best mag

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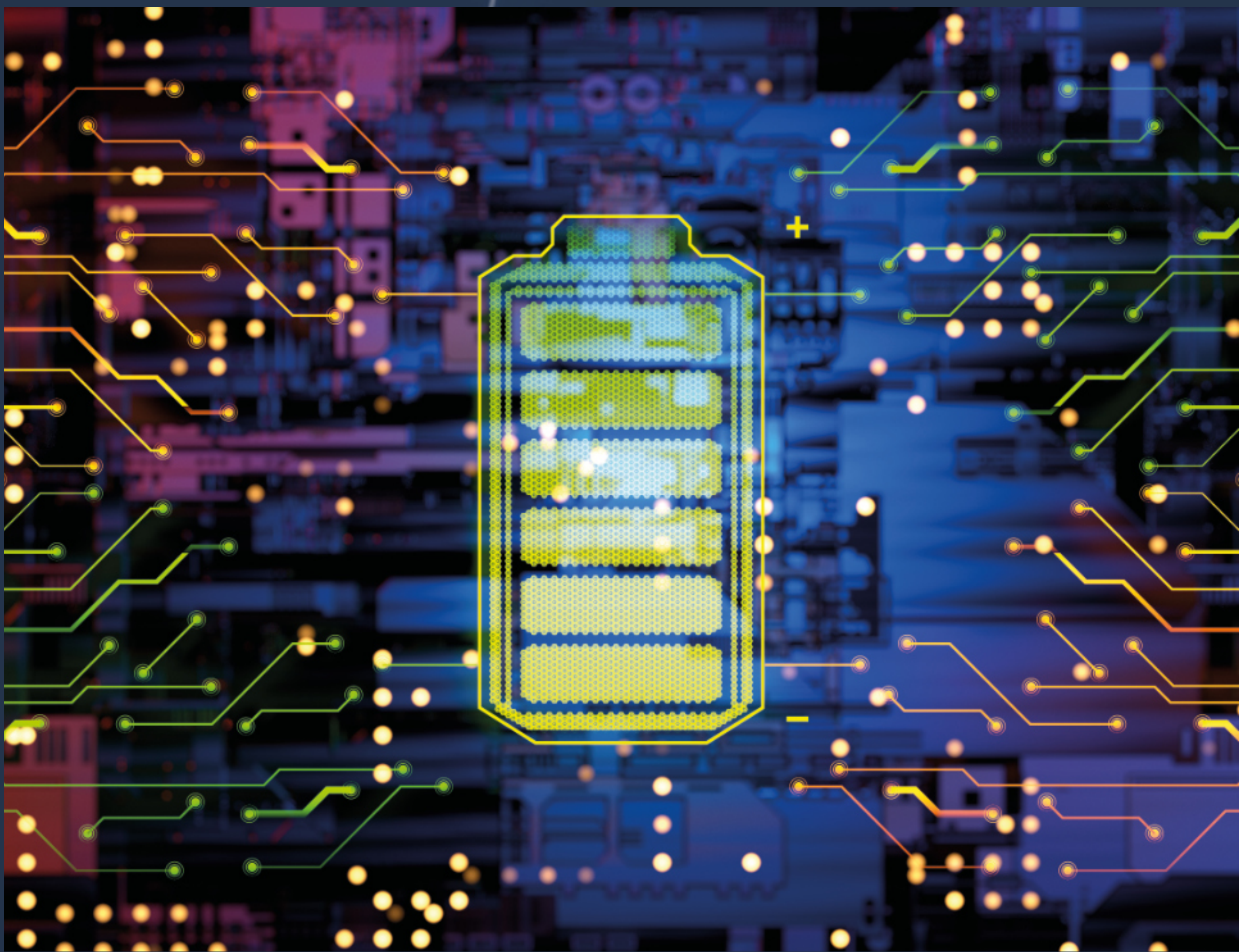
The international quarterly for the battery technology industry

Battery innovation

A catalyst for clean energy storage



Can batteries enable a truly sustainable future?

IP licences: the pitfalls and how to avoid them

Na-ion batteries: an alternative to lithium and lead

BATTERIES & ENERGY STORAGE TECHNOLOGY
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Fizzing batteries

This is my first issue in the editor's chair of *BEST magazine*, and I'm impressed at how innovation is fizzing throughout the battery industry. Researchers and entrepreneurs are working in partnership to produce batteries that are smaller, more powerful, and cheaper.

Analysts believe that continued investment in R&D in areas such as solid-state electrolytes and cell manufacturing processes – alongside capacity expansion – will help improve battery technology and reduce costs over the next decade.

Faster and ultra-fast battery charging will be needed to attract a mass market of electric vehicle users. That poses challenges for thermal management and of course people are working on a solution to that one too.

In this issue, our Asia correspondent Dipak Sen Choudhury considers how the Indian government is getting serious about battery waste management legislation, while I talk to Ace Green Recycling CEO Nishchay Chadha about his vision of eradicating 'informal recycling', a euphemistic term for unjustly exploiting the workers and the planet.

The European Lead Battery Conference returned with a bang in September, as the pandemic made its retreat. Attendees enthused about how lead still has a lengthy, if steady, future. It's tried and tested, is highly recyclable and doesn't catch fire. But a commonly held view at ELBC was that it needs better public relations. Many of the presentations hit the nail on the head in terms of lead-acid's future, according to *BEST* technical editor, Dr Mike McDonagh.

Also, in the battery technology mix along with lithium are zinc and sodium-ion, and their case is made in this issue.

Pete DeMar considers whether the US is finally catching up with the EU regarding the benefits of battery gas recombination devices. The answer isn't yet clear, but time will tell. We report on how the European Union is supporting efforts to make the battery value chain more resilient. More needs to be done to plug huge gaps between market supply and demand.

Vic Giles reports on the proliferation of lithium battery fires, keenly discussed at the International Congress on Battery Recycling in Salzburg in September. He asks if lithium batteries should be treated as the 'problem child' of the battery industry.

Our technical editor examines how emerging battery technologies are being considered for large-scale energy storage. Whilst much research is still centred on energy density, it is not that important for energy storage, he argues. He also tells the story of Indian SME lead-acid battery maker Microtex Energy, which is taking on the big guys and thriving.

Enjoy the read.

Andrew

Andrew Draper
Editor

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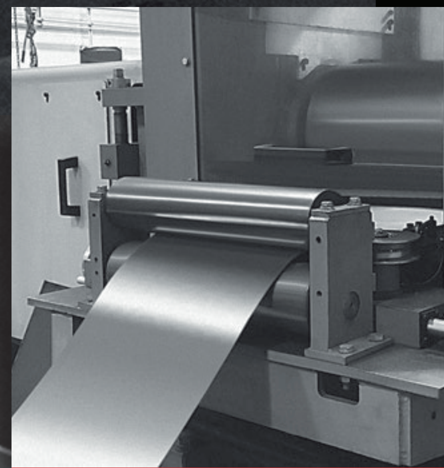

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Pressure tactics – How (not) to reverse declining fortunes

In Greek mythology, Icarus and his father, Daedalus, were imprisoned on an island by King Minos. To escape, Daedalus created two sets of wings made of wax and feathers. He warned his son not to fly too close to the sun, as the wax would melt. Unfortunately, Icarus aimed too high and fell to his death. '...the Icarus syndrome characterises leaders who initiate overly ambitious projects that come to naught, causing harm to themselves and others in the process.' Manfred F. R. Kets de Vries is the Distinguished Clinical Professor of Leadership Development & Organisational Change at INSEAD.

In this parable, there is a corporate group of battery manufacturers who annually review the performance of individual sites. During one such review, it is discovered that a particular factory has underperformed for the past two years. In addition, in the first quarter of the new financial year it had returned a worrying loss. Having posted a negative shift of over a quarter of a million USD for the first quarter, there was a substantial reason for both concern and action.

A new operations executive arrives

After an emergency board meeting it was decided to bring in a new operations executive, to turn the situation around as quickly as possible. The deal was to show an improvement in six months and get back into profit by the end of the year. In hard cash terms, it meant generating an additional $300,000 of profit over nine months of trading, on an annual turnover of $60 million. As the board was aware, a CEO capable of turning around an ailing company would not be cheap. They were looking at around $250,000 in salary, almost doubling

the profit requirement for that period. Highly paid headhunting companies were engaged to recruit a top executive with a solid track record in turning loss-makers into money makers.

After one month of searching, a person with the right credentials was found, able to begin within two months. The person chosen, Anthony, had an impressive track record of three high profile company turnarounds in the last 10 years – a pottery manufacturer, a retail organisation and a financial institution. At board level, it was considered that all businesses had a basic modus operandi, and that manufacturing was manufacturing, no matter the product or market. Anthony was in his mid-forties, a very tough and articulate proponent of goal-oriented management. Provide the targets and make sure that your goals exceed the requirements in order to ensure that you achieve them.

Spelling out the new targets

On his first day Anthony assembled the senior management including the incumbent MD in the boardroom. The meeting was a two-way communication exercise, allowing him to spell out the company's new targets, as well as for him to understand the operating problems and calibre of the management. This first meeting was attended by the board of directors from all departments. Sales, production, finance, technical, engineering and human resources were represented. Once introductions had been made, Anthony began the meeting with an account of the company's performance for the last two years and the targets that needed to be met to obtain a recovery in under a year. These included improving profit margins per product, raising sales levels and prices, cost reductions in materials and processing, cutting staff levels and a slashing of overtime and energy costs.

Once he had finished, he asked for comments. Then the hubbub began. All departments thought that they were doing a good job and that top management did not understand or appreciate their problems.

Darren, the production director, was first to voice his concerns. "Look, we all understand that things are going south but there are reasons," he said. "In production, for example, our

manufacturing equipment is ageing. We've had no real investment for the past seven years; we're holding everything together with string and tape. The cuts you're asking for are impossible to achieve: maintenance will be affected, manpower cuts will reduce output, and product quality will suffer as a result of pushing more out with fewer resources."

Anthony acknowledged the comment but simply responded by asking if there were any more reservations. There were plenty. Alastair, the sales director, made the point that sales were hard to come by and poor output from the factory and missed delivery dates were responsible for the current shortfalls. Unless that was addressed, there was no hope of meeting existing, let alone new, targets.

The other departments followed in like manner; the technical director, Ramesh, was unable to cut material costs as the battery materials could not be compromised. The lead content – 70% of the cost was fixed by the battery capacity, the other materials, and processing costs would only provide several percent at best. Equally, the engineering and finance departments could not reduce their staff levels without plunging the factory into chaos. Anthony listened patiently to all arguments without any questions. Then, as the clamour subsided he addressed the meeting.

I understand your arguments. However...

"I understand your arguments and concerns about the difficulties you will face in implementing these changes; however, changes there must be. How else can you hope to prevent making these losses? If you are telling me that it is impossible, and that you are unable to make these improvements, then I have only one course of action. I will report back to head office and advise them that I am wasting my time here, and that the current management is unable to deliver the required changes."

He paused for effect, **then slowly turned his gaze on to each person around the room.** "This will lead to one of two consequences: either the management will be replaced by more competent staff within the group, or this facility will be sold or closed for good." Again, he paused. "So, do I have your cooperation, yes or no?"

There were a few moments of murmuring as a ripple of frustration passed around the table. Then, speaking for the other directors, the incumbent MD, George, made a statement. "We recognise that things have to change in order to get into profit," he said. "However, there are specific issues that perhaps neither you nor the main board fully appreciate. We are the only manufacturer of forklift truck batteries in the group. You are not aware of the new companies from Taiwan and Korea that are actively flooding the market with cheaper batteries. At the same time our other competitors are amassing huge stocks to enable them to deliver in a couple of days. If you add to this their 120-day payment terms, we are struggling to make any headway at all; we are even losing our market share."

Anthony shook his head. "If your best response is to do nothing and allow the company to slowly bleed to death, then I may as well wrap this up now and save a lot of time, effort and expense. Or, each department can deliver its recovery plans by Friday, based on the financial information already provided in your briefing packages."

He paused again and looked slowly and directly at each person around the table. No-one spoke.

Taking your silence as a yes

"I will take your silence as a yes. We will meet again on Friday at 10:00 and I sincerely hope that you will not make any plans for an early start to the weekend. Good day, gentlemen."

The activity for the next couple of days was frenetic. Whilst there was resentment towards the new CEO, all directors accepted that there had to be a solution. During this time, George left the company. At age 61, he took early retirement and seemed to be quite phlegmatic about the situation. The general consensus was that he was expecting this development and without any formal announcement or ceremony, it largely went unnoticed.

At the Friday meeting each department made a presentation using spreadsheets and graphs to project the cost savings that would be realised if their measures were adopted. Derek, the finance director, was taking notes and listing the total projected savings for each department. The only departments not proposing any savings were sales and HR. In the case of sales, their proposal was to improve efficiency per person and increase revenue. The strategy was simple: allow lower prices and build up higher stock levels, and this should increase sales. For HR, it was even simpler. There were only three people in the department and could not make a 10% saving, it was mathematically impossible. In addition, there would be redundancies, new contracts, ACAS negotiations etc. Their workload would double over the next year.

The other departments, however, did manage to identify savings and efficiency improvements. In summary it looked like this:

Technical department

The total at that time was 13 staff; consisting of a designer, a lab manager, two lab assistants, a QA manager with three QA inspectors, three warranty engineers and the technical director. George, the technical manager, proposed losing two of the warranty engineers who were near retirement age and one lab assistant who had just joined. A grand saving of three people, or 23% of his staff.

Production department

A 6% cut in the workforce mainly from the packaging and finishing departments, the loss of three shift supervisors due to the reduced output, and a transition from three to two shifts in all departments, gave an overall staff saving of 6.5% and an energy saving of 12%. There was a caveat to this. Greg the production director gave a warning that if production picked up, he could not respond and this could jeopardise the company's recovery.

Engineering department

Bill, the engineering manager, gave the report. The proposals were maintenance staff to be cut by three, due to the loss of the nightshift, and that the toolroom was to go. As a consequence all tooling and moulds were to be outsourced, which was cheaper than employing full-time staff. This gave a further saving of three personnel. A total staff in reduction of 30%.

Finance department

There were no staff reduction proposals from Derek, the finance director. He argued that he was already understaffed and that he would have a higher workload than before the changes. He did however point to possible material savings by changing suppliers for some process consumables. Alternative suppliers were also available that could provide certain battery components more cheaply – separators, containers and lids etc. Energy suppliers had also been contacted to negotiate cheaper supply contracts. In his estimation, material costs and overheads could be reduced by at least 4%.

Once the costs had been collated by Derek, Anthony asked him if he could summarise all of the savings as a percentage of the total. This included direct and indirect operating costs. When Derek had given a reasonably accurate estimate, he passed the notes to Anthony, who announced that these measures were insufficient, and that more savings were needed just to get to a break-even position. In fact, he added 20% onto each department's targets. When the inevitable 0.3 or 0.5 of a person issue came up, the solution was simple: round up to a whole person or find an equivalent cost-saving by some other means.

Protestations waved aside

All protestations were waved aside and the choice of "do it or lose it" seemed to be sufficient motivation to procure all managers' cooperation. It was necessary to start the measures now, and to submit the final reduction plan in a week's time. The entire assemblage was sent away to make preparations, such as giving notice of redundancies, contacting suppliers for quotes and re-organising work shift patterns etc. All left, apart from Derek, who remained seated.

Once the room was empty it was Anthony who spoke first. "I'm sure you are curious as to why I made that blanket 20% increase."

Derek nodded. "Yes of course, you could see perfectly well that the total savings would give a gross margin sufficient to get us back into profit," he said.

Anthony leaned back in his chair, "I started life as a sports trainer 25 years ago," he said. "I very soon found that if a training programme were left to the athlete or player, it would not push them hard enough. I further found that an increase of 20% would give that extra two or three percent in performance; that is the difference between winning and losing. It's the same thing in business: if we need to achieve a 5% cost reduction, increase it by 20% and we will be more likely to meet the 5%. What's more, I know it works and I have made a very successful career based on this simple principle."

Derek wasn't convinced and said so. However, he would reserve judgement until the results were coming in. The meeting now done, Anthony made one last parting comment: "You do realise that this also applies to you, Derek?"

Frenetic activity

After six weeks of frenetic activity, a reasonable picture of the company's progress was emerging. Meeting Anthony's targets was proving to be the stuff of nightmares; even meeting the original targets was challenging. During the latest progress meeting, each department had to provide its target status. Basically, no one had made the extra 20%, there were one or two instances where the original targets had been met. These were in the numbers of direct staff within the factory workforce. In this case 11% had been obtained, thanks to a combination of removing one shift plus reorganising the warehouse area where orders were picked and wrapped.

The hardest task was the proposed materials cost reduction. Some new suppliers had been found, which at this point, added savings of 80% of Anthony's target. Similarly all other departments were getting to a point where the savings were edging closer to the original targets – without the extra 20% demanded by Anthony.

The meeting then homed in on the material costs. Clive, the purchasing manager, was responsible for the supplier negotiations. During his presentation, Clive had indicated that, as a result of showing the current materials suppliers the quotes from alternative companies, he was having some success beating down their prices to match the competitors' price quotes. These new prices however, were still short of the 20% upgraded targets.

Anthony was the first to ask a question: "That's good news, Clive. How soon do you think that you will meet the targets that we agreed?"

Clive started to explain that the best quotes from outside suppliers were consistent with the original targets, not Anthony's revised goals. A tense discussion then ensued.

Derek interjected, "I know that our current supplier is totally unable to meet the revised target price, I personally spent many hours in deep discussions on this point," he said. Anthony interrupted, asking if the alternative suppliers could meet the target prices.

Derek responded between gritted teeth: "It is possible that the new suppliers will be able to meet those prices. However, there are practical reasons as to why we need to run with the existing suppliers. If we change, then there are approvals, new specifications to be drawn up, new supply contracts and new delivery schedules. Some of these new suppliers will struggle to meet the new delivery date and we do not have any experience of their reliability. Part of the cost savings will require minor modifications to be made to some of the components already approved by the technical department. These will all take time. In addition to this, we are now running out of time and further investigations will eat up more weeks of our programme. If we agree these prices now, we can start the ball rolling and get back on target by using the original suppliers, but at a lower cost than we have now, and within 80% of the revised targets."

No chinks in the armour

This was a non-starter with Anthony. If he allowed this, then all the other departments would be looking for concessions, this would increase the risk of missing the savings target; the project and the organisation would be undermined. He was intransigent, and gave the assemblage one more week to meet the objectives. As they filed out, their original mood of optimism was replaced by a real sense of hopelessness, and even despair.

No one could see a way to achieve these savings without risk. In the case of production, lack of workers would prevent increasing output if sales increased – at least not without a lot of overtime which would negate or reverse the cost benefits of a reduced workforce. Sales knew this and were now nervous of finding additional sales revenue. The technical department had to rely on new suppliers' ISO 9000 quality records for material compliance rather than conduct their own tests. These were demoralising problems, and in each case, it appeared necessary that some element of risk had to be accepted in order to achieve the targets. And that is what happened.

At the follow-up meeting a week later, each department had put in a plan to reduce their costs to meet the target set by Anthony. New suppliers were appointed for most of the non-lead materials, incoming goods inspections were reduced to random checks with suppliers' own analyses being accepted, maintenance was no longer routine but 'as required'. The sales department's costs actually increased, as the search for new customers demanded more travel, entertaining and overnight stays.

All of the above concerns were raised and casually brushed aside with the comment: "If we don't do this, we will close anyway. So where is the risk?"

The first casualty

At this stage there was some relief, although tinged with caution, that the recovery plan had actually begun. Most people recognised that the company now had a fighting, albeit risk-burdened, chance for survival. It was imperative that the overall and individual department objectives be met according to the schedules. There were a lot of inter-dependant factors that had to happen in the right order to ensure that all the targets were realised.

Of course, that never happens in real life, and any plan without contingencies will pretty soon start to need some. The first casualty in the plan is usually the plan itself. In this case it was the supply of new materials – the separators, in fact. The supplier had sent the wrong backweb thickness even though the overall thickness, including ribs and mini ribs, was within specification. It was only noticed after one week of production when the line inspector had a complaint from one of the cell assembly operators that the material felt too soft and the automatic sleeve welder was melting through the land area of the separator. This was not good news. Despite the first delivery being checked at incoming goods, subsequent deliveries were accepted on the supplier's own analysis.

All the manufactured cells had to be checked and, if necessary, replaced or repaired by changing the sleeve separator on each plate in the group. This was costly, both in terms of staff and time. To make matters worse, it was part of a large contract with a new customer. The main reason for landing this order was the promise of an early delivery. It took three weeks to get the correct material in and a further two weeks to complete the first part of the contract. The first delivery to this customer was almost a month late. Existing customers also had late deliveries and were extremely unhappy. Some even cancelled existing orders and bought from competitors.

The turnover in the first two months of the leaner company was pitiful. About one half of where it should have been. Because of the overtime to recover the lost production space and the reworking of the cells, the costs were eye-watering. This was now month four in the nine-month plan to achieve the level of profit necessary to break even by the end of the year. So far, savings had not been realised, costs were sky high and sales were down.

Pressure mounts

By now, Anthony was receiving several calls a week from the board of directors. He explained his strategy and why it would give more profit in a shorter time due to his raising the cost-cutting and sales targets, despite the initial hiccough. He also emphasised the importance of sticking to the targets for every department, to avoid a precedent where underperformance could be tolerated. The call ended with an ultimatum to demonstrate a higher profit level by month five or rethink his position in the company.

The first two weeks of the month saw an increase in sales activity and revenue appeared to be improving. If the rising trend continued and costs were properly controlled, there would be a chance of reaching the required level of profitability. At a mid-month meeting Anthony felt confident enough to put a positive spin on his tactic of increasing the target requirements. He claimed that without the additional measures, it would not be possible to claw back the early losses and still meet the overall profit objective.

The knockout punch

It was in the third week that the long sharp and shiny last nail was firmly hammered into the coffin of Anthony's plan – a sudden surge of warranty returns, 90% of which were from the newly acquired customer. Analysis showed that badly fitted separator sleeves and some plate damage had resulted in early cell failures due to either partial or severe short circuits in all of the returned cells.

This was the knockout punch. The new customer cancelled all outstanding orders and wanted immediate and full recompense to the extent of replacing all the batteries with a competing brand as they no longer had faith in the product or the company's survival. This time it was the factory directors who called an emergency crisis meeting and summoned Anthony to the boardroom.

Greg, the sales director, began with a tirade about the best deal in the factory's history being squandered and how the sales team were utterly demoralised. Other departments threw in so many 'I told you so' cards, one could have played virtual snap.

Before Anthony could make any sort of response, it was Derek who took the floor. "I don't think there is anything more to be said on our present situation. I have spoken to Sir Geoffrey at head office and filled him in with the financial details. Needless to say, my message was not well received, but he was glad that I had informed them in a timely manner. They expressed surprise that the message had not come from you, Anthony."

Anthony was furious. "That's because you jumped in too quickly and undermined any recovery plan that we might have come up with before informing them," he said. "What do you hope to personally gain from this other than the satisfaction of seeing me fired?"

Derek was unperturbed. "There is already a contingency plan with head office. I prepared it yesterday and sent it last night. It was our original plan that you then upgraded by 20%. The financial analysis shows that the lower targets will lead to recovery and that we can get back into profit by the fourth quarter of the next financial year. The main board have accepted and endorsed this.

"Stay here! I'm calling the chairman"

Anthony was apoplectic. "What the hell, who gave you the right to….?" The sentence went unfinished. Anthony jumped to his feet knocking over his chair, then strode to the door. His parting words before slamming the door closed behind him were: "Stay here! I'm calling the chairman, Sir Geoffrey, to clear this up. I'll be back in a few minutes!"

Derek sat down calmly and gathered his scattered papers whilst the rest of the directors stared open mouthed at the door, then at Derek. Once his papers were in order and all eyes were on him, he spoke: "No, he won't be back. But now we can get on with a proper recovery plan that is achievable."

Incensed by the time he reached his office, Anthony furiously dialled Sir Geoffrey's direct number. Once on the line, he immediately launched a scathing attack on Derek and the rest of the staff, who, he claimed, had let him down. He then began to ask for an extension to the schedule, in order to demonstrate that his changes had been effective. The company chairman, however, was stone cold in his response. He simply asked Anthony what evidence he had that his changes were effective. Anthony immediately altered his approach. He argued that although he would not meet the set targets, he had installed genuine improvements which made the company a leaner operation and would be profitable, albeit less and later than he had originally planned. He also argued that with some creative accounting, the warranty losses could be amortised as development costs for a new product.

There was an extended silence before Sir Geoffrey finally answered: "Very sorry Anthony, I cannot allow that. You see, if we make concessions for one person, we would be expected to do the same for others. We would lose our credibility. You do understand, don't you?"

Our weekly newsletter is the BEST way to keep up with the fast-moving world of electrochemical storage. But, if you've missed an edition or more, help is at hand... with our digest of all the key developments in the sector over the past quarter.

News in review – Lead

The unrealistic focus on lithium as the only scalable solution to battery energy storage in most applications presents an opportunity for the lead battery industry, said the **International Lead Association**.

Opening the **European Lead Battery Conference** (ELBC) in Lyon, France, in September, Dr Andy Bush, Managing Director of ILA, said a result of that over-focus is "a yawning gap between that expectation and the practicalities of actually delivering it when the numbers simply don't add up.

ELBC was the first physical meeting of the industry since the Covid-19 pandemic started and was a chance for many companies to show off.

Hollingsworth & Vose, a supplier of filtration and energy storage solutions, showcased its PowerFill AGM lead-acid battery filling technology at ELBC.

The PowerFill was designed to solve the challenges of slow and uneven filling of the acid electrolyte by enhancing the surface of the separator to create open channels.

Entek's high-performance automotive battery separators were also on display at ELBC. The lead-acid battery industry has long been a mature, stable, global market with very predictable demand for flooded OE and aftermarket automotive batteries.

Battery separator suppliers provide a variety of PE profile types, backweb thicknesses, and rib configurations to satisfy the global demand for starter batteries required for combustion engines that power cars.

New developments for the fast and precise filling of even the smallest lead-acid AGM batteries and a High Rate Discharge – Impedance (ACR/DCR) was on show by battery equipment firm **Cmwtec Technologie** at ELBC.

Cmwtec is a small family-operated business in mid-west Germany producing high-quality machines for finishing lines in the production of lead and lithium batteries.

The **Consortium for Battery Innovation** (CBI) won a contract from the US military to design and prototype a power skeleton of batteries for when the military responds to domestic and international emergencies.

Dr Matt Raiford, Senior Technical Manager at the CBI, told *BEST* that the $3.5 million contract is designed for military response situations – on the battlefield and in civilian situations.

Lead battery manufacturing equipment firm **Sovema** has been bought by German metal forming company **Schuler Group**.

Schuler aims to use the sale as a stepping-stone to increase its ability to equip lithium-ion Gigafactories beyond its current offering of production lines for manufacturing prismatic and cylindrical battery cell housings.

News in review – Lithium

Panasonic Energy, a wholly-owned subsidiary of **Panasonic Holdings Corporation**, agreed a deal that will allow the firm to build an EV lithium-ion battery manufacturing plant in Kansas, US.

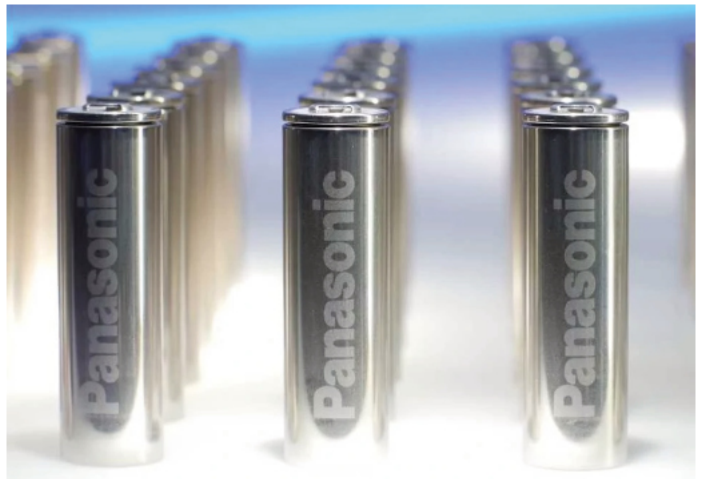
The announcement comes as Kansas approved an Attracting Powerful Economic Expansion (APEX) state incentive application submitted by Panasonic Energy.

While early estimates put the cost of the incentives at $1.3 billion, the Kansas Department of Commerce said Panasonic would be eligible for $829 million in tax credits, exemptions and other incentives.

Electric vehicle battery maker **LG Energy Solution** (LGES) and Japanese car maker **Honda** said they picked Ohio for their joint venture (JV) new battery plant. Total investment will total $4.4 billion, the pair said in a statement.

The JV will be formally established in 2022, pending regulatory approvals. Construction is planned for early 2023, with completion of the plant by the end of 2024.

Meanwhile, EV maker **Tesla** is changing its battery strategy to take advantage of US tax breaks and is suspending plans to make battery cells in Germany, according to media reports.



The *Wall Street Journal* reported that Tesla has discussed moving equipment used to make cells to the US. They were originally intended for use in the German factory.

The Inflation Reduction Act, which president Joe Biden signed last month, provides tax breaks to EV makers that source batteries from within the US.

Battery materials developer **Nexeon** is set to expand its annual manufacturing capabilities after securing $90 million in its latest fundraising round – bringing its total investment to $170 million.

The cash from the second round of fundraising will provide Nexeon with resources to mass produce "tens of thousands" of tonnes of its silicon-based anode materials for lithium-ion batteries.

SK On secured $3 billion from three investors from Germany and Korea to spend on building its lithium-ion battery manufacturing Gigafactory Plant No.3 in Europe.

The plant is under construction in Iváncsa, Hungary at a cost of KRW3.31 trillion ($2.5 billion) and will produce 30GWh of batteries a year from 2024.

The three agencies that took part in the financing are all export credit agencies (ECAs) and they will finance SK On by providing credit guarantees and insurance as the company applies for loans in overseas commercial banks.

Research developments

Engineers at the **University of California San Diego** developed a lithium-sulfur battery that performs well in extremes of cold and hot temperatures.

The researchers' electrolyte was used in a lithium-sulfur battery in which the cathode consists of sulfur grafted to the conductor polymer sulfurised polyacrylonitrile (SPAN).

A research programme to develop a standardised and commercially-ready replaceable cartridge lithium-ion battery for electric vehicles has begun in Japan.

Commercial Japan Partnership Technologies Corporation (CJPT) and **Yamamoto Transport** aim to solve electric vehicle concerns over charge times, increased load on grids during multiple charging and logistic downtimes for fleet owners.

CJPT was launched in March 2021 by **Toyota Motor Corporation** with **Isuzu Motors** and **Hino Motors** and has since been joined by **Suzuki** and **Daihatsu**.

A silicon dominant lithium-ion battery with less than 1% cell expansion has been developed by materials company **E-magy** and German research institute **ZSW** (Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg).

E-magy's nano-porous silicon, used as the active anode material, absorbs the expansion in the nano structure itself to enable a 0.9% overall cell expansion.

Silicon's tendency to expand and break during charging and discharging has been the main barrier to industry adoption.

Serbian battery maker company **ElevenEs** said it produced a prototype of the largest battery cell in Europe following a two-year development programme.

It claims it is the first and largest full-size lithium iron phosphate cell.

People movements

Conservationists and indigenous people are challenging plans for two lithium mines and a geothermal power plant in Nevada, US.

A report from *Associated Press* stated the federal government plans to transition the economy to green energy and EVs by 2035. But regardless, lithium mining for EV batteries must still comply with laws designed to protect wildlife habitat, cultural and historical values, and guard against pollution or other degradation of federal lands.

Lithium-sulfur materials company **Lyten** appointed former Tesla, Panasonic and Quantumscape battery expert Celina Mikolajczak as its chief battery technology officer.

As the leader of Lyten's Battery Product Innovation Group, Mikolajczak will be responsible for advancing the development of the LytCell lithium-sulfur battery to full commercial readiness and optimisation.

The founder of lithium-ion battery gigafactory hopeful **Britishvolt** stepped down from his role as chief executive officer at the company he launched in 2019.

The move was explained by Britishvolt as "aligned to the company's growth plans and 2050 vision" despite there being no full-time successor to Orral Nadjari's role.

Dr Graham Hoare has been appointed as acting CEO from his position at the firm of deputy CEO/ president global operations.

A team at **Rice University** in the US has developed a technique for brushing metal powders onto anodes that prevents dendritic growth in a lithium-ion battery.

By using the brushing technique, the team says the metal powder adheres to the anode and becomes a thin, lithiated coating that effectively prevents the formation of dendrites.

China's **EVE Energy** will supply vehicle OEM **BMW** with cylindrical 4680 lithium-ion batteries for its electric cars in Europe, according to reports.

The firm signed two contracts to become BMW's primary supplier of cells to be used in the German OEM's electric vehicles which are due to hit the market from 2025, according to *Reuters*.

Vehicle OEM BMW announced a recall of around 83 electric vehicles after concerns faults made during the lithium-ion cell manufacturing process could cause short circuits in the battery packs.

The Voluntary Safety Recall, effective from 21 July, follows three incidents in the vehicle manufacturer's iX SUV (model Year 2022 – 2023) and i4 Gran Coupe vehicles that were produced between 22 November, 2021 and 30 July, 2022.

The batteries in the recalled vehicles were manufactured by **Samsung SDI**, according to The **National Highway Traffic Safety Administration** (NHTSA), an agency of the US federal government.

EV fire ticking time bombs

Florida's chief financial officer and state fire marshal wrote to the National Highway Traffic Safety Administration (NHTSA) saying salt water reacting with batteries in EVs may be a "ticking time bomb" and cause more fires.

Jimmy Patronis said in a statement there would inevitably be more fires following Hurricane Ian as lithium batteries corroded as a result of exposure to salt water. There are large numbers of damaged or submerged EVs following the storm.

"I...saw with my own eyes an EV continuously ignite, and continually reignite, as fire teams doused the vehicle with tens-of-thousands of gallons of water. Subsequently, I was informed by the fire department that the vehicle once again reignited when it was loaded onto the tow truck.

"Based on my conversations with area firefighters, this is not an isolated incident. As you can appreciate, I am very concerned that we may have a ticking time bomb on our hands."

A major fire broke out in a Tesla megapack battery at a **PG&E** energy storage facility in Monterey, California. Roads were closed and local residents evacuated. They were allowed back home but warned to remain vigilant.

Numerous firefighters were called to tackle the blaze. County of Monterey stated the fire was isolated to a single battery pack at the facility and had been contained.

A fire that started in an Indian showroom with battery-powered electric scooters killed at least eight people and injured another 11, reported *Reuters*, quoting local police. It is the deadliest such incident in the country involving electric vehicles (EVs).

A series of e-scooter fires this year has alarmed the government. Investigation reports identified faulty battery cells and modules as among main causes.

News in review – Other tech

Battery storage capacity more than tripled in the US last year as the way utility-scale energy storage systems and their use cases evolved to meet changing grid operator demands.

Last year, more energy storage systems (ESSs) were used as an arbitrage resource to flatten renewable power generation curves alongside traditional services.

Installed capacity rose from 1.4GW in 2020 to 4.6GW last year, according to the early release of the 2021 EIA-860 data from the US Energy Information Administration (EIA)

The increase was driven by the addition of 106 utility-scale batteries with 3,202MW of capacity coming into commercial operation.

Battery materials and recycling company **Godi India** said it is to manufacture 3000F (farads) high-power supercapacitors at its Hyderabad facility. It claims this is a first for India.

Integrating Godi India's supercapacitors with battery packs would improve battery life in EVs and renewable energy storage system (ESS) applications, the company said in a statement.

"Godi India is producing cost-effective and plant-based Carbon-Carbon supercapacitors using water-based electrode processing. We have a variety of supercapacitor products ranging up to 3000F. At present, we are in the process of developing high-voltage lithium-ion capacitors as well," said Mahesh Godi, founder and CEO of Godi India.

Battery cell manufacturer **AMTE Power** has chosen Scotland to build a 500MW

"megafactory" to manufacture lithium-ion and sodium-ion cells.

The proposed new site at Dundee's **Michelin Scotland Innovation Parc** (MSIP) will manufacture pouch cells for the EV and stationary energy storage markets.

The company has licensed sodium-ion technology from **Faradion**, the UK firm bought by **Reliance New Energy Solar** (RNESL), a wholly owned subsidiary of **Reliance Industries**, in January.

Researchers from Russia's **Skolkovo Institute of Science and Technology** (Skoltech) and **Lomonosov Moscow State University** developed a sodium-ion battery cathode material that increases energy density.

The new material is a powder of sodium-vanadium phosphate fluoride ($NaVPO_4F$) with a particular crystal structure that gave the researcher's coin cell a practically achieved energy density of around 540Wh/kg.

The team developed the cathode active material by combining a $NaVPO_4F$ composition with a potassium, titanyl and phosphate group ($KTiOPO_4$-type or KTP) framework via a low-temperature (190°C) ion-exchange synthesis.

Japanese machine maker **Toyota Industries Corporation** has doubled its bipolar nickel-hydrogen battery production capability with the establishment of a new plant that will supply batteries for hybrid vehicles.

The Ishihama Plant is expected to operate at a production capacity of 20,000 units per month, and, together with the Kyowa Plant (which started battery production in May 2021), will boost its total capacity to 40,000 units per month.

The 20,000m^2 Ishihama Plant is due to begin production in October.

Sakuu, a solid-state battery manufacturer, announced a tie-up with **NGK Spark Plug Co.** of Japan, for the development and provision of ceramic materials for Sakuu's solid-state battery production.

Sakuu said NGK will co-develop and provide ceramic materials for Sakuu's solid-state battery production. This will range from ongoing battery material needs at its California pilot line facility to full commercialisation for its additive manufactured solid-state battery line. A spokesperson said details on the kind of ceramic and application is proprietary to the chemistry and construction of the battery.

Researchers at **Massachusetts Institute of Technology** (MIT) and elsewhere developed a new kind of low-cost battery, made entirely from abundant and inexpensive materials. The aluminium-chalcogen battery charges in less than a minute and is resistant to dendritic shorting.

It uses aluminium and sulfur as its two electrode materials, with a molten salt electrolyte in between. It is described in the journal *Nature*, in a paper by **MIT** Professor Donald Sadoway, along with 15 others.

The **Queensland state government** said it will develop energy storage and battery industry plans: an

Energy Storage Strategy will come out in 2024. It will outline Queensland's storage and firming infrastructure needs and encourage private sector investment in storage and firming. This strategy will focus on how much storage the energy system needs.

This will follow an energy and jobs plan that targets increasing renewables to 70% of the energy mix by 2032 and 80% by 2035.

The **Chinese Academy of Sciences** said the world's largest flow battery has connected to the electricity grid in Dalian, China.

In a statement, it said the 100MW Dalian Flow Battery Energy Storage Peak-shaving Power Station has "the largest power and capacity in the world so far", was connected on 29

September and will enter into operation in mid-October. It was built and integrated by **Rongke Power Co**.

News in review – Recycling

Battery materials firm **Ascend Elements** plans to invest $310 million in Phase 1 – and up to $1 billion over several possible phases – to build a lithium-ion battery materials facility in the US.

The facility in Kentucky will be known as "Apex 1" and use the US firm's Hydro-to-Cathode direct precursor synthesis process technology to recycle black mass into lithium-ion battery precursor and cathode active material.

The plant is expected to produce enough material for 250,000 electric vehicles per year. Groundbreaking on the facility is due in Q4.

Apex 1 will feature onsite chemical recycling capabilities and a wastewater treatment plant. Ascend revealed its Hydro-to-Cathode technology in April.

Recycling firm **Recyclus Group** has been granted a UN-standard safety certification for its battery boxes that allow for the safer transportation of lithium-ion batteries.

The battery boxes have received the ADR certification P911(1), a requirement for transporting hazardous substances by road within Europe.

The certification confirms the boxes adhere to UN standards (UN nos. 3090, 3091, 3480 and 3481) for the transport of damaged or defective cells and batteries liable to rapidly disassemble, dangerously react, produce a flame, a dangerous evolution of heat, or a dangerous emission of toxic, corrosive, or flammable gases or vapours under normal conditions of transport.

Finnish battery recycler **Fortum Corporation** said it set up a German subsidiary, **Fortum Batterie Recycling GmbH**, to provide EV battery recycling in central Europe.

It said it is "a major step forward" in its ambition to become Europe's top recycler of EV batteries and battery materials. The new company will address the European automotive and battery manufacturing industry's rising demand for battery raw materials.

Belgian battery materials production and recycling company **Umicore** inaugurated its production facility for cathode active materials for EVs in Nysa, Poland.

It claimed this makes Umicore the first company in Europe with a complete circular and sustainable battery materials value chain.

The Gigafactory will supply battery materials to Umicore's car and battery cell customers in Europe.

Battery recycler **RecycLiCo Battery Materials** and its R&D partner **Kemetco Research** announced that the leach section of a demonstration plant project achieved over 99% extraction. Lithium, nickel, cobalt, and manganese all came out of lithium-ion battery production scrap.

During the demonstration plant's leach stage testing, various operating parameters were investigated to determine the optimal conditions for ongoing commercial plant design and planning. Analysis of a range of leach data showed the successful extraction results.

RecycLiCo said the demonstration plant has leached a few tonnes worth of li-ion battery production scrap, the primary source of recyclable materials. The scrap material comes from losses in the battery cell manufacturing process due to incompliant quality.

Italian battery recycling company **Spirit** developed a recovery process to obtain active cathode powder (black mass) from end-of-life $LiFePO_4$ (LFP) lithium-ion cells. The technology, developed at the company's Chiampo plant in collaboration with an Italian university, produces recycled powder for use in new cells.

How batteries can save the world

And now for something completely different…?

In previous articles in this series technical editor Dr Mike McDonagh looked at applications for energy storage systems (ESS) – from pumped hydro to lithium-ion. In this article he will be looking at the new and emerging electrochemical storage technologies to see if they can bring some advantages to challenge for the energy storage crown.

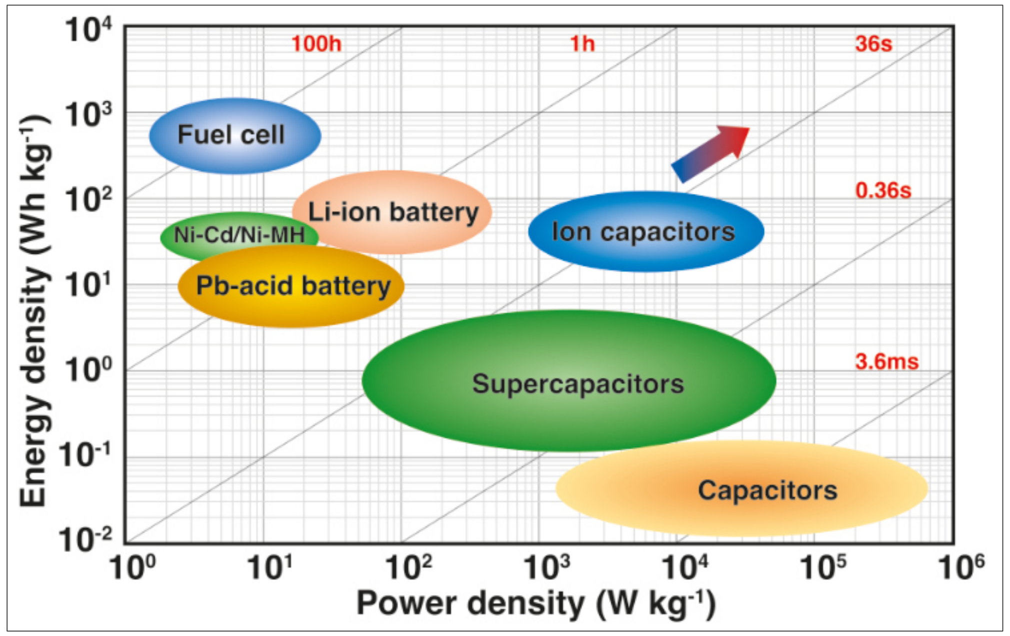
So far in this mini-series of articles, we have examined the current methods used to store energy to supply grid electricity. From pumped hydro to lithium-ion batteries, it was shown that electrochemical methods offered the most cost-effective, and versatile solution. The articles that followed have looked at the commercially available electrochemical alternatives for energy storage applications. These included flow batteries, traditional technologies such as lead-acid and nickel metal hydride, as well as the more modern lithium-ion range of battery chemistries.

