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The future beckons

Solid-state: leading the next battery revolution

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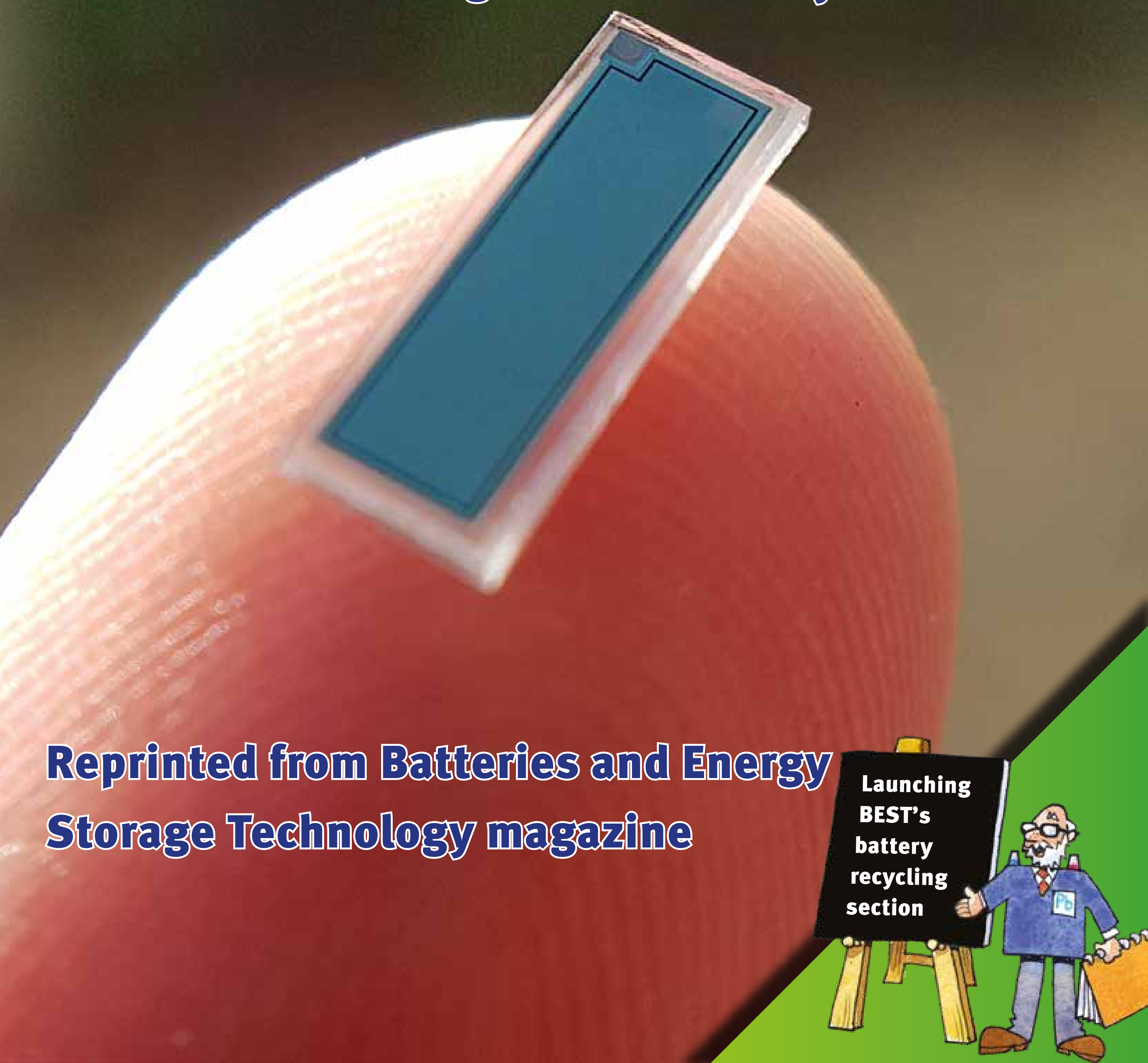


From theory to reality—connector-testing savings proved

Ongoing field trials over the last year show that manufacturers of lead-acid batteries can make massive cost savings, amounting to hundreds of thousands of USD per annum. Dr Mike McDonagh presents the field tests in conjunction with Digatron, UK Powertech and ESPL (BESTmag).

