LESSONS LEARNT PROJECT FULFIL

Final Report

December 2020

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Contents

1. Introduction

The hardest projects are the ones that get tantalizingly close to their goal without successful conversion.

Project Fulfil aimed to deliver an affordable and reliable battery monitoring and management system for operating lead-acid batteries in partial state of charge (PSoC) applications, as well as developing interfaces and tools to enable the use of the system with existing inverters, and predictive analytics to improve network integration. The project involved the commercialisation of the technology so the UltraBattery can compete in markets that require it to operate at a PSoC. However, circumstances have resulted in an outcome that will see Project Fulfil mutually terminated without Ecoult achieving all of its goals.

We remain convinced that lead acid technology can achieve the performance and consistency needed to significantly extend the contribution it is already making to supporting wider adoption of renewable energy generation and providing remote power where it is most needed and beneficial.

Ecoult has had the benefit of tremendous support from its parent East Penn Manufacturing (EPM) and from key stakeholders in its mission including ARENA. It also had the benefit of committed focus from a dedicated team of very talented employees.

The case can be made that Ecoult had access to adequate resource, and, that it is possible for lead acid systems to achieve the needed performance and consistency to attain a major position in the energy storage segment.

In this presentation of lessons learnt we have tried to present the circumstances objectively as there are many assessments that can be made. Innovation is a process of creating the conditions to uncover new knowledge and understanding and to capture it for productive purpose. The Ecoult team and EPM worked closely together toward innovation goals and decisions were made in a collective manner by a governance team with high mutual respect and trust based on our best understandings as we progressed.

One area of importance to consider as the Ecoult experience and project outcomes are reviewed with the benefit of 20/20 hindsight, is the timing and balance of apportionment of resource between early commercialization and the fundamental understandings needed to achieve the performance and consistency objectives.

A second is the tight boundaries in focus that were sustained by Ecoult. Ecoult was focussed on applying the capabilities of a single cell chemistry (UltraBattery®) to energy storage applications rather than responding to the defined needs of an understood user story. Our original business plan assumption was that we would get the UltraBattery device cost to a target cost of not more than 1.2X the cost of a standard valve regulated lead acid (VRLA) cell. In fact, the final EPM multiplier (based on actual cost of manufacture and conventional margin) was closer to 2X (Exide Industries UltraBattery cells were lower cost at 1.4 times an Exide standard). Despite meeting our KPIs for cost, this cell price premium was a showstopper in the end when applied to commercial assessment of the long-term viability of the UltraBattery systems against the lower prices continually being achieved by lithium.

In the later stages of Ecoult it was realized that the methods we were forced to develop in Ecoult to achieve the performance and consistency utilizing UltraBattery were effective and could be applied even to low-cost standard VRLA cells. This offered a potential pivot path to much lower cost and competitiveness; however, compounding influence in the final outcome though was the “time lag” it takes to achieve proof even where there is a high level of conviction with battery testing. In the simplest sense, Ecoult ran out of time to establish proof that it could achieve its mission with the technology it was stewarding.

For this reason, the dominant priority through each step development process must be a product outcome that can be warranted with confidence and that has all necessary standards and regulations compliance and certifications.

Project Fulfil was the correct step for Ecoult to take and was intended to uncover the understanding needed for the consistent high performance needed for the technology to be globally successful. Again with 20/20 hindsight, the workplan of Project Fulfil, the testing capabilities Ecoult established in Macquarie Park, and the advanced data analytics techniques that we applied to the challenge should have been put in place by Ecoult earlier in its journey, rather than being used for catch-up.

2. Background

The Ecoult team has been part of the energy storage industry's effort to support higher levels of renewable adoption from the very early days. It participated in the achievement of many industry breakthroughs alongside our customers, including:

- With CSIRO the 500kW demonstration site at Hampton NSW that showed that energy storage can mitigate variability from Wind Farms.
- With PNM (supported by US Department of Energy) in New Mexico the first large scale energy storage and solar facility.
- With Hydro Tasmania a MW scale energy storage solution at the King Island (KIREIP) project. (Still operating with the original UltraBattery cells after 8 years)
- With EPM (Supported by US Department of Energy) a 3MW Frequency Regulation System on the PJM grid (one of the earliest).
- With Constellation a dual purpose (power continuity and frequency regulation) solution for the Water Utility (AQUA) in Pennsylvania.
- With AGL multiple remote power systems to support gas mining operations.
- With Exide Industries in India pilots in remote telecom and microgrid.
- With Raytheon and US Department of Defence (Supported by ESTCP) a multipurpose solution using storage to provide a local microgrid in the case of grid failure while supporting grid ancillary services when the grid is operating.

These systems used UltraBattery (a unique lead acid product comprising battery and ultracapacitor characteristics in a single cell invented at CSIRO). Through Project Fulfil we aimed to attain the stretch in capabilities needed to establish sustained competitiveness for the UltraBattery platform as lithium turned up the heat on performance, consistency, and cost.

This "knowledge sharing" document of "lessons learnt" seeks to pass forward understanding in two key classes of experience gained and lessons learnt during Project Fulfil in:

1) **The pursuit of the performance and consistency needed for lead acid to extend current boundaries.**

2) **The stewardship of capital and human creative resources in innovation.**

   And a roadmap is offered based on the experience gained for:

3) **A path of continued development to establish the Project Fulfil goals and beyond with lead acid.**

Importantly, in considering the experiences as set out in this document, Ecoult's context as a subsidiary of EPM must be factored in and understood. This was a tremendous strength toward achieving the original mission as it focussed all efforts at the tightly defined scope of making UltraBattery successful in the (stationary) energy storage segment. This context though also defined the boundaries of Ecoult's flexibility and having not attained the mission with UltraBattery within the parent's (generous) runway left Ecoult with limited options.

3. In the pursuit of the performance and consistency needed for lead acid to extend current boundaries

We retain high confidence that lead acid can attain higher and consistent performance while reducing cost to extend upon the contribution it is already making toward supporting renewable technologies and remote power.

3.1. Cell engineering must be complimented by system engineering

One of the challenges Ecoult ran across in its efforts was that lead acid batteries are very robust and when optimised for cycling (for example using gel, or tubular positive electrodes) are, *almost*, good enough as they are. These technologies are applied and trusted by customers around the world and provide an effective solution for remote power solutions in ad hoc and harsh conditions with the chemistry being very tolerant to abuse. Until the development of the energy storage industry into applications that need higher performance and investment in large systems that need "bankable" performance consistency, lead acid was the dominant chemistry to complement renewable energy, and for critical and remote power systems. It remains strong and effective in these markets today.

Lithium has lifted the bar in terms of performance, and even perhaps more importantly, consistency of performance that underpins warranty. Huge investment has flowed to the lithium industry to achieve the performance and consistency demanded by the growing use of energy storage. Lead acid is a highly commoditised business and, although it has phenomenal fulfilment capabilities and strong sustainability credentials, the R&D investment is tiny compared to lithium.

While lead acid is a robust technology, it is also a complex technology and the vast majority of the modest research and development investment in the industry is made on cell engineering. To make the necessary jump in performance to the new energy storage markets, Ecoult's assessment is that the lead acid industry needs to complement cell engineering with system engineering that operates, protects and maintains every cell in every string in a manner that enhances and preserves performance and longevity.

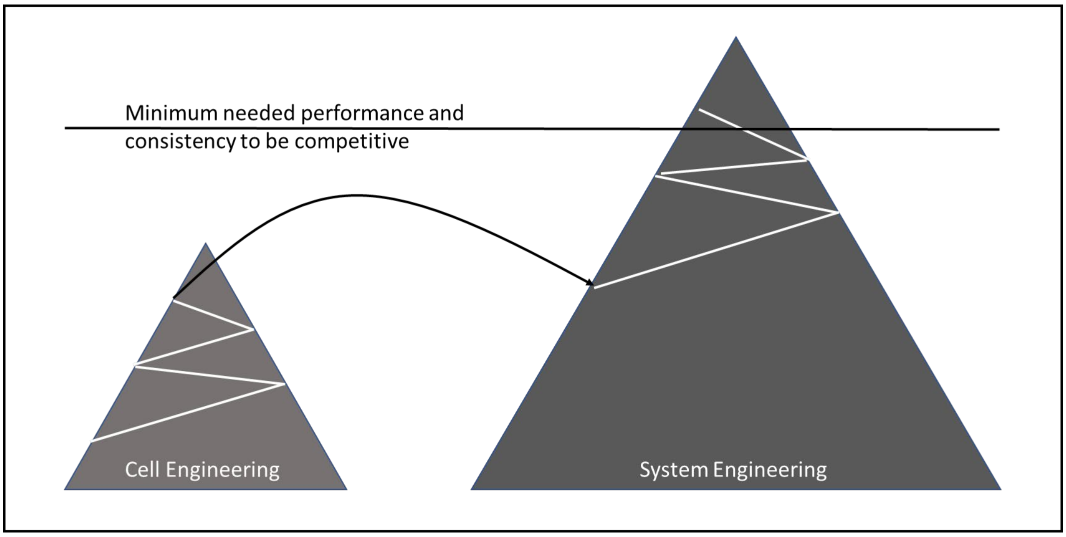

Figure 1 Lead acid needs to move from a focus on cell engineering to a system engineering

Lead acid has developed a dependency on using overcharge as both a method of cell alignment in strings and of resetting changes in cell morphology that happen with cycling and use. Particularly as price pressure has come on the industry from lithium, the added cost of any supporting electronics needed for cell management has been resisted. Perhaps most challenging are the gaps in research toward understanding of how to determine and understand state transitions while using lead acid batteries so that they can feed into supporting system technology.