It was concluded that, bearing in mind the nature of the application, the energy density benefits of the lithium-ion chemistry did not provide any real advantages. This was based on the conclusion that the majority of energy storage installations did not have significant weight or volume restrictions. In fact, the advantages of the alternative technologies lay in the lower carbon footprint, lower capital cost and better recyclability when compared to lithium-ion batteries.

Pursuant to the last feature, this article will be examining the new and emerging electrochemical storage devices, to see if they can bring some advantages over the existing contenders for the energy storage crown.

The applications for energy storage technology have been covered in previous articles. The important aspect, particularly for electrochemical methods, is the performance requirements for these applications. For the majority of uses, including commercial, grid, community, and residential purposes there is one common element – to store

Fig 1: Ragonne plot for various electrochemical energy storage technologies



energy when plentiful, and to release it when it's needed. That said, there are other requisites relating to the economic efficiency of the operation. Other parameters will also contribute to the effectiveness of an ESS. These can be summarised as follows:

- Storage capacity (autonomy)
- Round-trip efficiency from charge to discharge (RTE)
- Response time
- Financial return on investment (ROI)
- Capital cost
- Lifetime and cycle life
- Stand loss
- Carbon footprint of manufacture and lifetime maintenance (cradle to grave emissions)
- Present and future availability of raw materials

Table 1 lists the EU funding projects for BESS in 2018.

Emerging energy storage technologies

Searches of the literature reveal an apparent proliferation of new types of electrochemical storage, ranging from bendable and wearable batteries, to using the electron exchange of photosynthesis to turn forests into huge untapped sources of electricity. Although the latter idea seems far-fetched, it may be worth pursuing simply to slow down the rate of global deforestation, however impractical it may be. This highlights the need to place some restrictions on the scope of the new technology review. It must be scalable (to several MW and MWh of output and storage), transportable, not be location specific (as with dams), it should have good cycle life and low initial cost. Ideally, it should also be economically recyclable and be manufactured from accessible, sustainably sourced materials.

There are battery technologies that appear to meet these criteria, some claimed to be at or near to commercialisation, although a large pinch of salt is needed in some cases. The findings so far are based on flow batteries, solid electrolyte lithium-ion chemistries, alkali metal-ion chemistries, high temperature operation and all-solid constructions.

Unsurprisingly, the majority of new battery development centres around EV batteries where energy density and rapid charge acceptance are the most important features. As already proposed, this is not necessarily the case for ESS batteries. Using the following categories, we can list those technologies that are currently in the development stage:

- Lithium based chemistries, including LiO_2, LiS, SS lithium
- Flow batteries
- Aqueous batteries
- Dual-ion batteries

Technology	€ Worldwide	€ Europe
Lithium-ion	2,049,496	431,009
Flow batteries	322,148	3,880
Undefined	299,297	
Sodium-based	218,600	47,620
Lead-acid	173,937	15,685
Nickel-based	32,385	3,000
Metal-air	19,588	
Other	200	
Total	**€3,115,651**	**€501,194**

European Commission - N° ENER C2/2015-410 Support to R&D strategy for battery-based energy storage Technical analysis of ongoing projects (D12) - Final version

Table 1: Operational and announced capacity in kW according to DOE database (March 2018)

- Sodium-ion batteries
- Zinc-air batteries
- Aluminium-ion batteries
- Aluminium-air batteries
- Potassium-ion batteries

Unfortunately, the sheer weight of information available for these technologies makes an in-depth investigation for each impractical for one edition. For this reason, there will be a selection of battery types subjected to scrutiny, in this and in subsequent articles.

For this edition, the categories of lithium-based, flow and sodium-ion constructions will be covered. The selection process for these choices is not rigid; it is based partly on how close the roll-out of the technology is to commercial realisation, as well as its technical appropriateness.

There are, naturally, many claims (by various companies) concerning the state of readiness of these technologies.

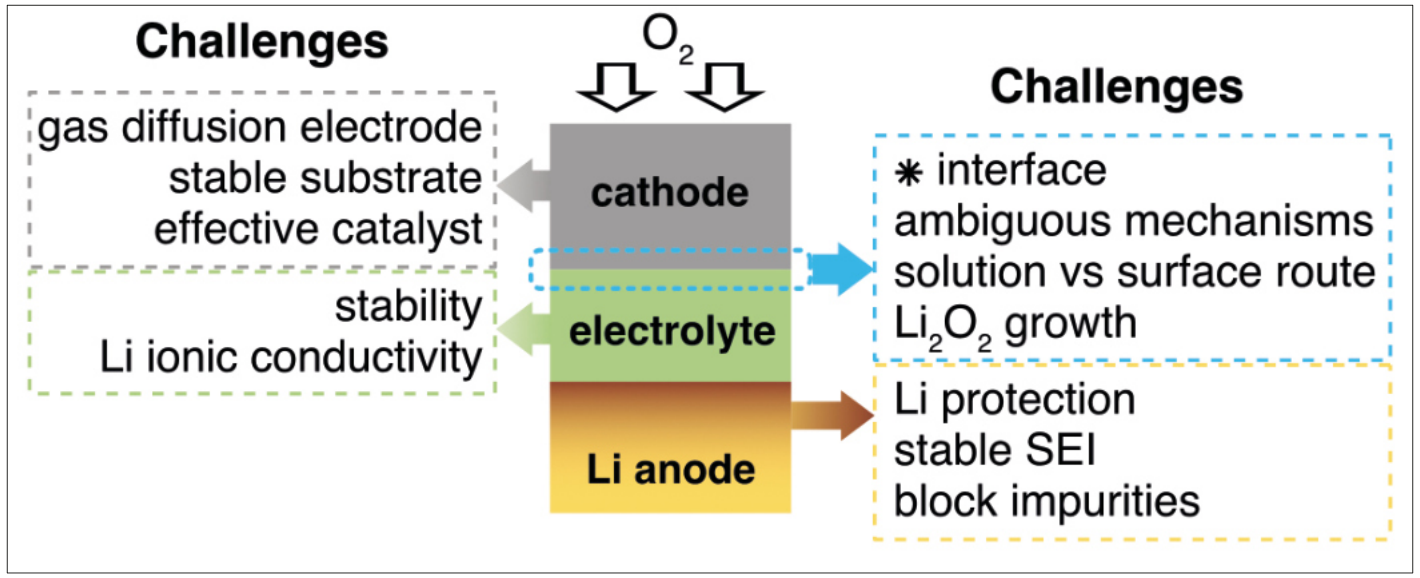


Fig 2: Schematic of challenges encountered with lithium-air batteries

It is difficult to assess how accurate the claims are and what resources are necessary, or available, to move onto that next vital stage of commerciality.

However, without spending months on detailed tail-chasing to track down the status of these companies, we can look at the technological barriers that these new designs are facing, and the methods used to overcome these difficulties. We can then make some sort of estimation of their state of commercial readiness.

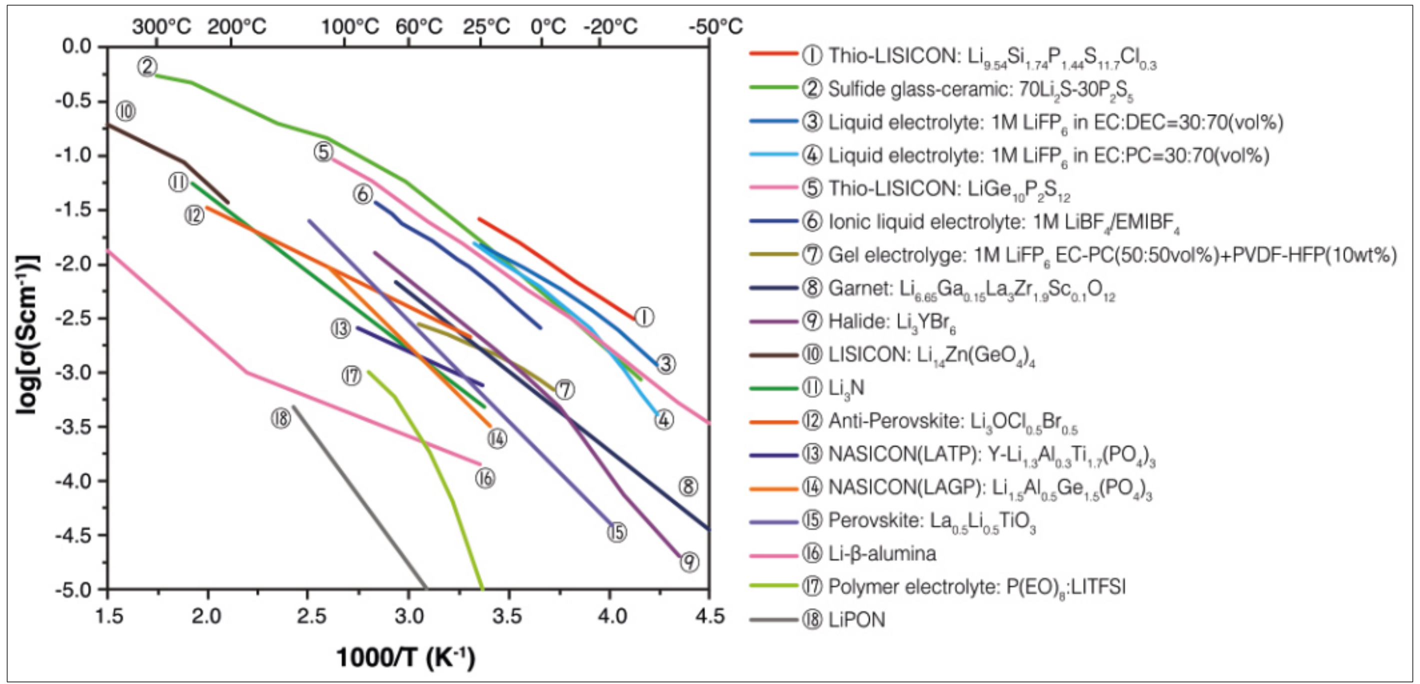
Additionally, within the above headings there are subgroups of differing chemistries or constructions that have claimed technical, environmental, or financial advantages. In some cases, the chemistries have been around for many decades but there are historic hindrances that a particular company may claim to have overcome. These aspects will be taken into account in the evaluation and, hopefully, some sense of the feasibility for that technology to make it to commercial reality can be gleaned.

The simplest approach is to look at each of the above battery types in turn. For this, we begin with the lithium group of batteries. The lithium-ion categories are pretty well known, and several variants such as LCO, LMO, LFP even more so, particularly for EV use.

The main performance challenge for this construction is the increasing need to extend the driving range of EVs. This means further increases in energy density, usually by either stuffing more lithium into the cathode – involving further materials science advances in electrodes – or increasing the voltage difference between the anode and cathode. As mentioned, energy density is a lesser consideration for a BESS installation. Other factors that are more relevant to BESS requirements are the cost, cycle life, energy efficiency, safety, and recyclability. In these respects, there are still major challenges confronting lithium-ion batteries.

The first lithium candidate is the LiO_2 cell. Usually air/oxygen cells are not rechargeable. However, advances in materials science in the first decade after 2000 revived interest in a technology dating back to the 1970s. Originally proposed as a possible power source for battery electric and hybrid vehicles, lithium-air batteries recaptured scientific interest late in the first decade of the 2000s due to advances in materials science. The potential specific coulombic density is high, compared to other metal-air systems, around 3.8Ah/g vs 0.82Ah/g for zinc metal air. This makes it a very attractive prospect for EV use.

The way it works is that under discharge, electrons follow the external circuit to do electric work and the lithium ions migrate to the cathode. During charge the lithium metal plates onto the anode, freeing O_2 at the cathode, ***Fig 2***. There is a non-aqueous option with Li_2O_2 or LiO_2 as the discharge products, and an aqueous version where



LiOH is the discharge product. Both of these variations have been considered for LiO_2 batteries. The aqueous battery requires a protective layer on the negative electrode to keep the lithium metal from reacting with water. There are operational problems: charge reversibility is one, where a Li_2O_2 passivation layer forms on electrodes in surface oxidation reactions. Then (as always), the formation of a stable SEI and an effective catalyst are yet to be resolved. In addition, O_2 recovery is not good. For this reason, high DN DMSO solvents are employed to improve O_2 recovery efficiency.

However, solvent decomposition due to increased lifespan of super-oxides in high DN solvents seriously reduces the battery life. Since this article is considering energy storage with the requirements previously listed, and not for EV use, it can be filed under the heading of 'limited interest'.

There is significant interest in a solid-state lithium-ion battery, and there are companies now claiming that they have all-solid-state lithium-ion batteries. These include gel as well as solid electrolyte constructions. Generally, solid lithium metal cathodes are included in this category. The well-known safety issues with liquid solvent-based electrolytes are the main driving force to develop safer battery constructions. A solid electrolyte version of the LiO_2 type described above is also currently under investigation. However, it is not yet near commercial status.

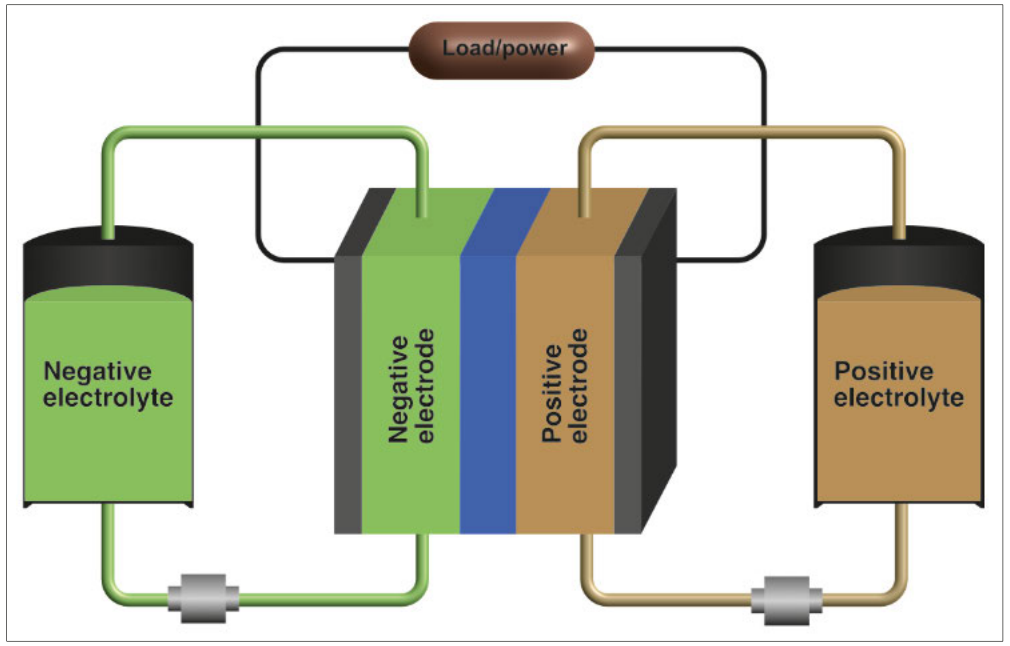
For EV application, the ultimate solid-state lithium-ion battery would replace the traditional anode material with a solid lithium anode, as well as solidifying the electrolyte. This increases the amount of lithium ions available and raises the theoretical coulombic capacity to

Fig 3: Properties of various solid electrolytes

3.86Ah/g. Again, not a critical factor for energy storage but of vital importance in the EV market.

The other main advantages of an all-solid-state lithium-ion (SSL) battery are the prevention of dendrite growth and the absence of a flammable electrolyte. Typical electrolytes under investigation are oxide types such as Ta/Ga/Nb-doped garnet, $Li_7La_3Zr_2O_{12}$. These have a Li^+ conductivity of 10^{-3} S cm^{-1} at room temperature, but suffer from poor wettability with the electrodes, i.e. a high resistance interface ***Fig 3***. Polymer electrolytes should, in theory, enable better contact at the electrode interfaces due to their flexibility and ease of manufacture. Unfortunately, they suffer from low conductivity at room temperature and poor thermal stability.

The problems associated with SSL batteries have been covered in previous articles in *BESTmag*.



However, a simple summary would be:

- Poor electrode/electrolyte contact or adhesion (high resistance, particularly in all-solid lithium-ion cells)
- Low conductivity of the electrolyte at room temperature
- Dendrite formation, particularly with solid lithium
- Large volume changes in the lithium anode on charge and discharge creates voids in a solid electrolyte
- Sulphur-based electrolytes are unstable in air, particularly where there is humidity
- High manufacturing cost of the electrolyte
- Polymer electrolytes have low conductivity and poor thermal stability

Fig 4: Redox flow schematic

Redox flow batteries (RFB)

Fig 4 shows the principle of operation for redox flow couples. There are several types currently in operation, mostly zinc- and vanadium-based chemistries. The advantages of this group are that they have a relatively high cycle life, they use abundant, non-toxic renewable materials that are recyclable and are potentially low cost compared with alternative chemistries.

However, there are some issues that still provide speed bumps along a widening pathway to energy storage heaven. These are mainly the low energy density, complexity of the pumping system, and electrolyte operational contamination. This has resolved into a maintenance and capital-cost question that most near-commercial companies claim to have resolved, without significant cost increase.

However, despite benefitting from low-cost maintenance, RFB deployment remains a modest fraction of proposed and operational global energy storage systems. This is primarily due to the high upfront costs of vanadium-based RFB systems. In particular, the high price of vanadium is at the root of the high electrolyte cost of around $125/kWh. Compare this with the USDoE target for an installed total system cost of $100-150/kWh and it is evident that VRFBs are enjoying an increasingly high take-up quota for ESS because of their long life and low maintenance costs, all providing a low LCoE.

For this reason, the focus for RFBs has been on lower-cost abundant redox couples, including zinc, iron, and chromium. There has been progress in use of these materials, particularly zinc-based systems, which appear to be at or near commercial status. The use of zinc has been covered in a Winter 2021 *BESTmag* article (It's time for zinc to swim). For these reasons, this article will examine iron-based RFBs, both iron/iron and iron/chromium couples.

Iron flow

In this chemistry, iron is used in two dissimilar electrolytes, each one containing iron in a different oxidation state. ***Fig 5*** shows the principle of operation whereby on charge the iron (as a dissolved chloride) is reduced at the negative electrode and oxidised at the positive electrode. This is reversed on discharge.

The overall reaction is

$$3Fe^{2+} = 2Fe^{3+} + Fe0$$

There are problems associated with this chemistry. Proton

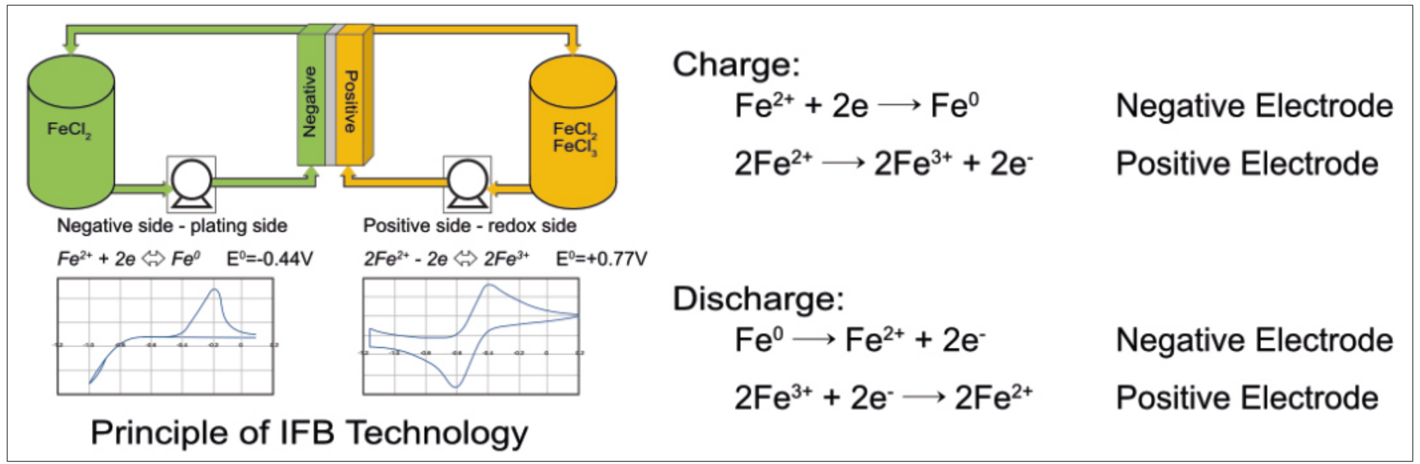


Fig 5: Iron/iron redox battery

reduction on the positive side causing hydrogen gas and loss of H^+ ions result in an imbalance in the electrolyte. This has been potentially solved by adding a proton pump to convert hydrogen back to H^+ ions. The current status of the all-iron RFB is that sales of microgrid containerised units of around 12 hours' operation have been supplied for 34 households, with a backlog in production. There is a planned large-scale unit, 150 x size of container units in partnership with Portland General Electric later this year. (MIT)

Iron chromium

Originally the brainchild of NASA in the 1970s, followed up by MIT, it has a price advantage over vanadium RFB, mainly in the electrolyte cost of around \$31/kWh. The development over time for this redox couple is shown in ***Fig 6***.

The operation principle is illustrated in ***Fig 7***. The straight chemistry involves both chromium and iron in the usual anode/cathode redox reactions. The example shown in the

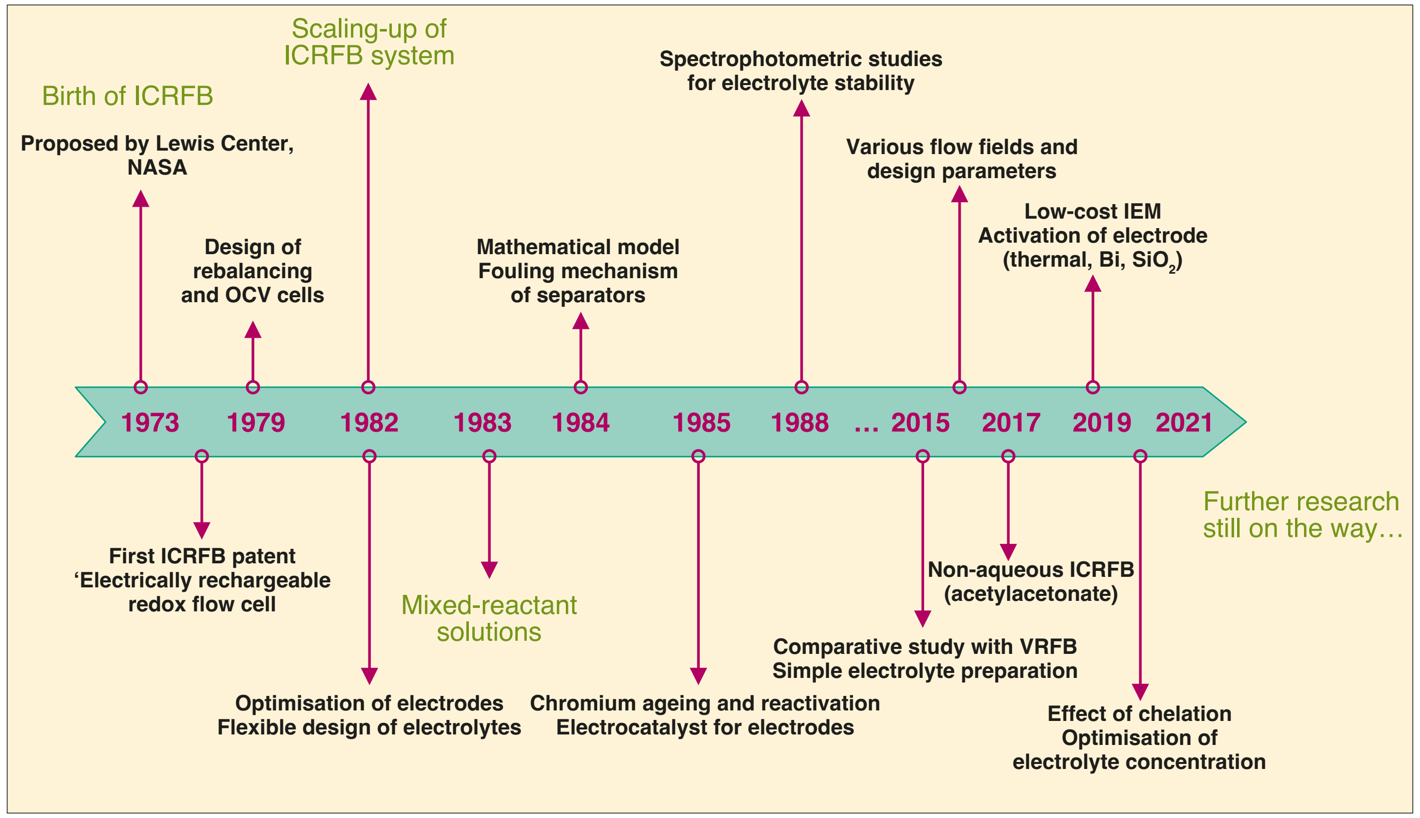


Fig 6: Development of Fe/Cr flow battery

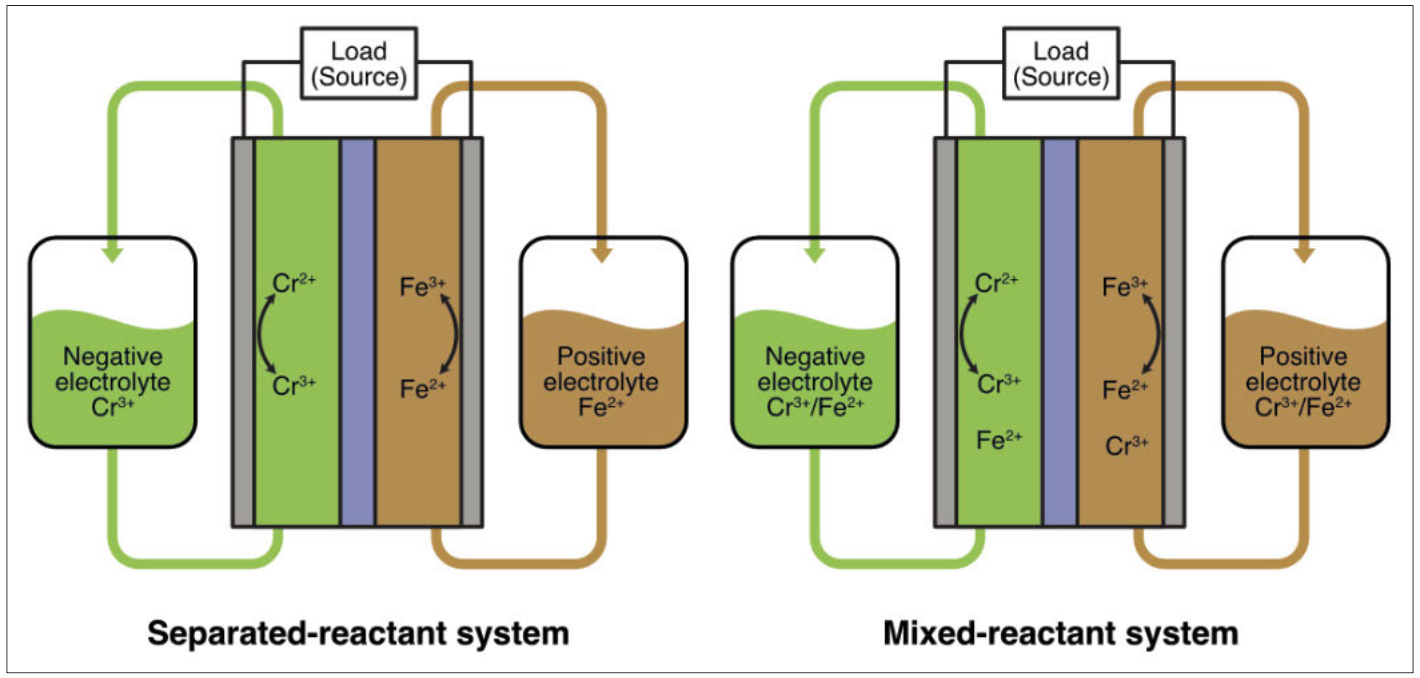


Fig 7: Fe/Cr redox flow battery

illustration gives an alternative mixed electrolyte option. This is one of the methods used to combat the ion species crossover problem encountered with many redox couples.

There are, of course, problems encountered with cross-contamination of the electrolyte. Originally, separate solutions had cross-contamination of Cr and Fe. However, it was found that elevated temperatures above 50°C were required in order to shift the equilibrium from the inactive complex $[Cr(H_2O)_6]^{3+}$, to its electrochemically active counterpart, $[Cr(H_2O)_5Cl]^{2+}$.

In addition, the negative electrode potential for the Cr redox reaction (E_o = -0.407V vs SHE) is close enough to the hydrogen evolution reaction (HER) E_o = 0V vs SHE (standard hydrogen electrode), to reduce protons to hydrogen gas. Recent reports cite HER as the cause of around 1% of capacity loss per cycle for Fe-Cr RFBs, which is 20 times more than the HER in VRFBs. The loss of protons leading to low round-trip-efficiency can be countered by purification of the electrolyte (pre-battery manufacture) to remove trace catalytic metals such as bismuth or indium. This can be achieved by chemical precipitation or electrochemical methods.

Degradation of the electrolytes leading to reduced cycle life is also related to HER and electrolyte imbalance. Methods for mitigating these problems have been developed over the last decades by commercial and start-up companies. Rebalancing is necessary and one company, Enervault, has a variety of methods claimed in their patent (Rebalancing electrolytes in redox flow battery systems, Chang, et al. December 23, 2) to facilitate this process. These can be summarised as:

- A separate rebalance cell, e.g. reducing Fe^{3+} to Fe^{2+} or anolyte, or reducing Cr^{3+} to . This provides a continuous treatment of the electrolytes
- In-tank electrolytic reaction cell. This can be either an electrochemical or a dosing treatment where the reaction tanks are immersed in the main anolyte and catholyte tanks
- Direct iron rebalancing. Excess tri-basic iron reacts with metallic iron $2Fe^{3+} + Fe = 3Fe^{2+}$
- Removal of excess $2Fe^{3+}$ by crystallisation and precipitation of a relatively insoluble species, e.g. $FeCl_2.4H_2O$

There are quite a few more related methods quoted, mostly concerned with reducing the excessive build-up of Fe^{3+} by either chemical or

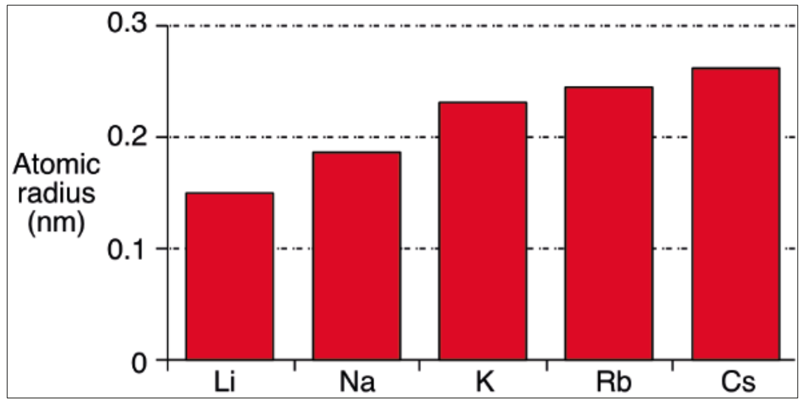


Fig 8: Atomic radii Group 1 elements (alkaline metals)

electrochemical means. There are also significant developments around the construction and materials used for the electrodes, in one case using a metal-plated, carbon substrate.

Whatever technology they are using in their commercial batteries (and believe me I have spent more time than I bargained for in searching for it), Enervault appear set to launch a larger 2MWh facility in California. This is a demonstration of confidence that they have resolved the performance and life-limiting issues still being investigated by R&D as well as commercial organisations.

Sodium-ion batteries.

Heralded as the natural successor to lithium-ion chemistries, the sodium-ion alternative is attracting a growing interest from major players in the energy storage business. It is claimed to be safe, recyclable, reliant on readily available abundant materials and much cheaper than the lithium counterpart.

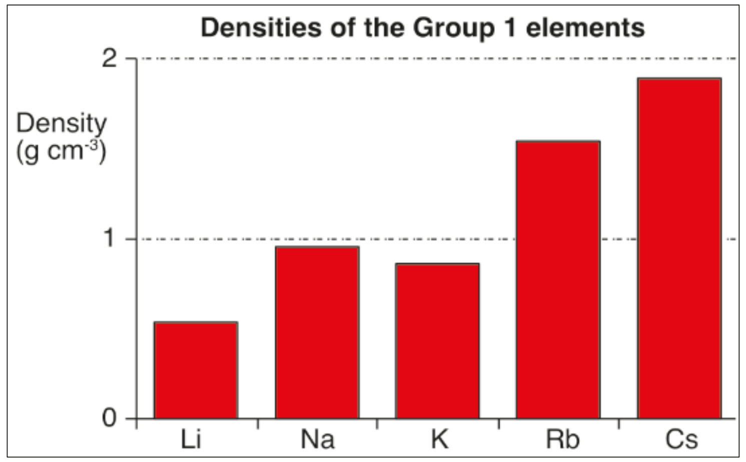
However, it has some inherent disadvantages when compared to the current market-leading lithium technology. Sodium and lithium belong to the alkali group of metals (group 1) in the periodic table. ***Fig 8*** shows the atomic radii of these elements. Why are these important? It is largely a question of how much sodium you can cram into the electrodes. Clearly, the larger the atomic/ionic radius the fewer atoms that can be accommodated in a fixed-size structure such as an oxide, mineral or carbon host. Fewer sodium atoms mean lower energy per unit volume. This applies equally to anode and cathode.

Another important spin-off from the larger atomic size is the slower diffusion of the sodium atom in solution, which decreases the transfer rate of charge through the electrolyte during higher charge/discharge applications. These factors are exaggerated when the ionic radii are considered, i.e. Na = 0.102 and Li = 0.076.

Another factor is energy density. Group 1 metals are characterised by their outer electron orbitals having a single electron. The electron shell structures of lithium and sodium are:

- Li: $1s^2 2s^1$
- Na: $1s^2 2s^2 2p^6 3s^1$

In each element, the outer electron experiences a net charge of +1 from the nucleus.



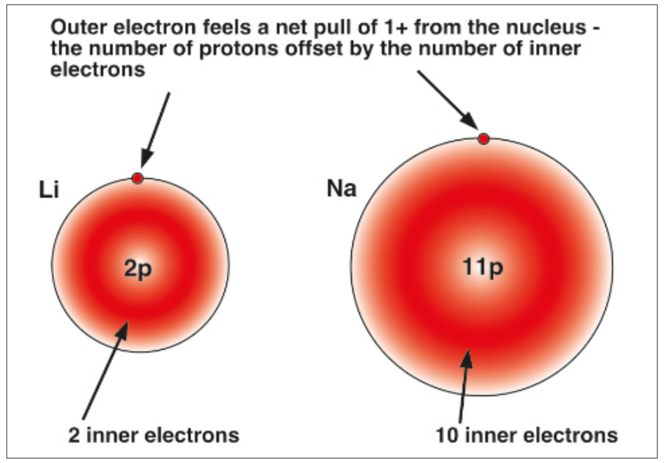


Fig 9: Density vs atomic radii of group Alkali elements

The positive charge on the nucleus is cancelled out by the negative charges of the inner electrons. The factor affecting the size of the atom is the number of layers of inner electrons which surround the atom.

More layers of electrons take up more space, due to electron-electron repulsion. Therefore, the atoms increase in size down the group. Increasing radius then affects the density of the element, ***(Fig 9)***.

This higher density of sodium, almost double that of lithium, results in a lower specific energy for the sodium-ion battery. The higher volume required for the electrodes means that the volumetric energy density is also less than that of lithium chemistries, ***Table 2***.

Much research has been instigated to find suitable electrodes to act as host materials for the sodium ions as well as for an electrolyte which allows fast movement of the Na^+ ions. This is where the size factor becomes critical. It has been found that the standard soft carbon used in the lithium-ion anodes is unsuitable for sodium intercalation, due to there being insufficient interatomic space available in the layered atomic structure. Other materials, including hard carbon and various transition metal oxides and mineral type structures, have been examined. Finding a suitable host has proved doubly tricky as the larger atom radius causes a high expansion and contraction distortion of the structure, leading to low cycle life and early battery failure.

Battery (18650 cell)	Voltage (V)	Specific energy of 18650 Li-ion cell (Wh/kg)	Energy density of 18650 Li-ion cell (Wh/L)
Graphite(C)/$LiCoO_2$ - (Li-ion)	3.7	206	530
C/$LiNi_{0.33}Mn_{0.33}Co_{0.33}O_2$ - (Li-ion)	3.6	210	530
C/$LiN_{0.8}Co_{0.15}Al_{0.05}O_2$ - (Li-ion)	3.6	285	785
C/$LiFePO_4$ - (Li-ion)	3.4	126	325
C/LMn_2O_4 - (Li-ion)	3.8	132	340
CNRS CEA 18650 cell- (Na-ion)		90	250
PNNL-WSU 18650 cell - (Na-ion)	2.7	150	375
ALISTORE 18650 cell - (Na-ion)	3.5	75	

Table 2: Specific energies and energy densities of 18650 size Li-ion and Na-ion batteries

The chemistry and electrochemistry of electrode materials for sodium-ion batteries (SIBs) are sufficiently different from that of their lithium-ion counterparts so as to delay finding candidates suitable for practical batteries until recently. ***Fig 10*** displays the schematic of a Na-ion battery cell. It has a structure similar to that of lithium-ion batteries. Laboratory test cells and representative prototype cells have been built and evaluated with hard-carbon anodes and cathode materials selected from layered transition metal oxides, transition metal fluorophosphates, and Prussian blue and its analogues.

The problem of finding a

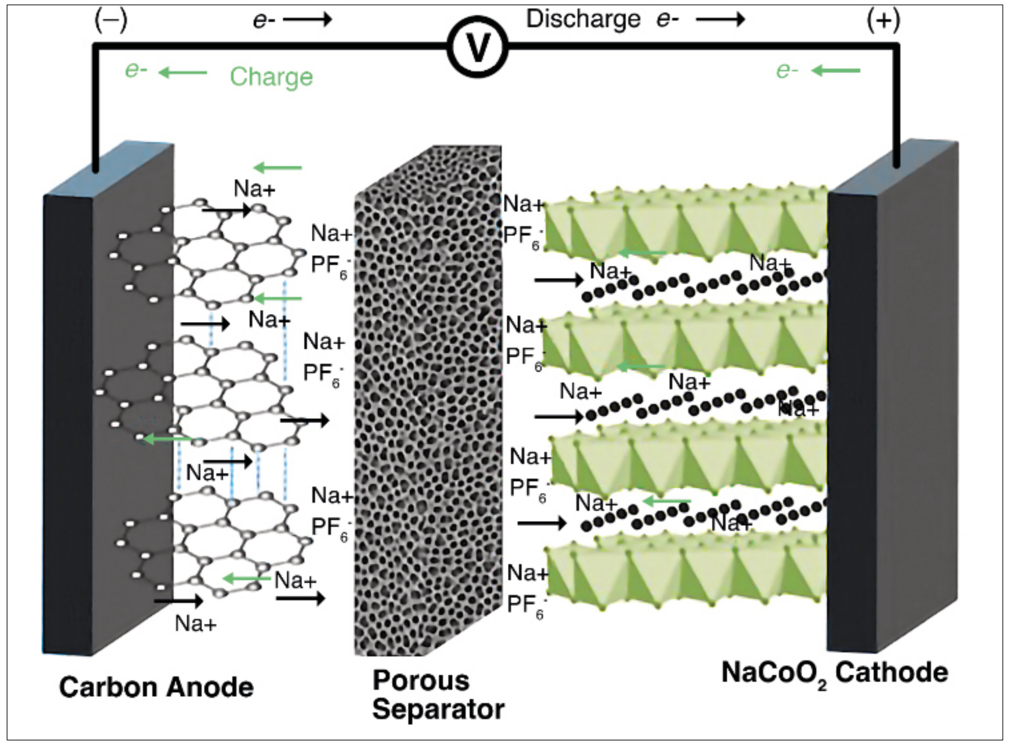


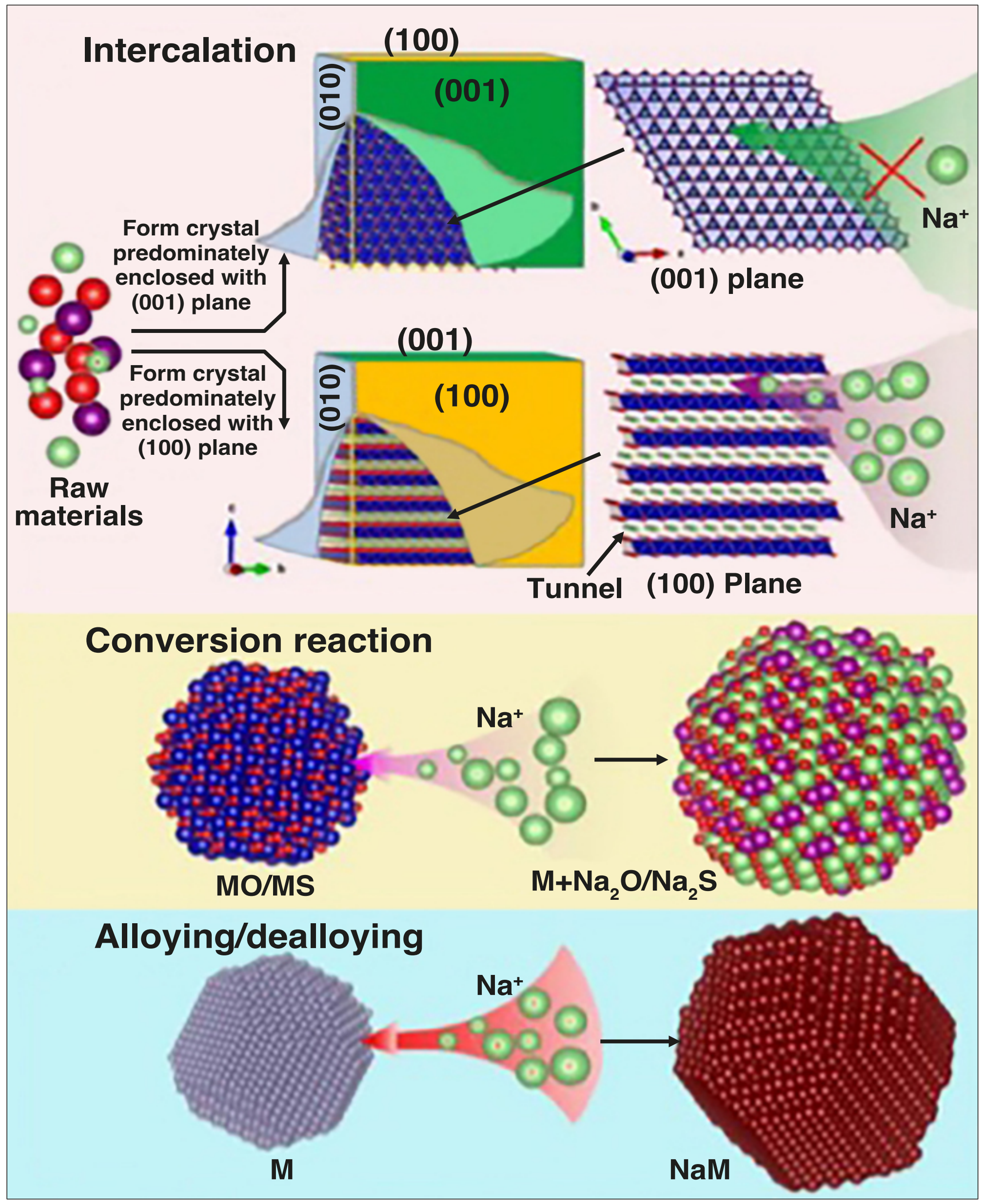
Fig 10: Sodium ion electrode chemistry

suitable host structure for Na atoms and ions is depicted in ***Fig 11***. Any crystalline structure has different interstice spaces depending on the plane of orientation of the lattice. In this diagram the (100) plane provides the sodium ion sufficient space to move. Even with a conversion or alloying mechanism the volume change is likely to be very large.

The type of electrolyte is also receiving critical attention due to the reduced mobility of the Na^+ ion because of its comparatively large size compared to that of lithium. This puts some limitations on the chemical makeup of the electrolyte.

Aqueous electrolytes, favoured for their non-flammability properties, do not perform so well with the larger highly electronegative Na^+ ion. Dissociated H_2O molecules are highly polarised and would exert a drag factor on the sodium ion. This, combined with higher viscosity, creates an electrochemical and physical impedance that reduces the battery's performance.