Since early last year, ESPL *(BESTmag)*, UK Powertech and Digatron, have been engaged in determining the effects on lead-acid battery manufacturers of having high connection resistances in their formation departments. The high resistance of the connections has been traced to the corrosion and damage of lead alloy terminal connectors resulting from the environment, working practices and the high currents used in modern formation departments.

Below: With a combined 75 years of experience Dr Mike McDonagh and Mark Rigby put the Digatron Powernet Tester to good use, and results from the field now back up the results

Inset right: The new design of connector

The causes and nature of the corrosion were identified using chemical analysis along with optical and SEM microscopy. This information and the electrical testing, using a Digatron rectifier (BNT-150-030-4-ME Powernet tester), at the laboratory in Ashton under Lyne, UK, were combined to build up a picture of the global problem existing in most lead-acid battery formation departments.

The impact on the batteries, the energy used, the damage to the batteries and connectors, the increased process times and the financial costs were quantified from the test data. This information was used to devise new maintenance procedures and designs for lead-acid battery formation connectors. Companies were then identified to make trials using the new maintenance procedures and new connector designs to measure the energy savings and the reduction in connector and battery damage when these were put into use.

At this stage there are five manufacturing sites taking part in the trials, one of which began over a year ago. The key areas under investigation are:

- Energy savings due to lower resistance from improved formation connections
- Battery scrap and rework resulting from connector arcing during formation
- Battery quality and warranty improvements consequential to better formation connections
- Formation time increases due to high temperatures resulting from formation connection resistance
- Carbon savings from reduced process energy as a result of improved formation connections

The team of UK Powertech, ESPL and Digatron have produced several reports published quarterly in *BESTmag* since last year. These have outlined the progress made since the testing programme was started, which can be summarised as follows:

- Identification of a high resistance layer in used lead alloy flexible formation connectors, which increases the electrical resistance of a battery string being formed
- Quantification of the formation energy losses and resulting potential costs for battery manufacturers
- Understanding the physical and chemical nature of the high resistance layer and then proposing both maintenance and operational procedures to minimise the effects of this layer.
- Measurements to identify the lower energy efficiency caused by the build-up of the high resistance layer
- Identification of the chemistry of the resistance layer on the connectors, its causes, methods to reduce its build-up, and the impact on the formation process
- Effect of the high-resistance layer on battery temperature during formation. In those cases where the formation process is temperature controlled it will result in a lower productivity
- Working practices and connector maintenance procedures that reduce the extent of the corrosion layer have been identified
- New connector designs that improve surface area contact with the battery posts and help to prevent formation of the high-resistance layer have been established

Whilst the companies in the field trials cannot be named, the results of the trials can be used to illustrate the significance of the laboratory work and also to quantify the benefits of using the new procedures and connector design. As can be seen from ***Table 1***, different companies are trialling different aspects of the new connector design's properties, with one company testing only the maintenance procedures. There are three key requirements for improvement, identified from the tests, which

Table 1: Field trials- factory matrix

Factory	Energy saving	Connector arcing	Operator efficiency	Process time	Battery scrap/rework
1	$180,000	-	-	-	-
2	3 – 10%	none	better	-	-
3	-	none	better	-	-
4	-	2	-	-	-
5	-	none	better	-	-