Examples of the differences between cell engineering and system engineering are given below.

Cell Engineering	System Engineering
VRLA technology	Separation of use of overcharge for cell alignment and for maintenance of crystal morphology and other cell state conditions
GEL technology	Methods of ideal overcharge
Tubular positive technology	Determination of lower boundaries of operation during ad hoc utilization
UltraBattery technology	Methods to maintain during operation and approaches to redundancy
Methods to inhibit gassing	Power solutions (integrated inverter)

Table 1 Cell engineering and system engineering examples

System engineering is the path to consistency but needs to be based on robust understanding and, in the case of lead acid battery technology, requires determination and tracking of the way the state of the cell and the processes are changing during use.

Partly because overcharge is such an effective “cure all” for lead acid technology and the chemistry itself is so complex, the tendency is to fall back on simple “rules” rather than methods that adapt to actual state. By defining control conditions for bulk charging, absorption charging, float charging, and a periodic equalization charge satisfactory performance can be achieved with many lead acid systems.

Within the lead acid industry, the research to advance the understanding of the state transitions does not carry the same focus as how to improve cell chemistry; however, this is changing with increasing effort going into cell modelling and runtime state determination using tools such as electrochemical impedance spectroscopy.

Informed by battery state understanding, system engineering can utilize runtime measurement methods that are found to reliably determine the key transition points that require actions in terms of control adaptation in order to achieve balance between application needs and battery longevity. Ecoult was at the forefront of this work in the industry as well as in the testing of outcomes (laboratory and field) and continuous improvement using advanced data analytics.

Given the complexity of the lead acid cell, quality (in the form of performance, consistency, and value contributed) is a function of balancing the needs of the application with the needs of the battery chemistry.

3.2. Overcharge maintenance must be cell specific

One of the most fundamental lessons learnt in the course of Project Fulfil was how lead acid cells could drift with respect to each other within strings (including the six-cell substring inside monoblocs) and the impact this could have on application performance and battery/cell longevity even using best industry practice approaches to overcharge equalization.

Methods of cell alignment beyond passive overcharge contribute both to enhanced functionality against application needs and to enhanced longevity for the cells.

The Ecoult 2V cell management system (CMS) that was developed during Project Fulfil provided methods to individually align cells in strings by bypassing current selectively and provided a flexible tool to adapt and qualify approaches to managing the cells.

The 2V CMS was developed in reaction to the identification that cells were drifting with respect to each other inside monoblocs under some cycling conditions and this was contributing toward limitations in the string and system performance and to early battery failure.

The CMS has proven to be robust and effective and was a useful step on the path to high volume production of a universal solution.

As shown in the diagram, representation below the purpose of the CMS was to map the Application needs of Safety, Availability, Flexibility, and Reliability across to the Battery needs of Protection, Avoidance (of operating limits), Alignment (of cells), and Maintenance (of cells).

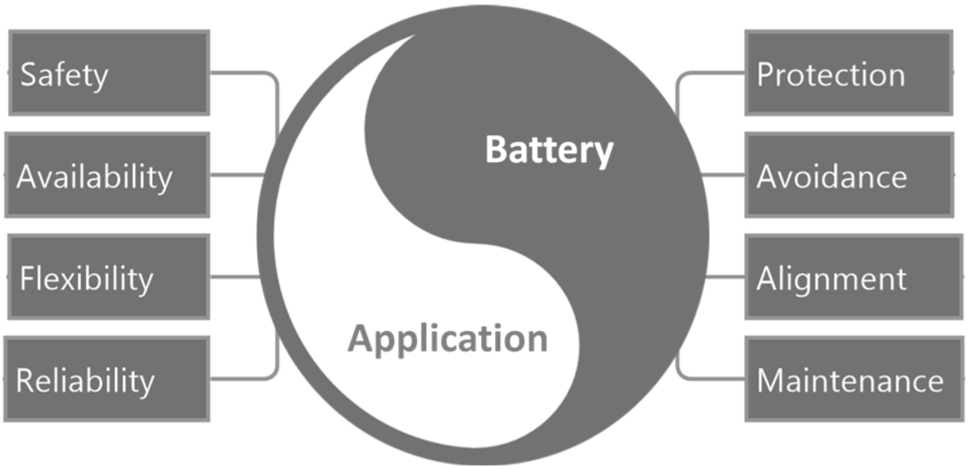

Figure 2 Application and battery requirements

The CMS was developed in parallel to commercial activity wherein Ecoult was offered opportunity to supply a significant contract based on outcomes of our work. In consultation with EPM we determined a verification and validation test criteria to use as the basis to determine it would be appropriate to accept the offered contract. During the verification and validation test we found that the combination of the system and the new 2V cell did not meet the criteria. Most directly it was found that very extensive overcharge periods (up to 90 hours) were needed to restore/sustain the capacity of the cells when applied to the test cycling pattern.

That the verification and validation test was not successful was a surprise and major disappointment as the combined Ecoult/EPM technology group (Battery Guild) we had assembled, which spanned cell development and Ecoult CMS and system development teams, had been confident that the test would be successful. Should the test have been successful, there was a clear path forward for Ecoult based on the commercialization footprint we had established.

Ecoult and EPM had progressively overcome many challenges in the Ecoult journey but, with the failure of the 2V verification and validation test, we were left in a position with the Ecoult entity scaled for commercial expansion but without an UltraBattery based (either 12V or 2V) we could fully rely on for sufficient consistency in performance to take on large deals. It was clear there were additional layers of understanding to be resolved even beyond the completion of cost reduction and UL certification of the CMS technology.

The most direct challenge identified in the verification and validation test was that the capacity of the new 2V cells we were using could not be maintained without excessive periods of overcharge. This was at the individual cell level meaning that, even removed from a string and run individually, the cells needed the excessive overcharge to maintain full function. This problem became clear and evident only after the cell alignment achieved the goal of getting all cells in the string a matched opportunity at overcharge.

UltraBattery proved its efficacy in terms of improved resistance to accumulating sulphation but the challenge of optimizing the process of restoring/maintaining capacity with a periodic overcharge has been ongoing throughout the Ecoult journey.

The behaviour of the new cells during the verification and validation test in terms of the amount and duration of overcharge needed to retain capacity appeared perhaps different and more excessive than other UltraBattery cells that Ecoult has used but we have not had opportunity to do quantitative comparisons. What it points to is a need/opportunity for understanding and characterization of the propensity of different lead acid cell design approaches to support quick/easy overcharge maintenance and rigor in understanding the optimum approach to overcharge to achieve quick/effective overcharge maintenance.

The lesson learnt in this is that, as well as the cell being appropriate for the application in terms of its resistance to accumulation of sulphation, whatever process is needed for overcharge maintenance (regardless of cell type) must also be understood and appropriate.

In the case of lead acid overcharge maintenance must be:

a) Able to be administered to all cells in a string to the optimum degree for the cell
b) Able to be delivered while meeting the needs of the application being serviced
c) Reasonable
d) The balance between ensuring there is enough overcharge to preserve the cell capabilities and that it is not excessive in terms of contribution to secondary degradation must be appropriate.

3.3. Additional work identified

For lead acid to be successful in energy storage, additional work is required:

- Cell design to support efficiency of the periodic overcharge mechanism used for maintenance of cell state
- Optimization of the process used for periodic overcharge
- Continuous improvement to state determination input to CMS and control algorithms for operation
- Optimization of cell alignment methods
- Development of approaches to separate the needs of cell maintenance and application
- UL certification of protection mechanisms.

4. In the stewardship of capital and human creative resources in innovation

4.1. Experience gained

Ecoult attained a number of key industry breakthroughs and developed the type of system solutions and project implementations that would ordinarily launch a business to a high growth path.

The achievements of more than eight years of continued operation of the King Island BESS, the Raytheon/Joint Base Cape Cod Microgrid/Frequency Regulation System, the multiple Moomba remote power systems, and the remote microgrid solution in India positioned Ecoult well for continued investment for expansion. The inhibitor to acceleration was the lack of performance consistency in the field, leading to high levels of support to deliver on customer expectations and preventing Ecoult from establishing a repeatable commercial model.