For this reason, much research has been conducted with electrolyte solvents similar to those used in lithium cells. They are composed of cyclic carbonates such as ethylene and propylene carbonate (EC and PC), and linear carbonates e.g. dimethyl, ethyl methyl, and diethyl carbonate (DMC, EMC and DEC) as solvents. These are usually combined with 1 M $NaPF_6$, again similar to the lithium model. The viscosity and conductance variation of two electrolytes with temperature,



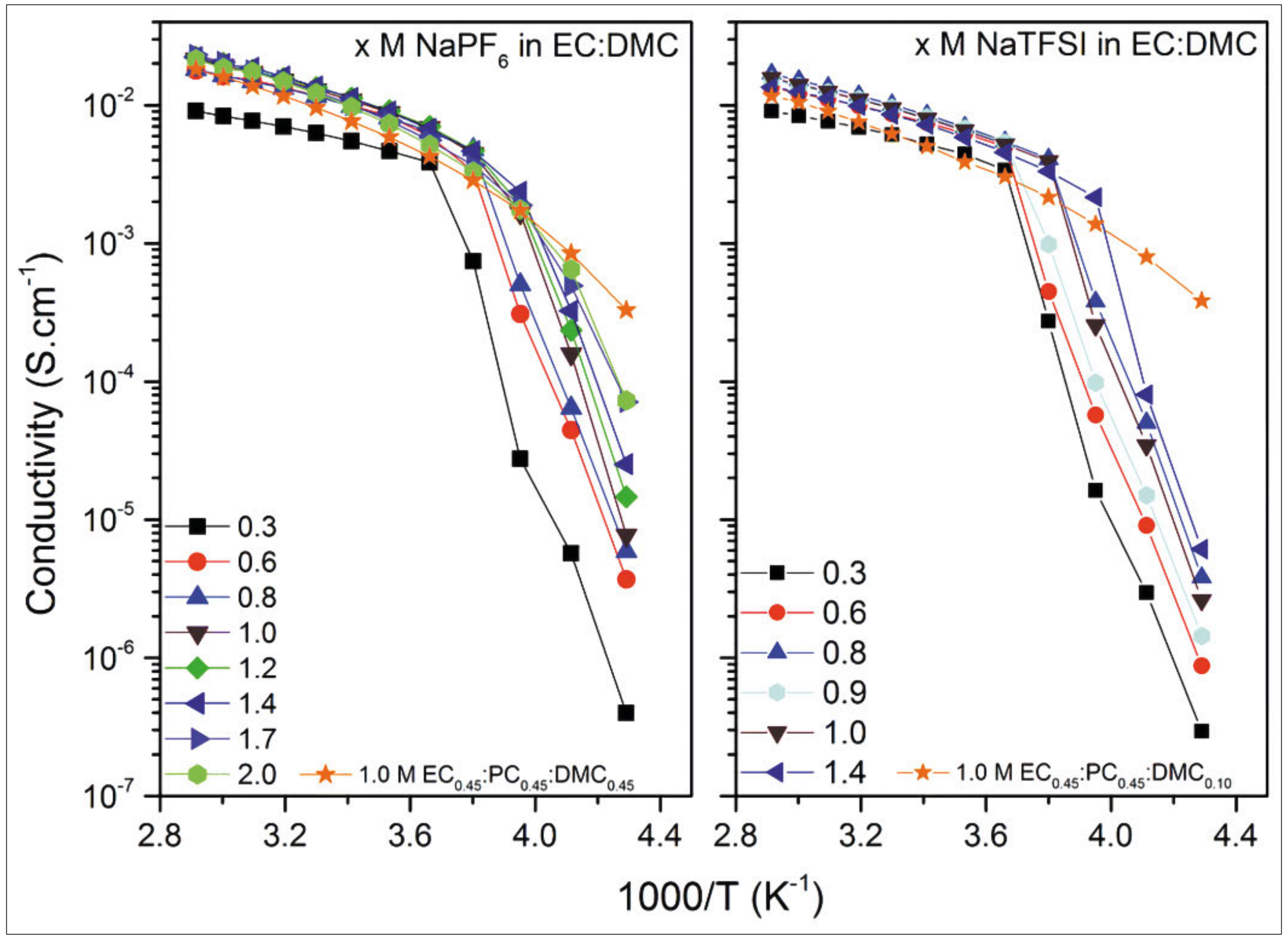
are given in ***Figs 12*** and ***13***.

Electrolyte considerations also lead to further lithium comparison, with the formation of a solid electrolyte interphase (SEI) layer for SIBs. There is not a lot of detail in the literature regarding this vitally important consideration. Formation of an effective SEI relies on the electrochemical stability windows (ESWs) obtainable for SIBs using these types of

Fig 11: Problems in finding a suitable host electrode for sodium irrespective of the chemistry, due to the atomic radius

electrolytes. Using ether-based solvents has resulted in instability of the SEI in SIBs.

Research by Pacific Northwest National Laboratory (PNNL) has resulted in an electrolyte – sodium bis(fluorosulfonyl)imide (NaFSI) salt in a solvent mixture of dimethyl carbonate (DMC) and tris (2,2,2-trifluoroethyl) phosphate (TFP). It is a low-solvation electrolyte (NaFSI/DMC:TFP) designed to operate in



4.2V high-voltage SIBs. PNNL claim that this provides an SEI layer stable over 300 cycles, ***Fig 14***.

Despite the problems of electrodes and electrolyte for SIBs outlined above, companies are claiming to be at, or very near, commercial readiness with their products. There are companies, e.g., AMTE, who have press releases indicating that they are in a position to supply large-scale batteries for energy storage. Naturally they do not give any indication as to the nature of the materials used in their batteries to overcome these obstacles. However, their press

Fig 12: Arrhenius plots of ionic conductivity between +70°C to -40°C for x M NaX in EC:DMC and 1.0 M NaX in $EC_{0.45}$:$PC_{0.45}$:$DMC_{0.10}$ for concentrations (x) ranging between 0.3-2.0 M for $NaPF_6$ and 0.3-1.4 M for NaTFSI

releases do display a high level of confidence, and, as I am sure you will all agree, confidence is generally far more ubiquitous than evidence.

Summary

This article has examined a small sample of the emerging battery technologies being considered for large-scale energy storage. Whilst much research is still centred on energy density, it is not that important for energy storage, where cycle life and capital cost are the prime drivers for its adoption. With this caveat, the drive to install higher energy density lithium-ion chemistries seems somewhat irrelevant. Additionally, looking at global supplies of the relevant transition and alkali metals, it is better for lithium-ion commercial development to concentrate on the EV market.

Whilst there is a great interest in flow batteries, due to the projected lower costs and cycle life, there is, as yet, no real evidence of long-term commercial installations matching the publicity claims.

Sodium-ion also has projected safety, cycle life and cost advantages over lithium-ion but, as yet, there is a lack of field data, publicly available at

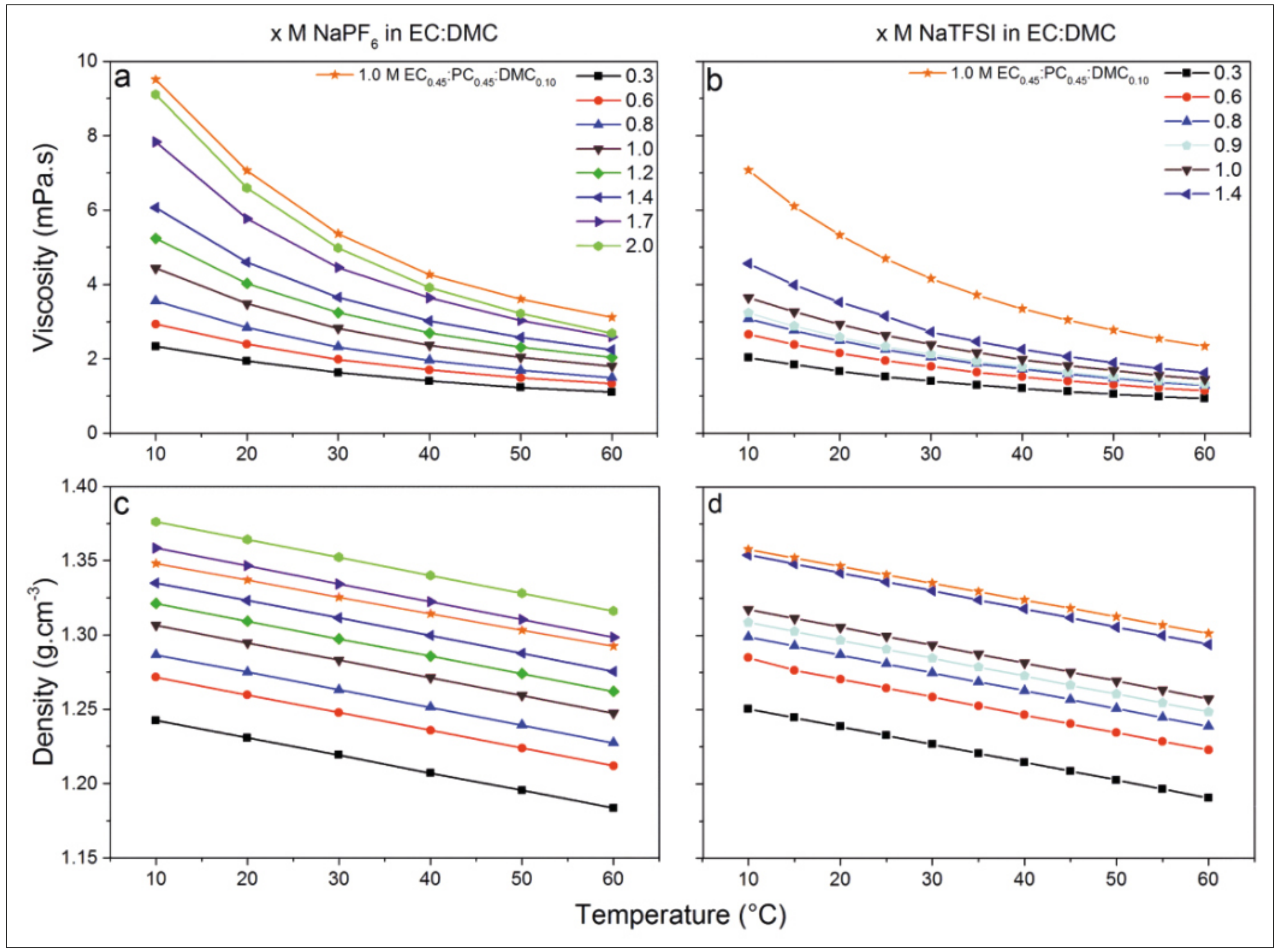


Fig 13: Dynamic viscosities (top) and densities (bottom) between +10°C to +60°C of x M NaX in EC:DMC and 1.0 M NaX in $EC_{0.45}$:$PC_{0.45}$:$DMC_{0.10}$ (left: X = PF_6, right: X = TFSI) for concentrations (x) ranging between 0.3–2.0 M for $NaPF_6$ and 0.3–1.4 M for NaTFSI

least, to substantiate these claims.

As an ardent exponent of safe, sustainable energy storage for grid applications, I would hope that the claims of 10,000 cycles and costs of $50-100/kWh can be made a reality. It is capital outlay, and LCoE that will be the driver for all countries and economies to adopt BESSs as a cost-effective solution to stabilise energy supplies and achieve global carbon reduction.

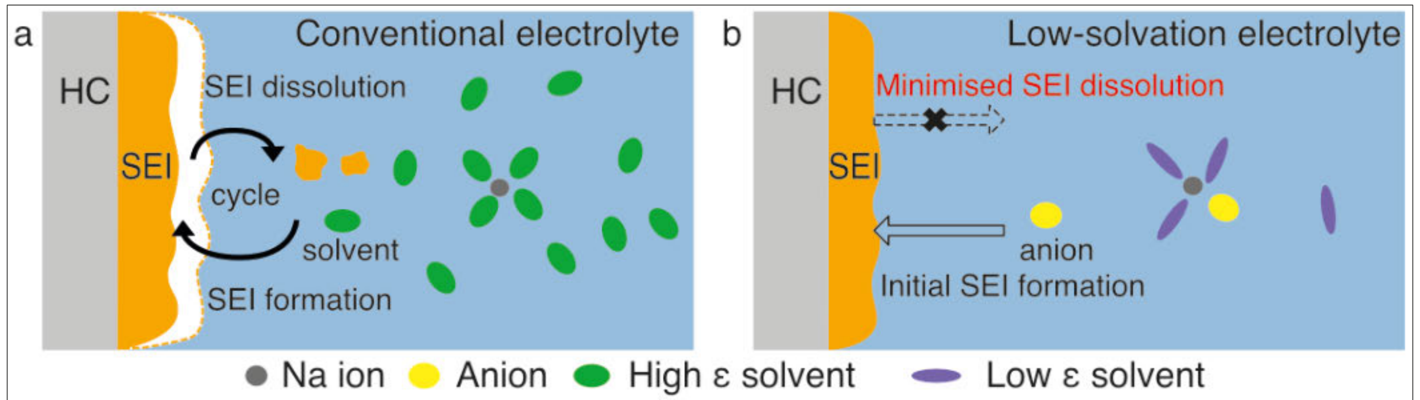


Fig 14: Benefit of low solvation electrolyte for stability of SEI

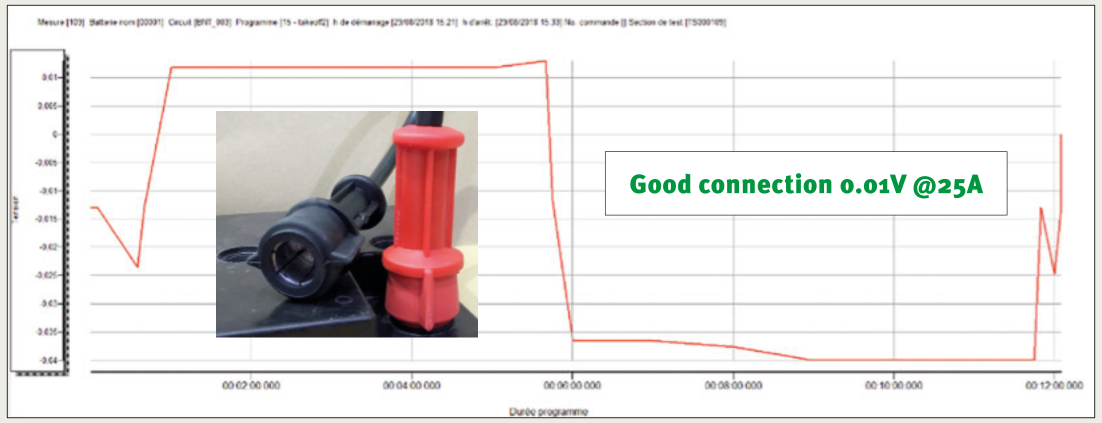
Connect your battery factory to millions of dollars of immediate energy saving

This is not hyperbole, not exaggeration and not even marketing. It is plain fact. Want to know how? The simple, overlooked battery formation connector holds the key to making millions more in your factory profits.

Did you know that your formation department consumes at least 50% of the energy used to power a standard lead-acid battery factory?

Are you also aware that the energy use depends upon the total resistance of the many battery charging circuits, constantly in use 24 hours a day.

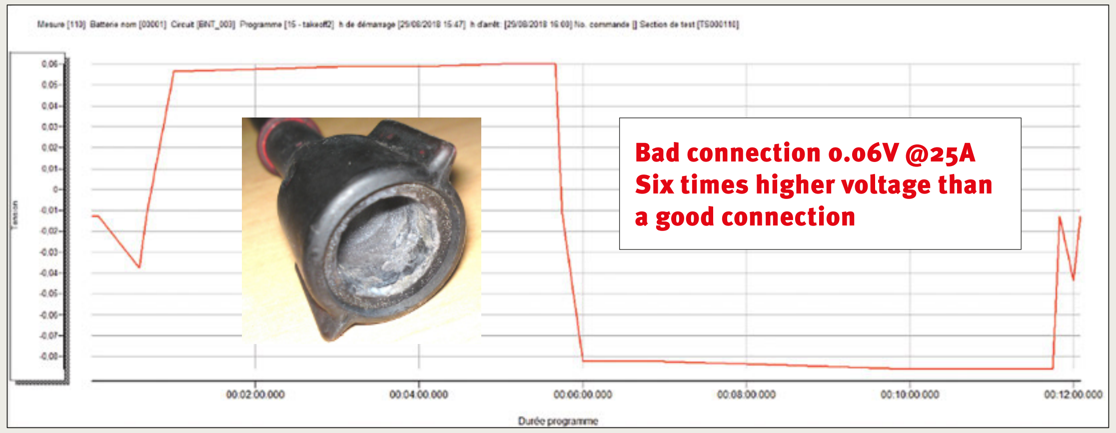
Do you also know that there is a direct linear correlation between increases in formation circuit resistance and the energy usage of a battery factory?



The reason, very simply put, is electrical resistance and its effect on the energy used during the formation process. The higher the connector resistance – the higher the energy bill.

The higher the connector resistance the higher the voltage and the higher the energy losses.

The higher currents and temperatures lead to faster corrosion and deterioration of the connector heads, which in turn increases the incidence of sparking, tracking, battery damage and even fires.



Are you aware of the causes of resistance in the formation circuits? Its effect on energy use, costs, factory output, battery damage, heat generation, CCA performance etc.?

In the last 15 years, the throughput time for SLI batteries in the battery formation process has more than halved. Consequently, formation currents have more than doubled meaning higher formation voltages and temperatures. New techniques of water cooling and acid recirculation have developed to enable this transition. The world has changed, but the standard formation connector has not.

Increasing economic uncertainty, rising energy costs, and diminishing margins, make manufacturing industries, including that of lead acid batteries, more vulnerable to financial loss.

One clear solution is to ensure low resistance connections. This is done partly by maintenance practices, partly by a scheduled replacement plan, and partly by modernising connector designs. The main message is:

'Focus on the importance of the formation connector'

In the present economic environment, the energy losses could be doubled, giving over 500,000 USD per 5 million batteries for an SLI manufacturer. The cumulative losses including scrap, damage and lost output, substantially exceeds 1 million USD for the same factory.

And now the good news: UK Powertech have identified all of this for you. They have also gone further: they have proved and costed every one of the benefits that arise from reducing connector resistance.

These cost benefits are not theoretical. They were established in field trials with major international battery manufacturers.

UK Powertech can help your company increase profits, reduce scrap and battery rework whilst improving product throughput and quality. This is not marketing, this is not hype; it is proven fact.

The equation is very simple: Formation is half of a lead-acid battery manufacturer's costs. The resistance of a connector directly increases the voltage according Ohms law:

V= IxR Double the resistance and you double the voltage.

Power = VxA = W **Energy = Power x time = Wh**

UKP has conducted years of R&D combined with field trials to understand the magnitude of the problem and to find cost effective solutions to help prevent connector deterioration and improve connector design. These measures have been proved in field trials, to save energy and prevent battery damage.

- **A simple solution to gain higher profits is to ensure low resistance connections**
- **The key is the formation connector**

Competing with the multinationals

In a rapidly changing business environment the ability to adapt is crucial. *BESTs* technical editor, Dr Mike McDonagh, interviews Ravi Govindan, owner of Microtex Energy to find out how a privately owned SME has been able to compete in a global battery marketplace.

The lead-acid battery industry has seen considerable evolution since the beginning of the 20th century. This has been largely due to advances in the engineering and chemical industries, enabling processing and product improvements unimaginable to the early manufacturers. The last 25 years, however, have seen an unprecedented shift in the global marketing and commercial model, from family and national enterprises to multinational expansion and new applications.

The larger companies with global reach enjoy well-funded R&D facilities, higher levels of capital investment in manufacturing equipment, and lower raw material costs. In fact, almost all have their own lead recycling facilities, which drastically reduces their product cost: lead accounts for roughly 65% of a battery's manufacturing expenditure. Despite this, there are still some smaller, often family-owned lead-acid battery factories, that are not only surviving but thriving in the present commercial landscape. This article examines one such company.

One company, a long-standing client of mine, Microtex Energy Pvt. Ltd. is an exemplar of how an SME, manufacturing industrial lead-acid batteries, can succeed in an increasingly polarised arena. Based in Bengaluru, in the state of Karnataka, India, they have been manufacturing since 1969. During this time, they have seen a rapidly changing global framework that brought in new market demands, requiring both product and strategic adaptations. Microtex proved that they were up to the challenge. Despite some serious speed bumps, they have managed to find their commercial bearings despite the current anxiety over lead-acid's future.

It is important not to underestimate the volatility of the present market conditions. Lead acid is under attack in almost every sector. The once-believed sacred cow of SLI is becoming more and more insecure as increased EV take-up and rapidly declining li-ion KWh prices begin to lap closer to lead-acid's shoreline. This encroaching presence of li-ion in all industrial sectors has even reached the forklift truck market. FLT manufacturers see a commercial advantage in tying the truck to the battery for life. This is easily achieved with the electronic controls associated with li-ion technology. In such a bleak landscape it is hard to understand how an industrial lead-acid manufacturer could survive, let alone prosper.

The Microtex team in Bangaluru, India

But prosper they have. To shed light on their accomplishment, I decided to visit the owner, Ravi Govindan, Chairman and Managing Director and owner of Microtex Energy, at his Bengaluru factory. I stayed for over a week, drawn as I was, into one of the company's battery development projects. It was also an opportunity to see first-hand how the staff went about resolving the challenges of introducing a new product. On top of this, I was keen to see how the company's non-manufacturing facilities, e.g. laboratory, purchasing and development resources would be integrated into the overall project strategy. For this reason, my stay at the factory was extended by a few days so that I could witness the process and outcome at first-hand.

As a matter of record, there was a team appointed with VP Production, Madhu, acting as team leader. The new product was a small 12V AGM 7 Ah deep-cycle battery, used mainly for burglar alarms and small standby power systems. The problem was the assembly of components that were smaller than anything ever seen before in this factory. Fortunately, the multi-grid mould had already been made, and the casting, curing and formation processes were already established. The next phase was to assemble the packs with wrapped AGM into the 3 x 2 layout, then cast on the strap and push the assembled groups into the box for heat sealing, followed by formation and initial testing. Commercial confidentiality prevents me from giving any more detail, but I can reveal that during a period of one week, a couple of COS jigs were made up and modified after the first test. Trials then continued with lug preparation methods, and two electrical testing phases. By the end of my stay, a fully functioning, consistently performing, 7.6 Ah battery had been successfully manufactured. As a bonus, the production rates were commercially respectable. Throughout this development programme, the team of engineering, production, technical and QA gelled perfectly. It is also worth noting that the owner and MD, Ravi Govindan was an integral part of the process, looking at every small detail, as well as making significant contributions to the whole process.

Ravi Govindan with Microtex product and saplings

This anecdote sets the scene for the main text which is the interview. In this, I drilled down on Ravi to uncover how, in such a rapidly changing commercial environment, he could identify and then steer the right course for his company. The interview is given below, and whilst redacted, it does clearly indicate what lengths he has been willing to go to, and how much has been invested, to future-proof Microtex.

McDonagh: Ravi, can you give a brief history of how your factory and business was founded?

Ravi Govindan: Microtex was founded in 1969 by Mr A Govindan, a first-generation entrepreneur, founder and promoter. When the industry was using inefficient and technologically outdated wooden/rubber separators in

Fully automated, state-of-the-art gauntlet-weaving machine

India, he was a visionary with values. He has several inventions to his credit and is highly regarded in the battery industry. When glass tubes were imported to manufacture tubular plates, he produced the first PT Bags in India. In 1975, he received a patent for his invention. Building a team of highly experienced and committed employees to create better storage batteries was his dream.

He cared for the environment very early on and took measures to ensure that the battery manufacturing was done with clean and green processes. Always, he kept abreast with the latest battery-making machinery and techniques. He employed world-leading battery consultants to passionately update manufacturing processes.

In recognition of his contributions, he has received various awards including the prestigious Udyog Patra from the President of India. He started the production of lead-acid batteries in 1977 and exported annually over 4,000 traction batteries to the USSR.

And what about the company? Please tell me more about it.

Microtex achieved accreditation as an ISO 9001 and 14001 manufacturing company. It has had approvals since 1994 for supplies to Indian Railways for the entire range of batteries used by them. Microtex supplies TSEC (technical specification approval centre)-approved batteries for the telecom industry.

The factory has a covered area of 26,700ft² on six acres of land, with 200 expertly trained people. Microtex manufactures specially designed lead alloys, lead oxides, grid castings, pasted plates, injection-moulded containers, multi-tubular gauntlets, PVC separators in-house, and produces the complete battery using state-of-the-art industry-standard battery-making machinery.

Are there any stand-out moments that defined your present course?

That is a difficult question, there have been quite a few. I think it is best to give a brief timeline for Microtex.

Mr A Govindan, our founder and first-generation entrepreneur, obtained a patent for the Pluri Tubular Bags in 1975. He established Microtex pioneering as the manufacturer of battery separator's tubular bags, which were import substitutes at the time.

Feb 1977 – The company started exporting traction batteries to the USSR. Only a handful of companies in the world have manufactured and exported traction batteries since 1977. Microtex has supplied over 4,500 traction batteries a year during that period.

March 1985 – Approval gained for the supply of 2V batteries for the telecom industry and started supplies of 2V flooded LMLA batteries to the erstwhile state-owned P&T.

April 1994 – We were approved for the supply of batteries for rolling stock and stationary batteries for signalling applications to Indian Railways.

July 2003 – The INtelliBATT 12v tall tubular inverter battery was launched. The Microtex 12V flooded range was designed for the huge inverter battery market and is highly successful.

Feb 2005 – Microtex establishes the manufacture of VRLA batteries for various applications. Obtained TSEC approvals for VRLA batteries from 2V 200Ah to 2V 5000Ah in a very short time. Supplies to BSNL, Idea, Airtel, Indus Towers, Huawei, Bharti Infratel, Viom, etc.

Apr 2006 – Dr Wieland Rusch, battery expert from Germany and inventor of copper stretch metal submarine batteries, joins Microtex to upgrade and bring our batteries to world-class designs for the complete range of batteries including traction. With him, we developed the complete range of OPzS and OPzV gel batteries. Microtex was the first company to launch gel batteries in India.

Apr 2008 – Began production of OPzS and OPzV battery. Microtex started supplying 2V OPzS batteries to nuclear facilities in India and exported gel batteries for various applications including telecom and solar energy storage.

Mar 2011 – Dr Mike McDonagh joins Microtex as CTO. With his rich manufacturing experience in various leading battery companies, Dr McDonagh established strong process controls in Microtex.

What products do you manufacture?

I think it best to refer to the catalogue to get the full picture: www.microtexindia.com

In general terms, we are an industrial lead-acid battery manufacturer. Microtex is probably one of the few companies that have an entire range of lead-acid types in flooded AGM and gel variants. We supply 110V 1100Ah VRLA train-lighting and air-conditioning batteries to Indian railways. In addition to 2V signalling cells, we supply diesel locomotive starter batteries, end-on-generation, TRD, EMU and electric locomotive batteries. The Microtex Diesel locomotive range is highly regarded by Indian Railways as a reliable diesel loco starter battery. These loco batteries are also exported to South America, Africa and the Far East.

OPzS and OPzV batteries are supplied to mission-critical users like Bhabha Atomic Research Centre, Nuclear Power Corporation of India, National Thermal Power Corporation of India and Indian Oil Corporation. OPzS and OPzV batteries are available in the complete international range of 100Ah to 3000Ah. With the complete gel plant imported from Germany, our 2V OPzV gel batteries have very high performance and have seen over 12 years' life.

Microtex has also developed 2V gel batteries from 100Ah to 5000Ah, in heat-sealed PPCP containers housed in steel modules to offer the same quality to cost-conscious users.

Microtex forklift batteries are supplied as OEM to Nilkamal forklifts and are very popular in the forklift replacement markets. Microtex offers traction cells in HS PPCP containers, constructed in accordance with

Microtex development team with owner and MD Ravi Govindan internationally accepted dimensions. They are available in both weld-on and bolt-on designs from 40Ah to 1550Ah in BS & DIN designs. Microtex traction batteries have seen a performance of 11+ years as well. Customer testimonials on our website https://microtexindia.com/about-us/testimonials

Can you briefly describe the markets that you are supplying

Microtex is a registered trademark in quite a few countries and owns multiple brands. To describe our distribution, it is best to answer by giving a summary in ***Table 1***. To find out more go to: https://microtexindia.com/about-us/microtex-trademark/

Why are you in these markets?

Microtex decided a long time ago to look at the higher-margin, niche applications for lead-acid batteries. We predominantly made industrial application flooded batteries from the beginning. We then decided to play to our strengths and took steps that included the use of well-known international consultants to assist in strengthening and widening our product range to cover wider markets. The result was the launching of products that are world-class, with improved manufacturing methods to ensure high-quality, cost-effective solutions for most deep-cycle applications. We specialize in VRLA designs for both AGM and gel chemistries and are industry-leading in these products. I can give some examples:

Microtex INtelliBATT inverter batteries are designed to deliver the rated capacity with trouble-free extra performance and longer life. Customers prefer INtelliBATT due to its assured lifetime. Microtex is currently setting up a countrywide dealership distribution channel, and the response has been overwhelming.

Microtex has a very strong presence on Indian Railways. Its batteries are proven in service and are considered failproof.

Microtex Limitless forklift batteries are the customers' choice – they inevitably become loyal clients after the first purchase. With extremely good designs, robust 3.3mm positive grid spine diameters, woven gauntlets, and a combination of selected and balanced active materials, Microtex traction batteries exceed customer satisfaction. The specific details can be found on our website.

Microtex Caddy golf cart batteries have become synonymous with good quality, especially with the robust tubular plate construction, which is the most ideal for semi-traction applications

Where Microtex is a registered trademark	Brands owned by Microtex
India	Microtex Limitless
European Union	IntelliBATT
United Kingdom & Ireland	Eternia Gel
United Arab Emirates	Microtex Caddy
Vietnam	Dunia
Yemen Sanaa	Aquira
Yemen Aden	Energybags
Mauritius	
Cambodia	

7 Ah AGM group stacking

Could you describe your processes and equipment?

We have the standard range of manufacturing equipment that you would find with any lead-acid manufacturer. However, in addition, we have equipment for manufacturing specialist materials that most companies would purchase from suppliers. We have not invested in strip casting as we are mostly industrial, and I believe that the conventional gravity-cast flat plate grid, plus a tubular design, is still the most reliable way to meet cycle and calendar life requirements. In brief:

Gravity casting

We have 10 standard grid size, and 3 Industrial machines.

PDC – 300mm 5 nos, 500mm – 1 no, 700mm – 2 nos

Oxide production

We have 2 oxide mills: a 24-tonne Sanhuan mill and a 12-tonne Sanhuan mill. Both are modified in-house to have a water scrubber before the outlet stack.

Paste mixer

2 nos. These are 1-tonne per hour Sanhuan paste mixers with programmable, automatic loading and mixing control.

Pasting machines

We produce a wide range of sizes and have appropriate pasting resources. These are: IndustroMac 23 inch, a Ganglih 300mm and 2 Sunlight pasters with a 300mm grid capability.

Curing and drying chambers

We have 11 curing chambers, all large-sized to take several skids.

Formation process and rectifiers

Microtex ensures the complete formation of all plates before assembly. We have 30 banks for formation with approximately 2,300 jars, 10 Jinfan chargers/dischargers and 10 other charge/discharge rectifiers.

Plate washing

Microtex regards this as a critical process to ensure premium quality plates. Due to this, we employ a 6-tank plate washing process with aerated DM water (recycled into the process after reaching 1.05 SG). There are two sets complete with overhead cranes.

Plate formation line for VRLA recombination batteries

Assembly lines

Because of our diverse range, we have a lot of assembly lines; these consist of two lines for 2V VRLA, around 240 cells (2V x 1100Ah) per shift, four lines of 12V SMF, giving 400 batteries per shift, two lines for 2V traction cells producing 400 cells per shift, one line for 12V flooded inverter batteries capable of 400 batteries/shift and one line for 2V flooded cells at 500 cells per shift.

Battery charging

Again, we have a very large capacity with more than 20 chargers/dischargers, each with 6-8 channels.

Inspection and packing

All products are washed with demineralised water before packing and are automatically 100% pressure tested after heat sealing. Between the machine-washing process and wrapping/dispatch procedures, we do final checks to ensure quality and consistency. These are mostly conducted with hand-held instruments such as HRD, IR, and conductance testers.

Electrical lab

Our electrical test lab is constantly in use to validate designs and ensure product consistency. We have Digatron 4 channels LCT and Bitrode 13 channels LCT.

Pollution control equipment

For airborne particulates, we have well-designed fume extraction and scrubbers. To maintain clean reusable wastewater, our effluent treatment plant relies on well-known physical and chemical processes to provide water quality that exceeds local and national regulatory requirements

What do you think makes Microtex uniquely placed to compete in your chosen markets?

Microtex is probably one of the few companies in the world that manufactures the entire battery in-house. We are always adapting to change, and this has been our greatest strength. It is the benchmark of our philosophy to constantly improve. Moreover,

Plastics injection-moulding machine for cell and battery container manufacture

we are flexible, lean and have a wonderful team. If we make a mistake, we learn, change and adapt to improve the situation at all costs. As well as our team, we have acquired state-of-the-art equipment, to ensure that all our sub-components are manufactured in-house, to the highest standards. In this way, we can keep control over the quality and cost of all aspects of our battery manufacture. I can describe this equipment as follows:

A 100-tonne per day lead alloying plant, ensures high-quality batteries with its ultra-low maintenance lead alloys, designed to withstand corrosion, and provide extra-long life battery performance. We were fortunate to have Dr Mark Stevenson of Global Lead Technologies design all our alloys way back in 2000.

An in-house plastic injection moulding facility, with the following IM machines – 60, 180, 200, 480, 650, 720, 850 and 1,300-tonne capacities to cater for the requirements of the smallest vent-plugs to the largest 730mm traction jars.

We manufacture in-house woven pluri-tubular gauntlets. From the manufacture of defect-free high-tenacity fabrics on modern high-speed rapier looms to the strongest woven gauntlets with extreme porosity and fine structure to provide instantaneous power at the plates.

We also manufacture PVC battery separators specially designed for long-life tubular gel batteries. The large pore size is a great advantage for the gel battery. PVC separators usually outlive the gel battery, which is more than 15 years. Only PVC separators can last that long.

We have our own toolroom facility for the repair and maintenance of all our equipment. This is equipped with high-quality surface grinding, milling, lathe and vertical drilling machines. We also have other necessary equipment to produce the tools, jigs, fixtures, and battery-making equipment and machines. Microtex has taken some unique measures to ensure that our H&S and environmental standards are as high as possible. These include:

- Installing heavy-duty high-performance stainless-steel scrubbers to the bag house exhaust outlets of oxide mills, thus ensuring clean exhausts from the ball mill
- Granite flooring in charging areas, with lead poured into the joints to seal off any acid spills. Chemical resins eventually give way at the joints and Microtex recommends using this time-tested method of pouring lead in the gaps to seal the acid ingress
- Plate wash water is processed back into the system
- A unique system of washing the footwear as you enter or exit the filling and oxide mill area with recirculating water and tank to catch any lead dust
- Zero effluent discharge plant
- Commercially, Microtex has been providing a tree sapling along with every traction battery supplied in India. The customer gets an additional 1-year warranty as an incentive when they plant the sapling and share a photo of it. This has been a great success and over the last four years, we have supplied more than 4,000 tree saplings with our traction batteries

We have been providing free lunch/dinner to all employees since 1974. The kitchen is hygienically staffed by our own employees. The organic kitchen waste is composted daily along with the fallen leaves from over 103 trees inside our premises, producing clean natural organic compost, free from any synthetic chemicals

What special features do you have to gain and keep customers?

We are a family-owned business. We listen to the customer carefully and we hear what they have to say in full. We are easily accessible, unlike large companies where the customer cannot obtain small product design changes. With larger companies, it is not possible to connect to the decision-makers if specific changes are required for regular fast-moving batteries. Because of this we can offer better value for money in our pricing compared to the large multinationals.

We believe our battery must perform to the complete satisfaction of the customer and we stand by this promise. It is a matter of great pride to hear from the customer that they are delighted with the battery performance.

Microtex batteries are prototype tested for life cycle before release to the market. Our modern electrical testing laboratory is complete with Bitrode and Digatron LCTs. All products are validated for performance and capacity, meeting international standards.

Microtex batteries have been TSEC approved from 2V 200 Ah to 2V 5000 Ah for supply to the telecom market. OPzS batteries are tested, approved, and supplied to the Nuclear Power Corporation of India, the Bhabha Atomic Research Centre, National Hydro-Electric Power Corporation, and the National Thermal Power Corporation. OPzV batteries are also supplied to the solar power industry. Microtex is a Part-1 supplier to Indian Railways and has been approved since 1994 for almost all rail applications.

Manufacturing practically all the components that make up the battery places a lot of quality control in our hands, and our dependence on outside suppliers is minimised. This gives us an edge over other battery manufacturers in ensuring complete control of battery quality.

How do you see the future for you and the industry?

Both lead-acid batteries and lithium-ion batteries will be the dominant chemistries in the future. While lithium-ion has seen the fastest growth in the last decade, it will not replace lead-acid completely. We are a flexible company and willing to adapt to newer chemistries.

Microtex is positive about the lead-acid battery business as the global energy requirements will continue to surge. We engage the best European consultants to keep our processes intact and to develop new products at regular intervals. This ensures the continuity of business.

We have for many years invested about 2% of our annual turnover to upgrade and replace our plant and machinery. This way we ensure that we stay abreast of the latest manufacturing techniques and are not encumbered with ageing machines or outdated manufacturing techniques. We see only opportunity as we move forward into this decade.

Right: Microtex mission statement

And there you have it, a company that looks for niche applications, is willing to adapt its standard designs to clients' individual needs and manufactures practically all the battery components in-house to ensure control over supply and quality. Add to this a flexible dedicated team, led by a hands-on, philanthropic MD, a belief in the capability of the company to embrace change and to invest in the future, and you have a recipe for success. What could be simpler?

The A-B-C of cell grading and testing

What happens when cells are not manufactured to the same quality standard? Power management innovator Chris Hale looks at the impact on battery packs of cell-to-cell variation and what the differences are between the-grades.

Above: Qingxi cell testing. Source: Inventus Power

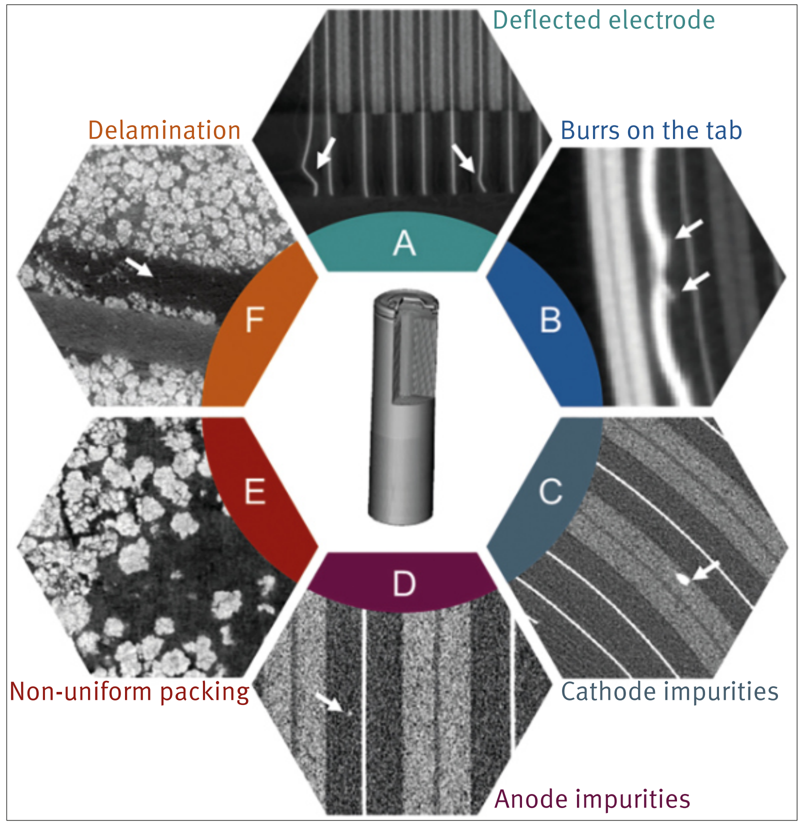
It is well understood how lithium-ion batteries can be highly reactive and susceptible to thermal runaway events or even catastrophic failures. It is perhaps less well understood how significant cell-to-cell variations at the manufacturing level dictate overall battery life, reliability and safety. The impact of faulty batteries can not only inconvenience the user and pose potential health and safety risks, but also end up costing and damaging a company's reputation.

Understanding the risks and potential reliability issues that may be faced using lithium-ion cells, first comes from an understanding of the batteries chemistry and failure modes, and secondly from understanding manufacturing process variations. The latter requires delving deeper into the mechanisms impacting reliability, accelerated degradation or potential premature failure and, for that, understanding potential issues during manufacture. For all the mechanisms influencing cell variation, a number of characteristic tests will be carried out, with thresholds dictating the eventual grade of the cell.

By better understanding the impact of potential defects, we can be more informed when selecting to opt for the safer A-grade cells, the riskier B-grade – or perhaps even the kamikaze route of choosing C-grade. Whichever route we take, we will still need to consider an appropriate level of testing to ensure a battery pack is balanced with cells of similar characteristics.

On the flip-side, if you're a consumer, how do you know the battery packs you're purchasing will safely last the distance? Selecting a battery based on the manufacture's specification, warranty offering and battery price may be all that we have to go on, but how much can we really rely on this? Testing is generally costly, if done thoroughly, but how much, or how little testing, is considered sufficient? Companies vying for competitiveness will be looking to keep costs as low as possible, but the question here would be 'where are those cost savings made'? If it is in testing, it might beg the question of whether a cheap battery is the right and safe way to go, especially if you can't guarantee corners haven't been cut – or low-quality B-grade or even C-grade cells haven't been used.

It may be fair to say that the intended application will likely dictate our bias on where we get our batteries. For example: reliability and safety are key factors if you're buying a new electric car with a warranty good for 8-10 years or 100,000 miles. For an E-bike however, it may simply be a question of cost, albeit with a warranty typically of just 12 months.



In retrospect, if you're buying a battery good for 2,000 cycles, you might well expect better than a 5-year life? However, if the warranty period falls far short of the expected life of the battery, with all the disclaimers on usage, can we really trust that the cells will go the distance? In the event it does fail within the warranty period, be mindful that not all warranties are worth the paper they're written on. BMS logging is a powerful tool to prove the one instance of 'abuse' rendering the warranty void by the time you come to claim.

To put this into perspective, I followed an interview with a warehouse operator using lead-acid batteries for materials handling applications. They reported that around 67% of their batteries failed before the end of the warranty period. Given the general day-to-day usage of the batteries, the warranty was almost always void for one reason or another! At the end of the day it is very easy to claim abuse, or use out of specification – more so in lithium-ion batteries with BMS logging facilities.

So where does this all fit in with testing? In this case I'd say reputation. If you can buy from a reputable source likely to honour a warranty (with a warranty period that makes sense), you can be fairly sure they would have a reasonable process of cell quality testing. From the manufacturers perspective, by understanding the causes of potential in-warranty failures helps to drive those failures down.

Opting to use B-grade cells because, for example, they offer a 30-40% cost saving on A-grade versions is fine, if we understand why they are B-grade and why they are unlikely to offer the same life. Even for A-grade cells, not all will be manufactured to be 100% of the specification. There are plenty of factors providing sufficient cell-to-cell variation, promoting the need for adequate quality sorting. There may also be a different view on what qualifies as an A-grade or B-grade cell.

Fig 1: An overview of various structural defects in the commercial 18650-type lithium-ion cell. Source: Cell Reports Physical Science

If we assume that not all manufactured cells are defect-free, the question would then be: what are the likely defects and to what degree do the defects impact on a cells performance, longevity and safety?

A good illustration of typical issues is depicted in ***Fig 1***, showing the key issues during manufacture, identified as:

(A) The deflected copper current collector, an example of cell component deformation.

(B) Burrs on the tab.

(C and D) Examples of impurity particles in the cathode and anode, respectively.

(E and F) High-resolution visualisations of the defective electrode regions with non-uniform cathode packing and delamination, respectively.

All of these defects could profoundly influence the battery performance in practical applications.

Regarding (A), the current collector (typically Cu), plays an important role in lithium nucleation/growth, local current density and lithium-ion flux distribution.

Burrs on the tab (B) will risk puncturing the separator, creating an internal short.

Regarding (C)&(D), depending on the composition, the metallic impurities can be directly involved in the chemical reactions. These particles could potentially alter the surface chemistry, leading to increased electrochemical impedance and polarisation.

