Energy Storage Publishing

The International quarterly for manufacturers and users of electrochemical power www.bestmag.co.uk

bestmag

Batteries & Energy Storage Technology

No. 68
Spring 2020

The best of both worlds gives us the best for this world

Inside

Optimised formation saves energy

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Since 2017 *BESTmag's* Technical Editor, Dr Mike McDonagh with UK Powertech and Digatron, has undertaken possibly the most comprehensive global study ever, of modern lead-acid formation methods. In this article, he shows that the results from the latest field trials with five international manufacturers and confirms the early cost savings predicted from the initial laboratory tests in the UK. If you want to substantially increase your bottom line by several hundred thousand USD then you could do a lot worse than start right here.

It has been four years since the 15th ELBC in Malta. It was at this conference that the team of UK Powertech, Digatron and ESPL was formed in order to start an investigation into the contribution of the formation connector to the problems of modern fast lead-acid battery formation. Digatron and UK Powertech are manufacturers of formation rectifiers and formation connectors respectively.

At this time their customers were experiencing problems of increasing battery fires, surface blemishes from arcing and a high turnover of inter-battery formation connectors. In the face of these problems, customers invariably sought help from Digatron and UK Powertech to identify and remedy the cause. In many cases, the connectors and formation rectifiers were incorrectly held responsible for this damage.

A brief discussion between Mark Rigby, Kevin Campbell and Mike McDonagh established a programme of work to ascertain the cause, or causes, of the increasing incidents of battery damage in modern lead-acid formation departments.

Some facts were consistently appearing and these were used to lay down the foundations of a joint investigation project. These were:

- The number of incidents, such as fires and battery/ connector damage, had increased sharply over the previous 5-10 years
- This coincided with reduced formation times in all of the lead-acid battery factories under consideration
- The reduced formation times required higher currents in order to provide the same amount of formation energy in a shorter period
- The common belief was that higher currents were permissible provided that the battery cooling during formation was improved
- The use of acid-recirculation technology to reduce formation times was also a factor in the use of higher formation currents
- The one component of these faster techniques that had not changed was the design of the formation connector
- Increasing the diameter of the connector cable to carry higher currents did not improve the situation

Based on the above, it was concluded that the connector might be the key to understanding these incidents. Working with battery manufacturers, a series of tests to ascertain their cause was established.

Initially, simple resistance tests were devised to establish the difference between new and used connectors. It was found that there was a considerable difference between the new and used examples taken from customers' formation departments. The differences were quantified and reported in *BESTmag* in 2017.

The cost in energy losses was also quantified, and predictions of total energy losses from this factor alone were calculated to be hundreds of thousands of US dollars per annum for a medium sized lead-acid battery factory.

Based on this, a formation and testing rectifier was provided by Digatron to carry out formation simulation trials using new and old connectors. These trials, using real formation programmes and batteries from customers, rapidly verified the original energy loss findings.

The next stage was to identify the causes of the higher resistance in the old connectors. Using a combination of chemical analysis, optical and SEM microscopy with EDX analysis, it was established that a barrier layer of predominantly lead sulphate was formed on the inside of the lead connector head. This layer resulted from the environmental conditions of the connector in service in the formation department.

In addition to this barrier layer causing an increased energy loss, there were also incidents of battery and connector damage. It was found that the damage was caused by arcing between the connector head and the battery terminal. The source of this arcing was two-fold: a bad fit between the connector head and the battery terminal due to operator error or defective battery posts, creating a loose fit which created sparks when current flowed.

The other cause of poor connector to battery post fitment was severe pitting of the internal connector head resulting from the break-up of the corrosion layer surface. The corrosion layer was not the primary cause but it did exaggerate the problem.

It has taken a couple of years to gather and to analyse the data from these tests, which have been used to construct maintenance procedures for the connectors. These procedures are designed to both reduce the build-up of the high resistance layer in the connector head, and increase the connectors' operational life.

In addition, a prototype for a new design of connector has been manufactured and is now on trial in five companies around the globe. This new design addresses the poor fitment due to battery pillar defects and operator working practices. It is also designed to keep the internal surface of the connector head isolated from acid on the battery surface as well as acid from fumes or mist, ***Fig 4***.

