without support for final commissioning of the battery bank with the Victron inverter. ITP has set all parameters detailed in existing documentation but is unable to complete commissioning 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.

Redflow

The Redflow battery pack suffered an electrolyte leak and was replaced in May 2018. This is the third time the Redflow battery pack has been replaced in this trial, and the second time it's been replaced due to an electrolyte leak.

Redflow attribute the leak to micro-cracking of the electrolyte tank that occurred during road transport. The problem identified was that the electrolyte trays were not sufficiently supported on the sides to withstand the weight of the electrolyte. Redflow state that they have since modified their transport techniques and believe this problem will be avoided in the future.

Redflow specified a Victron inverter as the most suitable for the trial. As the charge capacity of thjis inverter was insufficient to meet the requirement for 3 full charge/discharge cycles per day, Redflow provided a second Victron inverter to be installed in parallel with the existing inverter. The second inverter was only commissioned in September 2018 and, as such, there is no data available for this battery pack at this time.

It should be noted that the round-trip efficiency results posted in the previous report are not entirely representative of the cycle efficiency, as the issues described above meant few cycles were completed, with a large fraction of the energy imported therefore being consumed by parasitic electrolyte pump loads.

Tesla Powerwall 1

At the beginning of the trial (Phase 1), Tesla's Powerwall 1 was only compatible with a Solar Edge inverter. All other phase 1 packs, excluding the Samsung, were compatible with the market-leading SMA Sunny Island inverter, which the control system had been designed to control. While ITP was able to control the Solar Edge/Powerwall system via an online portal, the rate of charge and discharge was not able to be controlled. Hence, the Powerwall 1 is charging and discharging at its maximum rate (~2hr full charge/discharge) while other batteries charge and discharge over ~3hrs. This means the Powerwall has less time to dissipate heat, which may be causing higher battery cell temperatures leading to accelerated capacity fade. ITP is unable to analyse battery cell temperature data to confirm this hypothesis as the functionality is not provided by Tesla.

Tesla Powerwall 2

The Tesla Powerwall 2 has experienced commissioning delays due to an inability to control the battery pack. ITP still have no direct control over the battery (as Tesla do not allow this level of control of their products), but Tesla have enabled battery cycling through their load/generation forecasting software, Opticaster, which was initially developed in early 2018 for their utility-scale Powerpack units. This enables Tesla to schedule the cycling required under the trial, though this functionality is still unavailable to residential battery owners.

Monitoring of Tesla Powerwall's is only possible via mobile app. Tesla are yet to publish a local API for direct access to data. Nevertheless, community groups of Tesla enthusiasts have published a tutorial on how to take data from the battery online[2].

Due to the delayed commissioning of this battery pack, data is not presented below. Analysis will be provided in the next report after at least six months of cycling.

2.2. Capacity Fade Analysis

In previous reports capacity fade has been assessed by measuring capacity each month under specific *capacity test* conditions (see Section Appendix A). Because the capacity delivered between cycles can vary significantly, a single capacity test contains significant uncertainty. As such, this report provides data and analysis based on both the energy discharged during the monthly capacity tests, as well as on the average energy discharged per cycle per month. These results are presented below.

[2] https://mikesgear.com/2017/12/07/monitoring-teslas-powerwall2-on-pvoutput-org/