If the impurities are located near a separator, then there will be risk of penetrating the separator and creating an internal soft or hard short circuit.

Particle packing at the electrode level (E), plays a significant role in affecting the ageing and lifetime of the battery.

Delamination of electrodes (F) affects the electrochemical behaviour of the cell and is heavily dependent on the electrode adhesion and drying temperature.

Of course, each of these potential defect areas is generally introduced during the manufacturing process, and can arise from:

1. Raw material processing: the purity of raw materials used within the anode and cathode will have a significant impact on cell performance (one of the current concerns for using recycled material)

2. Mixing: both anode and cathode materials are mixed to give a level of uniformity, if the mixing isn't thorough enough uniformity may be impaired

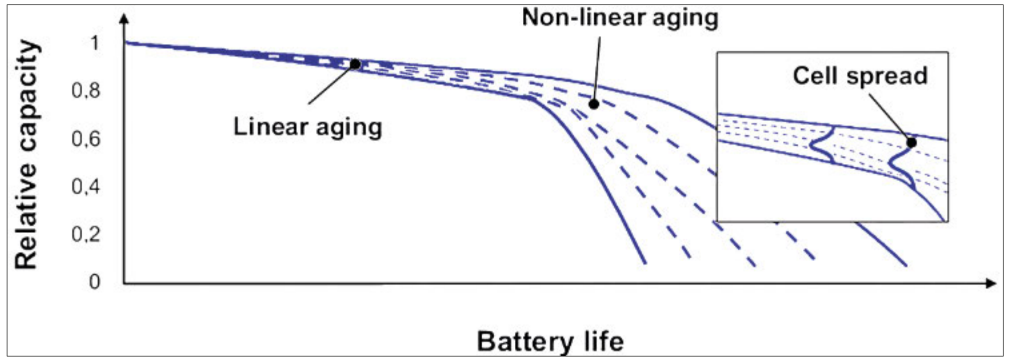


Fig 2: The impact of uncertainties on linear and non-linear ageing in battery systems. Source: Researchgate

3. Coating and drying: once mixed, the material is coated onto foil; however, uniformity cannot be guaranteed and the drying rates/time will also impact on the crystalline structure

4. Calendering: once coated and dried, the foil is passed between rollers to reduce the thickness; over-calendering can damage and distort the foil

5. Slitting: as the foil tends to be up to 1m wide, precision cutting is required to the right size, the cut edges can lead to splits and notches or rough edges that risk piercing the separator leading to internal shorts and higher self-discharge

6. Winding and filling: anode, cathode and separator material are wound and inserted into cans. At this point the cells are quality tested before filling as the last step renders the cell live. Filling is a process of adding the electrolyte – injecting exactly the same volume. Ensuring even distribution between layers is not easy

7. Formation: activation and cycling of the cells to identify voltage/capacity grading will identify initial B-grade cells

8. Ageing: 28 day ageing for stabilisation and testing of internal resistance, weight, size and appearance, grading further into A or B categories

If we assume that each manufactured cell will have a greater or lesser degree of potential defects, the question then remains of what impact does each aspect have to the life and operation of the cell? If we look at a typical battery over its life, we will generally see a fair spread of capacities between cells as they head towards end of life ***(see Fig 2)***; the weakest cell being the limiting factor for the useable life of a battery.

During manufacturing, cells will be tested and graded, with all those passing acceptable thresholds being grade-A, those that don't as grades B or C.

If we accept that there is a fair spread of relative capacity in aged A-grade cells, what can we expect from a spread of aged B-grade cells? Perhaps to

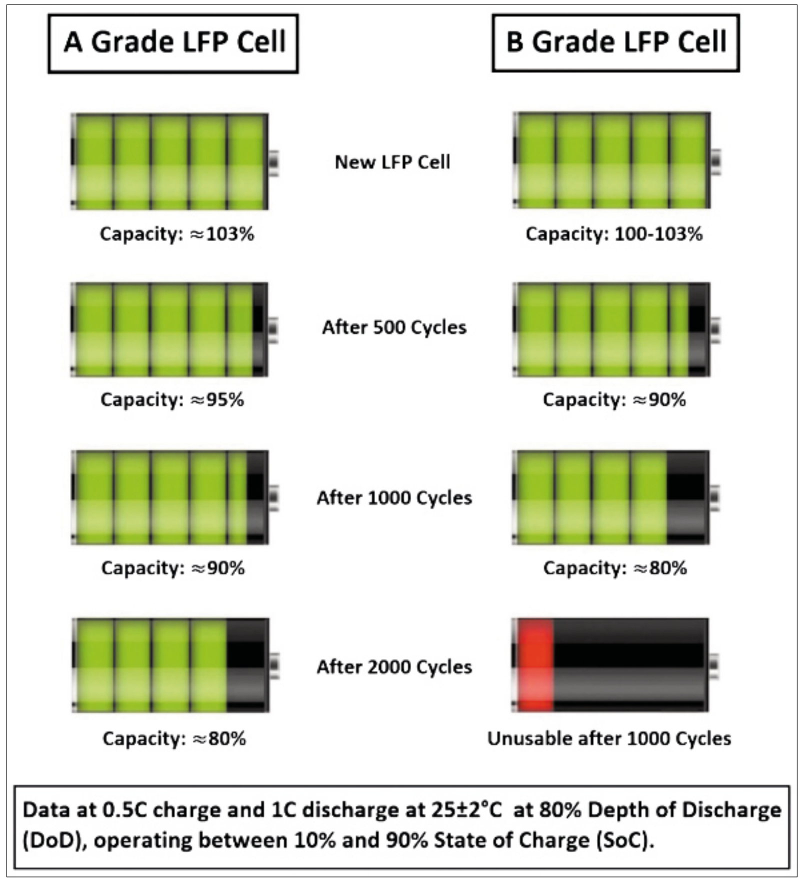


Fig 3: Comparing lithium-ion A and B grade capacity fade (ref: EVreporter)

understand this would be to look closer at the characteristics that can be impacted when defining what is A-grade and what is B-grade. Of course when we buy a B-grade cell, we may not know on what characteristic(s) it had failed.

A-grade vs B-grade

The A, B or C grading during manufacturing of lithium-ion cells follows a process of evaluating cell characteristics that generally follow:

1. Self-discharge rate: this is the highest risk as it represents the greatest potential for issues during use and storage – including a higher possibility of internal (soft/hard) short circuit
2. Low capacity: easy to identify and, if grouped with other similar capacity cells, would be less of a risk to use
3. Higher internal resistance: balancing will be an issue and ability to supply high current (especially as the cell ages), increased heat generation is also a potential issue
4. Size/weight out of spec: may represent packing density issues with tight fit battery enclosures
5. Voltage and capacity level mismatch: a cell's open circuit voltage(OCV) represents its relative capacity, which should be consistent from cell to cell
6. Stock storage duration: if an A-grade cell is on the shelf for too long before being sold, it may be down graded to B-grade

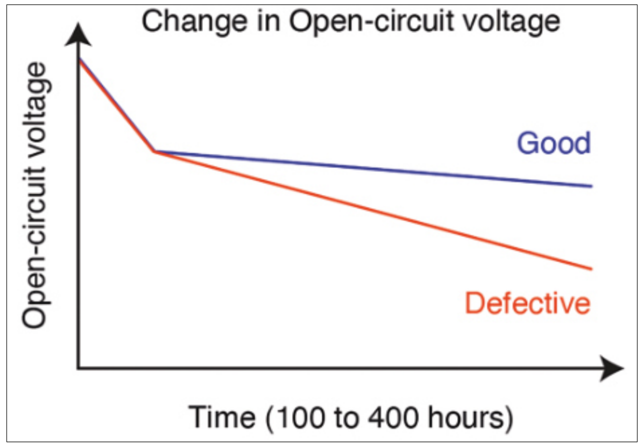
For C-grade cells, these would typically have a much higher self-discharge rate or capacity fade and would (should) normally be destroyed or recycled.

The use of B-grade cells, which should have any QR code markings removed by the manufacturer to aid identification, can be fairly unpredictable.

A few OEM's and battery pack suppliers have experienced issues with using B-grade cells and cell packs because the batteries struggle to perform to datasheet expectations and fail within warranty periods. ***Fig 3*** represents a comparison test of A & B-grade cells showing similar initial capacities, but with completely different capacity fade over cycling.

On the other hand, ***Fig 4a*** demonstrates a high self-discharge over a 400-hour period, which will impact greatly the capacity spread of cells in storage. The self-discharge rate will also be compounded at higher states of charge (SoC) when left in storage, especially if greater than 80% – as can be seen from ***Fig 4b***.

Due to the variable characteristics that represent a substandard cell, identifying sub-standard cells on first inspection might prove challenging. For those buying cells off the web, beware the 'genuine' ‹cell manufacturer› cells, they may be 'genuine' but not necessarily of a good grade.



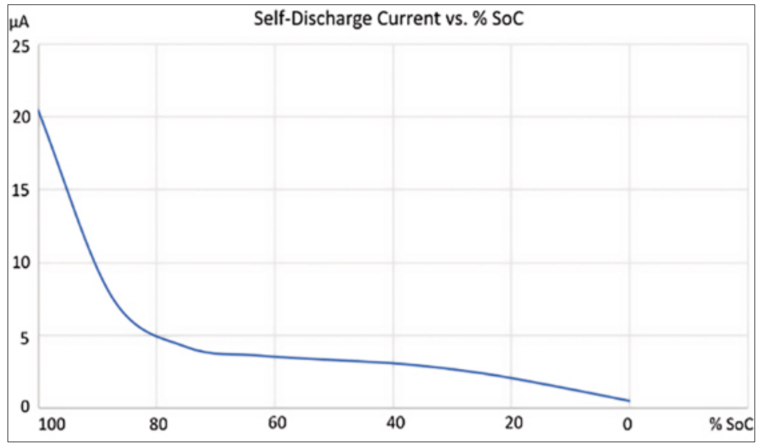


Fig 4a (left) and 4b (right): Cells self-discharge at different rates. Sources: Hioki and Keysight

Aside from increased capacity fade ***(Fig 3)***, increased impedance and higher self-discharge rates (as demonstrated in ***Fig 4a***) will also generate issues during storage. Both storage and operation of these batteries may well lead to an increase in 'balancing' issues for the BMS electronics, which could also impact on safety and rate of degradation for some of the cells, or simply cause the BMS to shut down with a 'balancing' fault.

So with all these potential issues, the method and degree of testing for each cell becomes more critical. The results from testing will of course generate a greater or lesser degree of useful information depending on the sophistication of the test for grading or qualifying cells for use in a battery pack.

To give an example, a simple test might involve just an OCV measurement as part of quality inspection. This test may determine a voltage spread amongst all the cells enabling grouping, based on voltage, to provide a more balanced battery pack. The spread of voltage may also indicate voltage/capacity mismatch or a greater degree of self-discharge. Self discharge, of course, depends greatly on the length of time cells sit on a shelf before testing.

A simple voltage test will not tell you much about capacity variations, internal resistance or self-discharge rates.

AC/DC impedance tests

Also an easy test to perform, either through an impulse load test or using more sophisticated electrochemical impedance spectroscopy (EIS) equipment. The internal resistance accounts for the voltage drop across the battery's terminals when a load is connected, compared with no-load, and can be derived from OCV measurements.

Capacity tests

Determining the capacity of a cell is a bit trickier without doing a full charge-discharge cycle. Gaining suitable indication of absolute capacity from quick and simple tests with any degree of accuracy is at the least, challenging.

Self-Discharge

The self-discharge rate of a cell is heavily dependent on SoC ***(Fig 4b)*** as well as temperature. Although there are several methods for determining self-discharge, given the very low rates of capacity loss over time, equipment accuracy and test duration becomes more significant. 10-14 days is often suggested, although there are those reporting reasonable indications of self-discharge rates from tests taking only 1-2 hours.

Voltage/capacity mismatch

OCV may well give indication of SoC following a nominal curve, however for some cells the OCV at a given %SoC may deviate from the nominal profile. Testing requires knowledge of a cells capacity as described above, with challenges of accuracy for any shortened tests.

In summary, all lithium-ion cells will have a degree of variation, whatever grade they are. The grade of cell and level of testing will ultimately impact on the reliability, longevity or safety of a pack. Going cheap, where a manufacturer specifies long life but offers a short warranty, is something to consider carefully.

Can batteries enable a truly sustainable future?

Pasidu Pallawelan, director of Edinburgh-based energy storage solution provider StorTera, explores the impact of energy storage systems and asks if sustainability can be measured.

Why should batteries be sustainable? The big picture
Energy storage systems are being employed to support an increasingly diverse range of applications, from megawatt-scale grid storage systems to microelectronic systems. In an era where humanity is fighting the climate crisis, energy storage is seen as one of the key enabling technologies to support the decarbonisation of modern energy systems. This fact, coupled with the increasing uptake of electric vehicles (EVs), which use significant volumes of batteries, means that battery manufacturing is expected to consume enormous amounts of the earth's natural resources.

One valid question is, how can batteries become a sustainable technology for the future? In a nutshell, if an energy storage system has low embedded carbon levels, low impact on natural eco-systems during its production, lower levelised cost of storage and if the energy storage system can be recycled or reused at the end of life, it can be argued that such an energy storage system is sustainable.

However, the true sustainability of an energy storage system cannot be quantified or compared accurately without having suitable sustainability metrics identified. This article considers the important metrics to measure the sustainability of battery technologies and the features necessary for truly sustainable battery systems.

Where have things gone wrong?
I'm celebrating my 20th year in the renewable energy industry this year and a colleague I've known throughout my entire career, who is a senior engineer in the telecoms industry, stated that a particular battery type (say battery chemistry B) with a carbon footprint of 52 eq CO_2 kg/kWh is more sustainable than lithium-ion batteries which have a carbon footprint of 70 eq CO_2 kg/kWh. On first observation, that sounds correct. On reflection however, I looked at the number of cycles each battery can perform before the end of life; battery B can only be used for 500 cycles, whereas lithium-ion could manage nearly 2,000 cycles under the same conditions in a telecom tower installation.

> "The true sustainability of an energy storage system cannot be quantified or compared accurately without having suitable sustainability metrics identified"

As a consequence, battery B would have to be replaced four times in order to meet the equivalent cycle life of lithium-ion batteries. Therefore, the real carbon footprint of battery B is actually four times higher than its quoted carbon footprint. While lithium-ion has 70 eq CO_2 kg/kWh, battery B now has a carbon footprint of 208 eq CO_2 kg/kWh, if it is used for 2,000 cycles. This simple example highlights the fact that sustainability metrics such as carbon footprint should be levelised for the number of cycles that it can perform before its end of life.

This is just the tip of the iceberg, as the carbon footprint is just one factor from a sustainability point of view. Stakeholders in the renewable energy industry such as policymakers, investors, developers, and consultants are not fully informed as it is extremely difficult to find reliable and accurate information about battery sustainability.

The present metrics used to measure the sustainability of batteries are misleading. Therefore, accurate and reliable metrics are needed.

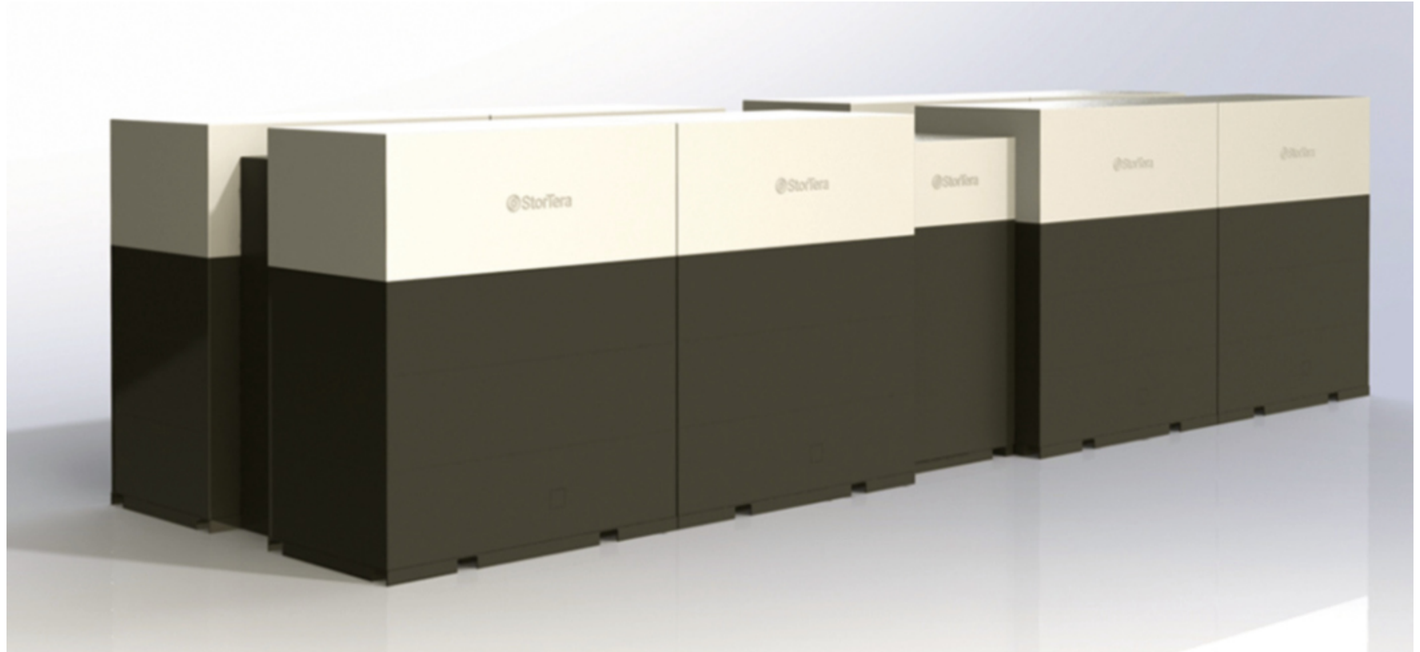
StorTera Energy Storage units manufactured in Edinburgh, UK

Correct battery sustainability measurements are important
The battery industry is growing fast with many stakeholders engaging at an accelerated pace. There are business leaders, policymakers, government bodies and many investment firms pledging more investment and resources into developing sustainable battery technologies for the future. But how can these stakeholders know which battery technology is sustainable when the techniques to compare sustainability of batteries do not consider the full picture? Or, what if the present measurement techniques and sustainability metrics used to compare the sustainability of battery technologies are not accurate? For this reason, it is important that correct and well analysed metrics be openly available.

The most effective battery sustainability metrics
There are many sustainability metrics that can be used and it is important to adapt different metrics to measure different products and services to fully understand and compare their environmental impact. Below are some of the most important quantitative metrics which are most applicable to battery storage technologies. As shown, it is essential that these metrics are levelised for the number of cycles that the particular battery technology can perform before end of life. The metrics selected to be discussed in this article are:

1. Levelised carbon emissions (LCE)

2. Levelised water footprint (LWFP)



StorTera's single liquid flow battery has a LCOS ‹ £10/MWh and a low levelised water footprint

3. Levelised ecological footprint (LEFP)

4. Levelised cost of storage (LCOS)

5. Percentage recyclability at end of life

If an industrial battery technology has low values of LCE, LWFP, LEFP, LCOS and a high percentage of recyclability at end of life, then this would truly be a sustainable battery. First, we need to understand what these sustainability metrics mean.

Levelised carbon emissions
Among the most commonly used battery types are lithium-ion batteries, which have a carbon footprint of around 70kg of eq CO_2/kWh *(Ishihara, 2020)*. This is an important metric, but not a comprehensive sustainability indicator.

The true lifecycle carbon emissions of batteries, or the levelised CO_2 emissions of a battery, are given by the LCE. This is a measure of greenhouse gases (GHGs) emitted per kWh stored and released using the battery with units of this metric in eq CO_2 g/kWh/cycle. Rather than just estimating how much GHG is emitted while manufacturing a kWh of a battery, this determines the concentration of GHGs attributable to each kWh stored in the battery, providing a true and comparable sustainability metric. Battery technologies with low carbon footprint and long cycle lives will have low LCE values.

> “If an industrial battery technology has low values of LCE, LWFP, LEFP, LCOS and a high percentage of recyclability at end of life, then this would truly be a sustainable battery”

Levelised water footprint
Another important metric is the levelised water footprint, i.e. the mass of water needed to generate each of the products and services. For batteries, this is measured in tonnes of water/kWh/cycle to determine the amount of water used per kWh stored and released in the battery during its lifetime.

Water is becoming an increasingly scarce resource and the use of water is related to water pollution and damage to aquatic life. If the battery technology has a longer cycle life then each tonne of water used can support more kWhs of stored renewable energy. The metric further improves if the battery technology uses less water during its production and operation.

Levelised ecological footprint
The ecological footprint measures the demand or damage on a natural ecosystem to supply the resources required to produce a product or a service. Ecological footprint is measured using global square metres (m²), global square decimetre (dm²) or global hectares. The levelised ecological footprint applicable for batteries is measured in global dm²/kWh/cycle.

In other words, this is a measure of the ecological damage the battery causes per kWh stored and released by the battery. This metric looks at the total ecological damage done during any form of manufacturing of a product or a service.

Levelised cost of storage
Levelised cost of storage is the cost of storing and subsequently retrieving a MWh of energy from a battery technology. This is measured in £/MWh. LCOS isn't a sustainability metric in itself, but it is indirectly connected. If the LCOS of a battery technology is lower than a particular threshold, it would enable rapid decarbonisation, leading the way to a sustainable future.

A recent report published by the US Energy Information Administration indicated that the levelised cost of energy [(LCOE) – all-inclusive cost to produce a MWh of energy using various generation sources] for natural gas combined cycle and standalone solar PV will be $47.40/MWh and $38.77/MWh respectively by 2024 (US energy administration, 2022).

SLIQ flow cells made of high density polyethylene and with 100% reusable catholyte. (Picture courtesy of StorTera)

Therefore, a battery technology with a LCOS of less than $8.63/MWh by 2024 can make on-demand renewable energy (energy generated by solar PV and stored in a battery to be dispatched any time when required similar to a fossil fuel generator) more economical than the cheapest fossil fuel-generated energy. This could unlock the potential of renewable energy, enabling its widespread use.

A more sustainable future must rely on the use of clean energy and so batteries with a low LCOS are important for benchmarking the technology.

Percentage recyclability at end of life
With the increasing uptake of Evs, coupled with numerous other battery applications, it's no surprise that mountains of used batteries are expected to be accumulated for recycling. According to data published by London-based storage recycling research group Circular Energy Storage, more than 1.2 million tonnes of lithium-ion batteries will reach end of life yearly by 2030. While lithium-ion batteries can be recycled, if existing practices for managing used batteries continue,

Sustainability metric	Lithium-ion	Sodium-ion	Lithium-air	Lithium-sulfur flow[1]
Levelised carbon emissions **$eqCO_2g$/kWh/cycle**	35	21.45	20.3	3.35
Levelised water footprint **Tonnes of water/kWh/cycle**	140	105	43	13
Levelised ecological footprint **dm^2/kWh/cycle**	150	61	58	9
Material reusability at end of life	<10%	No data	No data	> 60%
Levelised cost of storage (LCOS) **£/MWh**	40	30	No Data	10
No. of cycles before end of life	2,000	3,000	500	20,000
Carbon emissions **kg/kWh**	70	64.35	10.15	67

[1]It is assumed that the LCE, LWFP and LEFP of lithium-sulfur flow batteries per kWh are similar to that of lithium-sulfur batteries per kWh (Wang et al). We have levelised these sustainability indicators using the useable number of cycles for each battery type.

Table 1: Key sustainability metrics for lithium-ion, sodium-ion, lithium-air and lithium-sulfur flow batteries (such as the SLIQ) (Ishihara, 2020), (Wang et al, 2020),(Lazards, 2022)

recycling all end-of-life batteries swiftly will be a challenging task. Current battery recycling techniques are also highly water- and energy-intensive processes.

According to Naomi J. Boxall, an environmental scientist at Australia's Commonwealth Scientific and Industrial Research Organisation, barely 2-3% of lithium-ion batteries are collected and transported abroad for recycling in Australia. Similarly, the lithium-ion battery recycling rate in the US is around 1% (Yanamandra, et al 2022).

It is essential for batteries to become fully recyclable or reusable at the end of life. Reusing material at the end of life from a battery is far more beneficial than recycling, which, depending on the process, can be energy intensive in itself. Lead-acid batteries, for example, can be easily recycled, with 99% rates being achieved. However, only lead can be fully recovered (Yanamandra et al, 2022).

Novel battery technologies such as StorTera's single liquid flow battery (SLIQ) are made with reuse and recycling at the core of their design philosophy. The bulk of the battery comprises the liquid catholyte, tank and the power stack, all of which can be fully reused at end of life. The cell bodies can be recycled easily, as everything, including the cells and connectors, is manufactured using a single plastic.

Comparing sustainability metrics

Table 1 summarises the key sustainability metrics for four different battery types.

Multiple battery chemistries will be needed to satisfy the electrification requirements of various sectors of economy. Understanding different battery chemistries' sustainability credentials will be one important factor in making technology decisions. The top rows of the table compare the LCE, LWFP and LEFP for four different battery technologies (Wang et al 2020).

Battery technologies such as lithium-ion, lithium-sulfur flow batteries, and sodium-ion have similar levels of carbon emissions but, when the levelised emissions are calculated, battery technologies with long cycle lives – such as the lithium-sulfur flow battery – perform better in terms of sustainability compared to other battery technologies.

Lithium-sulfur flow battery technology is safe, has a low initial capital cost, has a high energy density compared to other flow batteries, and is durable. Therefore, this technology can be used for stationary energy storage systems, heavy goods vehicles and for the electrification of inland shipping vessels.

Some experts argue that novel battery technologies such as sodium-ion are sustainable due to the fact that they do not use lithium. However, sodium

	LCE $eqCO_2$ g/kWh/cycle	LWFP Tonnes of water/kWh/cycle	LEFP dm^2/kWh/cycle	LCOS £/MWh	Reusability factor
Levelised value	3.35	13	9	10	0.4
Assigned weight	5	0.75	1	1	15
Weighted average	16.75	9.75	9	10	6
Sustainability Index	12.875				

Table 2: An example of weighted sustainability index calculation for lithium-sulfur flow batteries. Assigned weights are indicative figures and not accurate.

ion battery technology has a comparatively higher ecological footprint and a higher water footprint (Huang, Hu, 2020) compared to the other novel battery technologies listed in the table. Therefore, on this metric, it is not as sustainable a battery technology as some others. This is a good example of how correct metrics can be used effectively to compare the sustainability of different battery technologies.

Is a sustainability index for batteries the answer?

Batteries do not come without a cost to the environment, despite their key role in increasing the integration of renewable energy sources into our economies and in decarbonising the transportation sector. Battery production and disposal have an impact on biodiversity as well as water and air quality, from mining and extraction of critical raw materials to their disposal and recycling, not to mention a potentially significant carbon footprint if inefficient manufacturing processes and carbon-intensive energy sources are used.

Therefore, it is crucial that key stakeholders such as governments, policymakers, green investors and environmentally conscious customers clearly understand how sustainability measures should be applied to battery technologies.

One good example is the European Commission's proposal, adopted in December 2020, for regulation of batteries and waste batteries. This was the first policy worldwide to cover the whole battery value chain, a significant step forward towards a sustainable future.

In one of the documents published, they mention that these regulations were imposed to put a truly sustainable European battery value chain in place (Enhancing sustainability of batteries, 2021). Although the first of its kind, unfortunately, this regulation does not address important metrics such as LCE, LWFP, LEFP and LCOS, meaning the effectiveness of the regulation must be questioned.

The European Union has implemented a genuinely important requirement but fallen short on delivering a truly sustainable policy. This is why it is so important that policymakers and key stakeholders in the battery industry start to debate and discuss how to identify the correct metrics for the sustainability of measuring future battery technologies.

> “It is crucial that key stakeholders… clearly understand how sustainability measures should be applied to battery technologies”

As a final remark, I would argue that the battery industry should formulate a Sustainability Index by assigning suitable weights to each metric and then calculating a weighted average to arrive at the final value to compare different battery technologies.

An example is provided in ***Table 2***, which shows the sustainability index calculation for lithium-sulfur flow batteries, using imaginary weights for each levelised metric. These metrics are not accurate and have to be agreed upon after a wider discussion.

An industry-wide dialogue should be initiated to identify correct units and weights for each sustainability metric, depending on their relative importance. This will give key stakeholders in the battery industry the ability to easily and accurately compare sustainability of different battery technologies in the future.

Basic battery troubleshooting – investigate it sooner rather than later

Six common lead-acid battery problems, including visual cues, related indicators and common causes are a headache. Rick Tressler, president & CEO, Rick Tressler LLC, writes that when an anomaly appears, the user should investigate it sooner rather than later. Ignoring a problem is a common user mistake, frequently leading to more problems and potential failure of the battery.

A lead-acid stationary battery is, for the most part, a reliable source of emergency power for a broad range of applications. In the normal course of operation, a problem can arise that requires investigation and corrective action. Some problems such as battery-wide cell voltages can usually be corrected with little more than a charger voltage adjustment or equalise charge. Others can be more insidious, requiring a bit of a deep dive into the cause and associated corrective methods.

Plate sulfation

Sulfated plates are one of the easiest problems to detect in a vented lead-acid (VLA) cell. Due to the construction of valve regulated cells, (VRLA) sulfation cannot be detected visually. It is best observed on the positive plates. Fully charged positive plates appear with a matte finish on the edges that is deep brown to black. Negative plates will appear grey and with the same matte appearance. Sulfated plates exhibit crystals on plate edges. This is lead sulfate. It is an indicator of a low state of charge (***Fig 1***). The photo illustrates a sulfated two-cell unit as evidenced by the sulfate on the positive plates. Heavily sulfated positive plates will appear with a light brown colour. Use of a bright flashlight is recommended to detect the condition. If a cell is heavily sulfated, a flashlight will not be needed. As a safety note, use of flashlights made of metal should be avoided.

There are related indicators to sulfation. One can be low cell voltage. A digital voltmeter (DVM) is required. Another is low specific gravity, so have a hydrometer on hand if it is to be

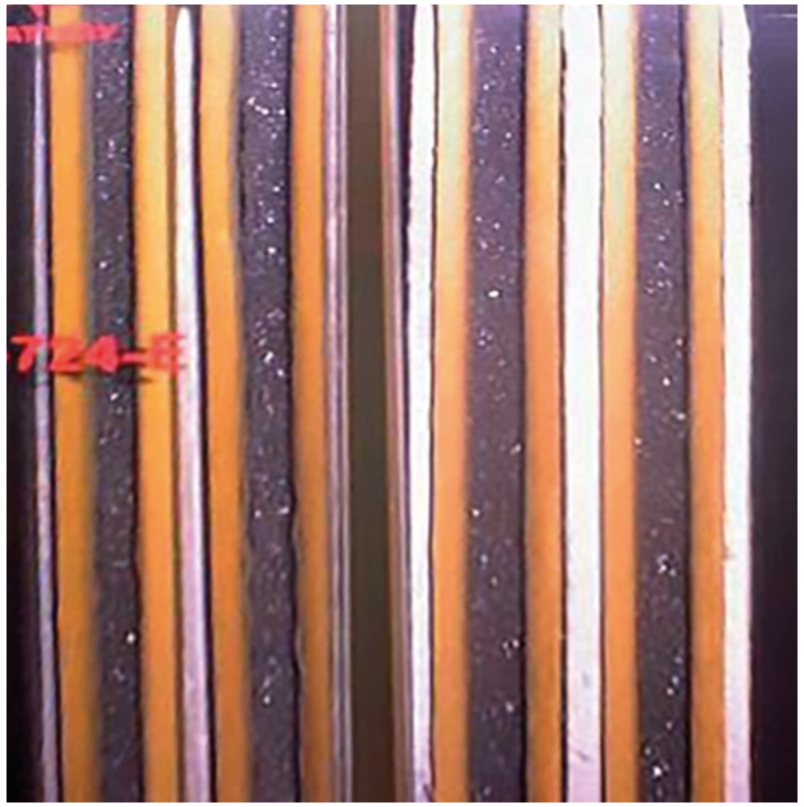


Fig 1: This photo illustrates an example of a two-cell unit with moderately sulfated plates. This condition can sometimes be corrected on an individual basis. The success rate is generally 50% and may not be a permanent fix.

Fig 2: A purpose built, single cell, line isolated charger. Designed for use on VLA and Nickel Cadmium (NiCd) cells.

checked. If only one cell is exhibiting sulfation, it is likely a failure and replacement is sometimes required. A sulfated cell may be recovered by administering a charge to the cell exclusively, although the success rate varies. This is accomplished using a purpose-built single cell charger ***(Fig 2)***. Such a unit applies an equalise charge to the problematic cell. For in-circuit charging, the charger must be a line-isolated type so as not to interfere with the DC system and its ground architecture.

However, if sulfation is observed battery-wide, the charger voltage should be checked and if found to be low, should be corrected immediately. An equalise charge is usually required to speed up the process of returning the battery to a fully charged state. Another cause can be a recent discharge without sufficient time for recharge. The battery is still in the recharge mode. In this case, the sulfation will reverse on its own, given sufficient time.

Fig 3: Digital hydrometer commonly used to sample specific gravity and measure electrolyte temperature.

Fig 4 (right): Conventional float hydrometer.

Low specific gravity

This condition is not detectable visually. A measurement of electrolyte specific gravity must be made with a digital hydrometer or conventional float-type. ***(Figs 3*** and ***4)***

Generally, specific gravity should be found within the manufacturer's recommended range. This is usually +/- 10 points (0.010). When the cell float voltage is within normal range, the specific gravity should be fine. There are exceptions, however. First, specific gravity can be observed to be low when maintenance personnel have recently made water additions. Water additions should be made after specific gravity measurements. Second, low specific gravity may be observed after a recent discharge has occurred. Cell voltages may have already recovered and appear normal. However, the return of specific gravity to a fully charged state can require from a couple days to a week or more depending on depth of discharge, elapsed time, ambient temperature and time on recharge.

An observation of low specific gravity in all cells without a recent discharge should be cause for concern. A decrease in specific gravity will always lag behind a decrease in cell voltage. The larger the cell, the longer the lag time. The same applies to recharge time.

The first item to check when this condition is observed should be to measure overall float voltage. It should be measured directly at the battery main positive and negative terminals with a calibrated digital voltmeter, referenced to the recommended float range found in the battery user guide. Adjustment of the float voltage will be needed if it is out of specification. An equalise charge may be needed to return specific gravity more quickly to normal.

The best way to avoid battery-wide issues such as this is simply to check the system float voltage monthly. This practice applies to all stationary battery systems. Follow the battery manufacturer instructions when performing a remedial charge. Never add sulfuric acid or electrolyte to increase specific gravity.

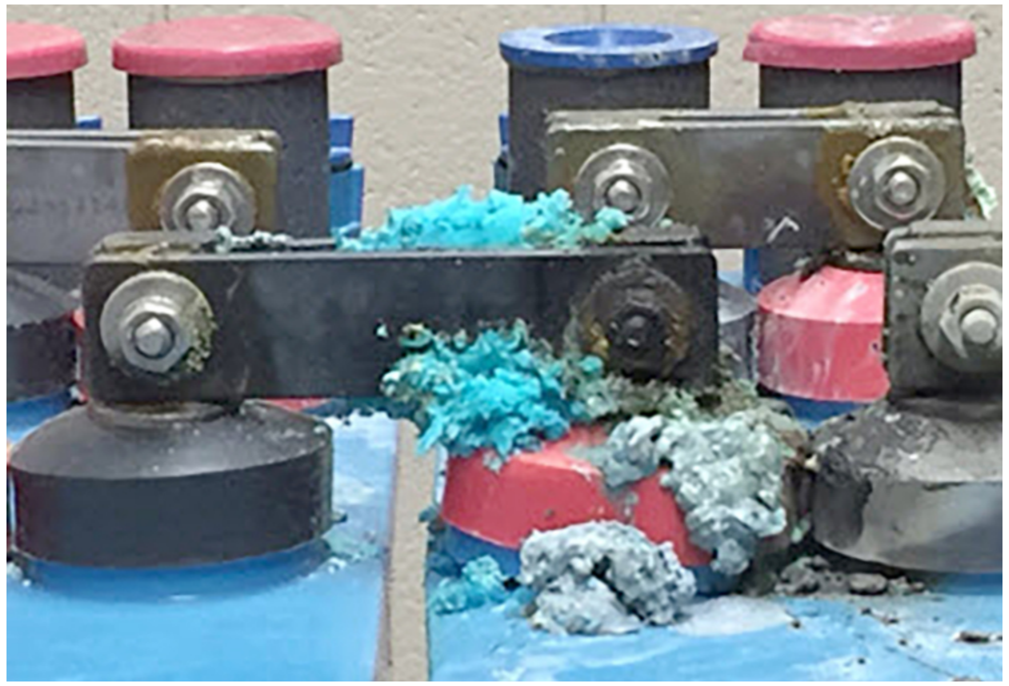


Fig 5: Extreme corrosion of lead plated copper hardware from leaking post seals that were ignored over an extended period. This battery is inoperable.

Terminal corrosion

Users employing lead-acid batteries will eventually experience corrosion appearing on cell terminals and connectors. The degree to which it occurs is a function of housekeeping practices and condition of post seals. Visual cues include brown, white and aqua-marine (copper sulfate) coloured discolouration of plated hardware such as tin or lead-plated copper intercell connectors, cables, terminal plates, etc. ***(Fig 5)***.

Corrosion starts when electrolyte attacks these surfaces. Electrolyte contamination frequently results from poor housekeeping practices, sloppy use of hydrometers, splashing and water additions, leaving droplets of water and electrolyte on cell tops and around connections, etc. Therefore, cell tops should be kept as clean as possible. Maintaining this condition helps considerably in the fight against corrosion. When housekeeping is not the problem, terminal post seals should be examined for leaks. When a post seal leaks, wetness or droplets of electrolyte will be observed around the seal area.

On a safety note, remember, electrolyte conducts electricity. Battery systems operating at more than 48 volts nominal can pose a serious, if not deadly shock hazard from the leak itself to ground and/or adjacent cells. Be aware of this hazard by checking the voltage with a DVM between the points of concern. Use of correct personal protective equipment (PPE) is essential.

To determine if a post seal is leaking, using a DVM, place one lead on the top of the suspect cell terminal. Place the other lead in the post seal area itself. Move the test probe around the

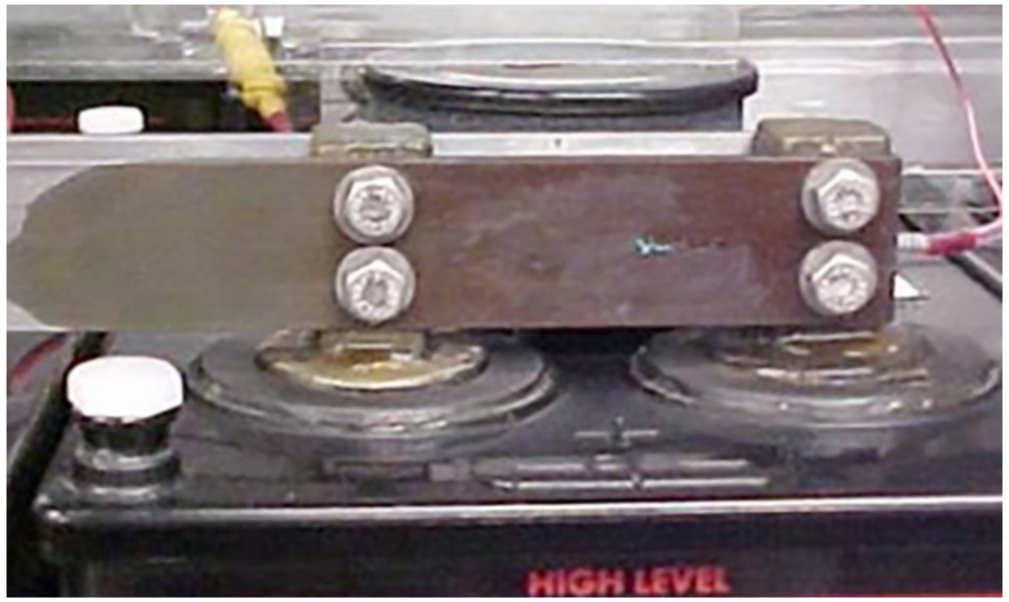


Fig 6: Moderate terminal lead peroxidation (brown colour) on the right-most terminal extending to the left resulting from a post seal leak.

perimeter of the seal. Voltage should be zero. Voltage detection indicates a leak.

Mild corrosion can usually be corrected through disassembly of the connection hardware followed by neutralisation, cleaning and drying. Extreme corrosion as illustrated in ***Fig 6*** warrants replacement of connectors and attachment hardware. Hardware and cell replacement is required for the extreme corrosion observed in ***Fig 5***.

Assuming a battery was properly handled during transport and installation, battery-wide post seal leaks should not be a problem. When most seals in a battery are found to be leaking, the user should consult the battery manufacturer for a possible warranty service visit.

When a connection requires servicing, the battery must be isolated from the charging equipment and its connected load. A temporary battery may be required based on site-specific conditions.

Electrolyte leaks

Post seals are not the only point where leaks can occur. Additional areas include cover-to-container seals. VLA cell covers and containers are bonded using proprietary adhesives developed specifically for the application. The joint is frequently a tongue and groove type and is quite reliable. VRLA batteries employing polypropylene covers and containers are mostly heat sealed to each other, making for an excellent bond. Non-heat seal methods use adhesives.

So how does a leak in the container-to-cover area begin? Firstly, post and plate growth occurring under the cover causes the post to lift vertically, stressing the joint. It can be manifested in the form of cracks in the cover, container or both. The affected area is where a leak can be formed. As for repair, there is little that can be done to quell the leak. If this is a battery-wide condition, it's likely the battery is nearing end of life if it is getting on in years.

Secondly, incorrectly installed flame-arresting vents in VLA batteries can result in leaks. They appear initially as wetness and droplets of electrolyte around the perimeter of the arrestor and its rubber sealing gasket. Should this be the case, the arrestor should be removed, cleaned, neutralised and thoroughly dried around the base. Inspect the gasket or O-ring seal for damage and replace if not in good condition. The cell cover must be cleaned, neutralised and dried. The assembly should be re-installed. Do not over-tighten. This should correct the leak.

Cell voltage imbalance

An imbalance of cell/unit voltages is another condition that cannot be detected through visual cues. This is a good reason for measuring and recording all cell float voltages quarterly per standards IEEE 1188 and IEEE 450. Early detection of cell problems is the key to keeping a battery in good operating condition. All cell voltages in a battery will never be equal, although a battery system can be ordered with voltage-matched cells for an additional fee.

Batteries employed in telecommunications central offices and related outside plant facilities historically required cell voltage matching. The author believes the specification was typically +/- 0.005 volts.

Most users do not require matching. It is common for individual cells to float within 0.05V of each other and the battery manufacturers usually specify that range or a bit wider in their user guides. The exception is the lead antimony where the range is usually 0.03V.

There are numerous causes for cell voltages to become unacceptably imbalanced. They include:

- Improper or no commissioning charge
- Chronic low float condition (charger set too low)
- Repeated discharge/recharge cycles with insufficient time for full recharge
- Wide cell temperatures range
- Poor housekeeping, including dirty cell covers, electrolyte tracking, leaks to ground, etc.
- Manufacturing defect

No commissioning charge

The commissioning charge, also called a freshening charge, is very important. Failure to perform this charge can create significant trouble for the user. Cell voltage imbalance is one problem, but failure of the battery to meet acceptance test criteria is another and that is a big deal. Essentially, the battery is not fully charged, so it cannot be expected to deliver rated capacity and cell voltages could be very wide-ranging.

Chronic low float condition

Battery systems operating in a long-term low float condition can experience 'cell drifting'. This will also affect capacity negatively. Once again, monthly checks and any needed corrections of system float voltage will preclude the introduction of the condition. Cells with a low state of charge contribute to low capacity, especially when the voltage approaches a critical level. Critical cell voltage is generally 2.12V for 1.215 specific gravity lead calcium cells and 2.16V for 1.250 specific gravity lead calcium cells. Check manufacturer user guides for your specific battery.

> "People are surprised when they learn that dirty batteries cause operational problems. One of these is cell voltage imbalances within the string. Dirt, dust, electrolyte tracking and other contaminants create multiple conduction paths on cell tops"

Repeated discharge and recharge cycles

The above, along with insufficient recharge time between those discharge cycles can result in wide ranging cell voltages on float. Once a battery has sufficient time to fully recharge, cell voltages should move closer to each other. An equalise charge may be needed in more extreme cases such as this. Consult the battery manufacturer for specific guidance for abnormal conditions such as this if normal recharging does not yield acceptable results.