The connector improvement segment of the project is now in its final phase. Results are coming in from all of the factories that are trialling the new connector design and the new maintenance procedures. The formation energy usage results from one of the factories are shown in ***Fig 1***. In this we see a clear and consistent reduction in formation energy used for the new design, the TSC type (blue line) compared with the new old design T type connectors (red line). There is an even bigger saving against used old T type design connectors (purple line).

Fig 2 compares the percentage energy saved in using the TSC and T types in the new condition against average used condition

Fig 1: Comparison of battery formation energy for old and new designs and used connectors

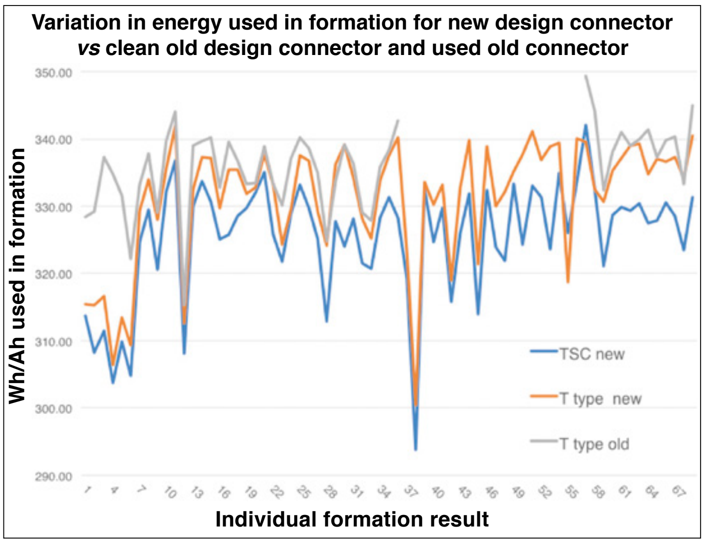
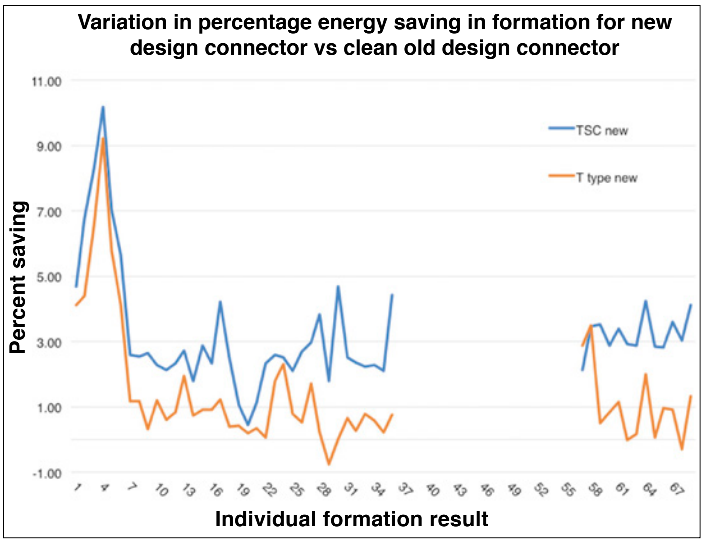


Fig 2: Percentage variation in energy saving of new connectors over used formation connectors



T types in an automotive formation department. The gap in the results represents maintenance carried out on the formation line using the used T type connectors. This graph shows that the initial advantage of the new T types over the used, diminishes with time as it gradually corrodes to approach a similar value, that is, almost zero difference. The new TSC design however, is levelling out at a steady 3.2% saving in energy, which appears to be sustainable.

Since the winter edition of *BEST* we have had results from more factories, and further results from the original factories. Those factories, which we reported on in winter, are still showing substantial savings for the new TSC connector design compared with the new and the used T types. Not all the new companies conducting trials have the capability to measure energy loss. They are confining their observation and results to monitoring the incidents of connector arcing, battery damage, longevity and ease of fitting of the connectors.

These results are now tabulated and ***Table 1*** shows the results from three factories in measuring the incidents of battery damage and connector arcing. There are also estimates of the benefits to the ergonomics of fitting the connectors to the batteries in the formation tanks. These results clearly show that there are almost no arcing or damage incidents for the new TSC connector design compared with the new or used standard T design.

There are two factories that are gathering data on energy usage as well as connector integrity and arcing incidents.

In summarising the results, it is clear that the new TSC design always gives the lowest energy usage during formation. How representative these results are, remains to be seen.