Phase 1 Battery Packs – SOH Estimates from Capacity Test Results

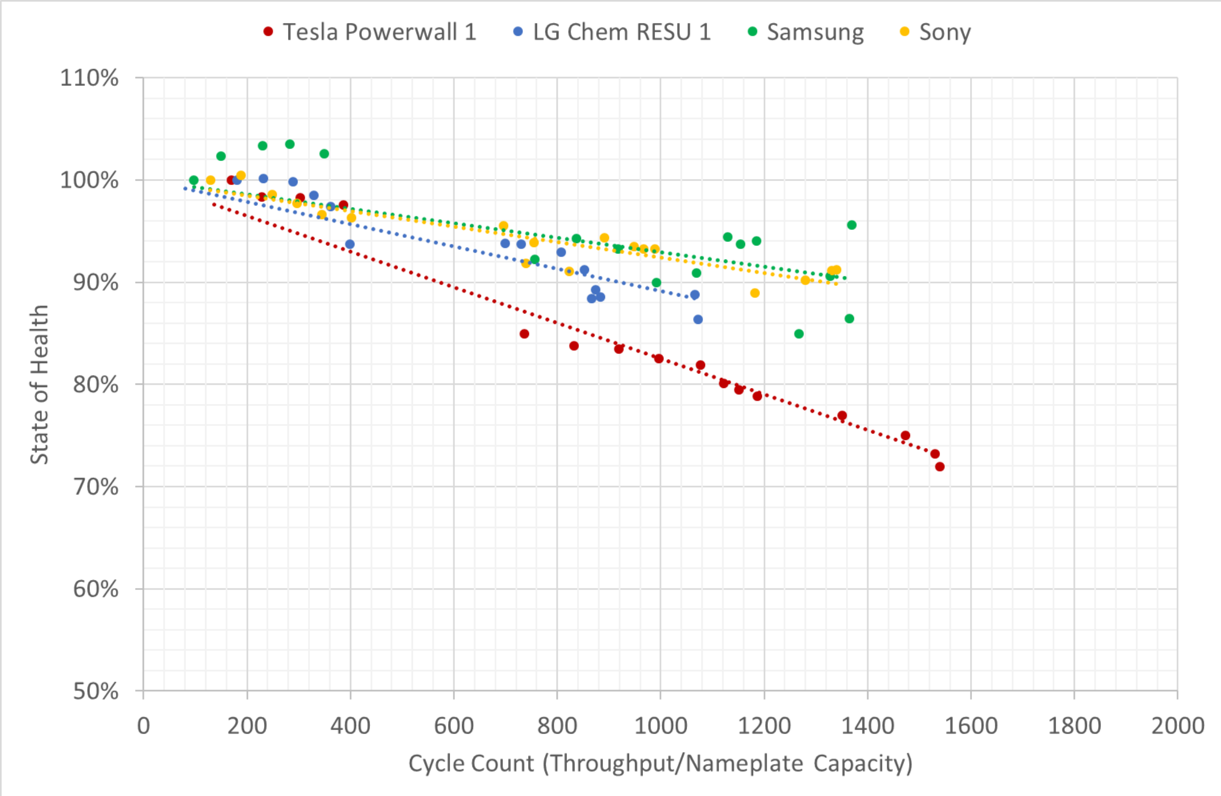

Figure 1. Capacity fade of Phase 1 battery packs based on monthly capacity tests

Figure 1 shows the energy delivered at each capacity test by each of the Phase 1 battery packs, relative to the energy delivered in each packs' first capacity test. From the data available thus far, the following is apparent:

- The LG Chem battery has made limited progress in terms of cycles completed owing to the issues with temperature de-rating and cell imbalance outlined above.
- The Sony and Samsung packs appears to demonstrate the slowest degradation of the Phase 1 batteries. Both have completed a high number of cycles due to generally high reliability.
- The capacity of the Tesla Powerwall 1 is fading notably faster than the other battery packs depicted. However, it should be noted that due to the limited control functionality (described above) the Powerwall 1 is charging/discharging at a higher rate (~C/2) than the other batteries under test (~C/3), meaning less ability to dissipate heat.
- The capacity test results of the Powerwall 1 have lower variance around the capacity trendline than the other battery packs. Further, the Powerwall 1 has completed significantly more cycles. This is consistent with more reliable SOC estimation and battery management, suggesting the Powerwall BMS is performing well.