This sustained level of intensity without breakthrough, combined with the relentless competition from lithium with massive investment and aggressive approaches to industry forming pricing, resulted in the Ecoult effort not attaining a sufficient price/performance/consistency outcome within the generous runway that East Penn supported the effort with.

As also noted in Introduction:

"The case can be made that Ecoult had access to adequate resource, and, that it is possible for lead acid systems to achieve the needed performance and consistency to attain a major position in the energy storage segment."

4.2. The user story must drive product development

Ecoult was formed with the very specific mission of making UltraBattery successful in the energy storage solution market.

The effort was born trying to fit a specific technology to a market rather than defining the market need via a user story and developing a solution.

From Ecoult's experience, the user story for the lead acid energy storage industry is:

- Safe operation
- Low cost

- Consistent and predictable performance even when supporting ad hoc application needs in often harsh and variable climatic conditions
- Minimum 10-15 years cycling capability with high throughput (lower expectations in areas with harsher conditions)
- Self-configuring and healing (prevents inadvertent damage and continuously optimises operation without intervention)
- High availability with any needed maintenance activity having no, or an acceptable, impact on application operation.

Project Fulfil was put in place to support attaining milestones consistent with the user story goals above and the effort applied by all parties was first class, but the goal was not attained.

At the commencement of the Ecoult journey, lead acid was the leading technology for the off-grid power subset of today's energy storage market.

New applications of batteries for energy storage were arising and it was seen that the key features of UltraBattery, including:

- Resistance to sulphation leading to
    - Higher rate charge acceptance (high-rate partial state of charge operation)
    - Higher efficiency
    - Better longevity
    - Longer time between refresh maintenance cycles

would present an immediate and complete competitive proposition.

4.3. Early assumptions and decisions impact future resourcing

Like many technology efforts assumptions were made early that were later discovered to be incorrect through trial and experience gained.

One such assumption was that UltraBattery was essentially commercialization ready and that by applying the cell enhancement technology and adapting existing lead acid approaches the expected performance improvement seen in side-by-side laboratory tests would translate in the field.

A second assumption was that in parallel to the solution development the price adder for an UltraBattery cell could be reduced to no more than 20% of the standard cell cost (1.2X). As it worked out, we were not able to meet business plan assumptions about cost reduction of the UltraBattery cell and substantial development around UltraBattery was needed for it to be commercialization ready.

From formation Ecoult demonstrated a capability to make rapid progress toward technology introduction by securing major demonstration projects.

At all stages in its journey Ecoult was blessed with having extraordinary engineers who demonstrated strong commitment to attaining results with all our endeavours.

Early in its development Ecoult became a subsidiary of EPM rather than taking an independent path. Once a subsidiary, Ecoult was supported very strongly by EPM toward its goals but also kept to a very tight original focus of commercializing UltraBattery solutions in the new emerging energy storage markets.

The company gained presence very quickly and was recognised as one of the top Global 100 Cleantech companies in 2013.

The commitment of following through for every customer and toward fulfilling our commitments that was embedded in Ecoult was shared by EPM, which is a company with exceptional people and community values.

The combination of high customer values and committed engineering saw Ecoult quickly establish a number of key projects in Australia and the USA. These projects had some limitations against expected performance and required follow up to ensure customers were satisfied but established Ecoult with a strong reputation and presence.

With a start to momentum but needing to push its competitiveness further Ecoult approached ARENA to partner with us in attaining the performance enhancement that we believed would get the technology to critical mass for broad adoption.

Roughly in parallel two decisions were taken that, while soundly based at the time, had later consequences.

The first was a technical decision to shift to a 12V monobloc battery rather than 2V cells based on a lesson learnt that the UltraBattery technology was more effective when implemented using plates with a lower length to width ratio than the 2V cells we had been using. The 12V battery approach had a number of advantages, including enabling us to build smaller systems, but a disadvantage not apparent to the team was that the cells inside the monoblocs could drift with respect to each other in the type of power profiles we were servicing and provided no means of internal equalization beyond high amounts of string overcharge (this only became apparent after significant throughput on long string systems).

The second was a commercial decision to develop the UltraFlex system (using the 12V monobloc) for a wide range of applications (each of which had different power profiles that required us to integrate into systems which used “smart” inverters that provided little capability for direct control unlike the inverters used with large systems). This proved to be a sensible decision from a market positioning perspective but resulted in the need to apportion a lot of the available Ecoult resource to finding ways to integrate the UltraFlex with inverters, make systems work as intended, and to maintain performance in the field for customers. This need became a resource soak on Ecoult, conflicting with the parallel effort needed to attain the minimum consistent performance level required by the market.

Regardless of the setbacks, the efforts by the Ecoult engineering team were heroic to try to attain the goals showing the character of innovation. The commercialization and business development teams also stepped up by finding market segments and customers that would use multiple UltraFlex units in the same application (lessening support needs) and attaining a customer commitment to a high volume deployment once the 2V system was complete. The Ecoult board (and EPM) backed the strategic risk decision to focus toward attaining the contract for the new 2V system, provided that verification and validation testing showed this to be a prudent decision. However, as earlier mentioned, the verification and validation testing of the 2V system did not prove out and Ecoult had to turn away from the opportunity established at the same time as Covid was heavily impacting commerce.

The chain of events was:

1) Shift to 12V as a result of plate aspect ratio.
2) Release of smaller systems (UltraFlex) to ad hoc applications.
3) Early success of 12V commercialization before challenges identified, resulting in:
   a) Inconsistent field results
   b) Associated legacy of high field maintenance of 12V sites.
4) Identification of need to shift from 12V to 2V.

5) Customer support for transition to 2V and board ratification of verification and validation test.
6) Negative result from 2V verification and validation result suspending commercial activities
    a) Excessive duration of overcharge needed for capacity maintenance
7) Distraction from completion of UL certification against overall corporate project plan.
8) Insufficient progress on UltraBattery cell cost reduction leading to lack of confidence that competitiveness would be attained.
9) Recognition that the time that it takes to move from conviction to proof, even though paths were seen, was inconsistent with continuing investment given lithium's progress.

4.4. Lessons learnt in the stewardship of capital and human creative resources in innovation

Innovation requires risk judgement and character.

Success is not guaranteed in innovation.

Ecoult's early project success underpinned the resource availability to reach for broad commercial adoption of the technology.

Early commercialization led to necessary understandings but also led to high support costs that detracted from ability to complete needed development progress.

Decisions at each point were taken within Ecoult via an involved leadership team process and following a rigorous governance validation process that fully informed and involved the board and stakeholders.

With 20/20 hindsight:

- The move to 12V missed the risk that cell behaviour inside the monobloc could present inconsistencies in performance depending on aspects of how the systems were used. (given high levels of observation and attention 12V systems could be coaxed/customized to adequate performance but with high overhead).
- Given understanding of this, the company had moved to commercialization too quickly and in particular the commercialization of a diversified field of small systems each running different applications.
- Supporting the breadth of commercial activities that had been taken on before the 12V issue was realized, including on complex projects like the microgrid/regulation services system developed with Raytheon in parallel to a deployment of small-scale systems (UltraFlex) stretched the team and generated a high operating expense.
- Once the consistency challenge and root cause in terms of cell variance inside the monoblocs was identified, the decision needed to be taken to move to 2V to reduce support levels if the Ecoult initiative was to retain an opportunity to succeed.
- The identified need to transition across to a higher performance 2V architecture put additional pressure on the team with the need to support legacy 12V commitments with quality even while delivering the next generation.
- By maintaining a high level of focussed attention on each customer (with EPM's support) Ecoult managed to maintain its reputation while doing the work to transition to the 2V architecture. (This included attaining support from the key customers to work with Ecoult's 2V system as soon as it was available.)
- A strong and supportive decision was taken by EPM to continue the effort toward commercialization based on successful verification and validation of the 2V architecture.
- The outcome of the verification and validation showed that there were deeper layers of fundamental understanding still needed and made it evident that commercialization had been too early. Ecoult was in a position where we could not continue to commercialise the

12V or 2V platform and would need to complete more understanding development with the consequent long timeframe for full validation.

Based on the combination of circumstances above, EPM took a very professional approach to stand behind Ecoult and support the Ecoult team to resolve suitable outcomes with every customer we had in the field.

In the introduction the statement below is made:

For this reason, the process of evolution through idea to a cost effective product outcome that can be warranted with confidence and that has all necessary standards and regulations compliance and certification must be the dominant priority and must achieved efficiently at each step.

In the case of Ecoult, the bottom line question this poses is: *Could the mission have been completed successfully if we had concentrated more on the fundamental understanding earlier?* Project Fulfil was put in place to achieve this and perhaps if we had taken on the scope of work in Fulfil earlier (before commercialization) we may have achieved the needed performance and consistency. On the other hand, it was the pressures of the commercialization that uncovered many of the technical lessons learnt and advanced the solutions.