A key design feature of the new TSC type is the ability to seal off the connected area between the pillar and the connector head from the environment. The corrosion layer on the inside of the connector head has been identified as mostly $PbSO_4$, which is an insulator.

Fig 3 is a Pourbaix diagram of lead in sulphuric acid

Fig 3: Pourbaix diagram of lead in sulphuric acid with regions of pH and voltage stability for lead compounds

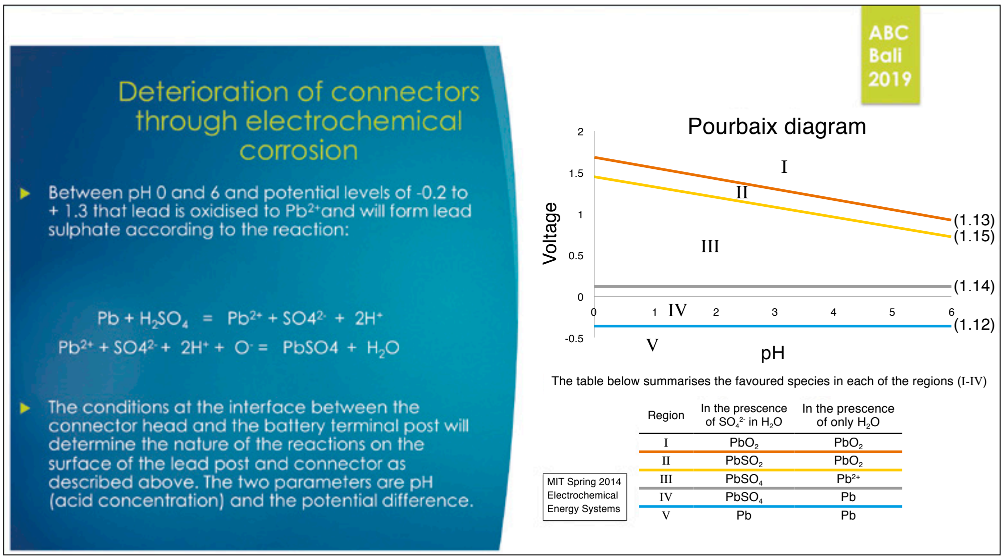


Table 1: Field trials- factory matrix February 2020

Factory	Average energy saving	Connector arcing	Operator efficiency	Process time	Battery scrap/ rework
1	180,000 USD	Not monitored	Not monitored	Not monitored	Not yet monitored
2	3.25%	Non TSC Several used T type	Better	Not monitored	Not yet monitored
3	Not monitored	Non TSC Several used T type	Better	Not monitored	Not yet monitored
4	Not monitored	2 New 8 old	Not monitored	Not monitored	Not yet monitored
5	Not monitored	Non TSC Several used T type	Better	Not monitored	Not yet monitored

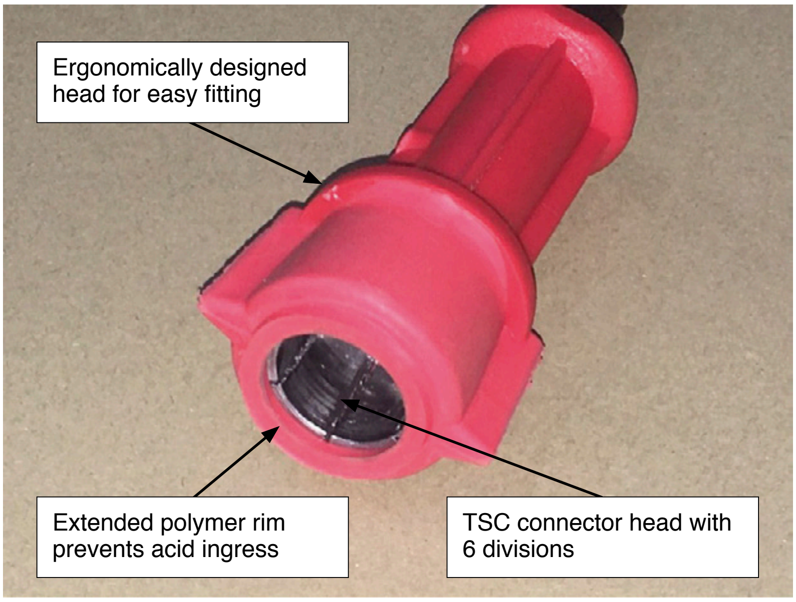


Fig 4: New design TSC connector from UK Powertech

showing the region of stability for various lead compounds as a function of acid pH and electrode voltage. It is clear that lead sulphate can be formed and is stable over a wide range of pH values from less than one, to just under seven. This means that it will form even if the connectors are washed with or dipped in water, due to there being some residual, albeit diluted H_2SO_4 on the inside surface of the connector head. Because lead sulphate is soluble its growth can be retarded by washing with a dilute caustic solution.