Wide cell temperatures range

The maximum acceptable average range of cell temperature from the coolest to the warmest cell in a battery should generally be limited to 5°F. For example, a battery system is operated in an ambient temperature of 75°F. Normally, cell temperatures will vary slightly from the lower tier to the upper tier of the rack or cabinet.

If the average cell temperature is 75°F, it is recommended to limit the cell temperature range to no more than +/-2.5°F, or 5°F total. When this range exceeded, cell voltages can depart the normal range. Cooler cells will float higher and warmer cells will float lower. This problem usually results from an inadequately ventilated space.

The typical corrective action usually requires improved air movement to better direct and mix the air in the space. For example, a battery with tall cells installed on a three-tier rack in a room with poor air circulation can be particularly susceptible to significantly warmer cells on the top tier and likewise cooler cells on the bottom. The range can easily be exceeded.

Cell voltage imbalance frequently occurs under wide ranging temperature excursions. Equalise charging will not correct the anomaly because this is not a battery problem. It is an environmental problem.

Figure 7: A typical example of poor housekeeping practice. Dust and electrolyte are present on the cell tops of this 125-volt UPS battery. The condition exists throughout the string.

Poor housekeeping practices

People are surprised when they learn that dirty batteries cause operational problems. One of these is cell voltage imbalances within the string. Dirt, dust, electrolyte tracking and other contaminants create multiple conduction paths on cell tops ***(Fig 7)***. This condition creates cell float voltage imbalance because of tracking and interconnecting adjacent cells through the contaminants and electrolyte. The effect is like connecting small resistors between cells. Equalise charging will never fix housekeeping problems.

The battery is not the problem; it is the housekeeping practices. This is a particularly good reason why a battery must be clean. A dirty battery also causes nuisance alarms where DC system ground monitoring equipment is employed. Note the terminal and connector corrosion. Keep in mind that when performing battery cleaning, hazardous voltages may be present between cell terminals and ground, and other points within the DC system. Always use appropriate practices and PPE.

Manufacturing defects

Manufacturing defects are rare. Contamination of the grids and pastes is one cause of cell voltage imbalances. Another is failure to depolarise cells at the factory. Defects in plate separators are another cause.

Thermal runaway

Today, thermal runaway is still thought by some to only be an issue with VRLA batteries. The fact is any battery can have a thermal runaway event under certain conditions.

First, let us look at the definition of the term and the note that accompanies it. Below is the IEEE 1881-2016 definition of thermal runaway.

"A condition that is caused by a battery charging current or other process, which produces more internal heat than the battery can dissipate."

NOTE – The emphasis on this definition is on the presence of excessive internal heat, irrespective of the cause, which could be joule heating and/or high ambient temperature. The consequences of thermal runaway vary by cell chemistry. An increase in current causes an increase in temperature which results in further increase in current until the battery or unit self-destructs.

Background is required before reading further. In the early days of the VRLA battery, design, metallurgy and construction specific to this type was new to the industry. Problems were common and the author was dealing with it in the field service sector at that time. The battery manufacturers were not the only contributor regarding thermal runaway. There was plenty of blame to go around. Marketed as a 'maintenance-free product, end-users took the term quite literally. They installed it and forgot about it. No maintenance, right? Users were already at a disadvantage with limited battery knowledge, having had years of successful experience with VLA batteries which are more tolerant of less than stellar maintenance.

So, what was meant by maintenance-free in this context? It means, by design, VRLA batteries do not require periodic water additions, nor do they require specific gravity checks because there is no free electrolyte in the cell. The electrolyte that does exist becomes absorbed within a fibreglass mat which also acts as the separator. Electrolyte can also be in gelled form. Oxygen evolved at the positive plates passes through the absorbed glass mat (AGM). It combines with the hydrogen that evolves at the negative plates to reform water. This is a recombinant design.

There are AGM and gelled electrolyte designs with the latter also being recombinant. Gelled electrolyte designs employ a more conventional separator like those in VLA types. It is noteworthy that the recombination process is exothermic. There is some heat generated because of recombination, however it is very low. When a battery is operated in accordance with the manufacturer's instructions, operational problems rarely occur. But when it is not, that is when problems can arise.

For years, many VRLA systems were installed in a wide range of locations with two common problems: poor ventilation and little or no temperature control (air conditioning). This was the end user's contribution to thermal events, compounded by a new battery design with its own problems that were not originally well understood.

Increased battery temperature, from operation in a hot room, increases the float (charging) current. Increased float current further increases battery temperature. Eventually the temperature and float current increase exponentially and thermal runaway can occur. In extreme cases, thermal events have ended in a fire ***Fig 8***.

Figure 8: This photo has been widely circulated on the internet. This is clear evidence of a VRLA battery that went into thermal runaway. Such events are easily avoided by simply operating any battery per the manufacturer's operating instructions.

In the years after introduction of battery monitoring systems, VRLA batteries were, and frequently continue to be, integrated to such systems that can measure, store and track multiple parameters, alerting a user to potential problems. Monitoring systems can be purchased and configured for VLA and nickel-cadmium batteries as well. Lithium batteries come with their own battery management system (BMS) by default.

In the past, there was no IEEE recommended maintenance practice for VRLA batteries. Today, we have IEEE 1188 but that did not help the problem in 1980s. It took 16 years to develop the standard. The first issue of the document was not published until 1996. All users had was the documentation that came with the battery system.

How is thermal runaway prevented? These are common preventive measures relating to the avoidance of thermal issues for lead acid. These are similar for nickel cadmium as well.

- Provide a good environment
- Use charge voltage temperature compensation
- Ventilate the space
- Perform proper maintenance
- Disable the auto-equalise function on the charger
- Monitor battery and environmental temperatures
- Don't ignore monitoring system alarms!

Taking good care of your battery in the first place is a great way to eliminate the need to troubleshoot problems.

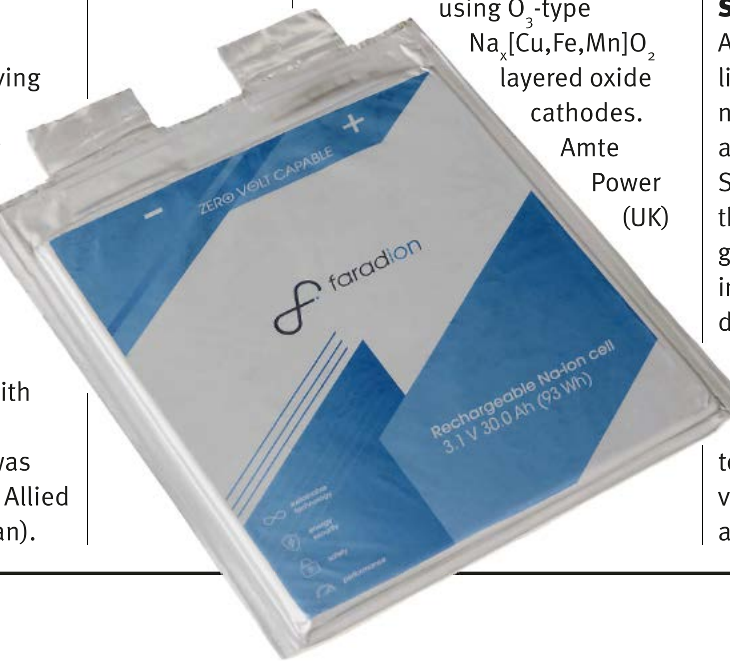
Na-ion batteries: a welcome alternative to Li-ion and PbA

As Frank Lev from Tavrima Canada explains, this article starts with a sobering note from Stanley Whittingham, the laureate of the 2019 Nobel Prize for chemistry. He states that the supply of raw materials for lithium-ion batteries (LIB) may run out within the next 5-10 years. Consequently, alternative batteries relying on materials other than lithium are required, as there will not be enough lithium left for future production of LIBs. The geographical distribution of LIB precursors is unbalanced, with more than 80% of the global lithium reserves clustered in Australia, Chile, and Argentina.

Cobalt is exported mainly from the geopolitically unstable Democratic Republic of Congo. In the last years, raw material prices have grown dramatically, driven by the ongoing demand for lithium-ion batteries by EVs, ESSs, power tools and electronic gadgetry. Despite all the efforts, there have not been viable alternatives to LCM-type lithium cells due to their beyond-competition high energy density.

However, a quickly maturing sodium-ion battery (SIB) technology is a plausible alternative to LFP cells. Having the gravimetric energy density of up to 160 Wh/kg while being equally safe, the SIBs are poised to substitute some LFPs in various EVs and other applications reaching 20 GWh by 2030.

The first SIB prototype with P2-Na_xCoO_2 cathode and sodium/lead alloy anode was introduced in the 1980s by Allied Corp (US) and Hitachi (Japan). Despite a good endurance of 300 cycles, their 2.7 V cells could not compete with the more energy-dense 3.7 V $LiCoO_2$ cells. Years later, Faradion (UK) unveiled its first 400 Wh cell with O_3/P2-type $Na_aNi_{1-x-y-z}Mn_xMg_yTi_zO_2$ cathode and a hard carbon (HC) anode. In 2017, Tiamat (France) introduced its first cylindrical 18650 cells with $Na_3V_2(PO_4)_2F_3$ cathodes and HC anodes, showing an energy density of up to 120 Wh/kg. At the same time, HiNa (China) developed 120 Wh/kg SIB cells using O_3-type $Na_x[Cu,Fe,Mn]O_2$ layered oxide cathodes. Amte Power (UK) recently announced that its new SIB cells are almost ready for validation. CATL (China) has unveiled a SIB prototype capable of 160 Wh/kg projecting to quickly reach the production target of 200 Wh/kg at a cost of $40/Wh. CATL claims that SIB technology is fully compatible with the LIB production lines and is easily adaptable for high-volume manufacturing. CATL has also introduced its novel LIB/SIB integrated battery system.



Sodium very similar to lithium

Although sodium is very similar to lithium electrochemically, it does not have the same capacitance and is three times heavier. Sodium ions have a larger radius than lithium ones, making graphite unsuitable for ion intercalation. Stevens and Dahn discovered hard carbon's (HC) ability to store sodium ions in 2000. Now, HC is the material of choice for many SIB technologies. HCs are made from various raw organic materials that are not graphitisable, even at

3000°C, producing a glassy carbon instead. HC has received an intriguing name: "The House of Cards", due to its disordered structure of graphene layers being not neatly stacked, like in graphite, but randomly distributed. The intrinsic difference between the graphite and HC structures results in differing ion-storage sites.

In graphite, the ions are stored mainly between the graphene layers, whereas in HC, the ions are accumulated in closed micropores and structural defects. The HC is difficult to characterise due to its complex, varying structure. A typical HC's theoretical gravimetric capacity is about 300 mAh/g, which is almost 20% lower than that of graphite. Various strategies are applied to increase the reserved capacity (RC) of HC by decreasing the diffusion barrier and increasing the electronic conductivity. The researchers have achieved good results by enlarging the interlayer spacing, improving the sodium-ion intercalation, and optimising the number of defects.

The porosity must also be optimised since a large surface area of highly porous HC may accelerate its parasitic reactions with the electrolyte. The specific surface area expressed by the BET (Brunauer, Emmett and Teller theory) is directly proportional to the number of open pores. For instance, the HC with a BET equal to 1272 m^2/g has an initial coulombic efficiency (ICE) of only 21%; in contrast, the HC with a BET of only 5.4 m^2/g has ICE equal to 83%. The RC is inversely proportional to the BET. Also, the

> "HC has received an intriguing name: "The House of Cards", due to its disordered structure of graphene layers being not neatly stacked, like in graphite, but randomly distributed"

HC's closed pores contribute to the high values of RC. Some studies show that RC of 438 mAh/g is achievable by optimising the percentage of closed pores.

Typically, the HCs are produced from precursors such as sucrose, glucose, petroleum coke, lignin, pitch, and cellulose, which are pyrolysed at about 1200°C. Such HCs provide RC of up to 300 mAh/g and suffer from slow sodium ion insertion kinetics and low volumetric energy density. To compete with LFP, the HC-based anode must have high RC and ICE, not achievable by the run-of-the-mill commercial HC products. The manufacturers of the commercial HCs include Xiamen Tob New Energy (China), Kuraray (Japan) and Stora Enso (Finland). For instance, Stora Enso produces a lignin-based HC product called Lignode, and Kuraray makes a coconut core-based HC called Kuranode. Both products target anodes for SIBs. Stora Enso uses its abundant supply of kraft lignin to make Lignode on its pilot production line, where lignin is reduced into a fine powder and pyrolysed at 1000°C in the absence of oxygen. Kuraray uses a similar process. Unlike graphite, mined and synthesised from fossils, the lignin and coconut shells are less expensive bio-renewable byproducts.

SIBs Market Review 2022 identifies at least eight global SIB developers using or intending to use the HC-based anodes. These are Faradion (UK), Novasis-e (Canada), TIAMAT Energy (France), Altris (Sweden), AMTE Power (UK), SHARP Labs of America, Sumitomo (France), and CNRS & RS2E (France).

Faradion's remarkable results

Faradion has achieved remarkable results using its patented SIB technology that includes a high-performance composite active material for anodes to improve the HC's low RC. In one of his media interviews, Faradion CEO, James Quinn, revealed that Faradion has successfully developed SIB cells with an energy density of 190 Wh/kg, ready to go into production. The company plans to increase the energy density up to 250 Wh/kg, bringing Faradion SIB technology in the ballpark with most LIBs of today.

The HC anode surface defects or doping groups may form electrochemically active sites capable of decomposing the battery electrolyte and lowering ICE. To mitigate the electrolyte decomposition, an HC-based anode was coated with a protective layer of soft carbon made from carbonised asphalt. The layer effectively isolated the HC surface from the electrolyte and delivered a record ICE of 94.1%.

Another promising option is to coat the anode surface with a

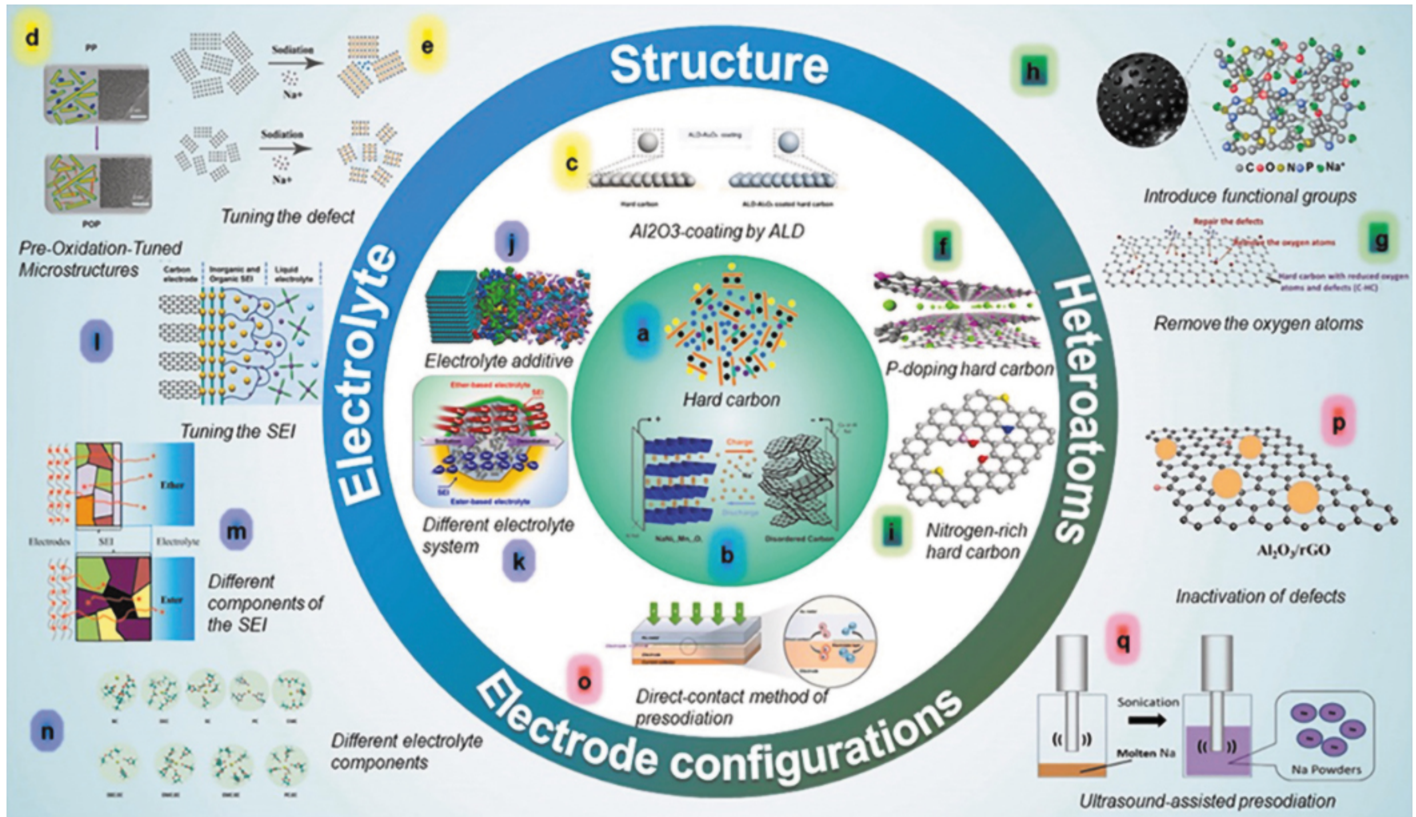


Fig 1: The fundamentals of HC-based anode technologies

thin layer of Al_2O_3 since it isolates the HC from the electrolyte, reduces the interface resistance and increases ICE. All these developments confirm that a protective layer of an inert material applied to the surface of an HC-based anode can effectively mitigate electrolyte depletion, prolong the battery's useful life and increase ICE. Also, the resistance (ESR) of electrode/electrolyte interfaces can seriously impact the SIB's stability and power output. The ESR depends on the characteristics of a solid electrolyte interphase (SEI) and a cathode/electrolyte interphase (CEI). The researchers use different strategies to optimise the HC surface defects mainly responsible for the SEI and CEI. An experimental anode with only 6 nm thick SEI has demonstrated an ultra-high ICE of 92% and excellent cyclability. In addition to the HC-based anode surface modifications, the optimisation of closed pores is another way to improve the interface stability of HC active materials. An electrochemical study revealed that the optimised closed pore structure had increased RC, ICE, and interface stability without the penalty of excessive electrolyte decomposition.

> "All these developments confirm that a protective layer of an inert material applied to the surface of an HC-based anode can effectively mitigate electrolyte depletion, prolong the battery's useful life and increase ICE"

Some SIB developers use non-carbonaceous materials for anodes sodiated by forming intermetallic compounds between inserted sodium ions and host elements, resulting in higher capacity. For instance, tin and antimony have shown the highest theoretical capacity of up to 847 mAh/g combined with good electrical conductivity. However, both metals experience volume expansions of up to 400%, conducive to the failure of the SEI and CEI interfaces.

According to numerous studies, anode materials storing sodium via an alloy reaction mechanism can regulate sodium ion transport and prevent the formation of sodium dendrites. Dendrites are needle-like filaments that grow on the surface of metallic anodes and cause dangerous battery shorts. The dendrites significantly impede the application of high-capacity Li-metal anodes in LIBs and Na-metal anodes in SIBs. The Na-metal, like Li-metal, has a high theoretical energy density but cannot be used safely without the dendrite growth mitigating remedies. A dendrite-free operation of over 100 h was made possible by depositing a thin layer of NiSb on a Na-metal anode to control its electrochemical plating process.

A new composite anode material developed by UT Austin may solve the dendrite problem, allowing higher RC and faster charging rates. The new intermetallic material is made by embedding the antimony-telluride particles into a thin sheet of sodium metal. Several such sheets are clad together to produce a composite sodium-antimony-telluride anode of the desired thickness. The composite anodes are less likely to form dendrites than the existing Na-metal anodes.

Natron Energy (US) is one of the leading SIB manufacturers using intermetallic anodes. Natron has recently joined hands with Clarios (US), a manufacturer of batteries for mobile applications, to produce SIBs on a large scale. The Clarios plant in Meadowbrook, Michigan, is expected to become the largest SIB plant in the world when volume production begins in 2023. Natron plans to capitalise on the lower costs and faster turnaround time by using a part of Clarios's existing LIB manufacturing facility to produce

“Noteworthy, PB is not toxic and is easy to make from cheap, abundant constituents”

SIBs without significant changes to its production equipment. The project has received support from the US Department of Energy ARPA-E agency SCALEUP programme.

Significant cathode progress

Significant progress has been achieved in developing cathodes for high-energy-density SIB cells. Similar to LIB, SIB cathodes store sodium via intercalation reaction but, in contrast with the former, their chemistry does not rely on costly and scarce elements like cobalt, chromium, nickel and vanadium. Layered oxides, polyanions, and PBAs are the materials of choice for SIB cathodes. Faradion was one of the first to develop a SIB cell with an O_3-type $NaNi_{1/4}Na_{1/6}Mn_{2/12}Ti_{4/12}Sn_{1/12}O_2$ oxide cathode, which delivered 160 mAh/g at 3.22 V. Such performance at the cell level is comparable to some commercial LIBs.

Other development efforts were focused on cathodes based on polyanions. These cathodes have proved to be durable and safe owing to their strong covalent bonds, but at the same time, they have a lower energy density than the oxide-based cathodes.

Sodium-vanadium phosphate and fluorophosphate have demonstrated excellent cycling stability and the capacity of up to 120 mAh/g at 3.6 V. Prussian Blue (PB), and Prussian Blue analogues (PBAs) are used as cathode materials because of their open 3D framework, adjustable structure, and chemical composition. PB has demonstrated high working voltages, flat cycling potentials and ease of synthesis. PB's formula is $AxFe[Fe(CN)_6]y\beta 1\text{-}y\sum zH_2O$, where A represents an alkaline metal ($0<x<2$), and β represents $[Fe(CN)_6]$ vacancies occupied by coordinating water ($y<1$). PB is suitable for SIB cathodes because its open framework has large interstitial sites allowing for the accommodation of Na+ ions and volume adjustments at cycling. Its theoretical specific capacity of 171 mAh/g at 3.3 V is higher than other SIB cathodes and is comparable to that of lithium-ion batteries.

Noteworthy, PB is not toxic and is easy to make from cheap, abundant constituents. However, despite high expectations, the actual RC of PB cathodes is less than 120 mAh/g at a 1C rate, which is significantly lower than its theoretical 171 mAh/g; its RC retention is only 36.5% after 70 cycles. Novasis Energies patented SIB cell with PBA $Na_2Mn[Fe(CN)_6]$ cathode that was capable of 150-160 mAh/g at 3.4 V. In general, the energy density of polyanions and PBAs is not as high as those of layered oxides, but their cycle life is better, owing to their robust structure. The polyanions and PBAs find their application in such SIBs where high energy density is not critical.

Altris is the Northvolt-backed Swedish producer of Fennac, also known as Prussian White (PW) high-performance cathode material for SIBs, made from plentiful materials such as sodium, iron, carbon and nitrogen. PW is the fully reduced and sodiated form of PB capable of improving the manufacturability of commercial SIBs as it makes it unnecessary to use the reactive sodium-loaded anodes. The large pores inside the material allow for storing a significant number of molecules. The PW-based cathodes have a theoretical capacity of 170 mAh/g at 3.2 V.

Altris made a deal with Sandvik MT to use its Sandviken facility to manufacture 2,000 tonnes of Fennac per year. Altris states that its Fennac is the most sustainable and cost-efficient SIB cathode material on the market today. It is not clear yet whether Altris intends to produce complete SIBs. It is interesting to note that while Natron uses cathode material based on Prussian Blue, Altris makes cathode material based on Prussian White.

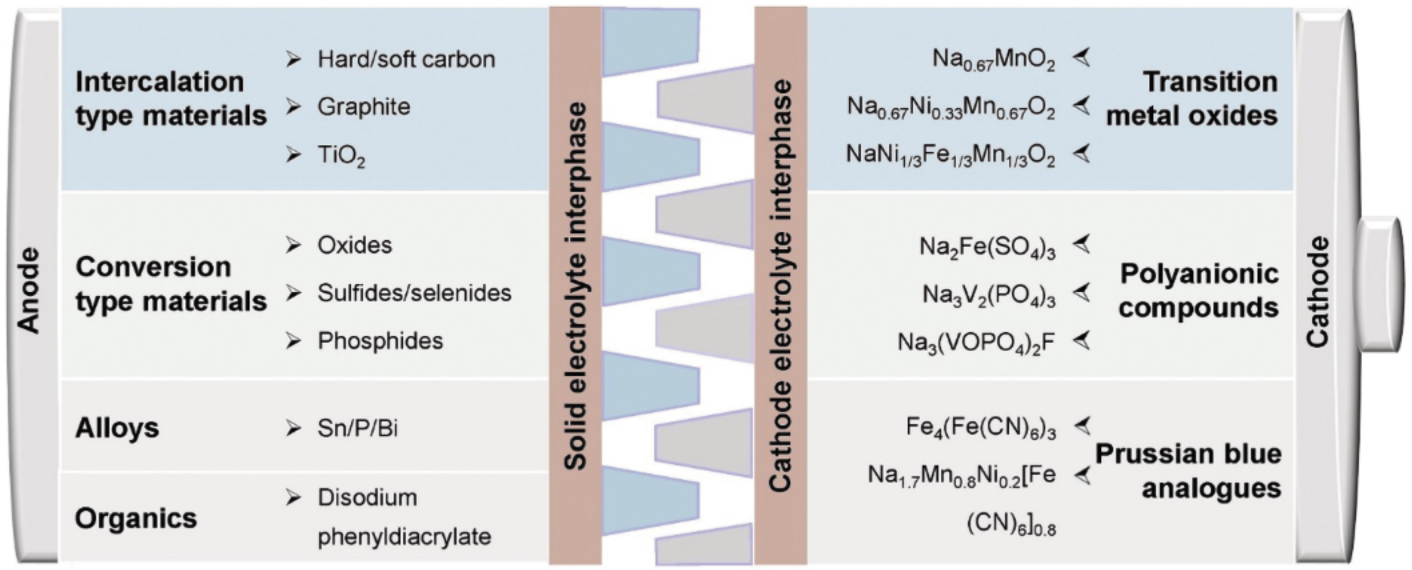


Fig 2: The fundamentals of SIB technology

Electrolytes for performance

The electrochemical performance of SIBs strongly depends on the properties of the electrolytes.

A research team from the Department of Energy of Pacific Northwest National Laboratory (PNNL) has developed a new electrolyte enabling it to improve the life expectancy of SIBs. Typically, a battery electrolyte is made of salts dissolved in solvents to provide charged ions for an electrochemical reaction. After several cycles, the electrolyte salts and solvents are gradually depleted, thus diminishing the cell's capacity. This process tends to progress much faster in SIBs than in LIBs. The PNNL mitigated the problem by creating a new electrolyte formula of 1.5M NaFSI salt in a solvent mixture of DMC and TFP. In laboratory tests, the new electrolyte maintained 90% of its capacity even after 300 cycles at 4.2 V, which is higher than what most SIBs are currently capable of, ***(Fig. 2)***.

“The electrochemical performance of SIBs strongly depends on the properties of the electrolytes”

The technology readiness level (TRL) of SIBs depends on the development and validation of active materials, battery design and manufacturing processes. Numerous SIB prototypes have been developed with encouraging results and a good prospect for speedy commercialisation. A demonstration SIB-based energy storage system (ESS) of hundreds of kW is being commissioned now. The current TRL can be assessed at 6-8 on a 10-point scale. Further development of SIBs is rapidly advancing, aiming to reach commercialisation in 2023.

The development of SIBs is driven by concerns about the

Parameter	Sodium-ion battery	Lithium-ion battery	Lead-acid battery
Cost per KWh	$40–100	$137-200	$70-100
Volumetric energy density	250–375 Wh/L	200–683 Wh/L	80–90 Wh/L
Gravimetric energy density	75–165 Wh/kg	120–260 Wh/kg	35–40 Wh/kg
Cycles at 80% DOD	3,000	3,500	900
Safety risk	Moderate	High	Low
Materials	Abundant	Scarce	Toxic
Cycling stability	High	High	Moderate
Round-trip efficiency	90-92%	85-95%	70-90%
Temperature range	–20 to 60 °C	–20 to 60 °C.	–20 to 60 °C
The number of charge-discharge cycles a battery endures depends on depth of discharge, C-rate and temperature.			

Table 1

availability and costs of lithium, cobalt and nickel, and their environmental impact. SIBs are projected to be relatively low-cost because their electrode materials are based on abundant precursors and the same manufacturing technology as LIB, enabling manufacturers to use existing production equipment. Another advantage of SIB technology is that its electrochemical window of operation allows using aluminium for both anode and cathode current collectors, contributing to cost and weight reduction. Also, replacing copper current collectors with the aluminium ones allows safer transportation and a longer shelf-life of SIBs in a fully discharged state. By 2030, SIBs will consume about 90 kilotons of aluminium, sodium, and HC, representing a market compatible with LIBs.

In March 2020, AMTE Power announced that it will use technology licensed from Faradion in batteries powering AceOn's portable energy storage systems in sub-Saharan Africa. A thousand SIBs will be assembled into systems to power solar energy storage units. Such a contract is a first for AMTE. The company's new site at Dundee's Michelin Scotland Innovation Parc (MSIP) will manufacture pouch cells for the EV and the stationary energy storage markets. The new factory will produce up to 1 GWh per year of SIB cells, reflecting the growing demand for SIBs and reaching its full production capacity by 2026.

The European Union Batteries Technology Development Report 2020 states that the energy density of some brands of SIBs is in the same ballpark as LFP batteries, which the latest SIB performance data fully confirms. ***SeeTable 1***.

> “The European Union Batteries Technology Development Report 2020 states that the energy density of some brands of SIBs is in the same ballpark as LFP batteries, which the latest SIB performance data fully confirms”

The foregoing is essential because, in its Q3 report, Tesla stated that it will use LFP batteries in all its standard-range vehicles. With a comparable to LFP energy density and technology based on abundant, inexpensive materials, the SIBs are facing an imminent commercial success. According to Max Reid, research analyst at Wood Mackenzie, SIB batteries are expected to replace some of the LFPs in passenger EVs and EES, reaching 20 GWh by 2030. Owing to the electrification of the automotive industry, the ascendence of SIBs may resemble that of the lead-acid batteries (LAB) in the past. With the further proliferation of EVs, the LABs will gradually concede their markets to the much more energy-dense, non-toxic, and equally inexpensive SIBs.

IP licences and how to negotiate them

UK and European patent attorney Ben Lincoln, Partner at Potter Clarkson LLP, considers the benefits of licensing intellectual property.

In the research heavy battery industry, licences provide a way for a patent holder to give permission to a third party to use their technology in exchange for a royalty.

The licensing of intellectual property (IP) provides great opportunities. For the holder of the IP rights, it presents an additional revenue stream or a means to commercialise the technology in a different country with a local partner while receiving a royalty. For the licensee, they are able to access patent-protected technology in exchange for a royalty and, depending on the terms, develop the technology and avoid the need for the upfront research and development costs.

In the fast-moving battery technology space, research such as in alternative battery chemistries, battery types and electrode materials is performed by many different parties. They include government-backed organisations, universities and small start-ups. In some instances, these parties may not have the means or desire to fully commercialise the invention in a global marketplace. IP licensing provides a solution. However, licences come with terms and conditions and there are important matters to consider for both the licensor and the licensee.

Example – Licensing of technology developed with the support of the US government

It has been reported by NPR that UniEnergy Technologies of Seattle, US, licensed[1] technology for a vanadium flow battery that was originally developed by the Pacific Northwest National Laboratory (PNNL), supported by the US Department of Energy's Grid Storage Programme. Vanadis Power, a company based in the Netherlands is reported to have sub-licences to the technology.

Government-backed projects often come with restrictions that a licensee would need to be aware of. In fact, the patents themselves, which are mentioned below, carry a statement that "This invention was made with Government support under Contract DE-AC0576RL01830 awarded by the US Department of Energy. The Government has certain rights in the invention."

The PNNL website lists patent applications that were applied for by Battelle Memorial Institute on behalf of the PNNL. Two patent families relating to Vanadium Redox Flow Batteries can be identified.

The first family has the title 'Redox flow batteries based on supporting solutions containing chloride'.

The abstract describes the invention as "Redox flow battery systems having a supporting solution that contains $C1^-$ ions can exhibit improved performance and characteristics. Furthermore, a supporting solution having mixed SO_4^{2-} and $C1^-$ ions can provide increased energy density and improved stability and solubility of one or more of the ionic species in the catholyte and/or anolyte. According to one example, a vanadium-based redox flow battery system is characterised by an anolyte having V^{2+} and V^{3+} in a supporting solution and a catholyte having V^{4+} and V^{5+} in a supporting solution. The supporting solution can contain $C1^-$ ions or a mixture of SO_4^{2-} and C^{-1} ions."

Applications were made in the US, Europe, Australia, Canada, China, Japan and South Korea. The US and European members of the family have patent numbers US8628880(B2), US9077011(B2), US9123931(B2), US9819039(B2) and EP2622675 A.

The second family has the title 'FE-V redox flow batteries'.

The abstract describes the invention as "A redox flow battery having a supporting solution that includes Cl^- anions is characterised by an anolyte having V^{2+} and V^{3+} in the supporting solution, a catholyte having Fe^{2+} and Fe^{3+} in the supporting solution, and a membrane separating the anolyte and the catholyte. The anolyte and catholyte can have V cations and Fe cations, respectively, or the anolyte and catholyte can each contain both V and Fe cations in a mixture. Furthermore, the supporting solution can contain a mixture of SO_4^{2-} and Cl^- anions."

Applications were made in the US, Europe, Australia, Canada, China and South Korea. The US and European members of the family have patent numbers: US8771856 (B2) and EP2622674 (Status: Not granted – deemed to be withdrawn).

[1] https://www.npr.org/2022/08/03/1114964240/new-battery-technology-china-vanadium?t=1660037141906&t=1662039515279

What is the right way to approach the licensing of IP?
Once an IP licensing opportunity has been identified, obtaining legal advice at an early stage is worthwhile. In some instances, obtaining advice before approaching the other party may be appropriate so that the fundamental feasibility of the deal can be understood before making your commercial aims known.

There is always a risk the proposed deal may not work for some reason or, at least, does not work exactly as the parties originally envisaged. In addition, specialist legal advice can ensure that the licence itself achieves your commercial aims (as far as possible).

Exclusivity and performance
Whether you are licensing out (as licensor), or licensing in (as licensee), the issue of exclusivity and its relationship with royalties is an important one.

Many licensing deals would not be concluded without the granting of some degree of exclusivity to the licensee. Although this is common, the situation the licensor needs to avoid in this situation is one in which the licensee underperforms but the licensor cannot bring the exclusivity to an end. Giving another party exclusive rights to exploit the invention while they underperform in bringing the invention to market could severely impact the incoming royalties. However, on the other side, if you are in-licensing you do not want to be subject to disproportionate constraints or targets.

Typically, an exclusive licence seeks to address the issue of licensee performance in a number of ways:

- It sets a contractual obligation for the licensee to use its best or reasonable endeavours/efforts to exploit the licensed technology or property as widely as possible and to meet all reasonable customer demand for the licensed product in the licensed field or territory
- The licensor provides specific performance metrics or KPIs which, if the licensee does not satisfy them, the "exclusive" nature of the license is lost, and the licensor may appoint one or more other licensees in the same field or territory
- A short licence term with the need for an exclusive licence to be re-negotiated and re-agreed, rather than automatic renewal taking place or a long licence term being agreed
- The licensee is required to pay a minimum royalty regardless of the number of actual sales or income in order to keep the licence in place.

Each of these ways should be understood by both parties because the impact can be wide when disagreements take place.

For example, in some jurisdictions, a "best" endeavours/efforts obligation, while not being an absolute obligation, is an onerous one for a licensee because it could require the licensee to apply all

its resources to the achievement of the object of the obligation (for example, meeting all reasonable customer demands for the licensed product) without having regard to the competing needs of other parts of its business.

In the field of battery manufacture, access to certain metals and chemicals can sometimes be challenging. With fluctuating supply and prices of such materials, the fulfilment of a "best" endeavours obligation in a licence could be challenging, at least in a way that is profitable for both parties involved.

The inclusion of such an obligation may be of real assistance to a licensor in dealing with an underperforming licensee, but clearly could be considered disproportionate by a licensee. However, because a "best" endeavours obligation is such an onerous one, it is rarely

given in this context, at least by a properly advised licensee, and is generally amended to “reasonable” or “all reasonable”.

The less stringent obligation should still assist the licensor in dealing with a licensee who is doing nothing, or next to nothing, to exploit the licensed technology or property by allowing the licensor to terminate the licence for breach. In other circumstances (e.g. where the licensee is performing in some areas but not others), it may be difficult for the licensor to prove a breach since, in determining whether the licensee is using its reasonable endeavours/efforts, other calls on the licensee’s resources and time must be taken into account.

In relation to KPIs, where the licensor is familiar with the business of the licensee, the prior agreement of specific targets or KPIs in a schedule to the licence which is reviewed on a fairly regular basis (for example annually or every three years) can be a pragmatic way for the licensor and licensee to agree a minimum expected level of performance from the licensee. This may include marketing spend levels, dates for milestones on which the licensee will launch specific products or in additional territories, or the number of “new” customers to be achieved in a specific territory.

It is not uncommon for an agreement to state that an exclusive licensee will lose its exclusivity rights if it fails to meet KPIs or minimum performance standards for two consecutive assessment periods. This mechanism can provide additional options for a licensor to supplement its income in a particular field or territory if the existing licensee is underperforming.

A licensor should also consider the administrative burden of auditing, and conversely, the licensee should consider the administrative burden of reporting and being subjected to audit on these factors before using this structure.

Licence term

A licensor is never obliged to provide a long-term licence to a licensee.

There are a number of benefits, including certainty of commercial arrangements, or perhaps guaranteed income (where a minimum royalty is used), to agreeing a long licence term. However, where the performance of a licensee is not established, or sensible targets could not be agreed, resorting to a shorter-term licence may provide the parties with the ability to exit the arrangement if it is not mutually beneficial, or even beneficial to one party.

This can be achieved by a number of methods, including a fixed-term licence where expiry is automatic, and a new licence must be agreed and executed in order to continue the relationship, or an elective break clause (e.g. two years into a four-year licence).

Minimum royalties

A mutually agreed minimum royalty obligation is usually a good way for a licensor to ensure a minimum level of commercial benefit from the arrangement.

In many situations, there will be a large amount of guesswork in predicting the sales and profits that a diligent licensee will achieve. Sometimes it turns out that the licensee can achieve the minimum royalty while still leaving a large part of the potential market untapped.

Careful consideration also needs to be given to the consequences of the licensee not achieving sales sufficient to generate the minimum royalty.

“Your legal advisors should be commercially astute and, where possible, understand battery technology and your market segments well to ensure that you receive the best results in your agreements and understand any KPIs that may be in place”

For example, should the licensee be able to avoid termination in these circumstances by making up the shortfall between the earned royalties and the minimum or should the licensor be able to terminate the agreement in any event?

As mentioned above, it may be more appropriate for the licensee to simply lose its exclusivity in that field or territory as a result of failure to achieve the minimum royalties for two consecutive assessment periods (for example).

If the minimum royalty was set at the bottom end of the parties’ expectations, a licensor will probably not wish to settle for the payment of that sum for, say, the 20-year life of a patent. Looking at this situation from the other perspective, it is rare, in our experience, for the licensee to be given any termination rights when earned royalties are below the minimum royalty level.

Yet, if this is the situation and it continues for more than a year or two despite the licensee’s best efforts to market and sell the licensed products, then the licensee may be as, if not more, concerned than the licensor about the agreement continuing for many further years as it is likely that the arrangement is not commercially beneficial for the licensee either!

The licensee should, therefore, at least consider seeking to negotiate a reciprocal termination right to cover this situation.

Approach to exclusivity and royalties

As we have explained above, there are numerous factors which can be used to try and ensure a fair and controlled relationship between licensor and exclusive licensee, which avoid the parties being tied into an exclusive relationship which is not beneficial for the party concerned.

Most commonly, balancing these controls both commercially and legally will take time and forethought, and these are best agreed in Heads of Terms. Engaging experienced legal counsel at the early stages of negotiation will mean that parties can receive guidance on a sensible balance of obligations as between licensee and licensor, and the implications of the proposed structures.

Your legal advisors should be commercially astute and, where possible, understand battery technology and your market segments well to ensure that you receive the best results in your agreements and understand any KPIs that may be in place.

Battery gas recombination in the US and Europe

Is the US finally catching up with the EU regarding the benefits of battery gas recombination devices? Pete DeMar, co-founder of Battery Research and Testing, (BR&T), considers the question and suggests: The answer depends on what you define as 'catching up'.

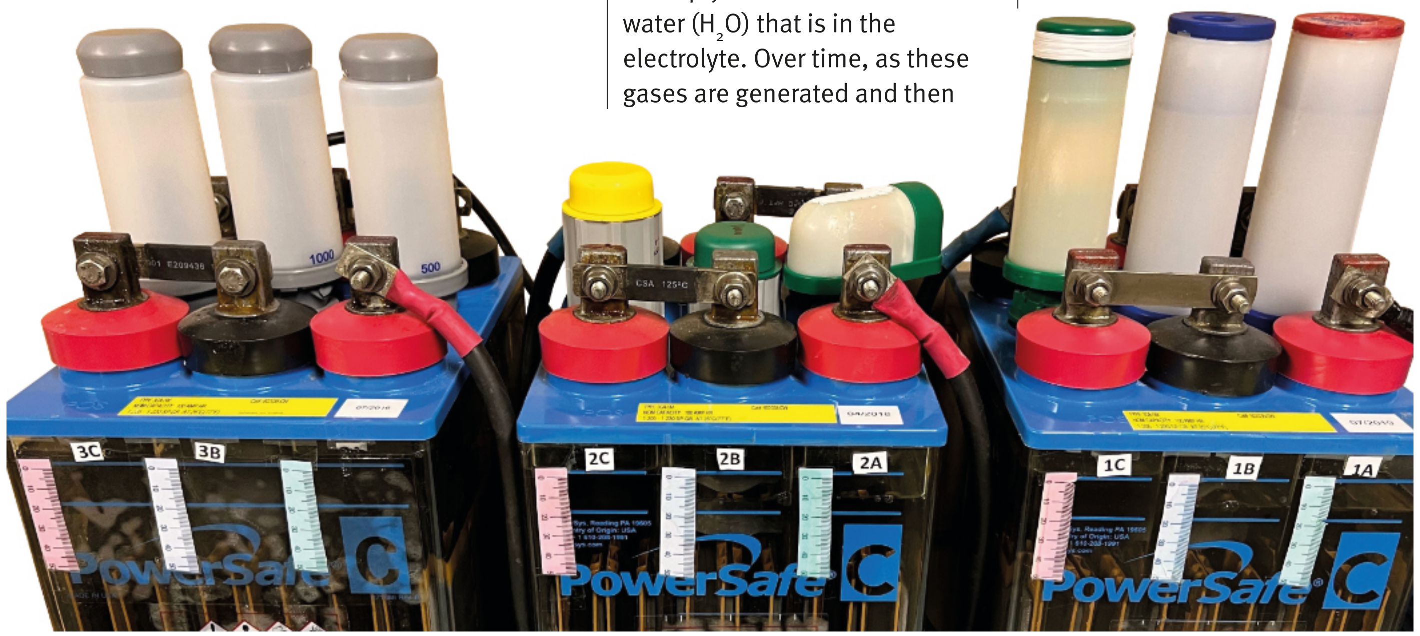
If your definition of catching up on battery gas recombination in the US is that the powers-that-be (standards writers and standards documents) define recombination vents/plugs, explain what they do and acknowledge their benefits and value, then the answer is 'yes'. That recently occurred in the US with the newest revision/update to the IEEE1635/ASHRAE21 document.

If you define catching up as the majority of the US end-users actually understanding how these devices function and the benefits they can provide, the answer might be 'not quite yet'.

The need to recombine

To explain this, it needs to be understood that the process required to recombine the gases (hydrogen and oxygen) that are generated during charging, of stationary batteries, has been understood since Thomas Edison's time. All vented lead-acid and vented nickel-cadmium batteries give off hydrogen and oxygen when being charged. This is simply the breakdown of the water (H_2O) that is in the electrolyte. Over time, as these gases are generated and then released from the cells, the electrolyte levels in the cells lower, which eventually requires the addition of water to keep the levels within an acceptable range. This is a normal and ongoing maintenance requirement. The interval between those required water replenishments is influenced by a variety of issues, such as the cell design, the average individual cell voltage setting, the average electrolyte temperature, and in particular the float current of the specific battery string.