Being in a position where it could not continue to commercialize the 12V or 2V system without further development, Ecoult could only have pivoted its customer facing team to a different technology (not appropriate under the EPM stewardship) or downsize to a core research and product function. Given the circumstances, EPM took the decision to discontinue support for Ecoult's Australian operations (while supporting a professional shutdown process) and transfer some activities and IP to the battery engineering team at EPM. Two of the fundamental pieces of understanding where cell improvement and/or understanding was identified as being still needed in the verification and validation process can be best achieved with the battery engineering resources at EPM:

- Cell design to support efficiency of the periodic overcharge mechanism used for maintenance of cell state.
- Optimization of the process used for periodic overcharge.

The goal of unlocking the potential for the lead acid industry to contribute more broadly within the energy storage industry than it does today given its enormous capabilities remains as relevant today as when Ecoult started its effort. The lead acid industry is still the largest chemical energy storage industry by total amount of energy stored, has a sustainable cycle, and remains very strong in remote power and complementing renewables.

Based on the lessons learnt at Ecoult and through our work during project Fulfil a section is included below that discusses a possible path to complement the capabilities of the lead acid battery manufacturers and the work being done to continually improve cell design to create a system outcome that has potential to both meet the market performance and consistency and be cost competitive. It contains aspects of approach that were outside the Ecoult defined focus but summarises a potential path (that would need qualification) based on the confidence that working with lead acid at the depth that Ecoult has brings that the chemistry is capable of significantly extended performance if supported by appropriate complementary technology approaches.

5. A path of continued development to establish the Project Fulfil goals and beyond with lead acid – answering the user story

We remain convinced that lead acid technology can achieve the performance and consistency needed to significantly extend the contribution it is already making to supporting wider adoption of renewable energy generation and providing remote power where it is most needed and beneficial.

There are two ways that this can be potentially achieved.

The first is by the lead acid industry coming up with a cell improvement and a maintenance approach that delivers the targeted performance and consistency without assistance from complementary technology.

This remains a possible path for the industry. With access to new technologies to understand the chemistry even during runtime (such as the work EPM and the Consortium for Battery Innovation CBI) are doing with Argon Laboratories breakthroughs are possible that may increase performance and reduce degradation mechanisms improving longevity. Additionally, different cell constructions such as bipolar cells demonstrate high performance through more even use of the active material.

A trap on this path is that efforts to improve the cell often increase the cost of the cell reducing competitiveness, similar to what we found with UltraBattery.

One effort that tries to achieve the performance using traditional maintenance while keeping the cell cost low is that being pursued by the team of battery engineers at EPM. They are continuing their awesome efforts that were focussed toward UltraBattery but pivoting toward the combination of lower cost carbon enhanced cells while retaining the traditional approach of using overcharge to both equalize and maintain the cells.

The second path is to take a slightly different view of the approach used to get best performance from lead acid technology and to support it with complementary technology availing use of lower cost cells. It starts by accepting the essential elements of the user story that have come from the Ecoult journey and designing a solution to meet them with a fully open view across the lead acid chemistry and industry capabilities.

A key objective of the Ecoult 2V CMS developed during Project Fulfil was to control UltraBattery reliably while using a 70% range of charge. In parallel to the testing at EPM using the new EPM cell, Ecoult also ran tests on Exide 2V UltraBattery cells and as a comparison on Exide 2V standard VRLA cells.

The tests were designed to look at performance capabilities for remote power systems such as microgrids where there is a need to take on charge quickly and overcharge needs to be tapered to ensure sufficient de-sulphation without excess overcharge.

Using the approach, we were able to sustain cycling of approximately 73% SoC for the Exide UB string and 67% for the Exide standard VRLA string and sustaining operation of every cell in the string in a very good state using a 6-hour charge period. (The EPM UB equivalent string is cycling at about 68-70%. Exide tends to under-rate the capacity of their cells, so this probably accounts for the difference).

The primary applications in the energy storage market have moved away from the higher power applications that UltraBattery was first conceived for and toward energy applications where lead acid economics improve relative to lithium due to the Peukert differences with rate.

Answering the user story using lead acid technology, the evidence from the Ecoult work during project Fulfil is that the techniques we developed to attain additional performance and consistency from UltraBattery strings apply directly to standard (low cost) VRLA technology as well.

The goal at the end of the day is to maintain every cell in a string ideally while also aligning the string in such a manner as to extract the greatest performance.

Results from Project Fulfil showed that even lead acid cells that have been manufactured to closely match each other need different amounts of overcharge to reach top of charge for maintenance. By definition then, if they all get the same amount of charge in a string, then some will be forced to excess secondaries or some will not get sufficient charge. The cycling performance of the standard VRLA cells showed the improvement that can be attained for all cell types just with appropriate alignment management.

UltraBattery is a technology that makes the cell more resistant to sulphation. If sulphation is accepted though and the challenge redefined to manage and maintain cells in strings to deliver the user story, then systems that use lower cost lead acid cells come into focus. The cell design objective becomes designing to have cells that have a ready ability to clear sulphates periodically (it was very difficult to recover capacity in the 2V UltraBattery once sulphation had reduced capacity).

A derivative (cost reduced) version of the Ecoult CMS that delivered functional safety for protection and regulation compliance, avoidance of limits for high availability and alignment (including support to maintenance objectives) costs about 5-10% of the cell cost in a system. Applied to standard (or low-cost carbon enhanced) cells the competitive cost analysis changes dramatically.

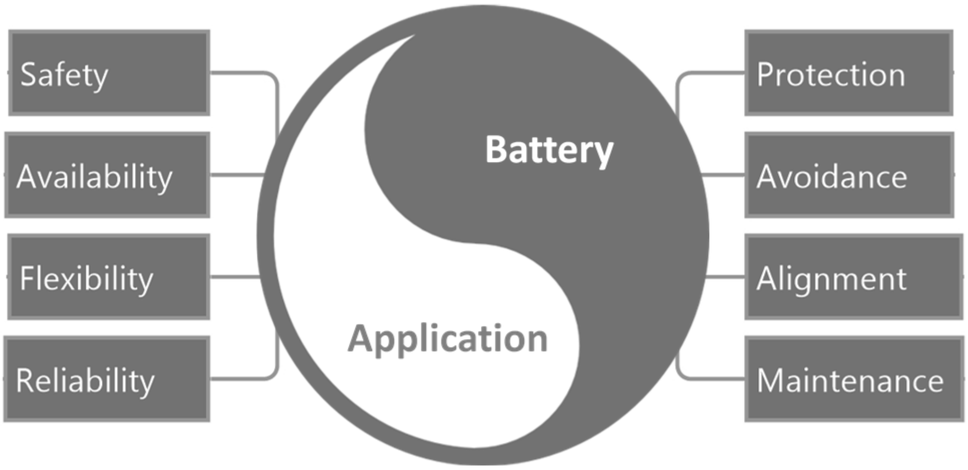

Figure 3 Application and battery requirements

To fully answer the user story, maintenance needs of the cells can be totally embraced and made transparent to the user.

There are two ways to achieve this.

One way is to complement the type of 2V CMS Ecoult developed with a multi-string DC bus architecture to allow galvanic isolation of each string and to support cyclic refresh so that each can be independently maintained even while continuing system support for the active application.

The second alternate product path would be to implement a solution that enable individual cells to perform a maintenance activity even while the string is being used actively by applications. Most systems are single string so this approach has advantages over a multi-string configuration and can also provide the ability to block out single cells creating redundancy for self-healing system. Most importantly, a system based on this approach can allow flexibility in the way overcharge is administered for maintenance to any cell separate to the application.

Such an approach can be the foundation to build a full solution for the clear user story defined above, moving toward unlocking the potential for lead acid technology in energy storage markets. ARENA and CEFC have supported a unique cell alignment technology effort that provides such a solution (at Relectrify) which would have potential to provide a solution for lead acid and other energy storage technologies that need periodic cell maintenance. That the Relectify technology can provide a capability to directly produce an AC signal by switching cells into and out of the string, also provides a path to full system outcomes that are more cost competitive than traditional inverter-based approaches and simplifying solution integration.

6. Appendix A – Individual Lessons Learned Through Project Fulfil and Summary of Each

Individual Lessons Learned Through Project Fulfil and Summary of Each

1. Lessons Learnt Report: Software Integration

Project Name: *UltraFlex GA*

Knowledge Category	Technology
Knowledge Type	Technology / Human Resources
Technology Type	Storage
State/Territory	NSW

1.1. Key learning

Software development of multiple interfacing components requires:

- Detailed APIs established and updated as the project progresses
- Where multiple teams are involved, all working on different integrated components, there should be "sprints" or periods in the schedule that interrupt the feature development and commit to an integration point.
- Since multiple teams and components are involved, managing the priority, progress and responsibility of the integration process is a key requirement and requires a person with a strong systems engineering background.
- Allowing teams to operate in isolation can hamper successful integration. Organizing multiple workshops between team leaders throughout feature development is a good way to facilitate communication and cross learning between teams.