However, the best measure is to design the connector to prevent acid ingress. ***Fig 4*** shows the design of UK Powertech's new TSC design. There is a plastic rim which tightly fits onto the battery post effectively stopping acid and acid fume or vapour from getting into the connector head once it is fitted onto the dry post.

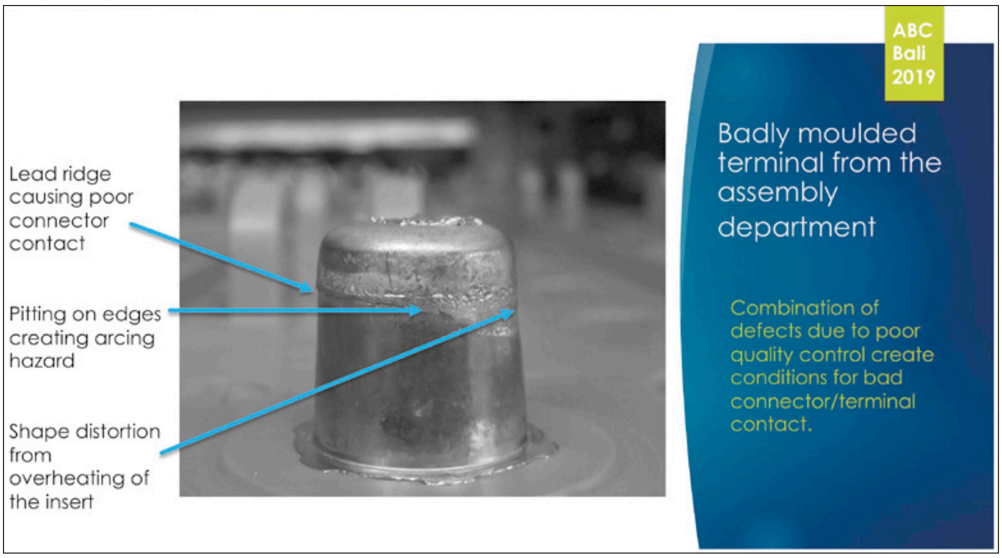
The other problem of poorly fitting connectors (due to either operator error or a misshapen battery post) is addressed by having a split head to provide a flexible rather than rigid coupling. This feature enables the head to accommodate irregularities and still maintain a high contact area. With a 6-part spherical head, a single irregularity in the battery terminal surface will only reduce the contact area by 17% or one split section. The remaining contact surface of five parts of the head still greatly exceeds the cross-sectional area of the connector cable.

Contrast this with the situation of a rigid connector head placed onto a connector with an irregularity ***(Fig 5)***. It is forced to sit at an angle with only point contact surface area. This means that in the case of a split connector head compared with a solid connector head, there will be a negligible effect on the total connector resistance due to battery pillar irregularities.

An added advantage is that there is pressure applied to the sides of the split connector head by the plastic moulding. This ensures that the connector head sections always have a positive pressure applied, which ensures a solid contact between the head and pillar surfaces.

A major variable in the trials is the operator's working practice. It is possible that operators taking part in the trials will not adopt their normal working habits. In this case we will not