Fig 1: A selection of battery gas recombination devices from different manufacturers mounted on batteries



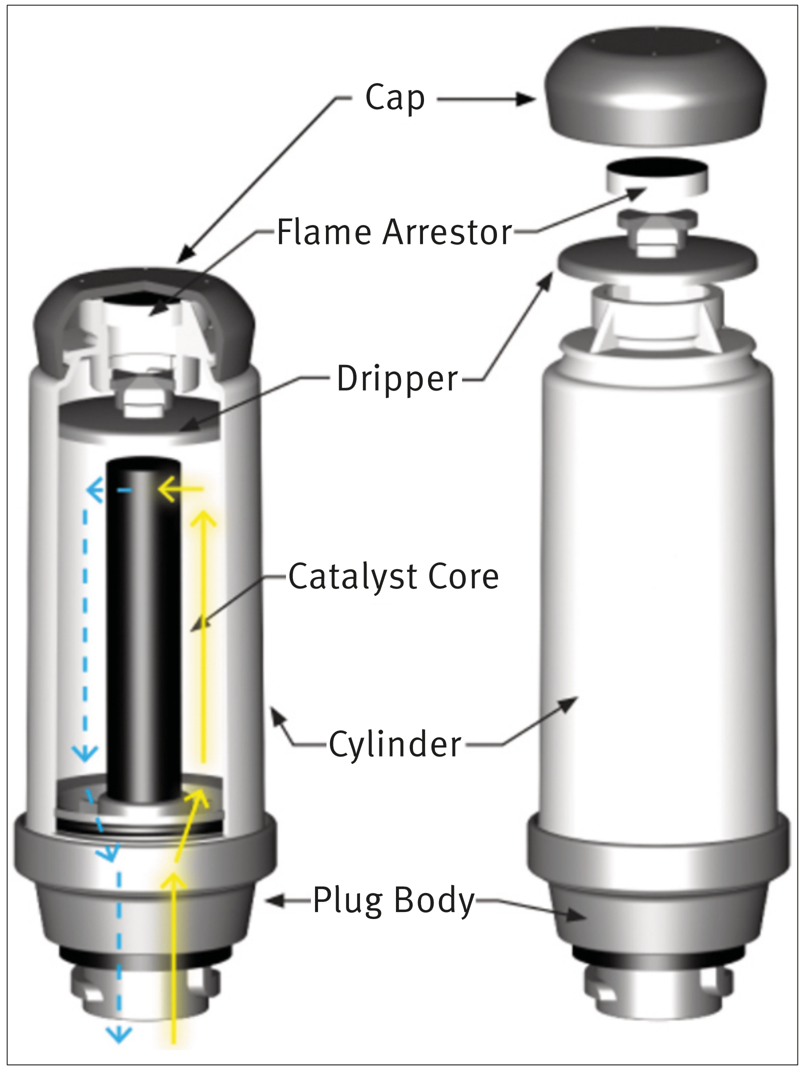


Fig 2: Standard recombination vent

Battery gas recombination has been known about since the early 1900s, with some early devices patented to perform this process. The earliest unit that I consider of a modern type design was patented in 1949 by Dr Palmer H Craig and entitled 'Storage battery cap with recombining means'. It was not until the late 1960s that a concentrated effort was made to create a modern-day type of recombiner.

In 1971 Hoppecke introduced the AquaGen plug, which made them the first battery manufacturer in Europe to offer recombiners to purchasers of their batteries – as far as I am aware. These were created with the main objective of extending the time interval when water would need to be added to the cells.

> "Everyone reading this must know that a Class 1E battery is the one responsible for the safe shutdown of nuclear reactors – the most important battery function anywhere"

Savings and safety

As users recognised the labour savings, and these devices proved their value, other manufacturers entered the market with their own recombiners. Obviously, as time went on, there have been changes and improvements made to recombination vents due to the knowledge gained through both research and that which came from actual users' experiences and feedback.

That these devices have proven their benefits, one only needs to understand that some Nuclear Class 1E batteries in Europe have them installed in their cells. Everyone reading this must know that a Class 1E battery is the one responsible for the safe shutdown of nuclear reactors – the most important battery function anywhere.

I personally do not know of a single battery manufacturer in the EU or the US that objects to a user installing recombination vents in their cells. After all, why would any manufacturer object to a user of their batteries wanting to make their battery rooms safer or wanting to reduce their maintenance costs?

These devices are often advertised as being up to 98 or 99% efficient. Even if the devices were only 90% efficient, that is a substantial benefit over any standard vent or flame arrestor, which is 0% efficient. Testing has proven that these devices make a substantial reduction to the volume of hydrogen and oxygen that is released from the cells. As all understand, it is critically important that the hydrogen and oxygen content in

a room or area is not allowed to reach an explosive value. Vents and flame arrestors do not prevent the gases or moisture from leaving the cells.

All recombiners perform the same function. They recombine those gases (hydrogen and oxygen) back into water. Some designs utilise a pressure relief valve internally, and some do not. The difference in efficiency is typically less than an estimated 2-3%. The upside of a pressure relief valve is a slight improvement in efficiency, but the potential downside is that by increasing the pressure in the headspace of the cell, if there are sample tubes in the cells this increase in pressure can cause an overflow of electrolyte from the tubes. Or if there are defective post seals, then the wicking of electrolyte, caused by that increase in internal pressure, can be accelerated. Some designs such as the Flux units also incorporate a condensate control method to capture evaporation. This also acts as a barrier to prevent electrolyte mist from exiting the cells.

European safety standards

The European Union's standards writing organisation has published standard 62485-2 IEC:2010. In *table 1*, which is used to determine ventilation requirement needs, *note 2* states: "In case of use of recombination vent plugs, the gas producing current/gas can be reduced to 50% of the values for vented cells." They realise that these devices are in the high 90% efficiency range, but I believe they used a lower value

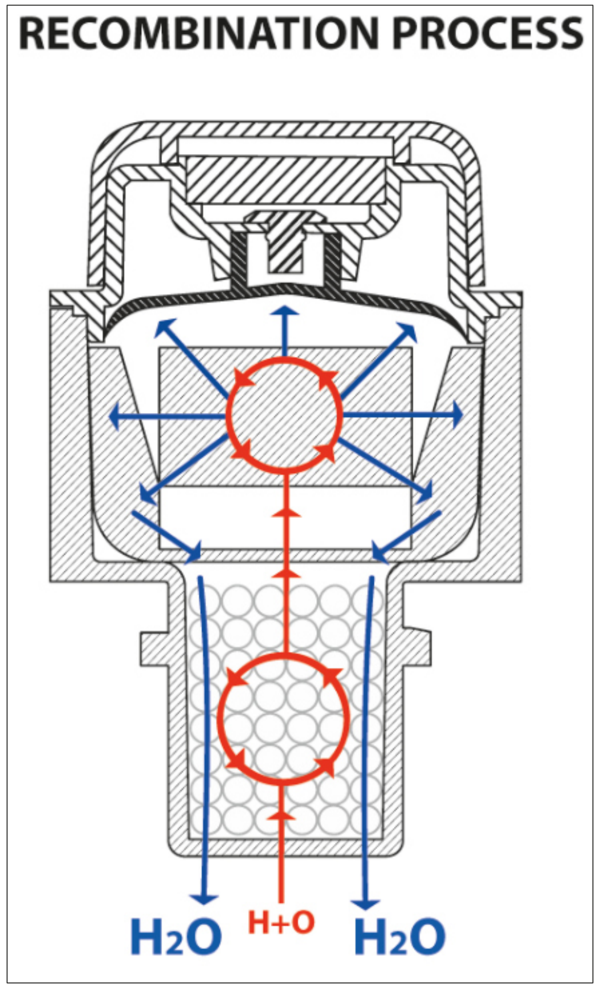


Fig 3: Diagram showing how all recombiners work. Hydrogen and oxygen gas rise up and interact with the catalyst material, and then condenses on the walls of the device and flow back down into the cell as water.

(50%) as a 'safe' specific value that they could include. This standard is titled *Safety requirements for secondary batteries and battery installations. Part 2: Stationary batteries*. The date indicates this standard has been around for a number of years.

Updated US safety document

The American equivalent to that safety document is the IEEE1635/ASHRAE21 *Guide for the ventilation and thermal management of batteries for stationary applications*. In previous versions of this safety document, there had been no mention of recombination devices. But the newest revision just updated (2022) now includes information regarding recombination vents. I believe that the fact that there had been no mention of these devices in any of the previous versions of this document was because, in the US, the majority of the stationary batteries installed are of the lead-calcium design – these normally require a lower float current for equivalent amp hour than a lead antimony or lead selenium – so no-one involved years ago was thinking about battery gas reductions. A lower float current equals less off-gas being generated. A simple oversight in my opinion. This has now changed.

The changes to the document start with the addition of a definition of what these devices are and what they do. That definition is as follows: "Recombination vent: An assembly on a vented cell in which most of the hydrogen and oxygen gases escaping from the head space of a cell are catalytically recombined and returned to the cell as water." As can be seen from this definition, it is understood that the majority of the hydrogen and oxygen is prevented from leaving the cells. It does not say "some" of the gases, it states that "most" of the gases are recombined into water and returned to the cells.

Later in the document, in *section 5.1.1.2* on vented lead-acid (VLA) batteries, and in *section 5.1.2* on nickel-cadmium (Ni-Cd) batteries, it states the following: "In some cases, recombination vents may be used to reduce maintenance.

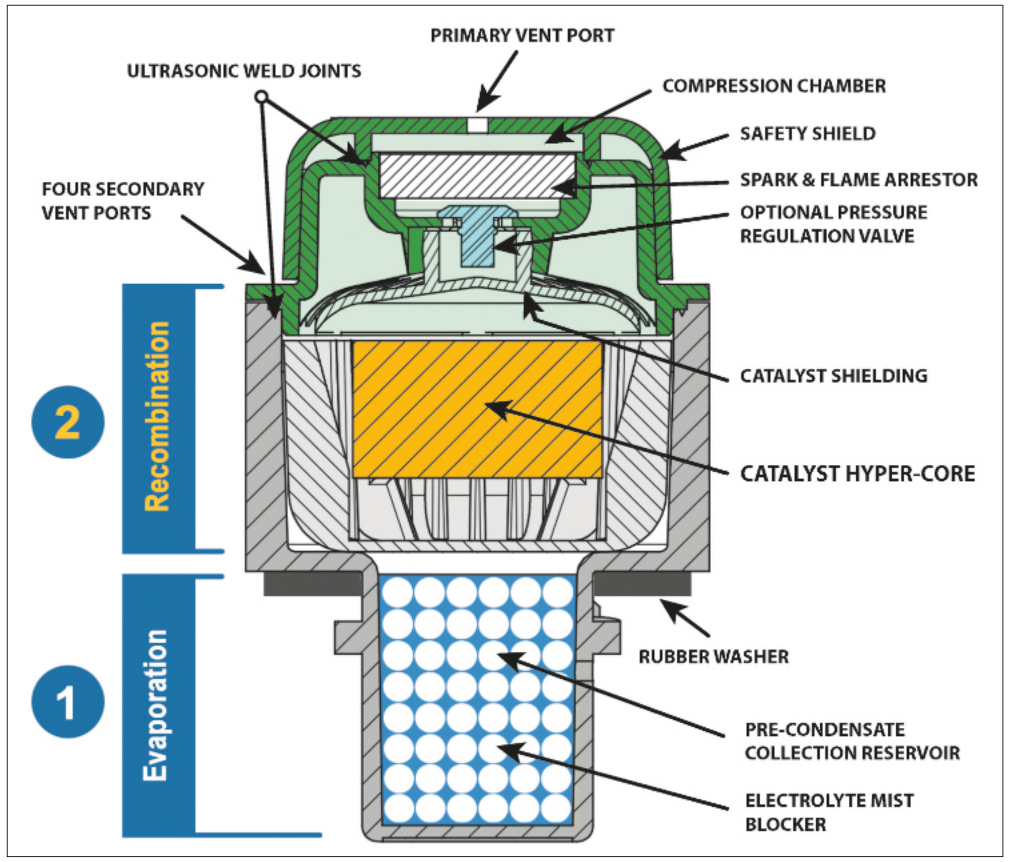


Fig 4: Short recombiner with condensate and mist capture

See 7.2.1 for recommendations for ventilation calculations when such vents are used."

In *section 7.2.1 General*, it states that recombination vents catalytically recombine most of the charge gases from vented cells, providing a significant maintenance benefit.

Based upon the present inclusion regarding information on the function and benefits of recombination vents, I believe that here in the US we have now caught up with the EU in terms of standards – providing valuable information for the battery users, as it relates to these devices.

Safety first

It is not mentioned in any documents, but there is one benefit that is normally overlooked when discussing recombination vents. That is their ability to prevent an explosive gas build-up in the battery room/area even if the HVAC ceases to function. Recombiners will continuously recombine those gases for as long as they are being generated. In other words, if the charger is functioning, the gases will be recombined back into water. If the charging source is not functioning, then no gases are being generated.

While every battery manufacturer and user in the EU understands and accepts these devices, in the US it is different, as they are sort of 'new'. In the US, Enersys has been the only American manufacturer offering recombination vents as an optional item for many years now. It was not until quite recently that other US manufacturers have developed an interest in these devices. There are some stationary battery sales agencies promoting and selling these devices for usage in all different battery manufacturers' models.

How long it takes for users in the Americas to actually experience the benefits of these devices is going to depend upon a number of things, such as, but not limited to:

- How soon they learn about them and come to understand the financial savings possible

- How much value the user assigns to increased safety in the battery room/area

- How the American battery manufacturers endorse and promote them

- How rapidly the insurance companies acknowledge the benefit of the reduced hydrogen releases and share that with their insured – some are already doing this

- The AHJs (authorities having jurisdiction) learn about and endorse them

- How quickly the stationary battery sales organisations realise that these devices are a profit centre, and they start promoting them to their customers. Profit is a strong motivator.

As for 'catching up' I believe that America is getting there, but only time will determine if I am right or wrong.

BCI shifts focus to energy storage as the natural market for lead-acid

BEST technical editor Dr Mike McDonagh reflects on the 2022 European Lead Battery Conference, held in Lyon in September. "The technical presentations seemed to hit the nail on the head concerning lead-acid's future," he says.

For the last few years *BESTmag* has been banging the drum for lead-acid to be a major contender in the BESS market. Other organisations have had the same theme and companies like YUASA have even developed a fully operational hybrid BESS, using a complimentary lead-acid and lithium-ion combo as a working solution to the industry dichotomy of longevity and cost.

The technical and commercial battery requirements for ESS are relatively straightforward. Technically, there is a speed of response in milliseconds, which all battery chemistries can deliver, and commercially the levelised cost of energy storage (LCoES) should be as low as possible.

It is the latter point that is perceived as the stumbling block for Pb-A chemistry due to its relatively short cycle life and low round trip energy efficiency compared to LIB chemistry. This specific point has been the subject of BEST articles and conference presentations written by the author, where simple solutions based on battery size have been proposed and evaluated.

The other theme of note in this conference was the monitoring and testing procedures used to control LAB's performance and reliability. Again, a very important and commercially sound approach.

Lead-acid's suitability for ESS

Looking at BESS applications for lead-acid, I was interested in the developments relating to enhancing lead-acid's suitability for ESS. To be an attractive option in this market, it is essentially the LCoES that will determine the likelihood of a technology's adoption. For this reason, I was interested in several presentations:

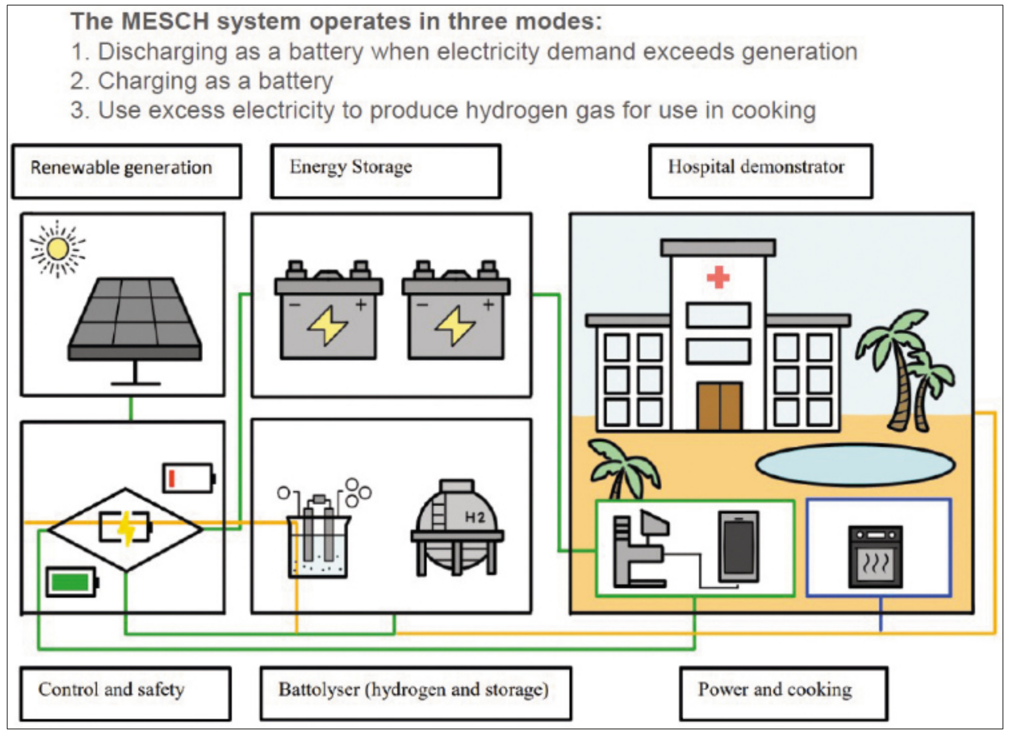
- Carl Telford's paper for the CBI – Pb-A BESS for energy storage
- Ed Schaffer's bipolar contribution for ABC
- Rainer Bussar's research on higher energy efficiency for formation of lead-acid batteries.

There is a general consensus within the Pb-A industry that lead-acid technology is a natural contender for the BESS market. There are several factors, including price, sustainability and recyclability that support the consensus. If you add this to typical applications within the ESS umbrella, ranging from peak shifting and load levelling to fast charging of EVs at a fuel station, then you have a product and market that seem to be made for each other.

Carl Telford's presentation examined the current state of Pb-A take-up in BESS applications. ***Fig 1*** is a list of the funded CBI collaborative projects that are related to energy storage. An interesting point is their collaboration with Innovate UK, supporting modular energy storage with clean hydrogen (MESCH/AfTrac) initiatives in Malawi. This is an ambitious programme to provide a BESS whilst also producing so-called clean hydrogen from solar-charged Pb-A batteries, ***Fig 2***. The electrochemistry for the battolyser (electrolytic hydrogen generator) will be interesting to

CBI European Public Funding Projects	Funding Instrument	Project Size
Low-cost, circular, plug-and-play, off-grid energy for remote locations including Hydrogen (LoCEL-H2)	Horizon Europe	€ 10,000,000
Feasibility demonstration: Circular, low-CO2, 12V xEV battery (The '9x.x%' recycled battery)	Horizon Europe	€ 5,000,000
Commercial scale advanced bipolar battery	EC Innovation Fund	€ 15,000,000
Deployment & demonstration of EV charging system with a lead battery buffer	?	tbc
Novel bipolar battery materials & technology development	?	tbc
Modular Energy Solution Including Clean Hydrogen (MESCH)	Innovate UK	£ 1,500,000
AfTrak - A micro electric tractor designed for Africa to mechanise land preparation.	Innovate UK	£ 400,000

Fig 1: CBI European Public Funding Projects (condensed)
Fig 2: MESCH system integrating Renewable energy source, Energy storage and H_2 generation



examine. What is the energy balance for using hydrogen produced this way, compared to using the electricity for its generation directly for cooking, heating etc?

From conventional Pb-A designs, we turn to Ed Schaffer's bipolar technology as a suitable candidate for ESS deployment. Interesting, but we have to ask what properties from this technology give it any significant advantages in this application. In his presentation, Ed pointed out the requirements of ESS, then contrasted the properties of LIBs and conventional LABs for ESS use. LABs definitely come off worst in the cycle life and energy efficiency department with a $/kWh cost of 0.26 c.f. 0.17 for LIBs. He also points out that conventional recycling methods for LABs require extensive pollution control measures to be regarded as safe, and also the high energy and CO_2 penalties for the pyrometallurgical recycling process. The plus points are mainly the lower capital costs, safety, and high recycling rate.

The negative aspects of Pb-A in ESS applications are addressed in ABC's EverGreenSeal technology attributes, shown in ***Fig 3***. The main problems of cycle life and round-trip efficiency for Pb-A compared to LIBs is tackled by controlling the depth of discharge and ensuring that the lead foil attaching to the PAM is of sufficient thickness to last for the required life.

The reasoning and design justification are described on slides 8 and 9 in the presentation. However, there are

Fig 3: EVERGREENSEAL™ solution for lead acid shortfall for ESS applications

parts of these slides that I need some counselling from ABC in order to fully grasp their meaning.

Based on their modelling system, ABC have drawn up a financial comparison between their Box-BE system and a Tesla pack used for a BESS application, ***Fig 4***. In this, the ABC technology shows a net total saving of 14% over the Tesla pack and a 35% saving for the net present value (NPV) calculation. If this is combined with the other innovations of low kWh cost and low environmental impact from the solvent-based recycling method, resulting from the GreenSeal Alliance, then this does represent a major step forward for the Pb-A battery industry.

Reduce production costs

Another way of improving the ROI for lead-acid is to reduce the production costs. One substantial part of that is the formation process. This element of manufacturing alone accounts for at least 50% of a battery factory's total energy cost.

Penox have picked up on this, and I found the presentation by Rainer Bussar to be quite remarkable. In essence, they have demonstrated in the laboratory, that they can reduce the formation factor (the number of times the battery capacity can be divided into the coulombic input from formation), from three times the capacity to 1.5 times the capacity, ***Fig 5***.

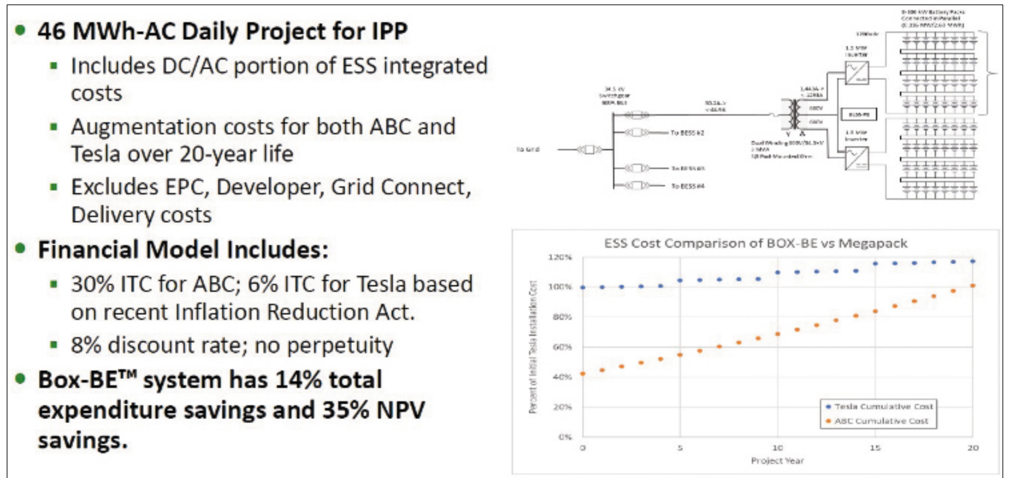


Fig 4: ESS comparison between BOX-BE™ and TESLA MEGAPACK™

PAM composition		PAM Structure	H2O Porosity	Formation Factor	Average Target: 85 +/- 3	UCHA, Ø
Battery Oxide weight%	Red Lead weight%	Av. 4BS content	%	(lower is better)	%	V
50	50	0% (3BS)	40	2.2	91.4	2.21
50	50	92.1 %	45	2.2	92.8	2.21
75	25	92.6 %	55	1.5	80.9	2.19
50	50	92.1 %	50	1.5	88.4	2.20
0	100	Mixed structure	(60)	1.5	93.9	2.19
50	50	0% (3BS)	45	1.1	67.8	2.12
50	50	92.1 %	50	1.1	71.4	2.11
0	100	Mixed structure	(60)	1.1	81.2	2.16

- Formation factor can be reduced to about 1.5 with 50% RL
- 4BS structure and higher porosity have beneficial impact on formation efficiency
- 100% RL is not allowing for a 4BS curing – *reason is the ratio of "free" PbO and sulfate in PAM*

Fig 5: Penox comparison of red lead content vs. formation factor and PAM structure

If this is proven in field trials, it means the total energy bill for a battery manufacturer can be reduced by around 25%. That represents a potential saving of millions of dollars per annum for Pb-A manufacturers and has even greater significance in today's unstable energy market, compared with a year ago.

Due to the shared goal of Penox and the UKP/Ecotech/Digatron/BEST consortium, in reducing formation energy, we have already started a cooperation in combining our methods to ascertain if there may be any benefits from this. Keep watching for progress in future editions.

Process control

Process control was also well represented by several contributors. Again, ensuring uniformity in all sub-components should give better battery life and fewer performance/warranty headaches. One of the problems with monobloc designs, particularly 12 V and above, is the measurement and control of inconsistencies between individual cells in a battery.

The end of life of a battery is determined by its discharge performance, i.e. how long it takes to reach the end of discharge voltage. This is the sum of voltages of the series-connected cells in the battery. A 10.2V final voltage for a 12V (nominal) monobloc will not be made up of six individual 1.7 V cells. It is more likely that one or more of those cells will be closer to 1.5 or 1.3 V, with the higher ones around 1.85.

In other words, weaker cells dragging down the better ones to give early failure. If all cells were at the higher end, it would extend battery life significantly. The sticking point is controlling the AM consistency and weight for every plate. Once pasted, a plate's characteristics are fixed. Variation between cells, and therefore plate consistency, is only apparent once the battery is acid-filled; by this time, it is too late to rectify. Contributions from Wirtz, CMWTEC, Mate Gauge and Digatron were examples of suppliers' progress in this direction.

Wirtz showcased their developments in continuous casting, Oxmaster paste-mixing equipment and steel belt pasting. A significant part of the emphasis of their equipment development was on the control of thickness for the strip-produced grids and the pasted plates. The other main focus was on the automation of various ancillary operations such as stacking, loading and unloading operations – important for minimising lead handling and operator safety.

For this article, however, it is the control methods, which produce greater product uniformity, that are of most interest. In this respect, the advances in the Concast strip thickness control, ***Fig 6***, and the steel belt pasting line, ***Fig 7***, will be welcome additions to the industry.

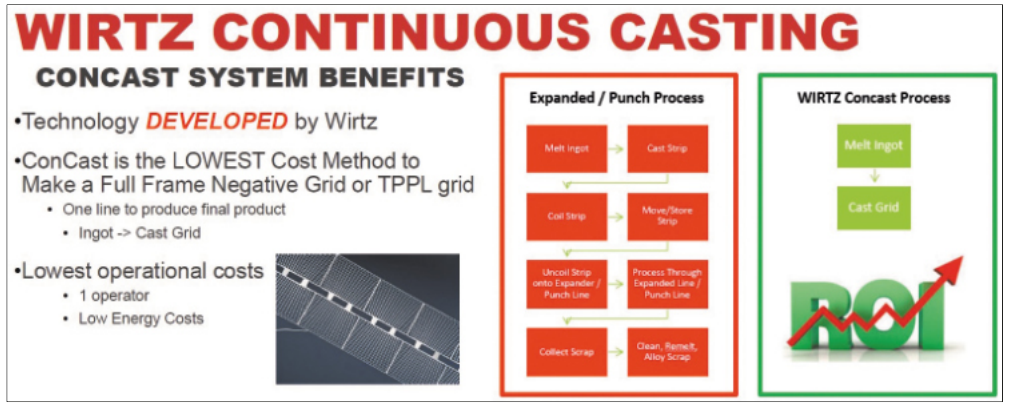


Fig 6: Benefits of Wirtz Concast technology for strip thickness control and cost reduction

Fig 7: New developments using steel belt for better material and cost control

Inconsistent pasting belt wear

As most manufacturers will be painfully aware, traditional pasting belts, be they made of canvas or polymers, are prone to inconsistent wear. This leads to variations in pasted plate weights due to variations in pasted plate thicknesses. Even without wearing grooves into a belt, there is some natural give in these materials, which can cause dips underneath a grid during high pressure pasting. Use of a steel belt pretty well eliminates this and enables tighter tolerances to be met consistently over a longer time period. This leads to better product uniformity, which in turn provides improved battery life and substantial cost savings in material due to weight control.

With the Wirtz SBP/RPC line, a promise of a 0.01 mm thickness control ensures that the savings and product consistency should be realised. On the same note, the improvement to the cooling water flow in the Oxmaster paste mixer cooling jacket should also provide more control over the alpha/beta ratio of the lead sulphate crystallography of the pastes. This should improve cycle life or CCA performance, whichever you opt for in your product range.

Monitoring and control systems

Staying with process control, Steve Mate, who is rapidly becoming an industry veteran, provided an insight into the importance of better monitoring and control, particularly in this new post-pandemic industrial landscape. His main mantra was that there is sufficient expertise in monitoring and control systems, from suppliers to the industry (in this case himself) that there is no point in companies designing and installing this equipment in-house. In fact, it is highly probable that without the correct expertise it is unlikely to be successful, or worse, it may even create problems.

To illustrate this, he provided information on his Mate Gauge, ***Fig 8***. This is a ready-to-use, plug-and-play instrument that provides fast, accurate thickness data, claimed to be easier and quicker than PLC set up and integration. ***Fig 9*** is a representation of how Mate gauge installation is claimed to reduce your production variability.

Digatron, no strangers to product testing and process control, made a presentation highlighting their test and production equipment. Since this was the ELBC, this article will focus on their Pb-A battery formation and testing business. Whilst they are very well known for their electronic expertise in providing industry-leading formation and test units, they now also offer acid recirculation machines through their partnership with Inbatec, ***Fig 10***.

By combining the monitoring control systems, via their battery manager software, with better electrolyte density regulation and full water bath control, a new level of formation accuracy is possible. The result should be a finely tuned formation process with lower energy consumption and a more consistent final product.

Another tool in the weaponry of manufacturers seeking higher consistency of product is the use of in-line testing stations. Whilst manufacturers assume they have testing (of course they do) CMW brings a new dimension with their "high current process control software", ***Fig 11***.

A simple HRD (high-rate discharge) station is transformed from a straightforward accept and reject point, to a source of diagnostic data. By building up data on battery in-line test performance and combining this with diagnostic data that can recognise the causes of fluctuations, much could be done to narrow the variables that exist in our industry.

Hitting the nail on the head

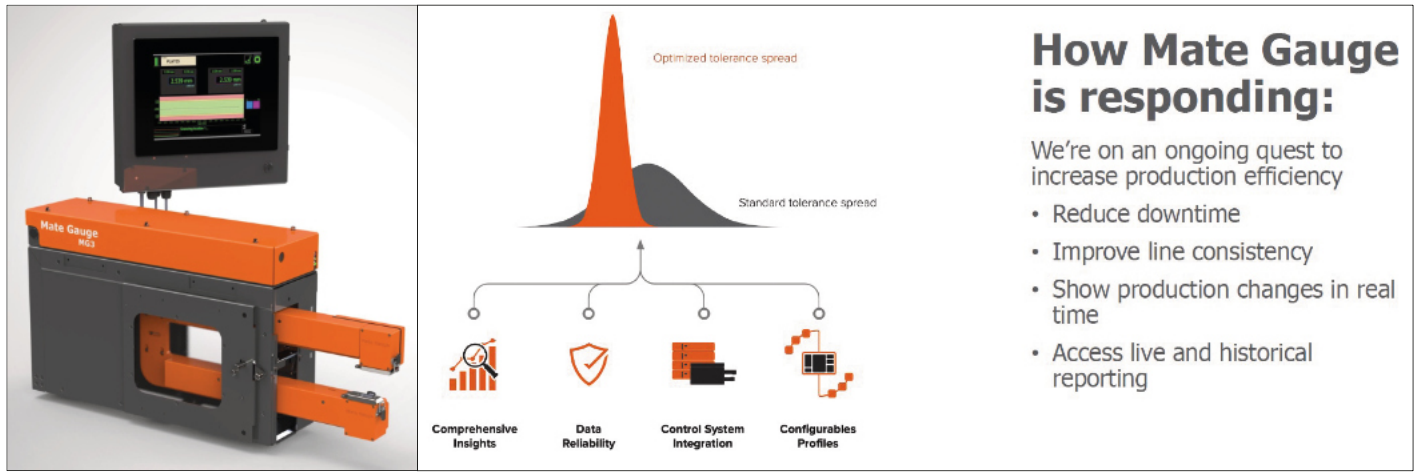
The overall conclusion from my perspective was that the ELBC technical presentations seemed to hit the nail on the head concerning lead-acid's future.

However, I will say (controversially perhaps), that the main source of variation in manufacturing Pb-A batteries has traditionally been within the materials. Think about it, what other industry would accept a standard for a lead oxide material of 24-30% free lead, or incoming traction 2V cell boxes with a +/-1mm bend between top and bottom?

Having spent many frustrating hours trying to find heat-sealing settings that can cope with a 2mm shift to left or right, from the same pallet of boxes, in order to keep a machine running, I am perhaps biased in my view. This is all routinely accepted on the grounds of cost. And should we want better accuracy then perhaps we should pay more for our materials and our manufacturing equipment.

The world has moved on since the 1980s; there are more applications and more diverse requirements. Price is still a factor, but return-on-investment, aptly labelled ROI, is arguably the new king of our industry.

In any event, if Pb-A batteries are to compete in future markets, we need to up our game in consistency, longevity, and reliability. The answers may have just been presented to us in this 2022 ELBC.



Figs 8 & 9: Mate Gauge and process variability reduction using Mate Gauge

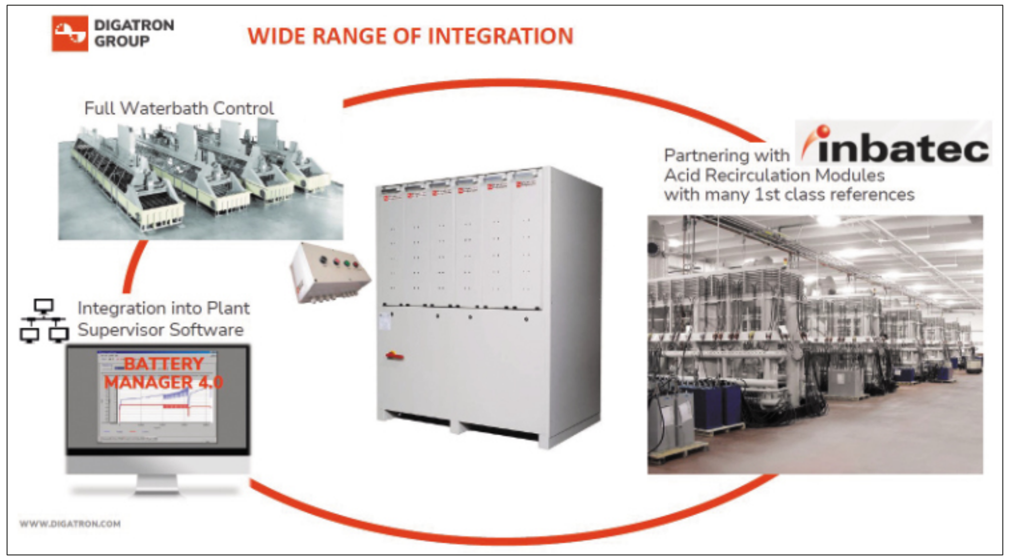


Fig 10: Digatron partnership with Inbatec provides more precise control for product consistency and energy consumption

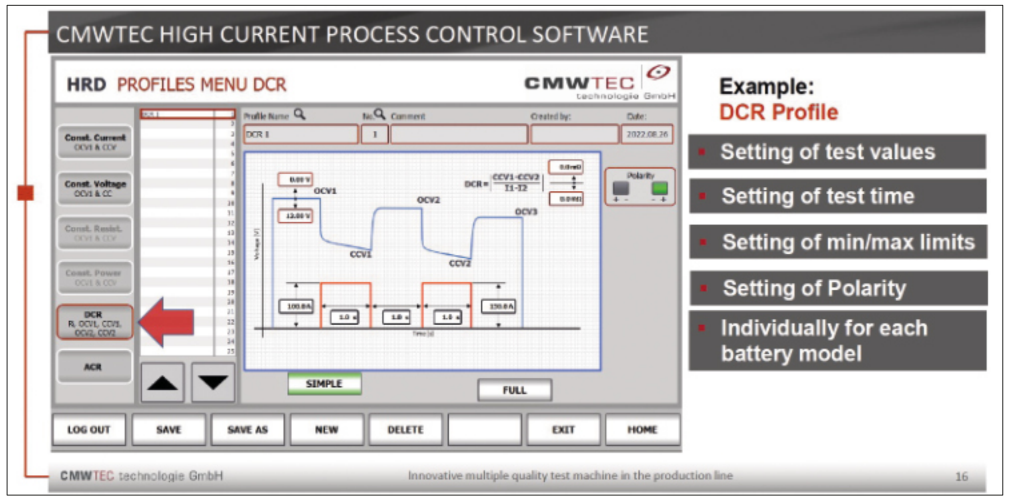


Fig 11: CMW's data logging and testing station enables diagnostics as well as quality control

Lead not dead but could do better

Lead is far from dead and has a future that will last many years yet. Market share for lead-acid batteries is steady and growth prospects are modest. But there is huge upside potential from ESSs and new opportunities are there for the taking. Andrew Draper reports from ELBC.

Lithium-ion batteries have enjoyed the highest growth rate and major part of the investments, but lead-acid batteries are maintaining a steady 50% market share in terms of volume, according to Fabrice Renard, Senior Advisor at Avicenne Energy.

Renard said (in a presentation to ELBC) the world-wide battery market hit 400 GWh last year, with Pb-A batteries maintaining 50% of that market share by volume. Overall, it was worth $116 billion (pack level), and notching up 10% growth each year between 2010 and 2021.

The lithium-ion market is dominated by just five producers, said Renard, noting they had some 70% of the 406 GWh in 2021. They include CATL on 26%, Panasonic with 12%, LG on 19%, BYD with 7% and SDI with 8%. That market is expected to expand to 700 GWh by 2030, he said. ***(Fig 1)***

In Europe alone, production capacity is set to hit 700 GWh in 2030 from 300GWh in 2025. ***(Fig 2)*** While a lot of investments are planned, not all will pan out as planned. "Some will disappear," he said. The shortage of available labour will hamper recruitment plans. "You always need a new team… It's difficult to hire a new team to make lithium. There will be competition to get good teams."

Industry is pushing to reduce time to bring new products to market, according to Renard. But it is taking time, and it will be an evolving market. A revolution will not happen.

In 2025, 5% of new cars could be equipped with lithium-ion. But 70% of the SLI battery market is aftermarket so the % of lithium-ion batteries for SLI is increasing very slowly, he said.

Renard believes the worldwide total lithium-ion battery market will reach 2.3 TWh in 2030, and xEV batteries will be about 90% of this market. The Pb-A battery market will go from 415 GWh in 2020 to 495 GWh. The market combined will be worth some $290 billion by 2030, up from $93 billion in 2020, he added.

Lead: a greyish-green future

The market for lead is facing "a bumpy road", with factors such as the war in Ukraine, exiting the coronavirus pandemic, inflation and supply problems all affecting the market. Neil Hawkes, Principal Analyst at research organisation CRU, told ELBC that, despite the uncertainty, it was time for "grey" battery metal lead to re-energise its resilience in existing uses and make tangible gains in new "greener" uses too.

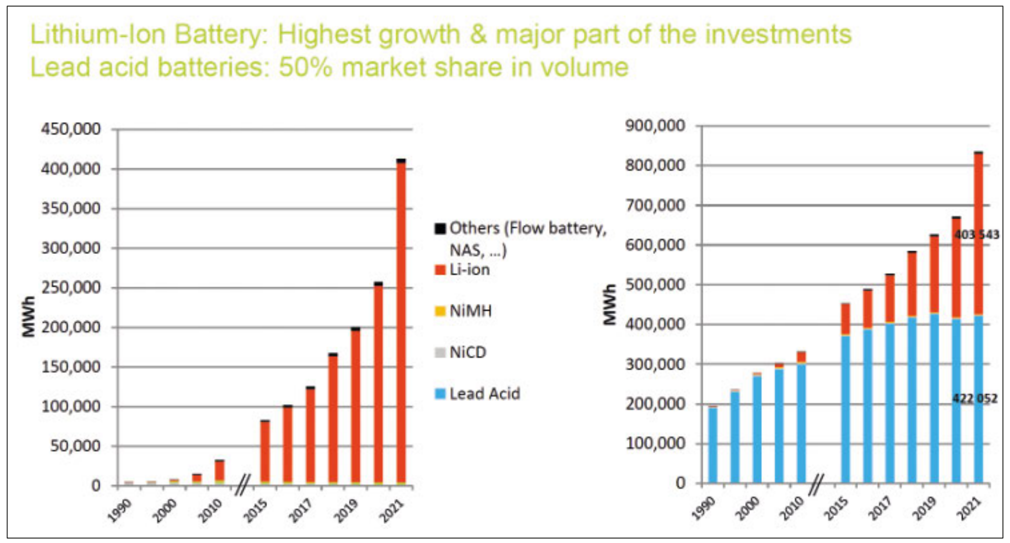
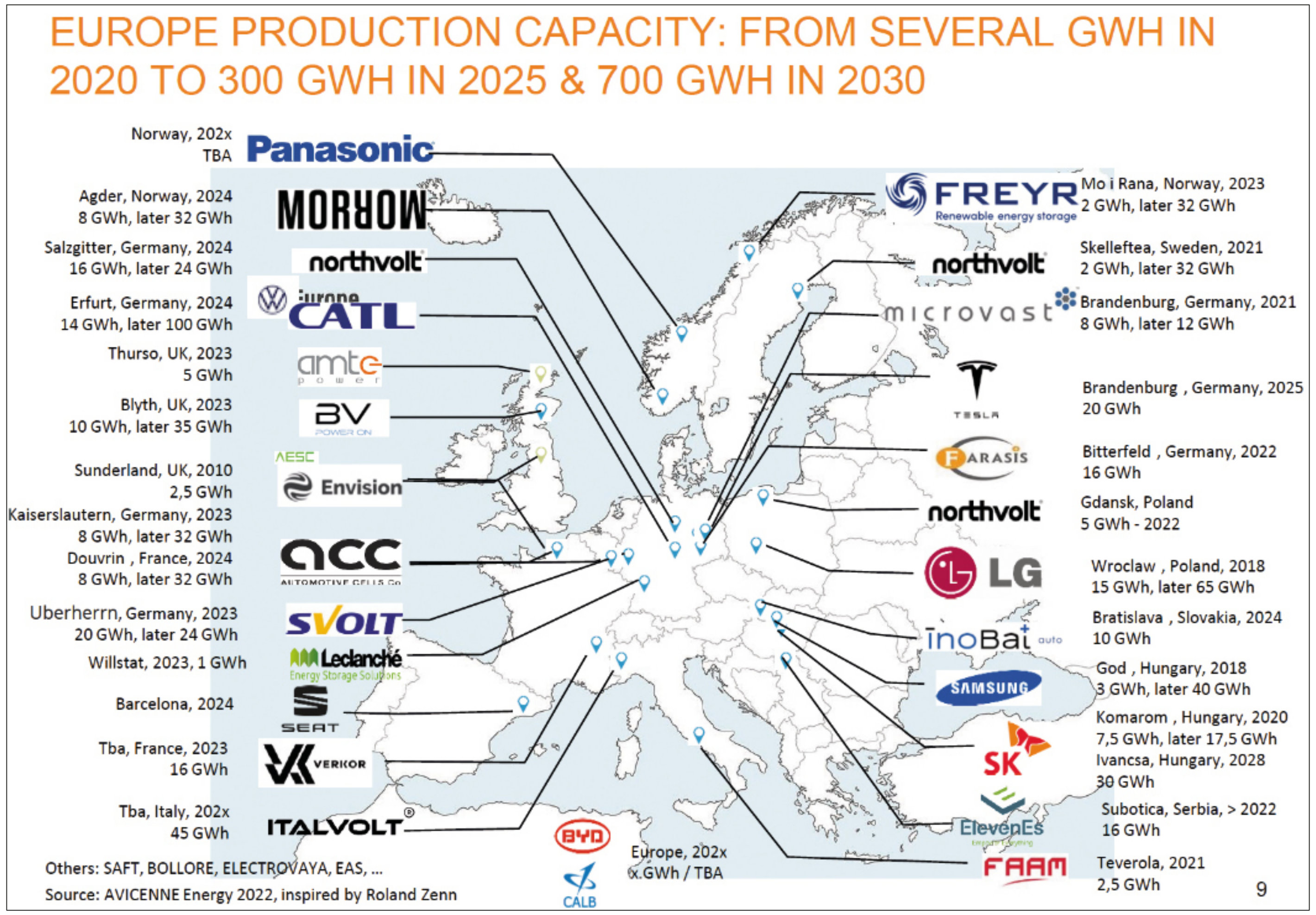


Fig 1: Lithium-ion battery: Highest growth & major part of the investments Lead acid batteries: 50% market share in volume



Lead pricing has retreated from testing the higher end of middle ground trading and is now in a range of $1,800-2,400 per tonne. At the end of September, it was trading at around $1,900/tonne. Other metals traded on the London Metal Exchange are facing much greater volatility.