Integration challenges:

- Each power electronic component we interface with requires significant development, because our interface is unique and the power electronic interface is unique.
- The interfaces and battery control methods in power electronics will limit the flexibility in how we can control the batteries. Rather than create our own control methods, we must work within the boundaries of the power electronic component control algorithms.
- Standardisation around an interface could potentially reduce the development effort, however this requires buy-in from the power electronics manufacturer.
- Reducing the scope of functionality by focusing on specific applications can help focus resources towards a goal. Leaving the applications too flexible increases the risk of finding limitations in the developed software.

1.2. Implications for future projects

Introduce quarter project milestones which require a minimal integrated product.

- Ensure a System Engineer is involved throughout all phases of the project. Feasibility, Design, Implementation, etc.
- Choose and support an interface that can be leveraged across the most 3rd party power electronic components.

- Focus on a few specific applications to be successful on and cross-check new feature requests against the ROI.

1.3. Knowledge gap

No Knowledge gaps were identified from this lesson learnt.

1.4. Background

Objectives or project requirements

Requirements of this stage of the project was to have an early working version of the Controller running on its intended hardware.

At this stage we should have our first version releasable to friendly customer sites. All facets of integration should be complete: between our internal software components, between external equipment (Combox, inverter and MPPT solar charge controller) and the Ecoult cloud offering EcoultLive. The aim is to support a single XW+ and a single MPPT–multi phase and multi-stacking on a single phase are not supported.

Process undertaken

There were multiple teams working on separate components. Each team used different management processes to achieve their objectives. A standard Project Management approach of weekly meetings between team leaders was used, however was not adequate to initiate the integration process earlier. There must be an additional process to manage the integration phases.

We implemented fortnightly sprints, where at the end of each sprint a new software version is delivered that can be deployed to our pilot sites. With a unified deliverable, teams were forced to communicate outside of their group to ensure integration.

As the project transitioned from early versions with limited to functionality, to deployable versions with bugs, organised and dependable testing became more critical. Finding bugs, documenting them, recreating them, and organising the fixes in JIRA issues provides a necessary framework for development teams to delegate and make the fixes. At the end of this stage, we implemented daily standup meetings to focus on the testing progress and involved the development teams to help out the Test team.

1.5. Supporting information (optional)

None.

2. Lessons Learnt Report: Electromagnetic Compatibility Compliance

***Project Name:** UltraFlex GA*

Knowledge Category	Technology
Knowledge Type	Risk Management
Technology Type	Storage
State/Territory	NSW

2.1. Key learning

1. Electromagnet Compliance (EMC) requires a system level approach. Although EMC testing can be carried out on individual components, the system level testing and interactions between all physical components can cause unpredictable responses.
2. Although the previous version of UltraFlex using a FitPC was compliant, the new version with the Single Board Computer (BeagleBone) showed failures.
3. To reduce risk of EMC Compliance failures or issues, establishing the full design, components and physical structure early on can allow a designer to test the system early on, which provides early feedback to make corrections. However, last minute system design changes will require testing the entire system again. On the other hand, waiting until you have a complete product before starting EMC Compliance reduces risk that there are last minute design changes, however it could mean delays to release if it fails to comply. Thus, the lowest risk option is to allow enough time at the end of the Product delivery schedule to cater for EMC issues and any rectification necessary.

2.2. Implications for future projects

In the future we would attempt to freeze the design earlier. So, spending more time planning to reduce the probability of last-minute changes. By freezing the system earlier, we can start the EMC testing earlier, and therefore reduce the probability that it will impact the manufacturing schedule. More time should be spent planning to reduce the probability of last-minute changes.

2.3. Knowledge gap

No Knowledge gap was identified from this lesson learnt.

2.4. Background

Objectives or project requirements

Establish that the product is EMC and FCC compliant.

Process undertaken

Having the fully built product tested in an anechoic chamber, while ensuring that all I/O interfaces were fully active.

2.5. Supporting information (optional)

Due to the relative unknown nature of Electromagnetic waves and their relevant generating components, Early and organised planning is critical to ensure EMC testing can be started as early as possible to reduce its impact to the critical path of a project.

3. Lessons Learnt Report: Laboratory Construction

Project Name: *ARENA Lab*

Knowledge Category	**Technology**
Knowledge Type	**Construction**
Technology Type	**Storage**
State/Territory	**NSW**

3.1. Key learning

1. Zoning for a building may be different from its surrounding area. Despite clear communication of our space and laboratory requirements to our agent, we did not discover the building (zoning) limitations until late in the contract negotiation stage. While the area is zoned for light industrial, the basement which we sought to occupy as our laboratory was classified as warehouse space. This then entailed a development approval process.
2. When applying for an embedded connection for exporting power, the building switchboard will need to be inspected by Ausgrid in addition to our proposed works. Despite the building being relatively new, the building switchboard did not meet current standards and needed to be upgraded adding to our costs and delaying our timeline. This was not clear until after contract negotiation.

3.2. Implications for future projects

Unlike previous property leases, we encountered a number of unexpected issues on this property. In the future, we will not accept agent representations at face value and will conduct detailed due diligence much earlier into:

- building/area use restrictions including approved building classification; and
- suitability of electrical switchboards, cables etc by engaging an experienced commercial electrical firm to inspect the main switchboard, etc, with preference being given to sites with existing embedded generation such as solar.

3.3. Knowledge Gap

While familiar with battery and electrical power products, battery test equipment and the installation requirements for these, Ecoult is less familiar with the process of obtaining building and/or development approvals and electrical metering approvals.

3.4. Background

Objectives or project requirements

Build a new larger battery testing lab with higher power capability to allow for the increased battery testing as part of the ARENA project.

Process undertaken

1. Find suitable space
2. Negotiate Lease
3. Apply for Development Approval to change function.
4. Engage Certifier for construction work
5. Engage builders and electricians
6. Modify existing rooms and build fire-proof battery rooms
7. Modify main building switchboard and install power distribution to all rooms in the lab
8. Build main battery system for enhanced peak power for our testing circuits (285 Amps per phase) and demand management
9. Move equipment from existing Frenchs Forest lab.

4. Lessons Learnt Report: Battery Room Construction

Project Name: *ARENA Lab*

Knowledge Category	Technology
Knowledge Type	Construction
Technology Type	Storage
State/Territory	NSW

4.1. Key learning

Building Code of Australia rules currently require a 120-minute fire-rated enclosure for battery systems over 24V in commercial buildings while AS5139 proposes 60 min enclosures. Guidelines do not differentiate between different battery technologies.

4.2. Implications for future projects

Ecoult plans to participate more actively in industry discussions surrounding battery room requirements and battery installation standards to help educate the public regarding battery storage safety.

4.3. Knowledge gap

Battery room requirements are not well understood today. The situation is compounded by the existence of different guidelines. This confusion added time and costs to the process.

A significant challenge when building our battery room was finding builders with battery room experience. While Ecoult itself is familiar with battery and electrical power products, battery test equipment and the installation requirements for these, we were less familiar with Building Code of Australia (BCA) requirements.

It became apparent that BCA's requirements for fire-rated rooms are in fact not well known by many builders. BCA's 120-minute fire rating limit (FRL) for any type of battery greater than 24V in commercial buildings in fact conflicts with an alternate proposed standard, AS5139, which proposes a 60-minute fire rating.

AS5139 would be less costly to comply with although BCA standards are arguably safer in the unlikely event of a fire in densely populated areas. Ecoult has now constructed a battery room that is compliant with BCA's more stringent 120/120/120 requirements. It is possible that BCA’s requirements may have been excessive given that Ecoult’s UltraBattery is a sealed VRLA battery made of V0 fire-retardant materials.

Neither BCA nor AS5139 appear to take into account differences in battery technology. There is a tendency for the public, including regulatory bodies, to regard all battery technologies as the same, when in fact, the different electrochemistries and history of safe use are indeed very different. This is somewhat in contrast to the stance of many Fire Departments around the world (e.g. NSW Fire Service, Fire Department New York, etc) who are a little wary of li-ion fire risks when stored in larger energy blocks because of a lack of history and experience and the flammable nature of the electrolyte.

While the risk of a fire starting is small, it is important to recognise that once alight, the electrolyte in li-ion batteries cannot be easily extinguished, at least, not to date. Appropriate containment of any potential fire risk is therefore a crucial control given potential fire hazards as evidenced by recent hoverboard and other fire incidents.

The controversy in Australia surrounding battery storage installation guidelines is clear example of the confusion surrounding what is, or isn't, safe for users of battery storage. Where should *product standards* start and stop vs *battery installation standards* vs *building standards* vs *fire department experience*?