Fig 5: Typical casting defects on an automotive battery post

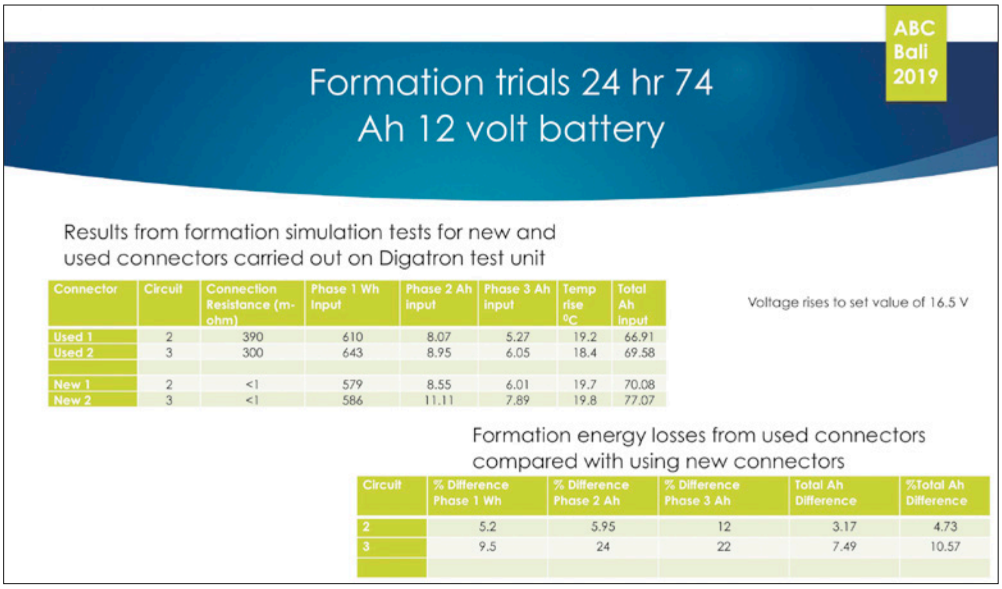


have a true picture of the real difference in energy usage or incidences of arcing between the different connector types. For this reason, the trials will continue for many months across as many companies as possible to improve the statistical confidence.

To back this up, we have energy usage results from the formation department of one lead-acid battery factory over a year. These show clearly that, on its own, correct maintenance of the connectors will reduce the build-up of the inner corrosion layer on standard connectors. This measure has already proved that real savings far exceed the projected savings based on our original and current testing.

This is an indication that perhaps in our laboratory tests and with our field trials, the operators are being more careful in their fitting of all of the connector types, when compared to their normal working practices. With this in mind, the potential savings when using the new TSC design could easily be double the real savings already found during our field trials.

The financial projections have so far concentrated on the energy losses due to higher resistance connections. However, in addition, there are potentially greater savings from preventing arcing damage to batteries and connectors, plus reducing lost production time from resistance created by high battery temperatures. The latter problem is related to specific formation programmes that rely on reducing or shutting off current flow when battery temperatures exceed set value limits.


ABC Bali 2019

Formation trials 24 hr 74 Ah 12 volt battery

Results from formation simulation tests for new and used connectors carried out on Digatron test unit

Connector	Circuit	Connection Resistance (m-ohm)	Phase 1 Wh Input	Phase 2 Ah input	Phase 3 Ah input	Temp rise °C	Total Ah input
Used 1	2	390	610	8.07	5.27	19.2	66.91
Used 2	3	300	643	8.95	6.05	18.4	69.58
New 1	2	<1	579	8.55	6.01	19.7	70.08
New 2	3	<1	586	11.11	7.89	19.8	77.07

Voltage rises to set value of 16.5 V

Formation energy losses from used connectors compared with using new connectors

Circuit	% Difference Phase 1 Wh	% Difference Phase 2 Ah	% Difference Phase 3 Ah	Total Ah Difference	%Total Ah Difference
2	5.2	5.95	12	3.17	4.73
3	9.5	24	22	7.49	10.57

Fig 6: Laboratory formation trials

In these cases, the programme has to continue beyond the designated time in order to provide sufficient ampere-hours to meet the programmed value. This results in lost production time due to circuits not being available to form more batteries. Field results and laboratory tests have demonstrated that up to 15% of production time, and therefore product throughput, can be lost in this way.

The field trials so far have demonstrated that there are substantially fewer incidents of arcing per connector using the TSC design when compared to the old T design, particularly when in service for a few months. This has not been costed, as there is insufficient information to calculate repair or scrappage costs, nor sufficient results to draw solid conclusions. However, comments received from the participating companies show a favourable response to the new design. These comments, along with the present data, give confidence that the number of arcing incidents, and therefore battery and connector damage, could be at least half of current levels.

There is the possibility to save formation time for temperature-controlled processes. Often this can be as much as several hours in a 24-hour programme. Early laboratory results ***(Fig 6)*** have indicated that the use of *new* old-style T connectors against *used* old style T connectors will result in lower battery formation temperatures. Results have been gained using real formation programmes run on green batteries supplied to UK Powertech that show substantial time saving using low resistance new connectors compared to used higher resistance connectors. Up to 40% less time was lost in the lower resistance case. When applied to production throughput this would give an additional 10% productivity, with lower energy cost and no capital investment.