The loss of some production facility capacity means that prices are "struggling to hold on," he said, but added lead was on a "steadier" price path due to:

- Smaller lead market imbalances than in other LME metals
- Relative illiquidity was discouraging excessive investor participation

"Lead is on a less volatile path. It should be steady lead," he said.

Hawkes said China is expected to remain a modest net exporter, driven by a tighter US-led ex. China market and easier domestic market. "China is going to define the tightness of the market going forward," said Hawkes. However, Korea and Australia are also key lead exporters, notably to the US, he said.

Fig 2: Planned European production

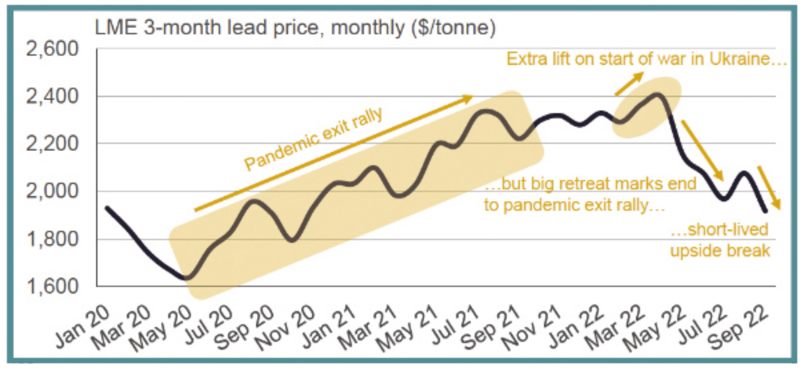


Fig 3: London Metal Exchange 3-month lead price, monthly ($/tonne)

The US lead market is tighter due to sustained demand strength and a lengthening list of local smelter exits, including Florence and Belledune. This has created a shortage of lead and jump in premiums paid. Lead is increasingly being imported to the US, up 13% year-on-year in the first half of 2022. This comes on top of a boom import year in 2021.

Tighter European lead market

The European lead market tightened last summer after Germany's Stolberg smelter shut. Market demand remained, but contract terms jumped to "unprecedented levels", said Hawkes. The market tightened further into the spring as war-torn Ukraine and sanctions-hit Russia slowed supply flows from east to west.

The summer maintenance – longer than usual for some – is expected to ease the market. But pre-winter battery restocking, economic slowdown, the expected Stolberg smelter restart, and energy-led smelter squeeze, will all be key in determining the degree of autumn retightening, according to his forecast.

He said upcoming contract negotiations will be especially important. Chip shortages, the war in Ukraine fuelling inflation, Chinese lockdowns and logistical logjams will all serve to stretch out global vehicle recovery into 2023-24.

"There's going to be a long tail of replacement of auto lead batteries," said Hawkes." You can buy a car and drive it for 10-15 years and replace the battery several times." That will result in net auto lead battery demand growth, albeit moderating through time. That will take decades, well past any ban on new internal combustion engine sales. Hotter summers and colder winters will also play their part in testing battery endurance.

> "Lead is part of the solution rather than part of the problem"
> **Hawkes**

Lead batteries' total cost of ownership is becoming more cost competitive with lithium-ion batteries, not only at grid scale but also for domestic use, said Hawkes.

New opportunities – battling for battery business

Emerging markets will continue to be drivers of new business opportunities, according to Stefan Stübing, CEO & President of Exide Technologies. He told ELBC that rural electrification in remote areas will also open up new business.

"Sustainability will continue to drive energy storage," he told his ELBC audience. That will require energy storage solutions for sectors such as telecoms. Virtual power plants (VPPs) – networks of decentralised, medium-scale power generating units as well as flexible power consumers and storage systems – will become more common and eventually prevail.

Energy-as-a-service (EaaS) will take greater hold. This is a business model whereby customers pay for an energy service without having to make any upfront capital investment. EaaS models usually take the form of a subscription for electrical devices owned by a service company or management of energy usage to deliver the desired energy service.

"Battery producers with a strong local presence in these markets have a strong position," he said. "And battery manufacturers will need a strategy to stay competitive."

Disappearing sector boundaries

Stübing believes the boundaries between automotive and motive sectors will disappear. "In recent years, things have changed. In future, we will face having a business environment with more challenges."

Electric vehicles (EVs) are expected to be a major opportunity for battery makers. While lithium-ion will feature, the rise in on-board technology will increasingly require auxiliary batteries, with two-battery systems common by 2030. Pb-A battery technology – AGM – is the preferred solution of OEMs, said Stübing. Lithium-ion will remain a niche for many years, but more than 97% of auxiliary EV batteries will be Pb-A, he said.

Cost competitiveness and performance will be crucial, he added. But a fighting spirit will be required, as the numerous options for improvement are confronted.

He called for greater clarity on the EU's End of Life Vehicle Directive, which is undergoing a revision proposal. The Commission is presently working on this, with an announcement expected in Q1 2023. The revision has to pick up speed if the market is to progress, he said.

Investors are more excited by "hotter" longer-term demand outlooks for "greener" metals such as copper, and other battery metals lithium, nickel, cobalt, and manganese. "But this attitude towards "grey" lead is misplaced. Lead is part of the solution rather than part of the problem," said Hawkes.

He added: "Industrial lead battery demand is most likely set on a modest growth path through the 2020s, albeit with huge upside potential (ESS)...The future could be more greyish green than you think."

- Strong "cradle-to-grave" credentials – consistently high recycling rates and cheaper battery cost compared to less recycling-friendly and higher cost lithium-ion-based batteries.
- Greater safety issues in lithium over lead batteries.

Lead is not dead

The global market for the industrial Pb-A battery should be worth $13 billion in 2023, up from $12.4 billion in 2021, according to Nick Starita, President of Energy Solutions and New Ventures at Hollingsworth & Vose. Two-thirds of the market will be stationary, with motive making up the rest. ***(Fig 4)***

He told ELBC that there is a lot of uncertainty in his forecasts: "If you want to find pessimism, you can find it. If you want optimism, you can find that too." His forecasts are based on a range of industry experts and sources.

He said electric truck orders rose 67% between 2019 and 2021. Economies improved as markets moved out of the pandemic. "What's distorted it though are long lead times for electric trucks. How long it's going to last is a good question," he said.

Motive power market drivers and trends

- E-commerce – decentralised, indoor warehouses; goods need to move quickly to final destinations
- Global distortion – freight costs, currency fluctuations, long lead-times and backlogs, supply availability, lead prices, new entrants
- Developing markets – economic growth, environmental regulations
- Regulations – emissions regulations

The stationary market is expected to grow in all regions, but especially in India and China, which accounted for $5.5 billion of the $8.2 billion in revenues in 2021, said Starita. Growth rates for the next two years should be 3-5%, he said.

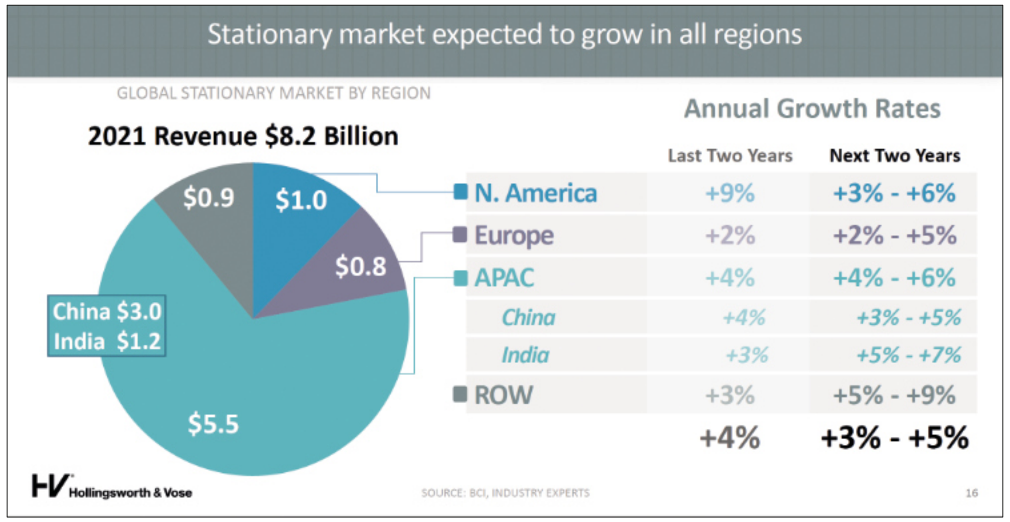


Fig 4: Stationary market expected to grow in all regions

In the telecoms market, the move to 5G networks will demand more power to run them. "5G towers can consume 2-3 times more power than 4G," said Starita. "That needs back-up batteries." In developing countries, infrastructure investments will provide growth. Overall growth in telecoms will be 3-6% a year, he said.

In UPS, the forecasted growth is 3-5% per year, driven by data centres, he said. UPS lead battery sales were due to hit $2.8 billion in 2021.

The ESS market is "absolutely massive", he said, adding that lead must find its niche there. Companies must ask what they are good at (and what lead is good at) to tackle the next frontier.

"There's no reason to believe the Pb-A battery is dead," said Starita. "It's reliable, it works... and it will be around for a long time." If companies can solve problems, they will add value.

LITHIUM AND LEAD BATTERY MATERIALS

	Unit	2022	Change from 2020	2026	Change from 2022
Lead	$/mt	2,150	+17%	2,150	flat
Lithium Carbonate	$/mt	66,600	Up 9x	16,400	↓ 75%
Nickel	$/mt	24,074	+74%	17,033	↓ 33%
Cobalt	$/lb	33	+112%	34	flat

Fig 5: Lithium and lead battery materials

Transportation battery forecast

- Market triples in five years to $450 billion
- Lithium growing 31%/yr. to $378 billion – driven by all EV apps
- Pb growing 5%/yr. to $72 billion; mix plus deep cycle apps

Ray Kubis, Chair of Gridtential Energy of the US, told ELBC that lithium-ion battery users are facing many challenges, including the cost and adequacy of materials supply, and safety. They also face huge investments in capacity and R&D. ***(Fig 5)***

Lead-based opportunities are "large and real", he said. The world needs more than lithium-ion alone can supply. Pb-A batteries offer low cost, safety, and ready recycling benefits. The technology potential is achievable, he added.

Electric vehicle (EV) sales are surging, and EV light vehicles are expected to make up 28% of the total in 2027 (9% in 2022). The power of these vehicles is also growing, expected to hit 75 KWh per vehicle (59 KWh in 2022). At the same time, cost per KWh is coming down – to $132 from $150 today. US consumers are favouring big, expensive EVs, while in China it's the small $5,000 vehicles that are selling most.

Kubis believes that small vehicles such as e-scooters and bikes will overtake the large vehicles. "People are using them to avoid pricing costs of congestion and avoiding public transport too during Covid." Delivery companies like Amazon and Walmart are turning to EVs for the "final mile" delivery to households, he said. ***(Fig 6)***

Low-speed light EVs such as the Indian TukTuk are growing in popularity. The TukTuk has more than 90% Pb-A batteries, and it's a similar story with China's three-wheelers.

However, there are still 1.5 billion cars on the road with an average age of 12 years. These run on Pb-A batteries. A combination of the pandemic and cost of living increases means their average age will rise. The market for Pb-A will not go away any time soon.

And as lithium-ion battery materials soar in price, not so many people will be willing to pay the rising replacement costs of the EV battery, said Kubis.

Banging the drum for the Pb-A battery, Kubis said: "I do believe that Pb-A batteries are working better than ever before. But they've not improved enough. We can also push for developments." Industry players need to work better together to improve the standing of lead.

Fig 6: Last mile delivery

Maximising BESS returns

Advanced Battery Concepts of Michigan, US, says energy storage technology must be economically, socially, and environmentally responsible. It claims its advanced bipolar battery technology achieves that. Ed Shaffer, Founder & CEO, talks to *BEST* magazine about costs and margins on ABC's battery energy storage system (BESS) products.

***BEST*: A number of markets have been highlighted for BESSs, arbitrage, balancing, capacity, and frequency response. Which of those would be suitable for lead-acid batteries to operate in?**

Shaffer: At a high level, any energy storage system can be optimised for any application regardless of chemistry. The question is "At what price" and then the more difficult question is "And how much do I make". In general, our approach is to offer the lowest price to power providers to help maximise their return. Our first project is for a wind farm that has high clipping losses.

With the new Inflation Reduction Act, we have 40% lower installation costs than foreign LIB batteries and a total 35% NPV cost over 25-year projects. That means that ABC's EverGreenSeal technology and our Box-BE energy storage products offer ESS customers much higher margins for all applications.

When did the light bulb go on in your head to concentrate on BESS applications for the bi-polar battery?

During Covid we had the chance to innovate in both the technical and commercial space. The "work from home" experience really stressed the importance of constant reliable energy, which led to our home emergency energy storage product (HEES) in 2021. From there we kept going, aligning technology innovation with commercial requirements for large-scale energy storage. The result was our EverGreenSeal technology.

What does the Box-Be offer that is special or even unique for BESSs; would you include environmental impact, resource availability and recycling in your considerations?

Yes. Box-Be offers three advantages over today's ESS products, specifically lithium-based solutions.

First, it is economically beneficial to developers. Based on real-world pricing we offer developers a 25-35% NPV saving over the life of the project. And with the limited supply of lithium and increasing demand from EV batteries, our economic advantage will only grow.

Second, it is simply safer. The use of aqueous electrolytes ensures that thermal run-away cannot result in auto-ignition.

And third, it is environmentally beneficial. Our ability to recover, disassemble and recycle all components with a low-energy, environmentally benign process makes our approach much more sustainable and eco-friendly than other ESS chemistries.

Is the control BMS system based on single batteries or strings?

We control at the string level.

If strings, how confident are you that the ABC bipolar battery can meet the consistency requirements?

Fairly confident, but our BMS is designed to monitor voltage and impedance and adjust recharge to keep the strings balanced.

How big can you go with this technology?

That's the best part – as big as you would like. Two things – first, there is ample lead available from both secondary and primary sources to ensure hundreds of GWh's of ESS deployment per year.

Second, Box-Be systems, like others, can be connected to go from kWh to GWh solutions. And we have a third-generation technology for >GWh energy storage, which results in significant cost reductions.

The economics look favourable according to your data. This is based on discharging to 58% and voltage limited recharging to maximise life and round-trip efficiency. Are you worried about partial-state-of-charge effects including stratification?

No. First, we start with extremely low stratification at the end of formation. We are seeing 2-3 mV one-sigma standard deviation across our 250 mm plates.

Second, we operate the batteries in pancake orientation to avoid gravitational effects. And third, we control the recharging to cycle it from 100% down to 42% so that we never really get stuck in a long-term PSoC state.

Are there operational issues with dry-out/gas evolution/ recombination?

Our recombination efficiency is very high which helps reduce the dry-out. Like all AGM battery manufacturers, we pay close attention to the charging voltage to avoid dry-out as our life limiter.

One big advantage of your Box-Be compared to, say, lithium is the low upfront capital cost. This makes it appealing to underdeveloped economies. Is this market on your radar?

Not yet, but it will be. Today we are focused on getting Box-Be units out in the US market, but we are looking for partners to take it to other regions, especially underdeveloped economies.

Do you see the economic advantages as paving the way for a faster route to global net-zero CO2 emissions?

Absolutely. The only way to ensure a zero-carbon electric grid is energy storage. But to achieve this, energy storage needs to be responsible – economically, socially, and environmentally – and that's exactly what our Box-Be solution does.

Tell us about your pricing model.

ABC's current price indication is $300/kWh installation with on-going maintenance costs of $12/kWh-PA for the life of the project for our Box-Be system (includes DC bay, power conversion system, BMS, controls and communications, systems integration, and site preparation). The $12/kWh-pa includes replacement costs.

Of course, I have to add "it depends" as every project is different. For example, we adjust the maintenance schedule depending on how the system is actually used versus projected use. But for our base case (4h discharge 360 days a year) the 25-year Box-BE system costs would be $300/kWh installation + $12/kWh-PA * 25 years maintenance = $600/kWh or $0.067/kWh-cycle. Today's lead batteries do not achieve this cost/performance level.

ABC claims its GreenSeal technology gives off fewer carbon emissions than other energy storage products and is based on the lead ecosystem. The company's EverGreenSeal technology is made to be disassembled and recycled back into life with the bulk of its own material composition.

Cementing Europe's battery value chain

Andrew Draper reports from the European Sustainable Energy Week on efforts at European level to make the battery value chain more resilient. More work has to be done to plug huge gaps between market supply and demand, and skills.

Making the European battery chain more resilient, indeed future-proof, relies on training 800,000 people and providing them with battery-specific expertise before 2030, according to Vincent Berrutto of the European Commission.

Speaking at a session of the annual European Sustainable Energy Week (EUSEW) in Brussels in September, Berrutto said a lack of skills represents a "real barrier" to the future development of the European battery value chain. He is head of unit in the Directorate-General for Energy.

He said the European battery market is buoyant and growing, and the need for batteries will become ever more important in the energy landscape. "We need a strong manufacturing sector to create jobs and growth in Europe and make sure we reduce energy dependency on imported products," he said. There has been "big progress" in battery technology in Europe, but several challenges remain to be overcome, he added.

He said 2021 was another record year for deployment of stationary batteries and EVs (1.7 million new EVs sold = 18% market share). Lithium batteries still mostly came from Asian manufacturers based in the EU, but gigafactories are being set up in Europe, especially in Sweden and Germany. That trend will mean a growing market share in Europe, he said.

The average global battery price fell 6% last year but the trend now, with the rising cost of materials, is that battery packs may be at least 15% more expensive in 2022 from the year before. In 2030, demand for stationary batteries could be double what was forecast two years ago, he said.

Upstream raw materials

"One area that remains very challenging is the upstream raw materials segment, which is the least resilient of the battery value chain," he said. "And so that is an area where we spent more effort. The supply gap for battery raw materials increased in 2021. Currently, batteries are mostly sent to Asia for recycling."

Berrutto pointed to Northvolt of Sweden as a success story. It makes battery systems and cells and, since being founded in 2016, has secured more than $55 billion worth of contracts. Key customers include BMW, Fluence, Scania, Volkswagen, Volvo Cars and Polestar. It is developing recycling capabilities to enable half of all its raw material requirements to be sourced from recycled batteries by 2030. "They claim they

Vincent Berrutto

produced the first battery made from 100% recycled nickel, manganese and cobalt," said Berrutto. "…With a European effort, that shows we can make a real difference."

"But a lack of skills risks being a significant barrier to investments…800,000 workers will need to be trained and equipped with battery-specific expertise across the battery value chain well before 2030. That's a major issue"

He believes the European Battery Alliance (EBA), set up in 2017 by the Commission, national governments, industry, and scientific community, is on track to meet its objectives. The alliance has attracted the industrial participation of some 750 actors and more than €900 million in funding from the EU's Horizon Europe funding programme for R&I.

At inception, European battery cell manufacturing had no significant scale, it accounted for only around 3% of the world market and faced a future dependent on foreign suppliers. The EU expects production in the EU will match demand by 2025. Production will rely on successful recruitment of the necessary skilled workforce, however.

The EBA aims to develop an innovative, competitive and sustainable battery value chain in Europe. It brings together EU national authorities, regions, industry research institutes and other stakeholders in the battery value chain.

Berrutto pointed to common projects under IPCEI (Important Projects of Common European Interest). A two-part IPCEI has been implemented to promote battery production: the IPCEI on Batteries and the IPCEI European Battery Innovation (EuBatIn). Under both programmes, participants represent the complete value chain, from materials and cells to battery systems and recycling. A €6.1 billion programme of funding has been established by 12 member states, with a further €14 billion of private-sector investment.

The projects have several working areas, including raw materials, cells/modules, battery systems and recycling. For example, under the programme, BASF has a new plant producing cathode active materials (CAM) in Schwarzheide, Germany. The project also includes intensive research for specific product properties and efficient recycling. BASF is planning a battery recycling black mass plant in Schwarzheide as well.

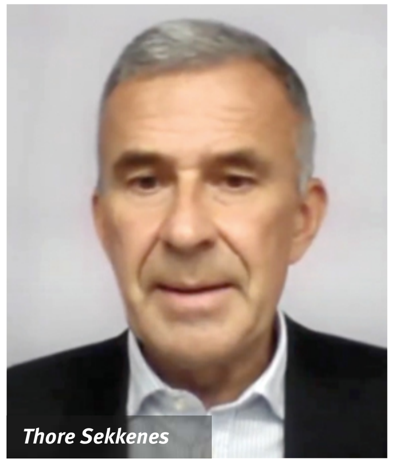
Berrutto said the EU is about to announce a plan for the digitalisation of the energy sector. The aim is to use digitalisation to reduce energy consumption and increase use of renewables in the energy mix. This includes the increase in bi-directional charging of EVs.

Wide supply and demand gap

Thore Sekkenes, programme director of the EBA, said his organisation knows of 50 cell-manufacturing facilities in Europe just starting construction or being financed. World-wide battery demand forecasts vary from 6.5 TWh to more than 9.0 TWh for 2030. Research body Benchmark Minerals estimates there is currently production capacity of 1 TWh. Battery demand in Europe is forecast at 550 GWh in 2025 and 1 TWh by 2030, Sekkenes, he said. This is based on the EBA's own analysis and on motor manufacturers' announcements (with 15% added for other sectors).

The gap between supply and demand – especially upstream – is very wide, said Sekkenes, adding meeting it is "a good business opportunity".

The upstream segment of raw or active materials is also facing enormous demand, as is the market for production equipment. "This is also something which, to the largest extent, we import from elsewhere. Production equipment is also something we need to build up our strength in in Europe," he said, adding that China dominates in terms of production and raw materials.



Thore Sekkenes

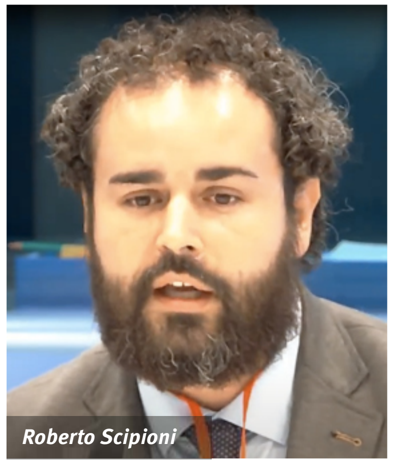
"We need far more skilled people," he said. Workers in other industries that face decline can be retrained in battery skills. The recycling industry is fragmented, with many questions unresolved: who owns the batteries, how are they transported, etc.

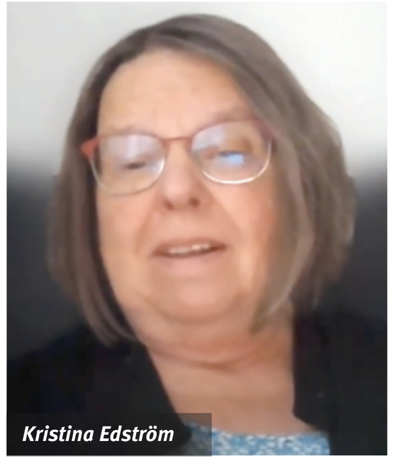
"We've come very far in only five years," he said, referring to a European battery industry that was almost non-existent five years ago. "The on-scale manufacturing picture is very different now and growing but has some issues…we need to focus more effort."

Feasible battery regulation

Michael Lippert, president of BEPA and Batteries Europe, director of innovation and solutions for energy at French battery maker SAFT, said he wanted the battery regulation in Europe to be feasible and take the industry in the right direction. Education and skills building are also important, he said. More academic positions and programmes are required, as is educating the general public about the shift in direction to battery energy.


Michael Lippert


Roberto Scipioni


Kristina Edström

Digital developments and advanced battery management systems – for example as part of the Battery Interface Genome – Materials Acceleration Platform (Big-Map) project is part of a radical shift in battery innovation. It is a consortium that aims for a dramatic speed-up in battery discovery and innovation time; reaching a 5-10 fold increase relative to the current rate of discovery by 2025-30.

Manufacturing improvements are important, he said. Areas include further development of lithium and solid-state batteries, as well as making batteries safer and cheaper, and with better battery management systems. The manufacture of stationary ESSs that are less dependent on critical raw materials is being supported.

R&I in Europe is in the hands of several bodies, each with its own area of activity. "The important point here is that we work together to avoid duplication. There are six working groups for the entire value chain. In conclusion, we believe R&I is a very important part contributing to the European battery industry."

Lippert is also vice-president of the European Association for Storage of Energy (EASE).

Future-proofing the value chain

Ilka von Dalwigk, EBA Policy Manager, said making the value chain future-proof was "not just a technological question". She told the session: "It's about collaboration, not only in European industry and academia. Our competitors aren't resting, they are developing all the time. We should do this as well."

Roberto Scipioni, technical leader of Batteries Europe, an EU body for researchers and innovators, told the session that digitalisation was "a challenge, but also an opportunity". He said: "What is it: It's important first of all because you have to identify each part of the value chain. Digitalisation is an important tool. It's very important to understand what it is." It allows visual representation of processes, for example.

In terms of gathering knowledge, he said large amounts of data are required. "We can collect data in many different ways, and we need to homogenise. In Big-Map, we've done a lot on the homogenisation of data. The other problem is not only making data available but how we get the data...We need to have a more trust-based market (between researchers and industry, ed.)."

Kristina Edström, Professor of Inorganic Chemistry at Sweden's Uppsala University, said she felt hopeful about the greater co-ordination happening across Europe. She is involved in the Battery2030+ research initiative aimed at creating tools for transforming the way people develop and design batteries in Europe.

There is greater work between researchers and industry as partners," she said. "It's not industry looking at research, or research sceptical of industry, but a real partnership. We have industry involved in long-term problems.

"We are skilling the students and teachers in schools...All this we need to bring together and harmonise in a European landscape. I think that's a very good starting point." Her young students are the research leaders of the future. Stimulating them and providing networks helps them develop, she said.

Insight, innovation and vision

Andrew Draper reports from Battery Cells & Systems Expo, held at the UK's National Exhibition Centre in Birmingham from 29-30 June.

It was apparent from the range of exhibitors and expo participants that there is no shortage of insight, innovation, and vision in the battery industry. Precision engineering, testing and pioneering production were on show, from automotive manufacturers, electric utilities, battery system integrators, cell manufacturers, academic research, and the entire manufacturing supply chain.

Among the conference debates were sessions on:

- succeeding in the international battery market
- what to expect of EVs in future
- solid-state battery powered cars
- transition to zero-emission technology for medium to heavy duty vehicles
- alternatives to lithium-ion with commercial promise
- recycling and the circular economy
- skills and investment
- regulatory frameworks.

Many delegates noted the expo was on at the same time as the Battery Show Europe Expo in Stuttgart, so footfall was a little thinner than might otherwise have been expected.

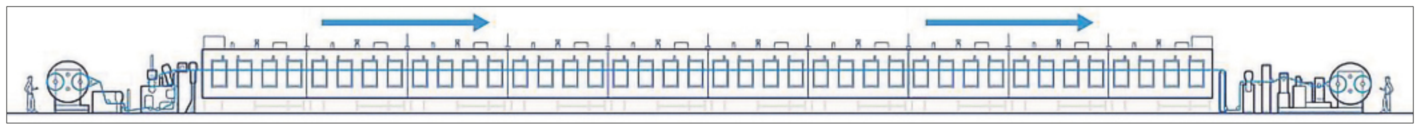
Among exhibitors, Dürr Megtec of Germany was showcasing its technology for coating battery electrodes. It says simultaneous two-sided coating using a tensioned web process and fast drying enables very fast production times. A vertically mounted slot-die coats both sides of electrode foil travelling horizontally. It can complete production runs with precision tolerances in a matter of hours rather than days. This has obvious cost advantages.

It claims it offers the lowest capital and operating costs for gigafactories through its electronic-grade solvents, which allow immediate re-fining and re-use on site.

HEL Group of London, UK, presented its solutions for hazard screening, safety and performance testing for the battery testing and process safety industries.

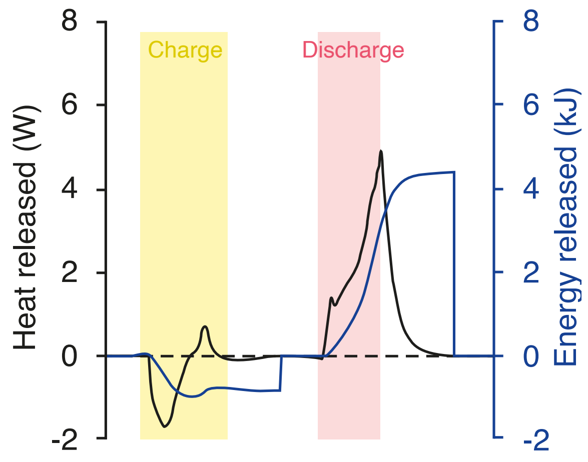
Ferreira emphasises the importance of reliable data for detecting exothermic runaways and dangerous gas generation. If investigating a plant-scale runaway, such data is crucial for root-cause analysis and control measures. Catastrophic failures and the conditions that lead to them can be anything from operating temperatures, incorrect installation and charging to physical damage to the battery.

Claudio Ferreira, Sales Manager for HEL Group, with the BTC-130 Adiabatic Calorimeter



Durr Megtec simultaneous two-sided coating

HEL Group was showing off its new iso-BTC+ calorimeter for isothermal battery performance testing. The iso-BTC+ defines cell, battery, or pack thermal performance and characteristics under normal and extended use conditions.



The model is designed to characterise the thermal behaviour and electrical performance of high-power battery cells. It highlights regions of increased thermal energy generation and identifies risks of thermal runaway. It is capable of characterising physically larger and more powerful batteries – up to 350mm by 350mm in size – and 200W.

Isothermal performance testing is used in EV manufacturing and consumer electronics. Additional features include accelerated aging tests, electrode composition analysis and battery chemistry investigations.

Heat release rate (power) is measured in watts and energy released, measured in kilojoules during charge and discharge of a gel cell battery at 40°C. Source: HEL Group

H&T Battery Components of Germany's Heitkamp & Thumann Group said, at the expo, it is planning expansion into the automotive market. In July, it signed a memorandum of understanding with Britishvolt to collaborate on battery can component supply for automotive applications. Clients include EV manufacturer Tesla.

Its H&T Battery Components Rechargeable unit will develop a new battery can production line at its manufacturing site in Blackburn, Lancashire. It supplies the rechargeable battery industry (and is the world's largest manufacturer of battery components for the consumer battery market).

Tobias Ott, President of H&T Battery Components Rechargeable said the company would support UK-based mass production, also with research and development from its new established centre in Germany for cylindrical battery can development.

AceOn Group of Telford, England, is working with the University of Wolverhampton to develop second-life battery technology. It has a project bringing old electric bus batteries back to use to store electricity for use on Cranfield University's campus near Bedford. AceOn has been working with Oxford-based specialists in power electronics and battery management systems Brill Power, as well as the university on the scheme, which it believes is the first of its kind in Britain.

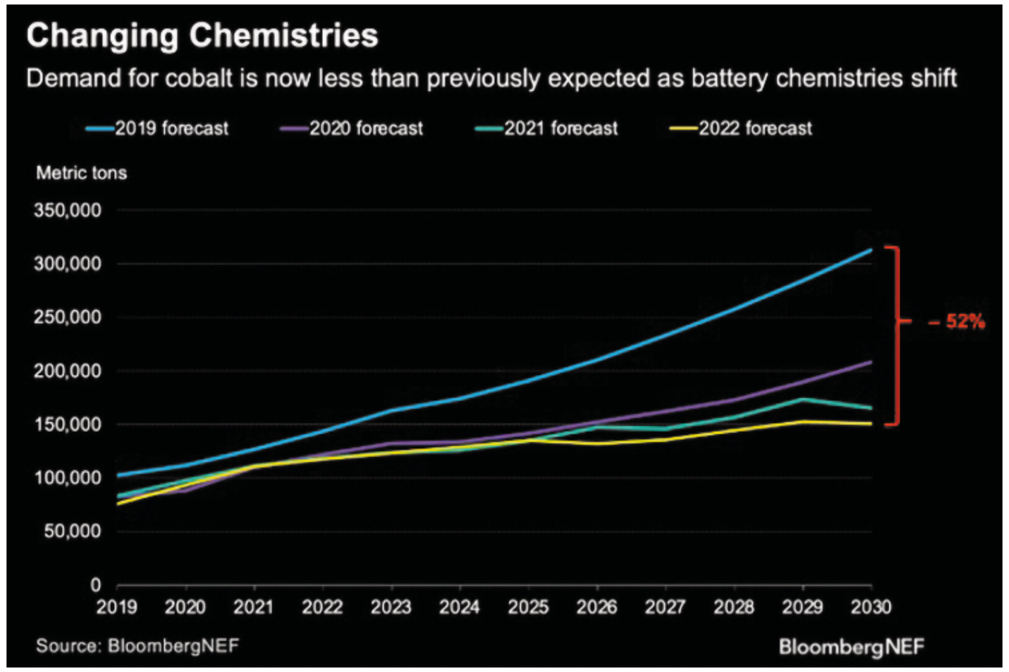
Two German companies were showcasing slurry mixing technology, Hauschild and Eirich. Hauschild says its Speedmixer helps reduce battery slurry manufacturing times, while its competitor Eirich claims its Mixsolver batch makes electrode slurry which can be held in tanks temporarily before being supplied to coaters on a just-in-time basis. It reckons its mixer is faster and uses far less energy than a conventional planetary mixer.

It said the first gigafactory for lithium-ion batteries in Asia to use its Mixsolver to manufacture electrode slurries was commissioned in May 2022.

Got its act together

Dr. Stephen Lambert, chair of the Automotive Electronic Systems Innovation Network (AESIN) and head of electrification at motorsport technology company McLaren Applied, was one of the conference speakers. He said he has seen huge change in the battery industry in the last five years as consumers switch to EVs. "As a result, the battery industry has really got its act together and started to focus and made sure that the products being developed at the cell or battery level are coming through in the right way to meet the requirements of the electric vehicle industry. And that's a really positive change and is in stark contrast to what happened 10-15 years ago in the vehicle battery industry."

Forecasting the future of motorsport is difficult, he said, but he believes there will eventually be a switch towards EVs as the automotive industry in general moves towards electrification. "The technology isn't there yet to make Formula 1



electric but over the next 30 years there will be an inevitable movement towards EVs."

The third phase of EV development will be around efficiency, he said. That means improving battery power and lowering cost. Smaller battery packs will mean they will become cheaper and in turn make EVs less expensive, especially on the battery side. Fast charge technology will also improve and that will lead to smaller, less expensive batteries too, he said.

Battery price bump

In its last annual battery price survey (from November 2021), research body BloombergNEF (BNEF) said prices for battery electric vehicle (BEV) packs in particular were $118/kWh on a volume-weighted average basis in 2021. At the cell level, average BEV prices were just $97/kWh. This indicates that on average, cells account for 82% of the total pack price, it said. Over the past two years, the cell-to-pack cost ratio had diverged from the traditional 70:30 split, a result of changes to pack design, such as the introduction of cell-to-pack designs.

But in July, it warned of a reversal: "There could be a bump in the road this year. Amid rising raw material and component costs, battery prices could increase for the first time since at least 2010. BNEF forecasts the average battery price will climb to $135 per kilowatt-hour in 2022, some 2% higher than a year earlier. If inflationary pressures persist, this could delay the point at which EVs reach the $100-per-kilowatt-hour threshold by two years, to 2026."

It says it is at around this price point that car manufacturers should be able to produce and sell mass-market EVs at the same price (and with the same margin) as comparable internal combustion engine vehicles in some markets.

High commodity costs could spur car manufacturers to adjust their battery manufacturing and opt for cheaper compositions, for example to substitute cobalt for nickel.

Kwasi Ampofo, head of metals and mining at BNEF, said: "Cobalt use in lithium-ion batteries has evolved over the last three years as a result of the higher prices recorded in 2018 and the ethical concerns automakers have around supply from artisanal miners in the Democratic Republic of Congo. These concerns have resulted in a shift to less cobalt-intensive battery chemistries, or those without cobalt."

Lithium, specifically lithium carbonate and lithium hydroxide, is a crucial ingredient in EV batteries, and it has been getting increasingly expensive. "Lithium carbonate prices have risen from $5,000 per ton in July 2020 to about $70,000 per ton in July 2022," he said.

The switch to higher nickel content, as well as the rapid uptake of lithium iron phosphate cells, means less cobalt will be used in batteries than previously anticipated. BNEF's latest forecast is that cobalt demand will grow by 28% between now and the end of the decade to over 150,000 tons. However, this is less than half of what was estimated in 2019.

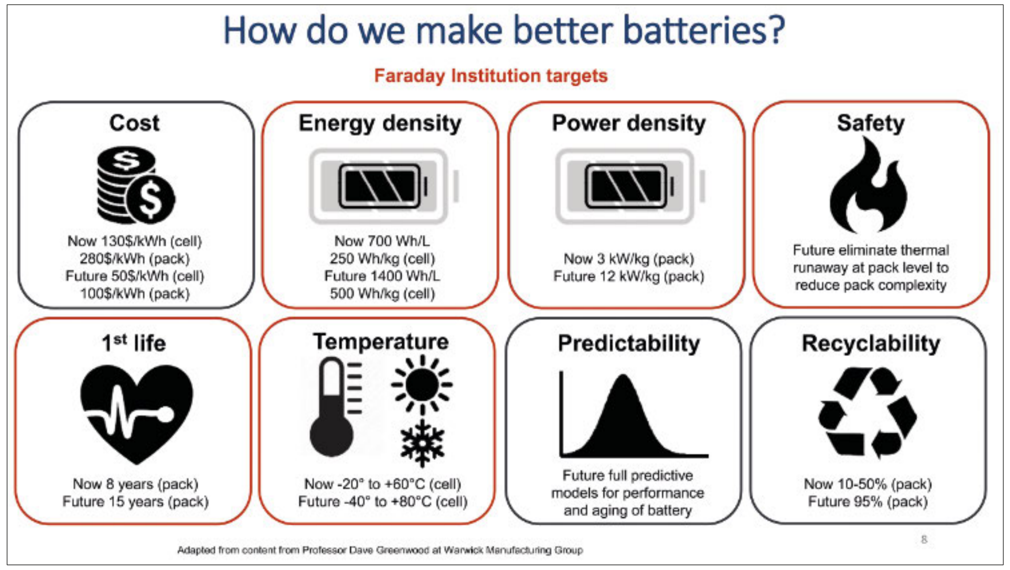
The path to achieving $100/kWh is clear, although the timing now looks more uncertain. In 2021, a wave of car manufacturers released battery technology roadmaps outlining how prices can be reduced below $100/kWh. Companies like Renault and Ford have publicly announced targets of $80/kWh by 2030, according to BNEF.

Continued investment in R&D alongside capacity expansion across the supply chain will help to improve battery technology and reduce costs over the next decade. BNEF said it expects next-generation technologies, such as silicon and lithium metal anodes, solid-state electrolytes and new cathode material and cell manufacturing processes, to play an important role in enabling these price reductions.

More efficient batteries

In her presentation to the expo, Dr Jacqueline Edge of Imperial College London and the Faraday Institution, talked about targets to make batteries perform better and last longer. Cost will have to come down to a pack cost of $100/kWh (from $280 kWh), energy density will have to double and power density must quadruple.

That raises the question of safety and preventing thermal runaway. The audience was told, in the session on ultra fast charging and optimal performance conditions using better thermal management, that safety, cell aging and performance are just a few of the reasons that good thermal management is crucial to H/EV success.



How do we make better batteries? Faraday Institution targets

The increasing demand for ever faster or ultra-fast charging is seen by many as crucial in attracting those consumers who want to replicate their experience of driving an internal combustion engine vehicle. A cohesive thermal management system can be the difference between maintaining a healthy, long-lasting battery and running the risk of thermal runaway or extreme degradation.

Thermal management is critical because it improves performance, limits degradation and improves safety. Battery packs in use today have large thermal management systems which aim to remove the heat. This substantially reduces the energy density of the battery pack as an overall system.

The Faraday Institution's Multi-Scale Modelling project has proposed changes to cell design to improve thermal performance. A new standard called the Cell Cooling Coefficient (CCC) allows car manufacturers to compare the ability to thermally manage commercial lithium-ion batteries across a set of performance targets.

Innovation in solid-state batteries (SSBs)

Specialist in all-solid-state battery technology for electric vehicles, Ilika Technologies of Romsey, England, and Comau (part of car maker Stellantis), which is engaged in SSB technology, have completed a one-year government-funded study into solid state batteries. They looked at the machines and processes required to manufacture oxide electrolyte-based solid-state technology at an approximate scale of 100 MWh per year.

They developed both a lab scale and industrial manufacturing process with a specific focus on utilising existing technologies and machines. The study identified that two-thirds of all-solid-state cell production steps can be achieved on standard or lightly customised equipment currently used in the production of conventional liquid electrolyte-based lithium-ion batteries and other markets. They are now scaling up towards mass production levels: 2 MWh per year by the end of 2023 and then gigascale after that.

They say Ilika's Goliath ASSB technology for EVs has the potential to improve pack-level energy and power density, enabling fast charging of below 20 minutes and operation to higher temperatures than conventional lithium-ion batteries.

Regulations and standards

The conference part also considered regulation and standards, and where regulation is needed – such as in vehicle battery standards and second life. Ben Lincoln, patent attorney and partner at Potter Clarkson, talked about optimising patent strategies to take advantage of a market subject to regulation.

He said: "The scope of regulation must be carefully controlled so that it steers the market towards a desired family of solutions without disrupting or overstretching the capacity of technical solutions that will fall outside the regulation. Thus, for the regulators, they must assess what the intentions of the regulation needs to be and gain a thorough understanding of what the market will look like once introduced.

"If the regulation is too restrictive, demand for the remaining technical processes can outstrip supply. If the regulation is too lax, then the desired steering of suppliers and consumers may not be achieved."

Innovation in battery recycling needed

Scooters left lying on the streets of Brussels paint a vivid picture of the care and consideration taken over this high-tech form of transport. Could this level of care be part of the reason for the proliferation of lithium battery fires that were being discussed at the International Congress on Battery Recycling (ICBR) held this year in Salzburg. Vic Giles asks if lithium batteries should be treated as the 'problem child' of the battery industry.

There is no doubt in the mind of this writer that lithium batteries have the potential for great good, but also great harm. The 'problem child' needs to be well managed if society is to be spared the worst of its behaviour.

In his opening address at the International Congress on Battery Recycling (ICBR), the chairman of the steering committee, Arie de Jong, set a challenging, if somewhat dismal, scene for the state of lithium battery recycling in Europe.

"Expect new challenges," he said. "Who among us dared to predict last year that an energy crisis would hit a large part of Europe? CO_2 targets are untenable for many countries, as we rely again on high CO_2 emitting fossil energy sources. In addition, the price of energy has exploded, which is a huge burden for the battery industry, since a lot of energy is needed for processing discarded batteries."

He said the capacity for recycling lithium batteries in Europe is very limited. Last year there were several calamities that worsened the situation.

"For collecting organisations, it is a huge challenge to have to collect the batteries to be recycled because the factories cannot take them in for processing after calamity.

"And speaking from experience, I know that lithium iron phosphate and lithium thionyl chloride batteries are hardly processed by any European recycling plant." Exporting lithium batteries for processing outside the OECD countries has become virtually impossible as authorities increasingly classify them as hazardous waste with all the associated restrictions, he added.