Phase 2 Battery Packs – SOH Estimates from Capacity Test Results

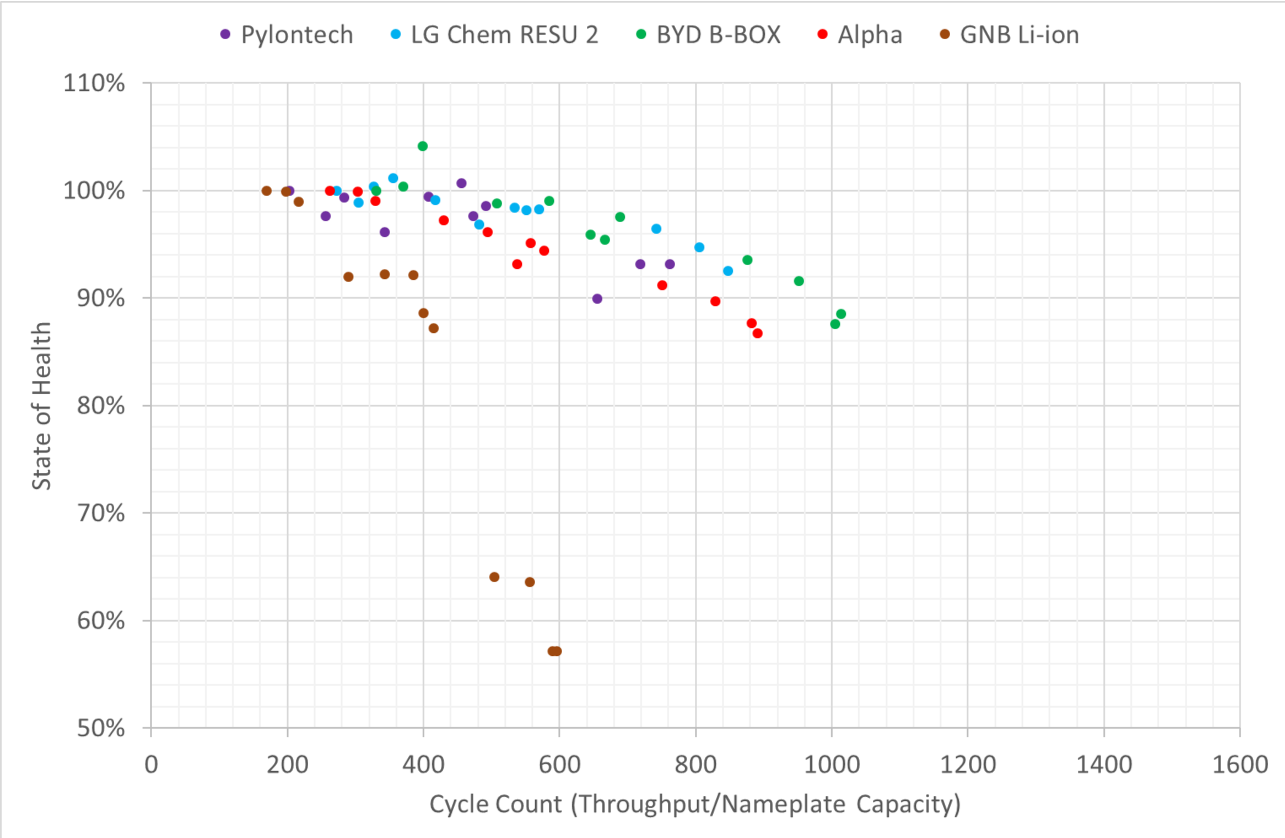

Figure 2. Capacity fade of Phase 2 battery packs

Figure 2 shows the energy delivered at each capacity test by each of the Phase 2 battery packs, relative to the energy delivered in each packs' first capacity test. From the data available thus far, it is apparent that:

- the BYD and LG Chem HV battery packs exhibit a slightly lower rate of capacity fade than the Alpha and Pylontech batteries.
- The GNB LFP battery pack exhibits a high rate of capacity fade.

Phase 1 Battery Packs – SOH Estimates from Average Capacity Discharged

Note that average capacity discharged will be systematically higher during warmer months and lower during cooler months, as the ambient temperatures inside the test centre move with these seasonal variations.

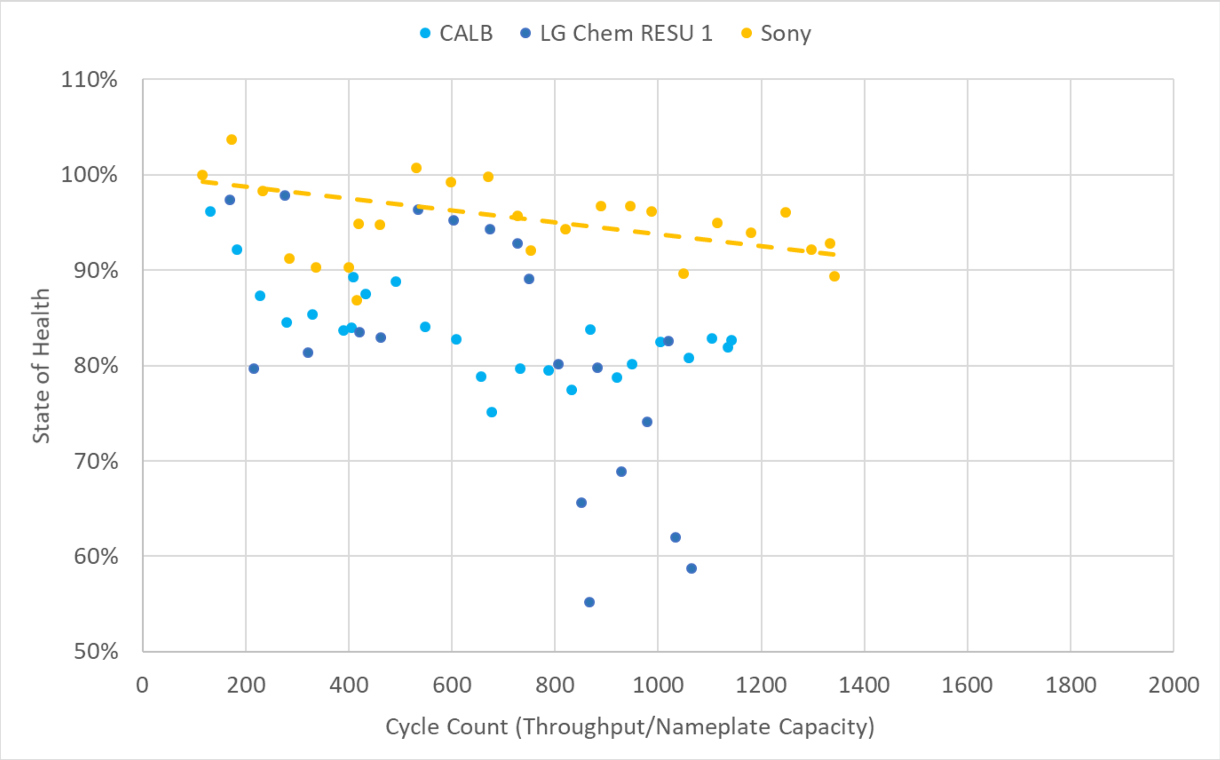

Figure 3 Average capacity fade results for Phase 1 Batteries

For the Sony battery pack, Figure 3 provides additional evidence for the strong performance demonstrated in the capacity test analysis provided above. As above, the CALB and LG Chem battery packs can be seen to be degrading more rapidly, but in this case the fade does not follow a linear trend. This can most likely be attributed to the issues described in Section 2.1.