This is an area that requires careful consideration and coordination given the role energy storage can usefully play in society and the scale of potential uptake in homes and commercial buildings. Being too cautious will add unnecessary costs while being casual about fire risks can be potentially life threatening.

4.4. Background

Objectives or project requirements

Build a new battery room for the increased battery testing as part of the ARENA project.

Process undertaken

1. Find suitable space.
2. Negotiate Lease.
3. Apply for Development Approval to change function.
4. Engage Certifier for construction work.
5. Engage builders and electricians.
6. Modify existing rooms and build fire-proof battery room.
7. Modify main building switchboard and install power distribution to all rooms in the lab.
8. Build main battery system for enhanced peak power for our testing circuits (285 Amps per phase) and demand management.
9. Move equipment from existing Frenchs Forest lab.

5. Lessons Learnt Report: Configuration for Backup

Project Name: *ARENA - Analysis of installations*

Knowledge Category	Technical
Knowledge Type	Operation and Maintenance/Construction
Technology Type	Storage
State/Territory	NSW

5.1. Key learning

There are many reasons a customer may choose to add Energy Storage to their property. In the case of grid-connected sites, foremost in their mind may be peak shaving, demand management or other ancillary services that allow them to do one or many of the following:

- Save money on their energy bills
- Supply peak loads beyond the capability of their grid connection or distribution board
- Earn money from the utility
- Other business reasons

There is also the implicit assumption that the energy storage system will be available for backup when the grid fails. This and the above value streams are a core part of our value proposition, termed Multipurpose Energy Storage.

We have found on some sites, that the backup aspect was not properly considered. For example, on one site the battery was installed at the main meter board and connected to the single phase with the highest load on a 3-phase site. This was done to maximise the customer's self-consumption of solar. This had a number of unintended consequences:

- The load (energy and max power) on the backed-up phase was often greater than the battery and inverter could handle, causing outages
- There were a lot more outages than expected and due to anti-islanding standards requiring inverters to stay disconnected for a period of time, after a momentary PQ excursion, batteries were required to support loads for longer than intended due to power quality issues on the grid (voltage sag and swell)
- Backed up only a single-phase with 3-phase equipment downstream. This equipment will not run in backup, giving no benefit during grid outages. More importantly, if the inverter disconnects from the grid due to power quality issues, there will still be power available on the other phases. There is a risk the backed-up phase loses synchronisation with other phases - causing damage to 3-phase equipment

5.2. Implications for future projects

Future projects will need to consider backup loads in addition to system behaviour in grid-connect mode.

- For the Selectronic inverter, we will recommend using an external CT and contactor to allow the unit to perform maximum self-consumption on the total load as per the Tech note below. This allows the installer to separate the loads to be backed up from the loads that will be managed in grid-connect mode. http://download.selectronic.com.au/documents/TechNotes/TN0071_02%20External%20Contactor%20of%20parallel%20insertion-Single%20SP%20PRO.pdf
- If 3-phase loads are to be backed up, a 3-phase inverter should be used, or 3 single phase inverters configured as a 3-phase system. If not, 3-phase loads should not be connected to the backed up circuit
- Grid voltage settings should be set at the maximum range allowable to minimise system disconnection from the grid. The exception to this is if the backed up load is sensitive to voltage sags or swells, in which case a large number of disconnections should be catered for in system sizing.

5.3. Knowledge gap

This is likely to be a common configuration issue and Ecoult will work to educate our installers, customers and the industry.

The recently released AS4777:2015 requires inverters to shut down when grid voltage exceeds 255V. This has been reduced from 260V and even 270V in the past. We have noticed grid voltage to often be over 255V on a number of our sites, causing system trips. It appears this rule has not been made with energy storage in mind. The energy storage system may have been charging at the time, helping the grid keep voltage down. In this case, tripping the system off the grid would cause the voltage to rise further. We believe the standard should instead mandate a system stops exporting above 255V, but allow the system to continue charging or feeding loads from the grid.

5.4. Background

Objectives or project requirements

Maximum self-consumption of Solar

Process undertaken

Ecoult supplied the battery system and our installer paired it with the inverter and configured it at the customer site. Ecoult's guidance was focussed on the batteries. Once the problem was found, Ecoult worked with the installer to minimise disconnections and helped upgrade the system with more batteries to support the connected backed up loads. It was not viable at that stage to separate the circuits to minimise backed-up loads, but this would have been easier at project conception stage.

5.5. Supporting information (optional)

None.

6. Lessons Learnt Report: Testing with integrated BMS/Inverters

Project Name: *UFGA*

Knowledge Category	Technical
Knowledge Type	Technology
Technology Type	Storage
State/Territory	NSW

6.1. Key learning

Battery BMS's alone cannot deliver power to most energy users, as typical energy users use AC loads, hence the need to pair a battery and inverter to produce power. All batteries have a defined set of rules in which they must be operated, whether it be voltage, temperature, current, SoC, or other parameters. Some inverters are able to accommodate these rules inherently, yet others need a specific BMS. Inverter control algorithms for grid/generator/load interactions are balanced with battery interactions. The inverter must be able to communicate with the battery through the BMS in order to keep the battery operating within their stated use rules. In order to ensure that the inverter and battery operate correctly, initial testing of the inverter and BMS operation must be done on the system before release, which is then followed by regression testing should either the inverter or BMS firmware change.

- When pairing a battery and inverter through communications and protocols it is necessary to test most likely operating scenarios.
- As battery/inverter system have many different use cases, it is difficult and cumbersome to manually test all possible scenarios. Automation is a good method of being able to change the possible operating scenarios and ensuring the system operates as intended.
- The testing should be done independently form the developers. Testing and development should be independent exercises performed by different individuals within different company environments.
- Regression testing catches the changes which developers make to solve a specific issue which may inadvertently affect a different operation

6.2. Implications for future projects

- Any new inverter which is integrated to our battery system will be subject to testing and regression testing as the BMS and inverter products mature and develop. When done automatically through software and manipulation of real values (automatic voltage changers), it allows for an efficient and robust testing system which develops over time and becomes more robust for the next inverter integration.
- Automatic testing an integrated inverter BESS system expedites the time to the field, by allowing changes from the development team to not have inadvertent negative effects, thus solving issues effectively and efficiently.

6.3. Knowledge gap

- Regression testing is required on any integration between two independent systems.

6.4. Background

Objectives or project requirements

- Requirements of the project were to integrate an inverter system to a BMS system.
- The integration had to allow the inverter to meet the requirements of the end user while also meeting the use rules of the battery.

Process undertaken

- Initial testing of inverter and BMS systems
- Regression testing of further improvements or changes on either the inverter or the BMS system

- Building of a library of test cases which make the next set of integrations more robust.
- Automation of the testing greatly accelerates the testing process. It is used whenever possible

6.5. Supporting information (optional)

None

7. Lessons Learnt Report: Knowledge transfer to external parties

***Project Name:** Hosur Project*

Knowledge Category	Technical/Knowledge transfer
Knowledge Type	Technology/Stakeholder Engagement
Technology Type	Storage
State/Territory	NSW

7.1. Key learning

- Partnering with other companies which are in the same business but at a different level of understanding of the work involved to integrate a complex inverter/EMS system can lead to difficulties when implementing field projects.

- External parties who are familiar with traditional lead acid batteries may struggle to grasp the differences and problems which can be associated with a variation of a traditional technology. While the technology is similar to traditional lead acid batteries, it behaves slightly different which causes confusion amongst traditional users.
- Engaging with both the engineering and commercial stakeholders when bringing in new technology is important so that understanding of financial benefits and technical benefits are realised at all levels of engagement.
- Communication can also be difficult when partners are in different time zones.

7.2. Implications for future projects

Having set rules of engagement for future work with a partner is important, and they need to be understood at the commercial level as well as the technical level. Methods of engaging customers, quoting on projects, and customer engagement expectations should be set at the beginning of a relationship to avoid misunderstandings. For example, when quoting for a project, the partnered entities must be in agreement with the scope, roles and responsibilities, and process for engaging with the customer. When these are not communicated or agreed, there can be assumptions on who performs what tasks, which can lead to either inaction, or conflicting advice.

7.3. Knowledge gap

Being able to effectively communicate and come to a mutual understanding with external parties requires resources such as:

- In-house or external training with both partners
- Detailed documentation for easy reference which is understood and clear to all parties
- Workshops with the appropriate individuals, preferably in a face-to-face environment which builds relationships.

7.4. Background

Objectives or project requirements

The Hosur Project is being built as a demonstration project to provide learnings to our partners about our battery system BMS in a long string configuration. This is done to prove the concept of the design with another battery manufacturer through the following:

- Proving that the design for the cooling methods are adequate.
- Setting up the supply chains to be able to reproduce the unit for another project.
- Continue to refine the design and rectify any issues.
- Prove the BMS long string capability to the customer.