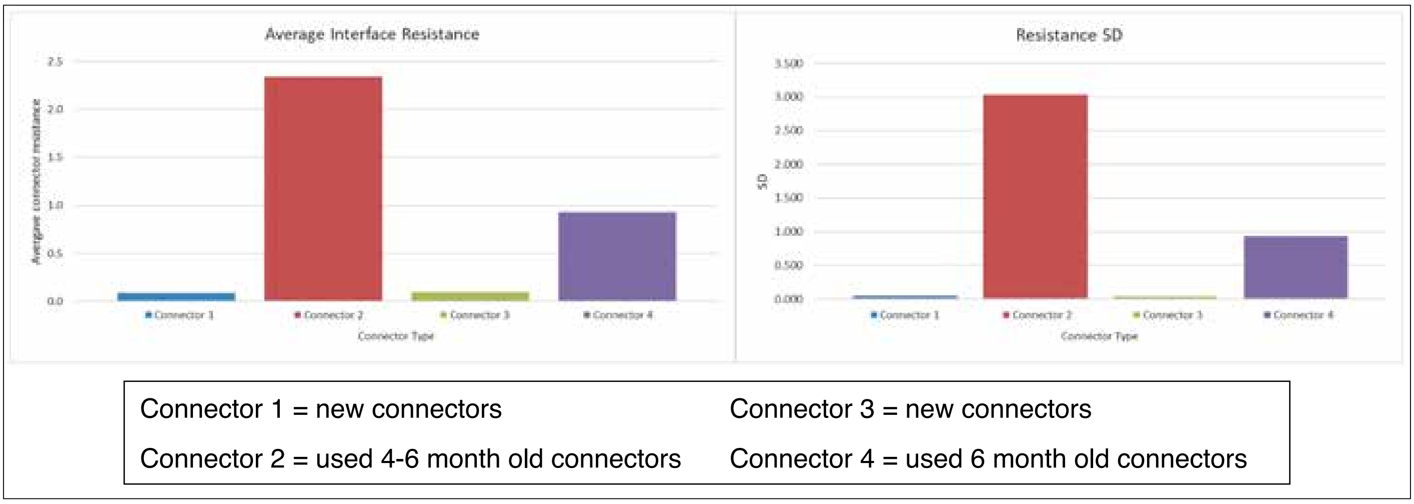


Fig 1: Average connector/ terminal interface resistance (mohms) and standard deviation

have a significant impact on the operational efficiency of formation departments. These are:

1. A connector design that maintains the connector contact area and pressure against the battery terminal even with a defective take-off casting

2. Maintenance procedures that slow down or prevent the growth of the high resistance layer on the contact surface inside the formation connector head

3. Working practices, and a connector design, that ensures a good contact between the connector and the battery terminal

The impact of the above factors on the factories' operating costs is not to be underestimated. The measurable energy loss resulting from higher connection resistance ***(Fig 1)***, for example, could amount to about 4% of the total energy cost for the whole factory. Most people are aware that the formation department alone accounts for at least 50% of the total energy used for a lead-acid battery manufacturer. Laboratory trials have predicted that on average, savings of around 8% are possible, based on resistance values found during efficiency tests and formation trials using the Digatron test equipment.

However, there is a question of whether or not the increased resistance of older connectors with a non-conducting corrosion layer would result in a measurable electrical response. And if it did, would it be picked up by the formation rectifiers and software. If we were dealing with ohmic conductors like metals then an increase in resistance would mean increase in voltage, which is measurable. We know from Ohm's law:

V = IxR

Increase R at a fixed current and you get a higher voltage, which is directly proportional to the resistance and easily measured. However, with a charging battery we have other factors of capacitance and inductance to add to ohmic resistance, and let's not forget heat generation from which we can consume additional energy without producing a measurable voltage response. In fact, as we all know, a battery on charge will decrease in voltage as the temperature rises. This would partially offset an ohmic voltage rise from an increased resistance. The point here is that measuring the energy losses attributable to high resistance formation connections in a lead-acid battery formation department is not straightforward.