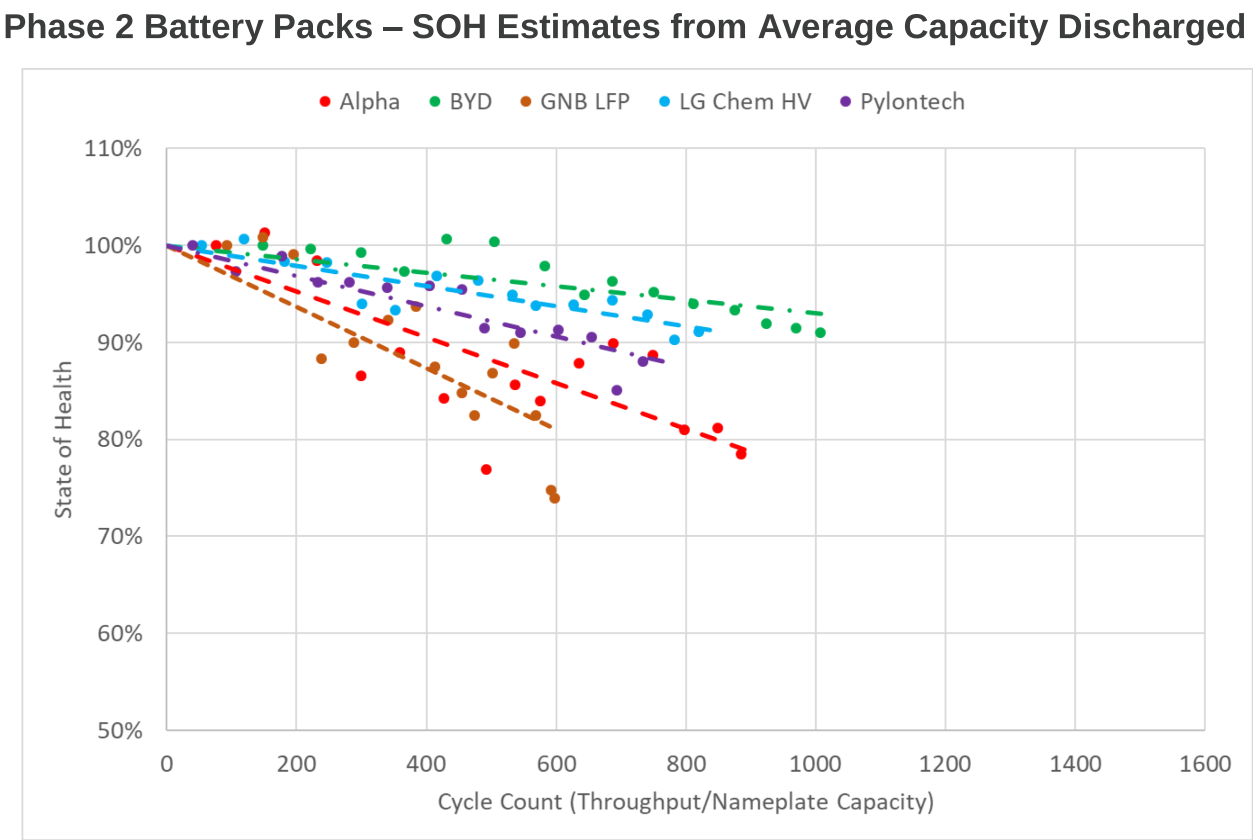

Figure 4 Average capacity fade results for Phase 2 Batteries

Figure 4 supports the observations made above. The BYD and LG Chem HV batteries appear to demonstrate lower rates of capacity fade than the Pylontech, Alpha, and GNB LFP battery packs, with the highest rate of capacity fade exhibited by the GNB LFP pack.

2.3. Efficiency Analysis

Estimates of round-trip efficiency based on a single capacity test each month have greater uncertainty than an estimate based on each cycle completed in that month. While ITP has previously reported efficiency as measured by capacity tests, inconsistency in SOC estimation has a significant effect on the results derived in this manner.

In this report, round-trip efficiency calculated from average energy charged/discharged per month is reported (Figure 5), with outliers filtered. The data shows all technologies delivering between 85-95% DC round-trip efficiency.