Process undertaken

- Improve the communication with the partner through regular visits.
- Came to an agreed method of engagement for future projects.
- Inviting the partner to attend our local office for training, workshops, and information sharing.

7.5. Supporting information (optional)

None

8. Lessons Learnt Report: Good Refresh is Essential

Project Name: *UltraBattery Characterisation and Modelling*

Knowledge Category	Technical
Knowledge Type	Operation and Maintenance
Technology Type	Storage
State/Territory	Global

8.1. Key learning

Good refreshes are necessary to maintain BESS performance and longevity. A "good" refresh is one that brings all cells to top of charge, corrects misalignment (charge imbalance) of plates, and does so with the minimum of forced secondary reactions. Our refresh protocols to date have not been sufficient.

8.2. Implications for future projects

Develop a good refresh protocol.

Expose data and conclusions to internal stakeholders to ensure the importance of good refreshes is understood.

Help create the culture that any implementation project that will struggle to achieve a good refresh (such as due to lack of sustained energy sources) is identified as a risk and approved at a suitably senior level along with accepted justifications and mitigations.

8.3. Knowledge gap

We still have some uncertainties on what forms a good refresh. Simulation and experimental work is not complete. We have not proved the benefits of significant bypass capability

8.4. Background

Objectives or project requirements

The widely agreed (within Ecoult) conclusion that our existing refreshes were not adequate is a result of a wide number of experiments, discussions, theory and analysing site(s) performance. No single project was dominant in us forming this opinion.

Process undertaken

See above. The conclusion that our refresh practice is inadequate is not a result of a single process. It is the accumulation of many sources of, sometimes confounding, information.

8.5. Supporting information (optional)

All those involved in battery management and research should read the Nelson chapter (Chapter 9) of Valve-Regulated Lead-Acid Batteries edited by Rand, Moseley, Garche and Parker.

9. Lessons Learnt Report: SoC Algorithm and SoC Control

Project Name: *IT Power*

Knowledge Category	Technical
Knowledge Type	Technology
Technology Type	Storage
State/Territory	Global

9.1. Key learning

The SoC algorithm used on the IT Power external test project may not have been suitable for the profile being used.

9.2. Implications for future projects

Especially for external test projects, understand and/or test in-house the effect of substantially new profiles. At least confirm that SoC is suitably accurate if these profiles rely on SoC control.

Undertake external test projects on standard product - so they get the standard routine KPI assessment, and human monitoring, of other systems. They also, then can inherit (with test operator approval) best practice control algorithms as they are developed and released.

9.3. Knowledge gap

Continue to refine SoC algorithm

9.4. Background

Objectives or project requirements

The project was intended to show how our system performed compared to other commercially available systems.

Process undertaken

Bespoke engineering process due to a) lack of completed product and b) unclear requirements.

9.5. Supporting information (optional)

None.

10. Lessons Learnt Report: Be Wary of Building Small, Low Volume, Customised Systems

Project Name: *Various*

Knowledge Category	Technical & Logistical
Knowledge Type	Technology & Operation and Maintenance
Technology Type	Storage
State/Territory	

10.1. Key learning

One-off or small volume, small-scale, custom systems require significant effort to design and maintain.

They often do not inherit the advantages of scale and systematic verification and validation as apply to a standard product.

They often require highly skilled and knowledgeable people to maintain and manage; maintaining coverage to support the system is difficult. It is a significant burden to maintain accurate documentation.

Customised systems should only be undertaken when there is no alternative and under approval of senior management.

Small customised systems require similar personnel overhead to a large system, possibly without the profit/income to justify it; so, such systems must clearly satisfy suitably high corporate goals.

10.2. Implications for future projects

To the greatest practical extent, our external test systems should be based on standard hardware and software.

Departures from standard product should be identified, reviewed and signed off.

10.3. Knowledge gap

Ecoult management needs to clearly set out the goals and aspirations of systems being targeted to external test sites. Management need to be aware of projects that cannot be satisfied by standard product.

10.4. Background

Objectives or project requirements

N/A

Process undertaken

N/A

10.5. Supporting information (optional)

None.

11. Lessons Learnt Report: Setting up for Independent Testing

Project Name: *External Test Projects*

Knowledge Category	Technical
Knowledge Type	Technology
Technology Type	Storage
State/Territory	NSW

11.1. Key learning

The experiences with IT Power, CSIRO and SANDIA provide a common learning, that it is important that all of the battery understanding and management technology Ecoult has developed needs to be embedded in the test systems set up by the independent test laboratory. Typically, test laboratories wish to test individual batteries, but they do not have the algorithms needed to successfully manage the batteries optimally or even within the Use Rules. Where feasible and acceptable to the laboratory, we supply our battery management system that encapsulate that technology. But test protocols sometimes require unsupported features such being able to accept a power command to follow a defined load profile. It is typically the inverter that needs to accept a power command and respond to it, but very few inverters have this feature. Ecoult has in the past developed custom control systems to solve this gap. This leads to the issue previously reported that there is risk in building custom control systems to provide those special functions. Bespoke systems may not incorporate all of the necessary technology, may not go through the same exhaustive verification processes as a commercial product, and likely will not be kept updated with improvements in the commercial product. The outcome is tests whose results are at best unrepresentative of the commercial product, and at worst, simply fail. There are exceptions – EAI has successfully run tests on a string of just 3 UltraBatteries using their own test rig and in close collaboration with Ecoult research engineers. The results of such testing reflect the battery capabilities alone, and not necessarily how the batteries will operate in an Ecoult battery system.

In short, the key learning is that independent tests should be carried out on commercially released standard systems, not batteries in custom test configurations.

11.2. Implications for future projects

Ecoult's resolution is to work with the test laboratories to enable them to build test systems around our standard battery management system, and where necessary, equip our product with the special features that may be required for test purposes. Ecoult's new BMS is more flexible for such applications. We will avoid wherever possible, submitting individual batteries for arbitrary testing outside the Ecoult management system.

11.3. Background

Objectives or project requirements

Workstream 5 of this ARENA project is Laboratory Testing and Analysis of Field Installations. Independent lab testing is a key component of the workstream that provides validation of the results obtained in internal lab testing. We would seek correlation between the real-world results of field analysis and independent tests running representative application profiles.

Process undertaken

Some independent tests require supply of bare batteries with instructions "Use Rules" on how to operate them. Such instructions may refer to, but do not include technical specifications of proprietary control protocols.

Other independent tests require supply of battery systems that can run an arbitrary power profile. Very few inverters have that feature. Ecoult took steps to solve that gap by adding custom controls around the standard system or a modified BESS system.

12. Lessons Learnt Report: Importance of Individual Cell Management

***Project Name:** Battery Characterisation and Modelling*

Knowledge Category	Technical
Knowledge Type	Technology
Technology Type	Storage
State/Territory	Global

12.1. Key learning

To achieve commercially competitive performance and longevity in Partial State of Charge (PSoC) applications, individual cell monitoring, management and maintenance are essential.

It was assumed that in Partial State of Charge (PSoC) operation, the cells within well-manufactured monoblocs would be similar enough as to have very similar responses to the common time varying current profile and that the job of battery management was to maintain monoblocs in alignment, and to provide regular refresh charges that ensure all the cells within monoblocs are regularly and effectively desulphated (and that there is a means for determining the completion of that process for all batteries and cells).

The reality of all lead batteries (not just UltraBattery) in PSoC is very different. Ecoult/EPM's testing of instrumented monoblocs showed that cells within monoblocs progressively diversify during cycling between refreshes. The primary reaction and multiple secondary reactions that occur within a lead battery are highly complex and interact with each other. Normal cycling causes cells and plates to slowly become misaligned. A monobloc is effectively a short unmanaged string of six cells. No matter how sophisticated the management of strings of monoblocs may be, the cells within the monobloc enter into chaotic interactions due to the common current generating different cell voltage responses within a common monobloc voltage. All battery monitoring is then only reporting the average response of the cells within monoblocs, so control algorithms are informed only by that average. Cells experience voltage excursions outside of the intended voltage control limits, and incur degradation from unseen secondary reactions. The extent of excursions is obfuscated by this averaging effect so there is nothing that external control can do to actively care for the internal cells. (The Lead Battery industry utilizes passive Top of Charge (ToC) methods to manage the best possible passive cell management. ToC correction is based on overcharge which aims to correct misalignment and delay sulphation but that introduces its own degradation to cells.

An extended refresh, or commissioning charge, at start of life has been found to assist alignment at start of life in both 12V and 2V systems. Commissioning charge for 12V systems requires labour-intensive manual charging of individual monoblocs.