At this point in our testing programme we were unsure that it could be measured on standard battery formation equipment. For this reason, we approached five manufacturing sites and asked them to participate in field trials, which were designed to compare new standard connectors and a new design of connector with old used connectors currently in use in their formation departments. The following parameters were suggested:

- Energy consumed per formation cycle
- Incidents of connectors arcing
- Connector damage
- Battery damage
- Temperature of the batteries
- Ease of fitting the connectors
- Time of the process

There were no companies who were able to measure all of the parameters mentioned and, to be honest, most formation department managers have enough on their plates without the extra bother of isolating specific circuits for testing battery connectors. On top of this we asked operators to follow strict fitting instructions, take measurements and record the results whilst under the usual production pressures. A bit of a stretch for any manufacturing organisation.

However, there was remarkably good cooperation, with every company able to participate in some sort of controlled trial and able to isolate circuits for comparisons. As a result of this, we obtained definitive proof of the benefits of adopting the new connector design and the modified maintenance procedures.

Looking at ***Table 1*** the results can be split into the findings of the individual participating factories:

- Factory 1: Energy savings
- Factory 2: Energy savings, ease of use, connector arcing
- Factory 3: incidence of sparks/arcing
- Factory 4: incidence of sparks/arcing
- Factory 5: ease of use

These factories were located in four countries and are all lead-acid automotive battery manufacturers. Their annual outputs range from 1.8 to eight million batteries per year.

Factory 1 has not yet supplied data for their trials but they have described their methodology and the amount of savings that they have achieved. Briefly, one year ago they adopted the recommendations made by the author and Mark Rigby, for maintenance procedures and applied them to their existing formation connectors. These connectors were previously supplied by UK Powertech to the company and represent the normal state of this type of connector in service. The maintenance measures ensured that the build up of the corrosion layer responsible for the increased connection resistance in a series battery string was greatly inhibited.

> **“We obtained definitive proof of the benefits of adopting the new connector design and the modified maintenance procedures”**

Their method to assess the impact of these procedures was simply to measure the energy consumed by the formation department from the mains supply, over the period of one year and then to compare it with the previous year’s use. In order to remove the variability of energy output due to different battery types they modified the results to a normalised battery size. This was important to get a true picture for comparison.

This simple method showed an energy reduction sufficient to save $180,000 per annum for 1.7 million SLI (equivalent) batteries. This was achieved for the standard connector, not the new design, and is the result of simple, almost zero cost, maintenance procedures.

For the other four factories, there are some results that are suitable for analysis. These organisations were asked to isolate three circuits, one for unused new-design connectors, one for unused old-design connectors and one for used, old-design connectors.

The same battery types and formation programmes were used on all three circuits to form batches of series-connected cells and take whatever measurements their software could obtain. Not all factories were able to measure energy used, or temperature. However, all were able to assess connector arcing and battery damage. Below is a summary

Fig 2: Energy saving from use of unused new design and unused old design connectors