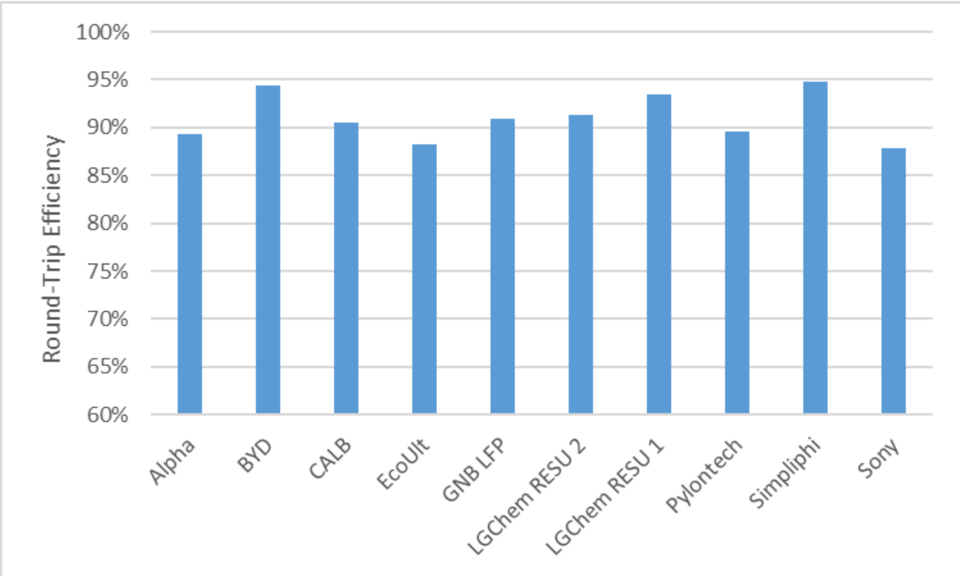

Figure 5. Average round-trip efficiency of various battery packs

3. LESSONS LEARNED

In terms of performance, several batteries are performing well and are meeting claims made by the manufacturer. For example, the Sony & Samsung battery packs from Phase 1 exhibit low rates of capacity fade, despite over 1,300 cycles having been completed. The capacity of the Tesla Powerwall 1 has degraded more rapidly (potentially due to higher charge/discharge rates – see Section 2.1), but it has also completed the most cycles of Phase 1 battery packs, demonstrating its reliability.

Of the Phase 2 battery packs, the BYD battery pack has completed the most cycles and demonstrates the lowest rate of capacity fade, suggesting both reliability and longevity.

Nonetheless, the trial continues to reveal performance and reliability issues with some batteries. In most cases the issues can be attributed to inadequate product development and/or a lack of understanding on the part of local salespeople/technicians in regard to product integration (ie. with inverters or control systems). These are symptomatic of new technology and a new market, and should improve over time.

With respect to the market at large, Tesla have been the clear price-leaders, but a battery cell supply shortage continues to hamper their ability to deliver on their order book. Lesser-known large-scale manufacturers like LG Chem and BYD have not quite matched Tesla's pricing (on a $/kWh basis), but have generally managed to meet (lesser) demand for their products.

For mass-market uptake, further price reductions are required, alongside improvements in battery management, integration with inverters and control systems, and technical sales support.

4. KNOWLEDGE SHARING

An important part of the battery testing project has been to maximise the demonstration value of the trial by:

- Sharing the knowledge with the largest possible audience
- Publishing data in a way that is highly accessible and user friendly
- Adding value to the raw data through expert analysis and commentary

The Knowledge Sharing seeks to publicise data and analysis generated by the battery testing in order to help overcome the barriers impeding the up-take of battery storage technology. In particular, it seeks to overcome the barrier that there are no known published studies of side-by-side battery comparisons which test manufacturers' claims about battery performance. This lack of independent verification contributes to investor uncertainty.

The intended users of the information generated by the project include:

- Future energy project developers, including technology providers and financiers, who will be examining the investment case of a range of energy storage options.
- Energy analysts involved in projecting future renewable energy costs and uptake rates.
- Electricity industry stakeholders including generators, TNSP, DNSPs, and regulators.

The Battery Test Centre website[3] was established as the key mechanism for this Knowledge Sharing. The website includes background on the project, live tracking of battery status, and a virtual reality component that replicates the battery test facility. To date the site has had over 103,500 page views with an average of 1:57 minutes spent per page and 4:09 minutes spent on the reports page.