High current refresh/high voltage refresh attempt to force cells into alignment but high current can cause plates to misalign even while it is bringing cells into alignment. Very slow, lower voltage refresh may achieve alignment with less collateral damage but is generally not commercially acceptable in PSoC applications. Different cells require slightly different refresh voltages and charge limits depending on their characteristics and aging processes.

Eventually cells within monobloc can become so misaligned or individual cells become desaturated so that it is impossible within practical constraints to align and/or dissolve sulphates in both plates within viable refresh periods. From this point refreshes are inadequate, meaning cells become sulphated, and range-of-charge while cycling is progressively narrowed by the deteriorating states of the highest and lowest charge cells.

Successful PSoC operation requires individual cell monitoring, management and maintenance. Ecoult's 2V BMS implements all three functions and the maintenance function includes an automated commissioning charge feature.

Implications for future projects

Ecoult is well advanced in migrating all product development to 2V systems incorporating unique circuitry that enables each cell to be individually managed as if it had its own charger.

12.2. Knowledge gap

The project identified a risk that cells may diversify within monoblocs (knowledge gap) and then closed the gap with instrumented testing and later, finite element analysis simulation of the UltraBattery.

12.3. Background

Objectives or project requirements

The decision to commercialise UltraBattery in the 12V format (six 2V cells in each 12V monobloc) was predicated on the common practice of running reserve power applications on 12V monoblocs. Such systems are typically "float" systems where batteries in strings spend most of their time in a fully charged state, fed a constant low float current that maintains battery state. In this state the cells within monoblocs naturally and gently reach alignment at full charge, referred to as passive equalisation. This process aligns both cells within monoblocs, and plates within cells. PSoC systems in contrast spend most of their time away from top of charge.

Processes undertaken

Extensive lab testing on instrumented 12V monoblocs.

Finite element analysis (FEA) simulation of UltraBattery

Development of a new 2V Battery Management System incorporating individual cell charge control.

Development of refresh and commissioning charge protocols to partially mitigate the problem for monobloc systems.

Verification and Validation of the 2V BMS.

13. Lessons Learnt Report: Experience with Field Realities (Development of User Story)

Project Name: *Final Learnings*

Knowledge Category	Other (Business Planning)
Knowledge Type	Inputs
Technology Type	Microgrid
State/Territory	Global

13.1. Key learning

Incorrect assumptions were made that it was a reasonable expectation that systems would be installed with cells aligned and that maintenance could be scheduled when needed.

- Assumed that users would follow directions given around use and maintenance
- Extraneous factors – pulsing, etc.

There is a lot of experience in the field around using standard lead acid batteries with "smart" inverters to implement simple systems. When it comes to modern microgrids, which integrate multiple different types of generation sources and can have haphazard loads, it cannot be assumed that the integrator is going to implement a sensible solution or commission it correctly. The energy storage asset must be:

- Self-configuring and healing (prevents inadvertent damage and continuously optimises operation without intervention)
- Deliver consistent and predictable performance even when supporting ad hoc application needs in often harsh and variable climatic conditions.

13.2. Implications for future projects

This experience was captured into the understanding of the overall user story for remote power systems within Ecoult. Commissioning practices were adopted for 12V systems and self-configuring methods designed into the 2V CMS product design.

13.3. Background

Objectives or project requirements

To ensure the Ecoult product and solution offering delivered a full answer to customer needs to support accelerated commercialization.

Process undertaken

Incorporated into Ecoult product management and application engineering processes.

13.4. Supporting information (optional)

None.

14. Lessons Learnt Report: Insufficient individual cell testing and research to understand and determine optimum maintenance practice before commencing commercialization

Project Name: *Final Learnings*

Knowledge Category	Technical
Knowledge Type	Technology
Technology Type	Storage
State/Territory	Global

14.1. Key learning

There is a significant gap in regard to full understanding about the processes inside lead acid battery chemistry during overcharge maintenance and hence the frequency, duration, and conditions for primary maintenance activity associated with cell overcharge to prevent accumulation of sulphation. Understanding of the process is based on trial and observation, rather than strict scientific rigor.

14.2. Implications for future projects

Without progress in this area, the extended Ecoult/EPM team had to make qualitative adjustments based on diligent observation of the operation of systems to cater for the particular power profile in use and based on the state of the batteries/cells at any point of time in order to maintain quality of service for our customers. This created a high post sales cost.

14.3. Knowledge gap

The current process is that the battery manufacturer specifies a overcharge practice for each cell/battery. A single practice cannot fit all systems or cater for the effect of different power profiles on batteries. A consequence of this is that some systems get too little overcharge and some too much. In fact, the need and the ideal voltages and duration of overcharge all change. In order to achieve an optimized system, it must be based on understanding and tracking of the actual state of the cells. This factor, more than any, controls the ability to provide consistent performance from lead acid chemistry.

14.4. Background

Objectives or project requirements

N/A

Process undertaken

Ecoult formed a battery guild that reached across both our engineers and the EPM battery chemistry engineers in order to build the understanding and to achieve progress toward the goal. Ecoult also invested in the development of a finite element model of a lead acid cell and commenced analysis using electrochemical impedance spectroscopy. The lead acid industry has a consortium (Consortium for Battery Innovation) that was set up to do or fund areas that were of common need and this group is progressing analysis in this area.

14.5. Supporting information (optional)

None.

15. Lessons Learnt Report: Commercialization Focus before Establishing Sufficient Understanding

Project Name: *Final Learnings*

Knowledge Category	Financial
Knowledge Type	Financial information/Risk Management
Technology Type	Storage
State/Territory	Global

15.1. Key learning

The lead acid industry is a mature industry where products move very quickly through the development and commercialization process. Ecoult had the double challenge of developing understanding of how to harness consistent performance from a lead acid cell with completely new characteristics and maintenance needs, while also implementing complex systems into an emerging market. As set out in other lessons learnt summaries, this resulted in many challenges being identified and overcome.

Ecoult progressed very quickly on our path to commercialization. At all stages there was a concern that, if we did not move quickly, lithium would establish an incumbency in the markets we were addressing. Additionally, with the commercial maturity of the lead acid industry there was a continual view toward large scale production of the "next release". Unfortunately, as we progressed new challenges continued to arise that had not been previously encountered. Ecoult and EPM sustained at all times a determined position toward delivering a quality experience for every customer and so early commercialization created a high overhead in terms of field maintenance, detracting from the resourcing available to focus on completion of the understanding needed for performance and consistency and of the underlying platform.

15.2. Implications for future projects

The process of evolution through idea to a cost effective product outcome that can be warranted with full confidence and that has all necessary standards and regulations compliance and certification must be the dominant priority and must achieved efficiently at each step.

15.3. Knowledge gap

Specific remaining gaps in understanding are set out in other "lessons learnt"

15.4. Background

Objectives or project requirements

N/A

Process undertaken

At all times Ecoult maintained an excellent governance approach that had both leadership team and board deep involvement in key decisions and strategic planning. Appropriate consideration of risk and opportunity was taken with each stage of the innovation and commercialization processes. Processes were set up for very tight collaboration across the Ecoult engineering team and the EPM battery engineering team.

15.5. Supporting information (optional)

None.

16. Lessons Learnt Report: Disruptive vs Mature Commodity Approach to Commercialization

Project Name: *Final Learnings*

Knowledge Category	Technical/Financial
Knowledge Type	Financial information/Risk Management
Technology Type	Storage
State/Territory	Global

16.1. Key learning

The lead acid industry is a mature commercial industry. With Ecoult being a subsidiary of EPM we had the advantage of access to the guidance of their leadership team and to the tremendous fulfilment capabilities that EPM could bring. EPM was tremendously generous and stalwart with their support and Ecoult could not have reasonably asked more of EPM; however, a challenge we had was that the emerging energy storage industry was such a growth industry that it attracted enormous amounts of innovation funding to new technologies and companies and encouraged aggressive forward pricing approaches to establish incumbency. In the course of our progression, Ecoult received offers of interest toward investment from sources that could open markets and that accessed paths consistent with emerging technology innovation, but we remained a 100% EPM subsidiary. As an EPM subsidiary, our path to volume was more assured because of the deep engagement and experience throughout the full fulfilment process. What was unanticipated was the level of technology understanding that needed to be generated as we proceeded which may have benefitted more from commencing a fundamental research program before commercialization.

16.2. Implications for future projects

All of the outcomes of innovation cannot be known up front. Ecoult and EPM stewarded the effort strongly collectively as an innovation effort and risk assumptions were generally appropriate. Governance was oriented at getting the product to market whereas in hindsight a greater focus could have been on readiness. For future projects more critical and objective assessment of technology readiness would be appropriate.

16.3. Knowledge gap

N/A

16.4. Background

Objectives or project requirements

N/A

Process undertaken

Ecoult maintained first class governance and strategic processes internally and at a board level. The CTO maintained rigorous and appropriate processes across the technology development and led a competent and involved team.

16.5. Supporting information (optional)

None.