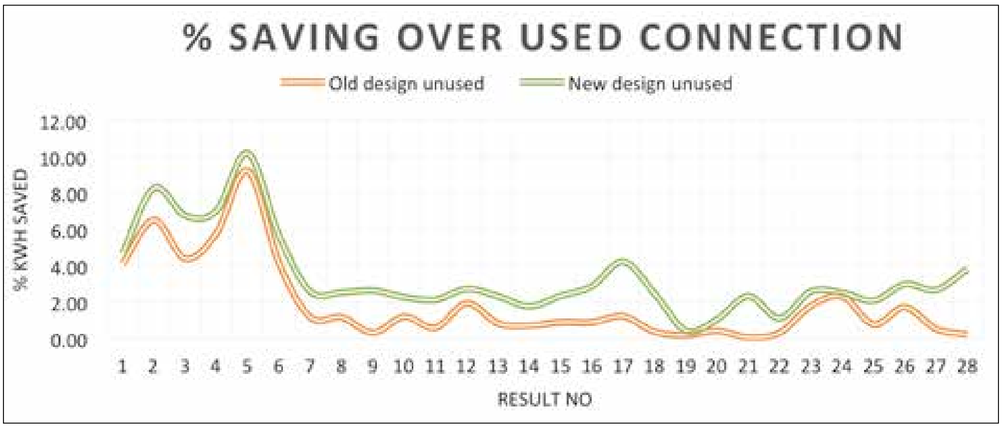


Fig 3: Reduction of CO_2 per battery resulting from better formation connections

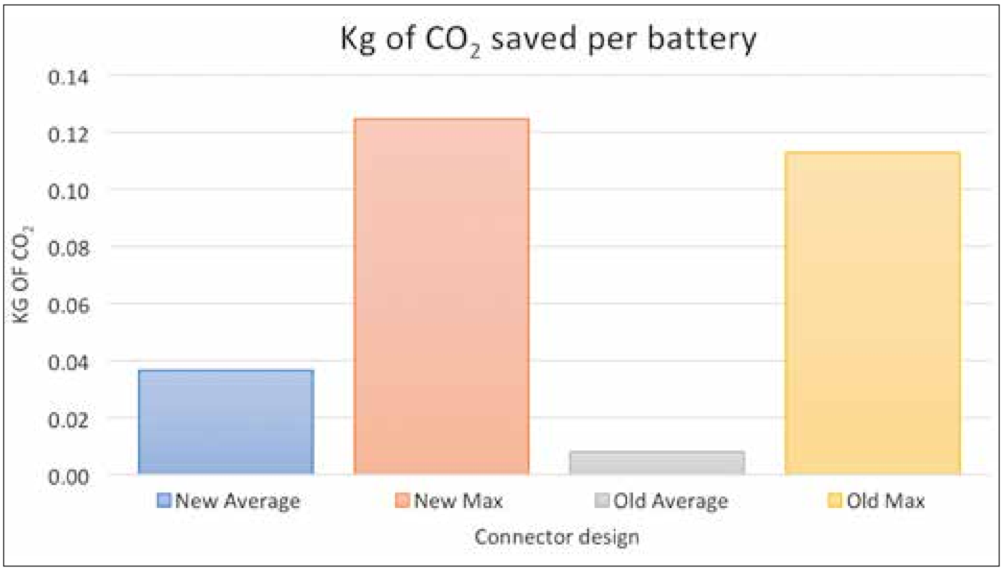
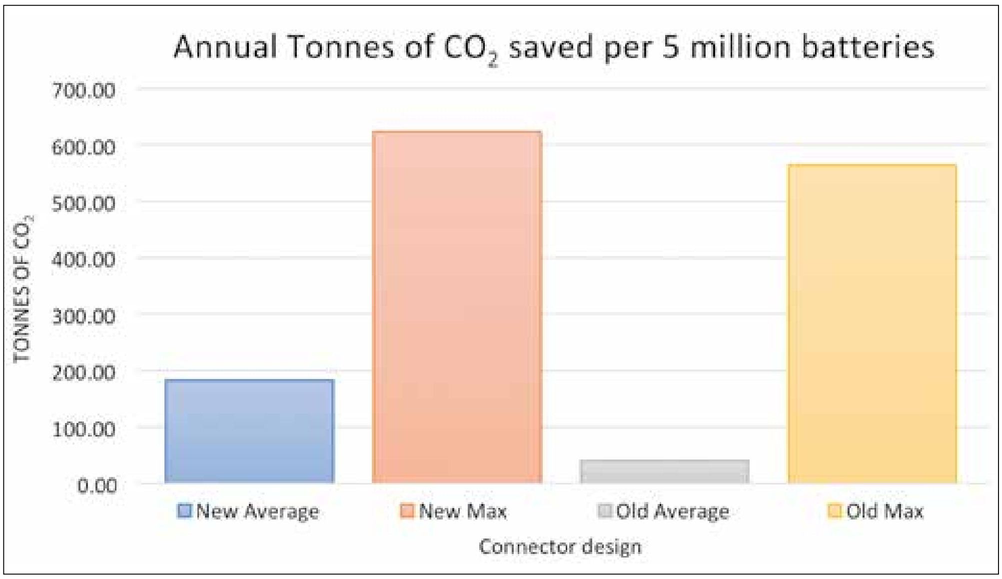


Fig 4: Annualised CO_2 reduction for a medium-sized lead-acid battery factory



of the procedures used and testing carried out, for the four remaining factories:

- Factory 2: comparison of energy used, arcing and connector damage
- Factory 3: comparison of arcing incidents for different connectors
- Factory 4: comparison of arcing incidents for different connectors
- Factory 5: comparison of energy used, arcing incidents and battery damage

Although it is early days for these four factories, and tests have been conducted for a just a few months, there is sufficient data from these factories to tabulate and produce some graphs. The results obtained so far can be split into two groups: energy saving ***(Fig 2)*** and connector arcing.