[3] www.batterytestcentre.com.au

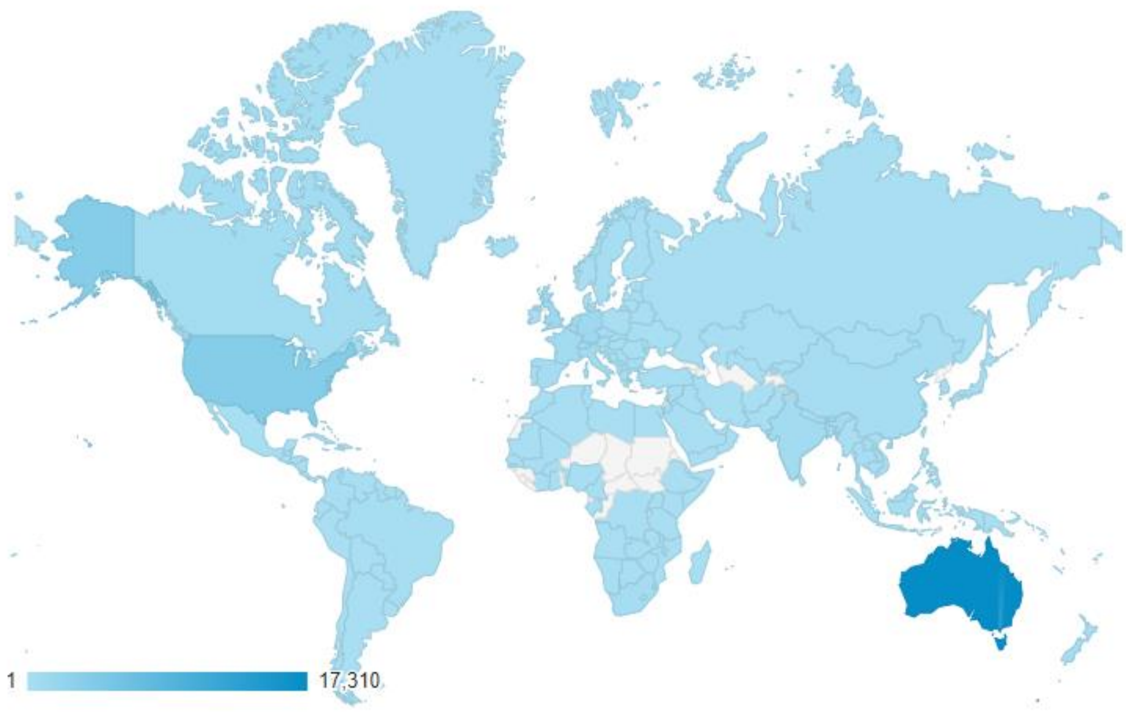

Figure 6: Number of sessions by country

The data from the website shows that the key audience is Australia, with Australian IP addresses accounting for 26,378 sessions. A session is logged as a single viewer who may view multiple pages within a restricted period (periods are normally reset after 30 minutes of inactivity). Australia is followed by 4,898 sessions from the United States, 1,542 from Germany and the United Kingdom not far behind on 1,472. It is interesting to note, however, that the content has been accessed from right across the globe.

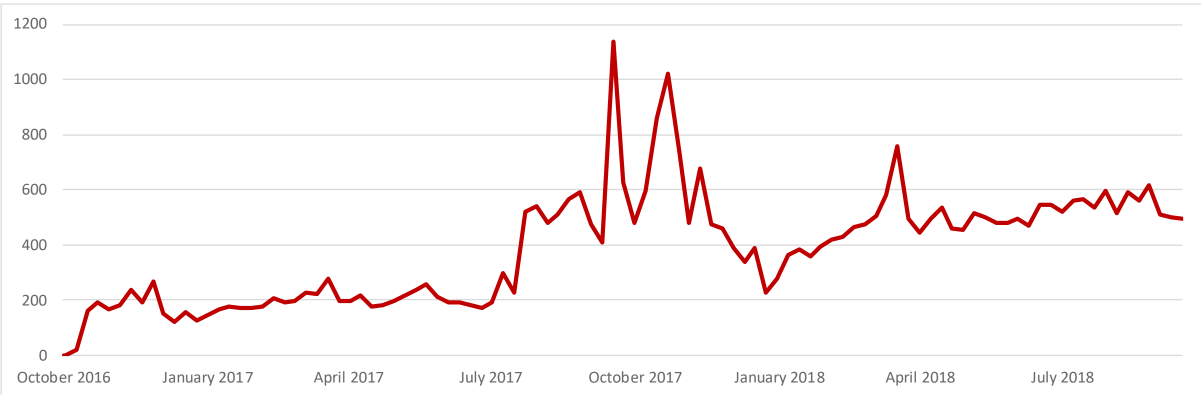

Figure 7: Weekly active users

Figure 7 above shows the number of weekly active users that have accessed the website and there is a clear rise between the Phase 1 figures at around 250 weekly users, to the launch of Phase 2 in August of 2017 when the weekly averages nearly doubled to around 500 active weekly users. The peaks coincided with media articles that were distributed on those dates.

There is a good spread of views across the website, particularly the technology and results pages; the top five most viewed pages after the homepage (19%) are the results page (14%), LG Chem RESU (10%), the reports page (5%), the background page on lithium-Ion technology (4%) and Pylontech US2000B (4%).