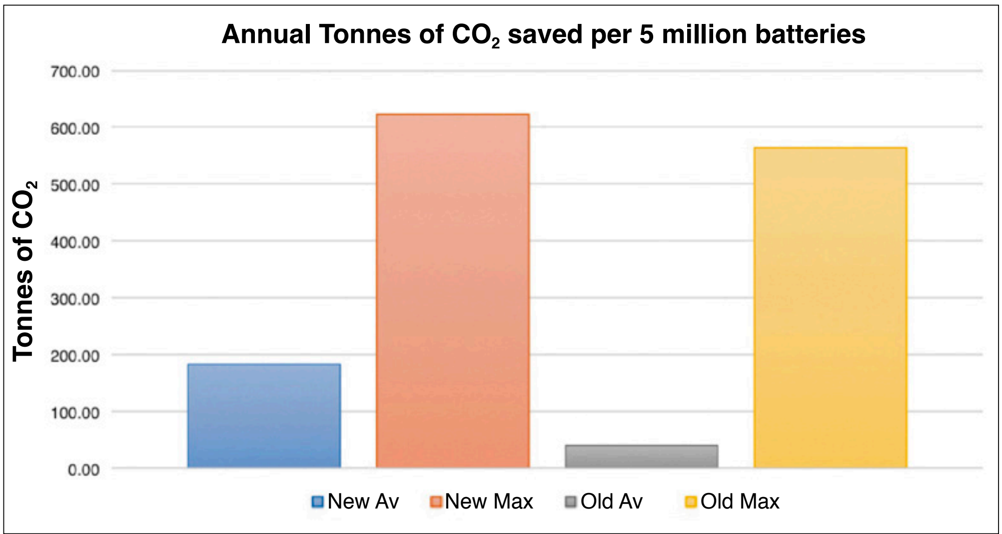


Fig 7: Projected CO_2 savings for a five million automotive battery production plant

Conservative estimates for the financial benefits, based on the work done so far for a typical five million battery per annum turnover are at least $300,000. However, the other major consideration, which will have a financial impact on all manufacturing operations, is the amount of carbon produced by the processes. ***Fig 7*** shows the reductions already experienced for carbon emissions from a battery factory based on the current connector trials. Apart from possible financial penalties, a substantial reduction in carbon generation could be a decisive factor for the survival of lead-acid battery manufacturers in the very near future.

In summary, laboratory tests over two years have quantified the energy savings possible from using lower resistance connections in a lead-acid battery formation department. Field trials across several companies are providing data to test the laboratory findings. At this stage the measured values from field trials are a close match to the energy savings predicted from the laboratory tests.

The other savings are the reduction in arcing incidents and process time saving. These can be tentatively estimated but with the caveat that further trials may reduce or increase those values.

> **“If use of a TSC connector saves the damage caused from just two arcing incidents, then this design will have more than covered the additional cost.”**
>
> **Mark Rigby, UK Powertech**

The additional cost of using a new design of connector, and its impact on the projected cost savings, have not yet been mentioned. At this stage the new TSC connector is a prototype and the final cost in bulk manufacture is not yet completely established. However, it is not expected to have significant impact on the projected savings and in the words of UK Powertech’s MD, Mark Rigby: “If use of a TSC connector saves the damage caused from just two arcing incidents, then this design will have more than covered the additional cost. And, importantly, this is before we count in the energy and time savings, which have already been proven.”

In another 6-9 months, the current field trials and prototype connector design should be concluded. This will have been an important first step in the improvement of the operating cost and quality of lead-acid battery formation processes.

It is a first step because phase two of operation ‘Lead-acid battery Improvement’ will have already started. This is a new process regime that is designed to maximise the energy efficiency of the formation process as well as the quality of the product. It is built on an award winning and patent pending charging protocol, already proven to improve battery quality and minimise time, energy and water loss with lower operational temperatures.

In order for this to be effective, it was necessary to first remove a potential process variable, which was the formation connector resistance. Until this was eliminated it may not have been possible to accurately measure any benefits from this new process. Now that the connector resistance issue is resolved, the stage is perfectly set to start the next phase of the improvement programme.