The energy saving graph gives the savings that result from the reduced formation energy when using unused new-type and unused standard-type in comparison to used standard-type formation connectors. The consequential reduction in CO_2 emissions per battery, derived from using less mains supplied energy has also been calculated and is shown in ***Fig 3***.

The new connectors clearly show that for a medium-sized SLI company levels of carbon reduction of up to 600 tonnes per annum are achievable ***(Fig 4)***. It is obvious from ***Figs 2 and 3*** that the new design has a distinct advantage, which has been maintained for the duration of the trial.

However, the standard-design connector, after a period of use, moves closer to the performance of the used standard connector. Presumably cleaning the connector would improve its performance. A future trial to ascertain the point in use where the connectors should be cleaned in order to maintain a better performance, will be carried out.

The incidence of arcing is not so well documented but there are numerical results for at least three factories shown in ***Table 1***. Again, it appears that for reduction of arcing alone, there are distinct advantages using new connectors. The new design has the same advantages, but in addition, it provides even higher energy, carbon and cost savings. The commercial decision for adopting the new design can be justified by the cost benefits of the savings alone.

In addition, the longevity, on the basis of the results so far, could exceed the existing design, however, this is still being proved. The cost of wasted energy has been calculated by assuming a business rate of $0.14/kWh, and the carbon emission values were obtained using 0.54Kg CO_2/kWh. These values will vary according to country and region.

These field trials, although in their first stages, are beginning to show, very clearly, the accuracy of the predictions made from the results of the connection testing carried out in the laboratory. The partnership of Digatron, UK Powertech and ESPL along with the combined knowledge of UK Powertech's Mark Rigby and the author, amounting to some 75 years in total, has been able to identify a significant source of losses resulting from current formation practices, connector design and connector maintenance.

"The humble connector could be a significant factor in improving lead-acid's fortunes and also make a significant and positive impact on our planet's climate"

The formation practices include the charging rate, the method of pushing the connectors onto the battery terminals and the maintenance of the connectors in use. All of these factors have been addressed to provide a new connector design and an operating guide for the correct procedures and maintenance practices to minimise the inter-battery connection resistances during lead-acid battery formation.

The benefits of this have been partially realised by factory 1, which has already seen hundreds of thousands of US dollars gained from energy savings alone in just one year for their formation department. There are other benefits, these include: reduced scrap and reduced battery repairs, which could amount to tens of thousands of US dollars annually.

In addition to this, another cost saving is the connectors will also last longer before being replaced due to irreparable damage. Laboratory tests also show lower resistance connections ensure that batteries will run cooler by several degrees. This can have a huge impact on the throughput for those factories operating a temperature-controlled formation programme. In fact, tests and field trials have shown that at least 5% extra throughput can be obtained, which for a five-million-a-year battery factory would result in around $5 million additional annual revenue at negligible cost.

The other hot topic (literally) is climate change. According to the figures obtained so far, we could be looking at annual savings of between 300 and 500 tons of carbon for a modest lead-acid battery factory, just from the formation department.

When all of this is added up, it does seem a little far-fetched that simply looking at a formation connector and its impact on the processes, quality and cost for a lead-acid battery factory could produce such disproportionate benefits.

However, the results speak for themselves. Starting from a simple conversation between the author and Mark Rigby, three years ago in Malta, to global field trials with multinational companies, the humble connector could now be a significant factor in improving lead-acid's fortunes. What's more, it could also make a significant and positive impact on our planet's climate.