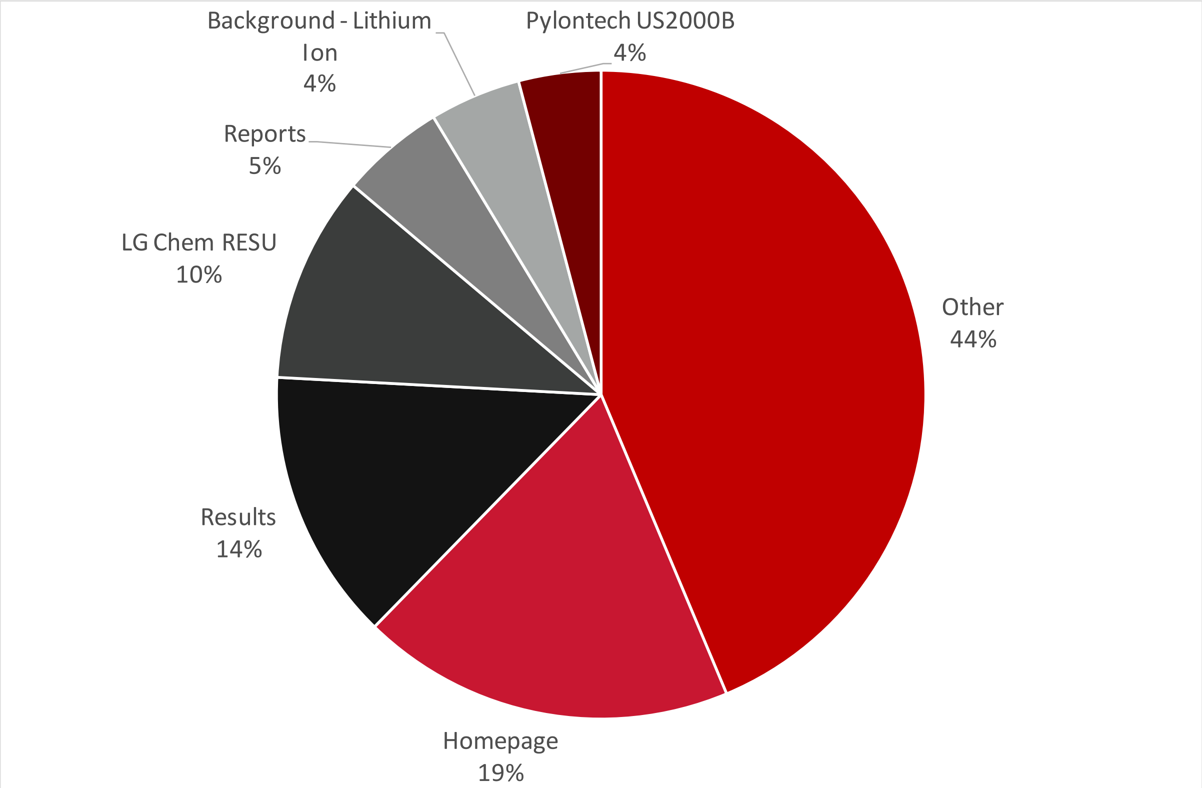

Figure 8: Breakdown of the 103,500 page views

APPENDIX A. 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 3: 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

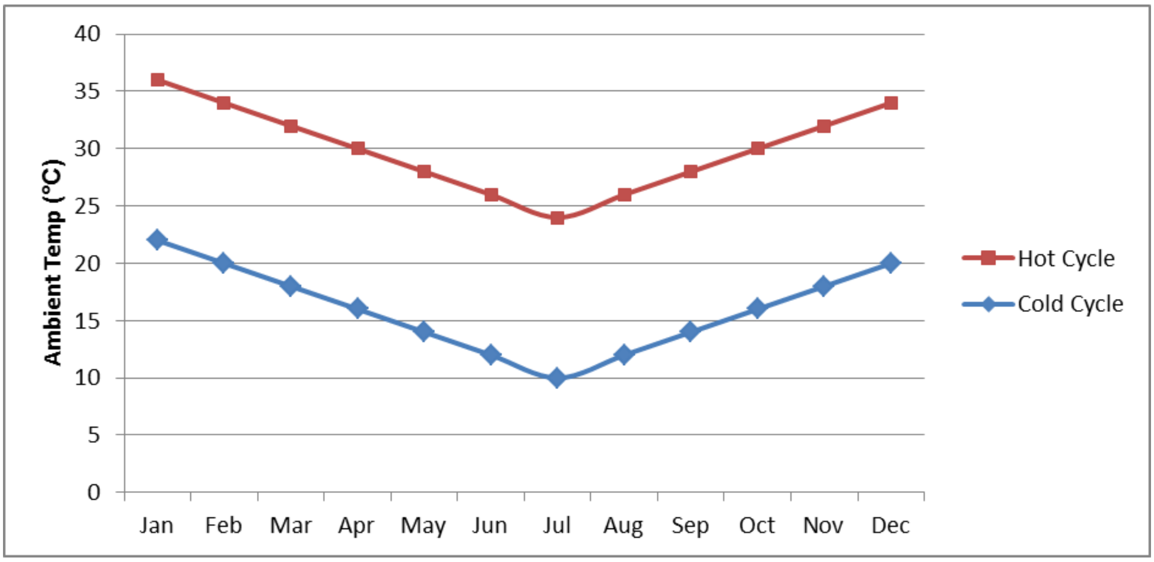

Figure 9: Daily hot and cold cycle temperatures throughout the year

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.

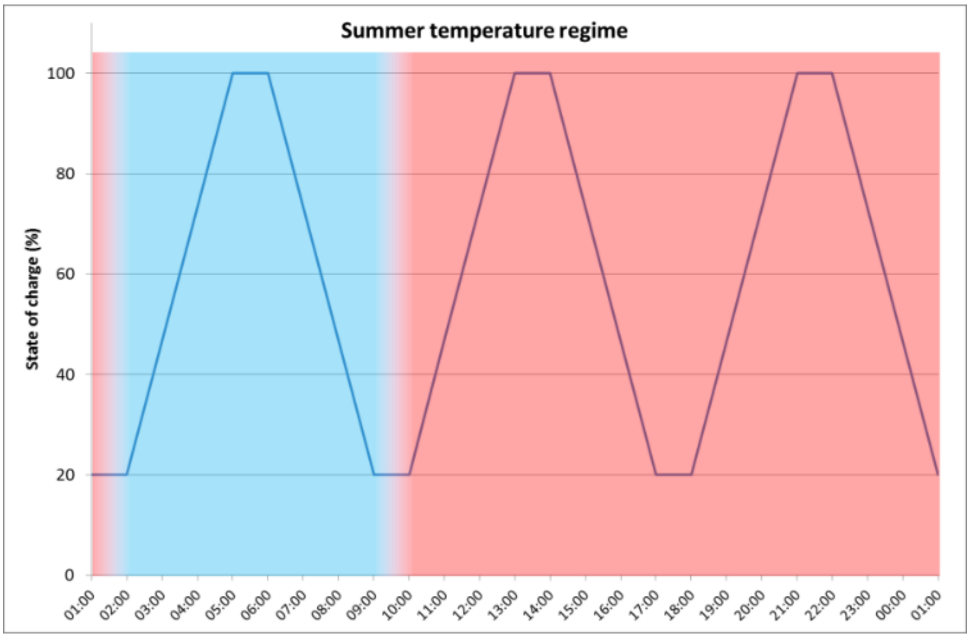

Figure 10: Summer temperature regime and charge regime

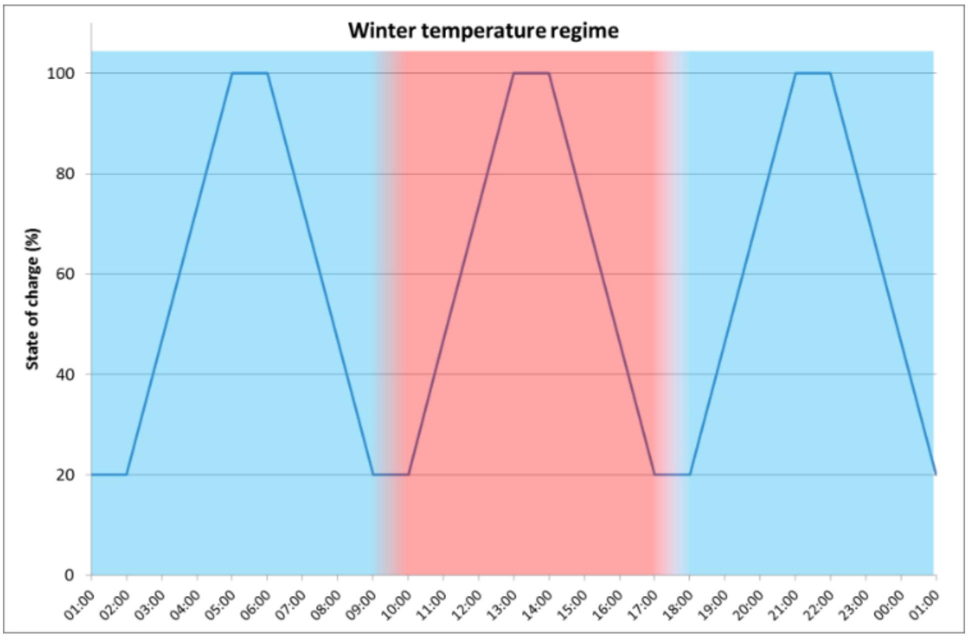

Figure 11: Winter temperature regime and charge regime

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.

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