He went on to say that battery regulation is another challenge facing EU countries. New battery categories will be defined in terms of waste, battery passport, use of recycled materials, carbon footprint, recycling percentage of various materials, and strict rules for industrial batteries and collection percentage for portable batteries of 65%. And that is very far away from the actual result of many compliance schemes.

"Also, safety is a huge challenge," he said. "Fires caused by lithium batteries are reported from all around the world. We can't get around it. There's work to be done in many areas to increase the safety around lithium batteries. Of course, lithium batteries should be prevented from ending up in household waste, scrap collected or anywhere else where it does not belong. There are also measures employed at collection and sorting companies and fire detection is necessary. Discarded e-bike batteries are often identified as the cause of fire."

Innovation in battery recycling is needed, he said. Many materials are still being lost and the upcoming battery regulation in the EU will probably require a high recycling rate.

EPAC battery reverse logistics

When it comes to portable batteries it is the reverse logistics that presents one of the greatest problems for the recycling industry ***(Fig 1)***. Getting many millions of portable batteries back to collection points relies firstly on consumers realising the inherent value of the cell and being motivated to return it for recycling. Secondly, it must be a safe process because we're talking about class-9 waste, the state of health of which is often unknown.

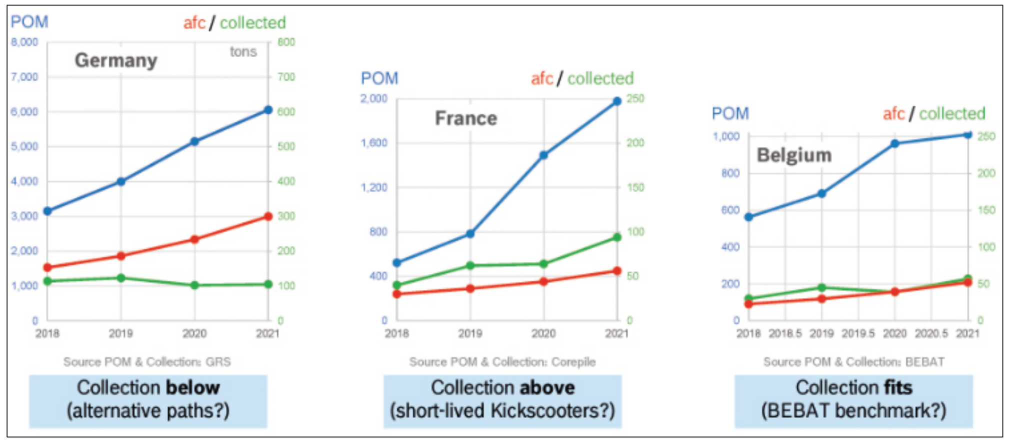


Fig 1: The 'available for collection' model looks reasonable considering the regional variations. Germany is repairing most; France is collecting more than expected; Belgium fits the benchmark. Also, in Germany a stockpile was created due to lack of sorting.

For example, electrically power assisted cycles (EPAC) sales are forecast to be double that of cars by 2030 reaching some 30 million bike sales per year. With a usability average of eight years, a hoarding average of three years and an average collecting point retention of 0.8 years, estimates show it will take around 20 years to collect all 'available for collection' batteries.

Gunter Flinspach, eBike systems, management consulting (BMS) at Bosch is adamant that packs should not be repaired. He said these are hazardous goods stored in houses. "Batteries are very compact, as they are a lifestyle product – this leads to batteries being made as safe as possible, which leads to a problem when opening, repairing and closing the battery. This has an impact on safety and certification, which will be lost upon opening.

"There are consumers who think the battery is an investment rather than a consumable. This also leads to hoarding of used battery packs."

Flinspach told BEST that batteries have software built in that, and when a fault is detected, it can disarm the battery; it could then start a deactivation process and notify a collection agent that the pack is available for dispatch to a recycler (3D battery recycling might catch the imagination).

The pyro vs hydro question

Bart Verrecht of Umicore said: "It's not pyro vs hydro, it's always a combination of a certain type of pre-treatment of which pyro is an example; followed by a further hydro refining of the alloy or the black mass that is produced. The type of pre-treatment, your performance and efficiency determines the yield of your valuable metals – so the economics. It also determines the ease, cost and complexity of your further hydro processing ***(Fig 2)***.

"If you cut your batteries to pieces in a shredding process you will inevitably lose some of your precious metals (Ni, Co, Li) in the different side-streams and those losses can be significant (up to 5-10% of these important metals)."

Umicore admit to having created the market perception that tends to favour hydro over pyro processes in terms of CO_2

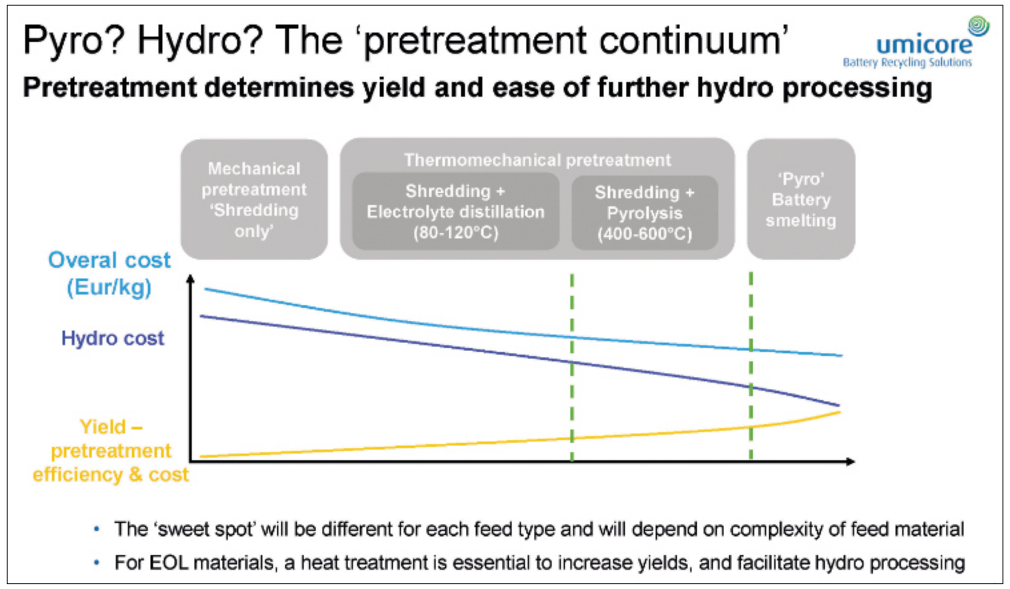


Fig 2: As pretreatment costs rise, they are more than compensated for by the reduction in hydro costs, which give higher yields

footprint. However, this is often based on incorrect, incomplete, or outdated LCA claims, said Verrecht. "We are likely partly to blame for that at Umicore. In 2007 we actually wrote a patent describing a shaft furnace for battery recycling, which required a large amount of coke and that's what we call the old pyro process" ***(Fig 3)***.

The new process uses the chemical energy from the battery to deliver energy for the process and also act as reductants. No external energy is needed and excess energy is created for uses such as heating and the hydro processes.

"Sustainable battery recycling is key for the transition to sustainable electric mobility. Both pyro and hydro flowsheets have challenges and opportunities towards decarbonisation, but the lowest end-to-end CO_2 footprint is obtained through a smart combination of pyro and hydro," said Verrecht.

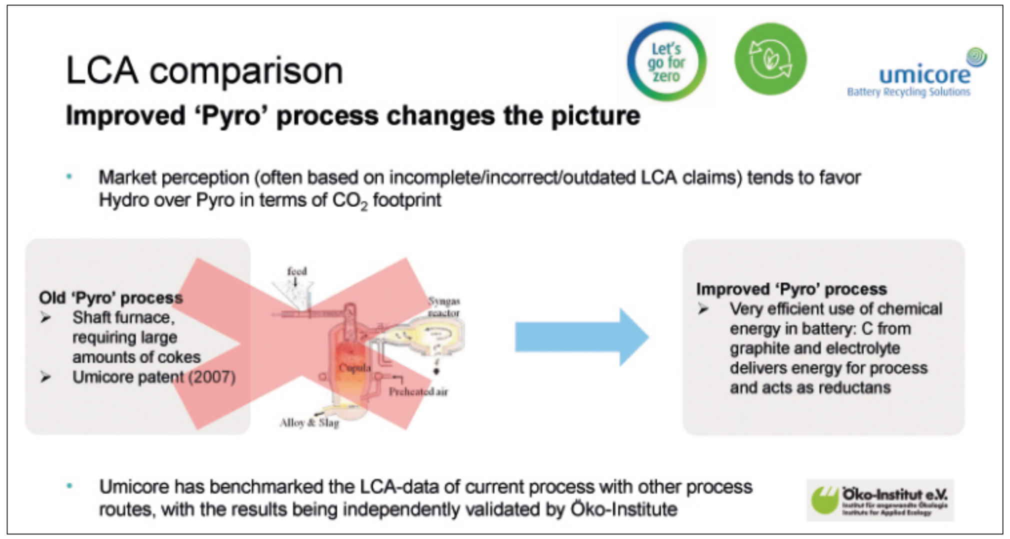
Composition of black mass

Tobias Elwert, global expert in battery recycling technology at BASF, evaluated the metallurgical process options for black mass. He said: "Black mass is a mixture of the electrode active materials contaminated with a wide range of impurities." As there is a wide range of cathode materials (NCM, NCA, LCO, LFP, etc) and graphite/silicon on the anode side, it follows that the chemical composition of black mass can vary considerably ***(Fig 4)***. The main impurities are aluminium and copper from the electrode foils, then flourine and phosphorous from the conducting salt and certain plastics. Depending on how you source and produce the black mass you may also have different types of organics along with elements from mis-sorted batteries (Cd, Pb, etc).

If black mass is thermally treated the organics can be destroyed, along with the CAM structure, which means different leaching conditions are required in the subsequent hydro stage.

In the co-processing of black mass, Elwert said: "You use organics and graphite as reductants. I know this is controversial but, as Bart said, as long as we don't have industrial solution for graphite recycling I would also see it as an advantage of this type of process." The disadvantage is that without prior separation lithium is lost due to dilution in the slag, which means the process will be unable to comply with regulatory requirements for element-specific quotas. "Without these types of adaptions… these processes will disappear from the market." The

Fig 3: Old style hydro is replaced by a new improved process for greater efficiency



Element	Concentration	Origin
Al	1-5	Conducting foil, NCA
Co	3-33	NCM, NCA, LCO
Cu	1-5	Conducting foil
Fe	0.1-0.5 (without LFP)	Casing, screws, wear particles, LFP
Li	3.5-4.0	$LiPF_6$, CAM
Mn	3-11	NCM
Ni	11-26	NCM, NCA
Graphite	~ 30	Anode
F	2-4	$LiPF_6$, PVDF
P	0.5-1.0 (without LFP)	$LiPF_6$, LFP

Other (trace) impurities:

- Silicon
- Doping elements, e.g., Ti, Zr
- Coatings, e.g., B
- Additional halogens (Cl, Br)
- Organics (solvent residues, binders, plastics)
- Elements from missorted batteries, e.g., REE, Cd, Pb etc.

Fig 4: The chemical composition of black mass will vary depending on the feedstock

highly corrosive content (lithium and flourine) treatment of the feedstock and a comprehensive off-gas treatment means smelting capacity is limited.

Elwert said that in Europe there is a trend towards shredding under N_2/drying, which means the majority of black mass is not optimised for direct hydrometallurgical processing. However, the majority of planned investments in Europe are hydrometallurgical plants aimed at producing battery grade chemicals.

How to decrease carbon footprint

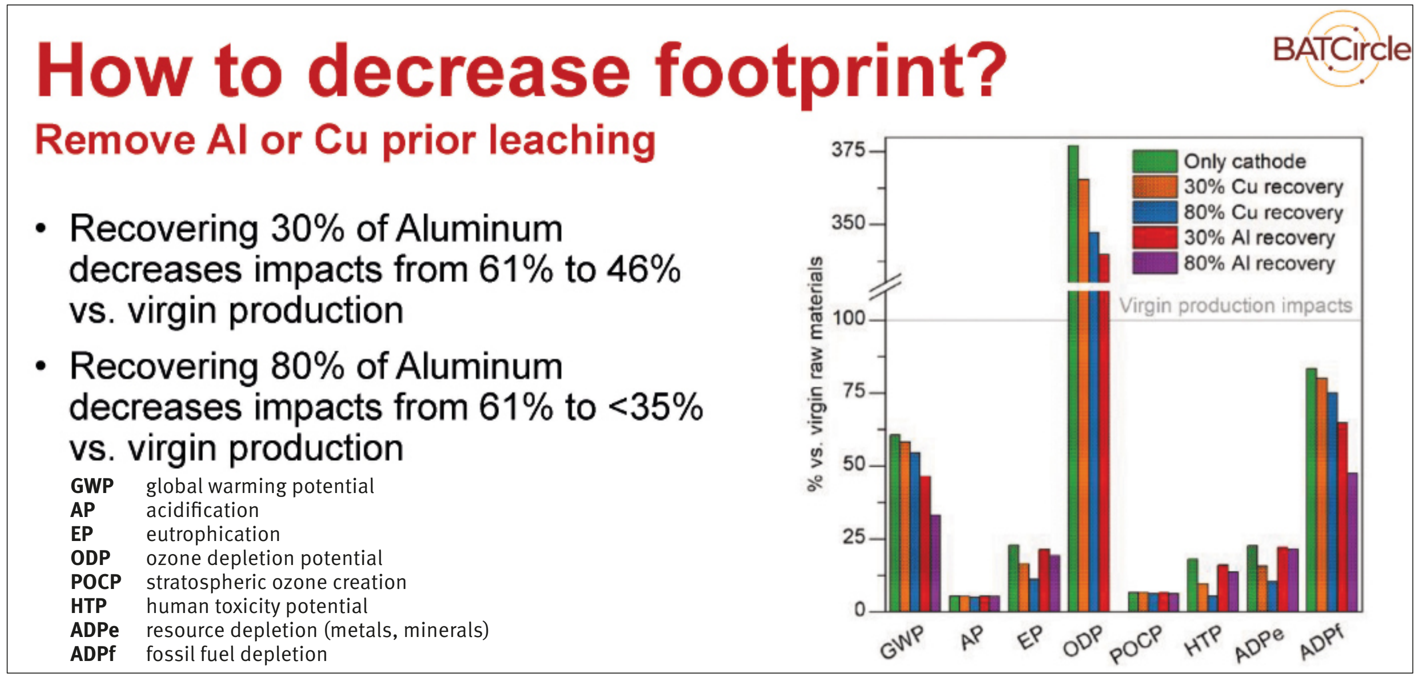
The electrification project is all about reducing carbon footprint. But how much difference does it make? And how much effect does recycling have?

Professor Mari Lundström of Aalto University said that recycling can fulfil <10% of raw material needs for batteries 2030 (~50% 2040). Mining and primary production in the EU need to be enhanced, all recycled battery materials and pre-production scrap will need to be accessed, and consumption needs to be reduced.

Battery recycling processes need life-cycle analysis (LCA). All input of a recycling process must have an output, from the current collectors and active materials to the binders, separators, electrolytes and casings.

Research at Aalto University shows that using hydrometallurgy to treat 1kg of battery waste in LIB-NiMH recycling would generate ~4kg CO_2-eq. The burden came mostly from the neutralisation chemicals. The burden to produce the equivalent materials from primary product was ~6kg CO_2-eq. To improve on this saving they looked at removing Al or Cu prior to leaching. The results can be seen in ***Fig 5***. A major reason for the saving is because virgin aluminium production is an energy heavy process.

Fig 5: Environmental indicators comparing recycling to virgin material products. Aalto University



Project ReDesign

At present LIBs are designed for manufacturing and application, not recycling. Sebastian Hippmann of Fraunhofer said: "It is not possible to meet the raw material demand for Ni, Co, Li through mining alone. The concentration of these critical metals is so high in batteries we must have urban mining to secure the materials. Distinctive fractions are the necessary materials for the production of new batteries. In an ideal world these will be easy to produce and more cost effective for producing new batteries."

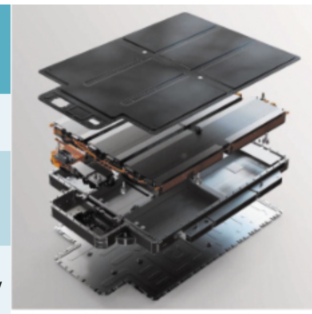
Call it what it is – not to do this is short-sighted and damaging to the very environment EVs are trying to save. Crushing and shredding battery packs results in contaminated fractions that present difficulties in purifying. "At the end-of-life (EoL) state of the battery it can be more cost-effective for the producers when the cost for recycling is lower because of the better recycling concept in the design," said Hippmann.

New trends are not always positive. Cell to body raises more transport, safety and separation issues. The complexities of all-solid-state-batteries are still being investigated. The foam packing materials used in the Tesla Model Y means the pack is very difficult to disassemble. 'Better batteries' may not always be best, there is a trade-off between performance, lifetime and recyclability.

However, EPR means that the producer is responsible for the cost to recycle the battery at EoL. The more complex and difficult it is to recycle the battery, the more that will be paid to the recycler – this is independent of the value of the battery. That cost, of course, will be passed on to the consumer who will have little option or say in the matter.

Are new trends always positive?

Performance information	Influence on recycling
Mix of various cell chemistries	Maybe Fe, P contamination
Cell-to-Pack	Less pack periphery, separation of cells
Cell-to-Body	Less pack periphery, transport/ safety issues, separation of cells
Higher volumetric energy density	Even more safety issues during disassembly
ASSBs	Complex material sandwich, may contain S, P



Design of hybrid-cell (NIO)

Disassembly of a structural battery (C2B) (Tesla Model Y)

India: The nation is now on the move

BEST's Asia correspondent Dipak Sen Choudhury shares his thoughts on how the Indian government is getting serious about battery waste management legislation.

The nation is on the move! This was the slogan of the Indian government as it went to the polls in 1977. The Indian National Congress Party government of Indira Ghandi had achieved nothing. The call for restoration of democracy by revoking emergency powers is considered by many to be a major reason for her sweeping defeat by the opposition. It will be remembered as a footnote in the history of the country as one which had taken a lot of liberty with the freedom of the people but ended up in the dumps in a very short space of time. The image of a nation on the move economically, socially, and culturally remained a promise based on unreal foundations.

Fast forward to the present and observe how this country is now planning to move ahead, thinking long-term, trying to secure the future of two of the basic pillars of life – energy and environment. The current Indian government of Prime Minister Narendra Modi has an obsession. An obsession to be known as an administration that did things differently from all its predecessors. Prime Minister Modi loses no opportunity to make the point that his government is only fast-tracking things that should have been started long ago by earlier governments.

Legislation on battery waste management

Look at India's new battery waste management legislation from the above point of view. It may be understood that this is a major attempt to kickstart a few essential activities, including technology breakthroughs that could complete a circular economy with clean sustainable energy solutions. One may call this unrealistic, but someone must mark the path ahead and hope for things to fall into place.

The country has had specific legislation before on battery waste. In 2001 the government brought in the Battery Management & Handling Rules (BMHR) for adoption across the country without exception. Highlights were:

- This legislation was solely directed at lead-acid batteries – both for automotive and industrial use
- The rules would apply to manufacturers, importers, re-conditioners, assemblers, dealers, recyclers, auctioneers, consumers, and bulk consumers. Bulk consumers meant government departments like railways, defence, and telecom
- Responsibility lay with manufacturers, importers, assemblers, and re-conditioners to ensure that used batteries were collected and exchanged for new batteries sold (excluding those sold to original equipment manufacturers and bulk consumers)
- Ensure that used batteries collected were sent only to registered recyclers

- Recycled lead to be bought from registered recyclers only

Collection targets during rules implementation:

Year	% of used batteries collected/new batteries sold
1	50%
2	75%
3	90%

Did the legislation deliver the objectives? The answer is a vehement no!

Throughout the country, there are thousands and thousands of unregistered recyclers with crude operations that are neither environment- nor health and safety-friendly. Their scale of operations can vary from a few hundred kilograms to a couple of tonnes of recovered lead per month. They are always offering much better rates for used lead collection compared to the registered recyclers. They are neither paying for all safety and environment protection in their operating set-ups nor are they paying the government any taxes.

Technology cost for them is zero as they use the crudest of furnaces to remelt the waste batteries. The acid is usually dumped into the municipal sewers, if available, or into the soil. Lead from users, including the so-called bulk consumers, more often than not lands up with the unregistered dealers while the capacity with the registered dealers remains idle. The bulk manufacturers and their dealers are hardly able to exhibit more than 20% of used battery collection as a percentage of new batteries sold by them. The government knows this but pleads helplessness and only pressurises the manufacturers to come up with better collection figures.

Informal recycling in India. Courtesy ILA. Photos by Brian Wilson, ILA advisor

Against this, one must now examine India's rush towards transitioning to electric vehicles (EVs). As of now, the only commercially-matured technology to serve EV demands is the lithium-ion battery (LIB). A report from the Indian Council for Research on International Economic Relations (ICRIER) stated that by 2030, India will be producing 1.4 million tonnes of LIB waste, most of it from EVs. With no source of lithium and cobalt in the country and no sign of any credible LIB recycling anywhere in the world, the sustainability of India's EV dream looks suspect and some major incentivisation is needed to maintain the momentum of aspiration. It is in this perspective the new battery waste management legislation needs to be viewed.

What is different? The rules cover all types of batteries – lead-acid, LIB or any battery for EV, industrial or automotive application. It explicitly prohibits disposal of batteries through landfill or incineration.

Extended producer responsibility

The new rules on battery waste management introduce the concept of extended producer responsibility (EPR). This makes producers and importers active participants in the collection, recycling, and re-use of battery waste materials in fresh battery manufacture. To meet the various obligations of EPR, producers may engage or authorise any other entity to collect, recycle or refurbish waste batteries.

Under the new rules, the government has launched a centralised online portal that allows producers and recycling agencies to exchange complete data on collection and recovery – for complete recycling transparency.

The new rules certainly incentivise the setting up of new industries and entrepreneurship in waste battery recovery and recycling. This would be of major consequence in the LIB industry as subsequent legislative mandates make using recycled materials compulsory.

The new rules mandate the use of a defined percentage of recycled material recovered from waste batteries in new battery production. The figures look very challenging indeed, from the LIB point of view, ***(see Table 2)***.

Sl no.	Battery type	Minimum use of recycled material as a % of battery total dry weight			
	Year	2027-28	2028-29	2029-30	2030-31 on
1	Portable	5	10	15	20
2	EV	5	10	15	20
	Year	2024-25	2025-26	2026-27	2027-28 on
3	Automotive	35	35	40	40
4	Industrial	35	35	40	40

Table 2

For lead-acid the targets even for 2027-28 are by and large already achieved. However, for LIB the recycling targets for domestically produced batteries, though aspirational, may encourage investors to act seriously. Moreover, the targets set are to be reviewed every four years and may be revised to suit the state-of-art at the review point – up or down.

The new rules have also clearly prescribed the minimum recovery rates of various metals from waste batteries that have to be achieved by recyclers, or else face financial penalties. The figures are shown in ***Table 3***.

Table 3

Sl no.	Battery type	Recovery target, %		
		2024-25	2025-26	2026-27 on
1	Portable	70	80	90
2	Automotive	55	60	60
3	Industrial	55	60	60
4	EV	70	80	90

The expectations for LIB and other exotic chemistries are certainly stretched too far and very unlikely to be complied with. However, the expectation is to challenge the industry.

Finally, non-fulfilment of EPR will attract fines by India's Federal Pollution Control Board and the respective state boards where the producer conducts business.

What is being achieved?

First, it is not just lead-acid but all chemistries of storage batteries that are now being brought under the umbrella of toxic battery waste management controls. Second, the responsibility is extended beyond users, manufacturers, and dealers to achieve maximum collection of waste batteries.

The concept of EPR is precisely to enlarge the scope of defining the stakeholders who collectively deliver an efficient circular economy that would, by itself, minimise the environment damage potential of waste batteries going into the normal waste streams.

Incentives have been proposed to get the energy storage industry to shift up a gear. Perhaps these might be just the spurs that would lead to major breakthroughs in the overall industrial health and economics.

Ace Green plans to eradicate informal recycling

Meet the CEO: Nishchay Chadha of Ace Green Recycling tells Andrew Draper of his plans to grow the company and raise recycling standards.

Nishchay Chadha has a life steeped in internationalism, so it's little surprise that the expansion plans for his company have a strong international dimension. Born and raised in India, he moved to Singapore with his work and now divides his time between the company's two bases, Singapore, and Texas in the US.

Ace Green was set up in 2019, just before the coronavirus pandemic hit, and so did not get going with its operations right away. But Chadha already has his sights set on the emerging markets in Africa and Asia, where there is so much informal recycling, poor standards and where ignoring the rules is common. Chadha confirms the company is set to announce new facilities in Asia, Europe and the Middle East by early 2023.

It's time to change and improve standards

"People work in compliance in western markets," Chadha told *BEST*. "But we go much harder in emerging markets where people shy away… We're talking to people in Africa, where they think they don't need recycling. We want to be the player who tries to change the industry and turn it around. Not just in the developed world but also in emerging markets." True success for them would be convincing more players to do things properly, he adds. "Be a market partner for sure, but everyone is part of the solution. Not just in Europe or America, but in Asia, the Middle East and Africa too."

He says they are talking to potential partners in Africa. "Many of them don't believe it's time for Africa to do something clean. You still see people setting up with cheap equipment in countries in Africa, and you see these organisations setting up shop there. I won't name names but it's time to change and improve standards. To be honest, even if people want to do smelting, fine, no problem, but at least have the correct smelting standards and equipment. There's good quality equipment available, there's good pollution control equipment. Please use that. I'm not saying don't do it, but do it properly."

Asked how 38-year-old Chadha got into recycling, he says: "I started off as a mining engineer many, many years ago… and was in charge of buying a lot of chemicals, dump trucks and so on. There, we had some recycling programmes as well… I was 21 years old and that was my first impression of recycling. In terms of actual proper recycling, there's a company called Trafigura, which I joined as a scrap trader. That's where I got good exposure to recycling – copper, aluminium, ferrous… many different forms of scrap."

Trafigura moved him to Singapore as part of its lead and zinc business. Being involved in lead (the most recycled metal going) meant he was also involved in recycling. "I built the business for them through Singapore, and that was how I found a love for recycling and saw an opportunity."

The industry he saw was full of issues and challenges, and it was highly fragmented and had little scale, he said. "I started to realise we could create a good structure and create skills and synergies through a platform. It was also during this time that Chadha had the shock of his life when visiting a plastics recycling plant in Vietnam. The memory stays with him, despite having visited hundreds of plants over the years, many with terrible conditions.

"There were some kids in a factory and there was dog poo in the factory, and they were eating on the floor in the factory… and they were sending final waste in the drains. And I thought I'm making money in this industry, decent money as the company paid well, I've got to do something about it, this can't go on. I'm the father of two children. This is how the industry was and I thought I had to do something about it. People like us were taking things for granted."

So in 2019 Chadha took the plunge and set up Ace Green as a trading platform. He and his colleagues were all successful professionals, but he said they were driven by a vision of doing things better in the recycling industry. "Money wasn't a factor for us, or a reason to leave cushy jobs with great bonuses." He said it was the chance to bring a "very deep understanding" of the industry to a new undertaking. This included knowing all about supply chains and logistics, and having plentiful contacts, which put them in a unique position to create solutions, he says.

In 2021, Ace Green merged with Verdeen to build on the latter's expertise in zero-emissions battery recycling technology. "I came from the business. If you have the technology but have no network, there's only so much you can do," he says. The merger brought together capital, supply chains and technology.

"Right now, we're working with so many players who are in the lead industry, helping them with the transition to lithium batteries," says Chadha. "We see the businesses as complementary. We see the lead industry is continuing to grow. But it's had a lot of negative publicity."

Ace Green is working on zero-emissions technology. So instead of smelting metal at high temperatures (often over 1000°C) and using fossil-free fuels in the course of the work, the process is electrified. Costs are lower and environmental impact is reduced, says Chadha. He says they are already seeing a 98% extraction rate of metals from lithium batteries too, using this technology. The melting process in electric kettles is four hours, a fraction of what smelting requires, he says.

> "And I thought I'm making money in this industry, decent money as the company paid well, I've got to do something about it, this can't go on… People like us were taking things for granted"

Talking to solar power companies

Reliable electricity supply is an issue in certain places, but Ace Green is looking at rolling out the use of electric kettles in certain countries, as well as looking at using solar power to run its operations.

The company is working on technology to recycle EV lithium batteries. They have found a way of separating copper and aluminium from black mass and are working on introducing robotics to the battery-breaking process, which is still done by hand.

"These batteries aren't meant to be recyclable," he says, "so it's a big challenge today to open up these batteries. I don't think anybody in the world has a commercially viable solution now through robotic systems. But we're working on these systems. It's going to take some time."

In May, it announced plans for a $400,000f^2$ recycling facility in Texas, US, which will operate with emissions-free technology. It will recycle both lead-acid and lithium batteries from the automotive and other industrial sectors. It is expected to hit full capacity by 2025, processing up to 100,000 tonnes of lead-acid batteries and 20,000 tonnes of lithium-ion batteries.

Industry collaboration
Ace Green operates as a trading platform and if it is unable to handle a recycling job itself, it will sub-contract it out. Chadha says while Ace Green has its own technology and is setting up its own plants, it's quite happy to involve others. "What we do, if you're a battery player and come to us, we process things ourselves if we have a facility. If not, then we pass them to someone we know. We select the right players."

The firm is also happy to invest in its partners operations too if need be. "We're trying to help them with the technology. We see ourselves as a platform… we're open to whatever collaboration."

At present, it's a 50-50 split between recycling done in house and sub-contracted. "As our own facilities get set up, that own share will increase… but we can't be in 100 countries. We will end up being in 10-15 in the next few years." It is present in five countries now. And in Vietnam, there is also talk of modernising and electrification.

He throws out an invitation to other recyclers to come together. "I never treat anyone in the industry as a competitor… it's not like a monopolistic market. Some companies will have their own shortfalls, but we can help each other collaborate."

Partnerships in the pipeline
Asked what keeps him awake at night, Chadha says the industry is sometimes slow to change. "When they see something new and different, the speed at which they want to change is very slow and they always want someone else to take the first step before they do. I believe some have already done. I think we have managed to break that ceiling and in 3-6 months there will be announcements from us on partnerships that will help us break that glass ceiling... You just need to take the first step and change your mindset. I think people will come round. There's a huge push to electrification and sustainability."

Every day in a start-up is different. And as for switching off, Chadha says he doesn't. "I woke up at 2.30am yesterday. I woke up with an idea and started working on it. I'd slept on an idea, and I had a solution… That's start-ups, that's how our life is. There is no Plan B, this is all in. I think switching off is impossible."

Green futures
Chadha declines to reveal company financials but says it receives government support for what they are doing everywhere, including in emerging markets. He says he's hopeful about the future as awareness has grown and everyone is talking about recycling.

Programme launched to combat substandard and informal lead battery recycling

Four industry bodies representing the lead and lead battery industries have launched an initiative to help reduce substandard and informal lead battery recycling in low-to-middle income countries (LMICs).

The programme is known as LeadBattery360° and includes principles agreed among the associations in 2020. They include the International Lead Association (ILA), Battery Council International, EUROBAT and the Association of Battery Recyclers. It is designed to promote and recognise best practice in the responsible management of lead throughout the lead battery value chain – from mining through to battery manufacturing and recycling.

The quartet said lead batteries operate in a closed loop in Europe and the US, with up to 99% of spent batteries being collected and recycled. But in some poor countries, there is a flourishing industry in informal recycling, where ignoring the regulations is the norm.

Programme director Dr Steve Binks of the ILA said: "We all want to see an end to informal and substandard battery recycling and manufacturing where it exists, and this initiative aims to help countries where this is a problem improve through practical support and sharing best practice."

As worldwide demand continues to grow, the initiative will promote ethically sound battery recycling and manufacturing with these principles:

- Environmental health and safety excellence
- Continuous improvement targets
- Adoption of responsible sourcing policies
- Minimising environmental impact
- Promotion of human and labour rights, work against corruption
- Transparently engaging key stakeholders.

US charity Pure Earth of New York estimates that "hundreds of millions" of children are being poisoned every day by lead. They ingest and inhale dust from informal used lead-acid battery recycling operations, eating lead-infused spices and food contaminated by pottery with leaded glazes. They may live in homes with peeling lead paint or work alongside their parents to salvage lead and other heavy metals from e-waste.

Pure Earth calculates, from an economic standpoint, childhood lead exposure and the resultant intelligence degradation costs LMICs in Africa, Asia, and the Latin Americas and Caribbean to be almost $977 billion in annual GDP losses ($1.1 trillion in 2020).

It estimates that there may be over 12 million substandard or informal used lead-acid battery recyclers who are poisoning themselves, their children and their communities.

27 November - 1 December

SIPS 2022

Phuket, Thailand

SIPS 2022 is a yearly event that is deeply science-focused and technology & engineering-oriented dedicated to achieving sustainability through science and technology. It incorporates summit plenary lectures from well-known speakers that address the link between scientific, technology and engineering domains in the pursuit of sustainable development, as well as specific science, technology and engineering symposia that feature technical presentations with the same goals in mind.

Info: www.flogen.org/sips2022/

5 - 6 December

International Conference on Lead & Lead Batteries – Energy Storage, E-mobility & Environment

New Delhi

Organised in association with ILA, ILZSG, CBI, IBMA & REIAI. Morning of 5 December 2022 will be devoted to innovations in lead batteries, to be conducted by CBI. Thereafter there will be keynote addresses followed by technical presentations on lead battery manufacture, energy storage, electric mobility & recycling of used lead batteries. Presentations will be made by several overseas & Indian experts.

Info: www.ilzda.com/

7 - 9 December 2022

ees India

Gujarat, India

With three parallel energy exhibitions, The smarter E India is India's innovation hub for the new energy world. It presents cross-sector energy solutions and technologies and reflects the interaction of the solar, energy storage and electric mobility industry. The smarter E India addresses all the key areas along the value chain and brings together local experts and international stakeholders in the energy future. The smarter E India brings together the renowned Intersolar India, ees India and Power2Drive India.

Info: www.thesmartere.in/en/ees-india

15 - 17 March

Interbattery 2023

Seoul, Korea

Launched in 2013 InterBattery is Korea's leading battery exhibition showcasing new products and technologies related to the battery industry. InterBattery is the largest rechargeable battery exhibition in Korea. With an expanded area, 500 companies and 50,000 buyers are scheduled to visit. The InterBattery Networking Day and the Battery Conference presents the battery industry with opportunities to meet colleagues working in the rechargeable battery industry.

Info: https://interbattery.or.kr/en/about-2/show-overview/

30 November - 1 December

Global Lithium & EV Battery Raw Material Supply Chain Congress

Live in Detroit and online

The OEM-led congress, will explore ideas for reinventing the lithium and rare metals supply chain and encouraging OEM collaboration with mining, extraction, investment, and battery technology/chemical firms. OEMs, the end-users of lithium and rare metals, will map out and define their requirements at this conference in collaboration with the battery material supply chain.

Info: www.lithium-battery-raw-material-supply-chain.com/

5 - 8 December

AABC

San Diego, US

ABC was founded more than twenty years ago to review the status of automotive battery technology and provide informed glimpses into the future. This year the program will uncover the underlying technical and business issues that will impact the pace and path of vehicle electrification worldwide. The event is an opportunity to network with chief battery technologists from leading automotive OEMs, who will share their development trends and projected battery needs, as well as their key suppliers who will present their latest offerings and roadmaps for the future.

Info: www.advancedautobat.com/us

15 - 17 March 2023

Battery Japan

Tokyo Big Sight, Japan

Battery technologies are the key to achieving carbon neutrality by 2050 as they will largely contribute to the popularisation of renewable energy and EVs. BATTERY JAPAN gathers a broad range of technologies, components, materials, and devices for rechargeable batteries development & production. The show attracts professionals from all over the world.

Info: www.wsew.jp/hub/en-gb/about/bj.html

20 - 23 March

International battery seminar & exhibit

Orlando, Florida, USA

The longest running annual battery event will continue leading the charge in battery technology. 1,500 battery technologists from key OEMs, leading cell manufacturers, and the entire advanced battery ecosystem participated in Florida and online in March. This was the largest International Battery Seminar ever! Expect more of the same in 2023

Info: www.internationalbatteryseminar.com/

10 - 11 May

World Energy Storage Exhibition & Forum

Rotterdam Ahoy, Netherlands

As we work towards a decarbonised world, energy supply will be primarily sourced from renewable power sources such as wind, solar, hydro, thermal, creating an unprecedented need for huge energy storage capacity, innovation and technology enabling the world to shift to a new energy reality. The energy crisis and the war in Ukraine have highlighting the urgent need for countries to be less dependent on the spot trade of energy and increase their resilience through energy storage capacity.

Info: https://www.world-energy-storage.com/

23 - 25 May

The Battery Show Europe

Stuttgart, Germany

Meet manufacturers, suppliers, engineers, thought leaders and decision-makers for a conference and trade fair focused on the latest developments in the advanced battery and automotive industries. Explore the latest products and solutions at the largest trade fair in Europe. The only place to find all your supply chain contacts in one place — from raw materials to recycling.

Info: www.thebatteryshow.eu/en/home.html

19 - 22 June

AABC Europe

Mainz, Germany

As more European nations and international automotive OEMs invest in their commitment to vehicle electrification and eMobility, the 2022 AABC Europe event in Mainz propels that momentum forward, presenting unparalleled coverage of the research and development that helps drive outcomes and supports the next generation of electric vehicle batteries.Take part in this event and explore development trends and breakthrough technologies shaping the future of vehicle electrification.

Info: www.advancedautobat.com/europe/

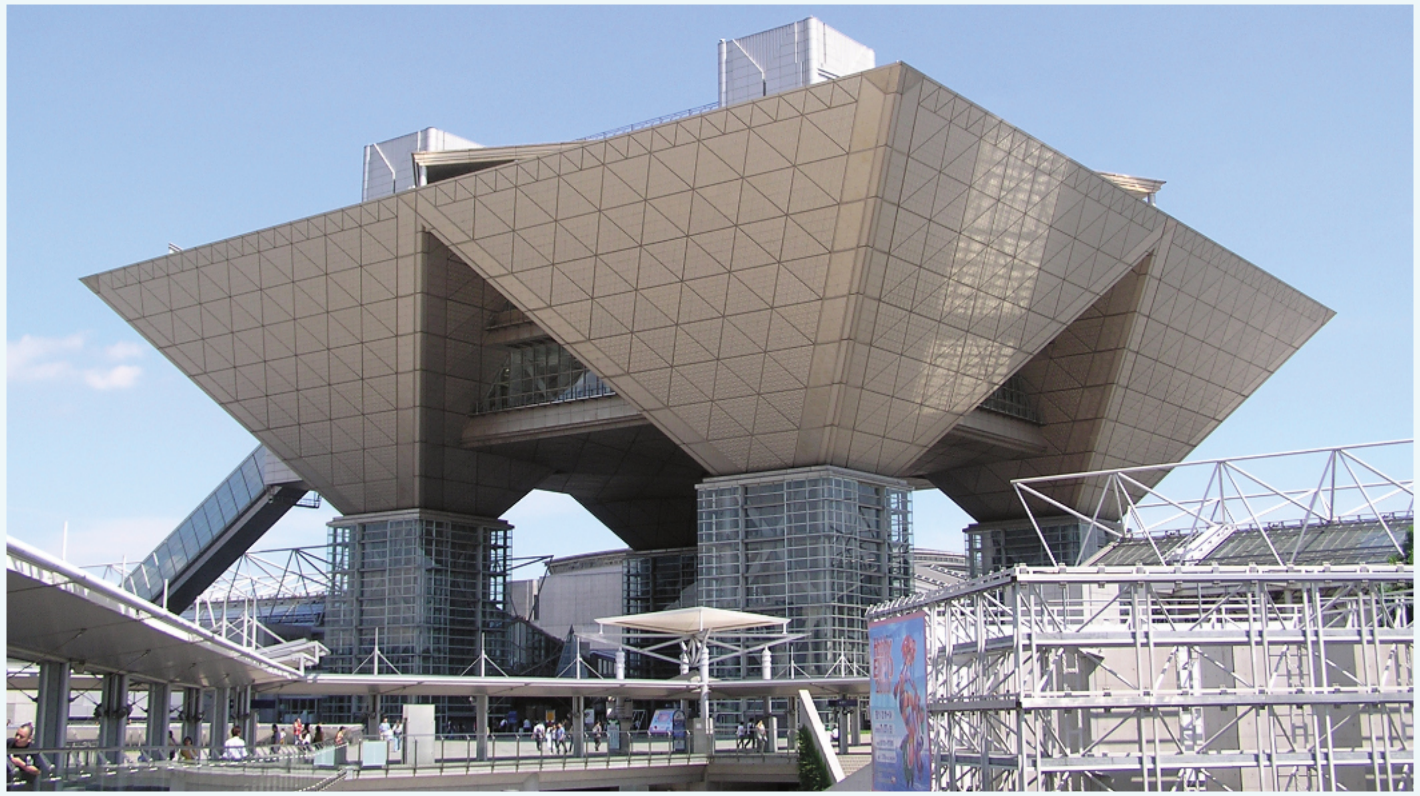
28 - 29 June

Battery Cells & Systems Expo

Birmingham, UK

Battery Cells & Systems Expo will bring together automotive manufacturers, electric utilities, battery system integrators, cell manufacturers and the entire manufacturing supply chain. A truly unique showcase, companies from around the world will use the show to launch products and demonstrate their technology to an audience of over 4,500 professionals. Featuring a global list of exhibitors and speakers, the entire world of battery manufacturing and integration will gather in the heart of UK manufacturing, Birmingham.

Info: https://batterysystemsexpo.com/



If your desire is for unusual shaped buildings Tokyo's Big Sight is one of the most iconic with its glass and titanium-panelled Conference Tower

Company	E-mail	Website	Page
Abertax Technologies Ltd	info@abertax.com	abertax.com	111
Accumalux SA	sales@accumalux.com	accumalux.com	86
Accurate Products ApS	mhc@accurate.dk	accurate.dk	138
Advanced Battery Concepts LLC	rrenaud@advancedbatteryconcepts.com	advancedbatteryconcepts.com	103
Batek Makina Sanayi ve Ticaret A.S.	info@batekeng.com	batekeng.com	124
Batterie Fullungs Systeme GmbH (BFS)	info@bfsgmbh.de	batteryfillingsystems.com	117
Bernard Dumas SA	bdumas@bernard-dumas.fr	bernard-dumas.fr	23
Biasin SRL	g.gallo@biasinplast.com	biasinplast.com	80
CAM Srl	cam@cam-srl.com	cam-srl.com	64
Dalton Electric Heating Co.	sales@daltonelectric.com	daltonelectric.com	20
Daramic LLC	troe@daramic.com	daramic.com	IFC/3
Dross Engineering SA	info@dross-engineering.com	dross-engineering.com	123
Eagle Oxide Services	eaglesales@eagleoxide.com	eagleoxide.com	26
Ferrazza S R L UNIP	info@ferrazzanet.com	ferrazzanet.com	24
Froetek	info@froetek.de	froetek.de	107
GEA Group	Laura.Vazquez@gea.com	gea.com	21
Hammond Group, Inc.	info@hmndgroup.com	hmndgroup.com	39
Inbatec GmbH	info@inbatec.de	inbatec.de	56/57
JBI Corporation	joe@jbicorp.com	jbicorp.com	116
Jinkeli Power Sources Technology Co.	jkl@jinkeli.com	jinkeli.com	91
La Pneumatica SRL	info@lapneumatica.com	lapneumatica.com	106
MAC Engineering and Equipment Co.	maceng@mac-eng.com	mac-eng.com	BC
Maccor Inc	sales@maccor.com	maccor.com	50
Microporous	sales@microporous.net	microporous.net	IBC
Penox Group GmbH	engineering@penox.de	penoxgroup.com	16
Pinco SA	info@pinco-sa.com	pinco-sa.com	79
Ross Mixers	mail@mixers.com	mixers.com	17
Sasha's International Inc.	sashas@sashas.net	sashas.net	24
Sorfin Yoshimura Ltd	sorfin@sorfin.com	sorfinyoshimura.com	4
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UK Powertech Ltd	sales@ukpowertech.com	ukpowertech.com	40/41
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Zinc batteries: powered up for the energy transition

Dr. Josef Daniel-Ivad, manager of the Zinc Battery Initiative puts the case for zinc as part of the Energy Transition. Reasons include the secure and stable zinc supply in addition to the sustainability, recyclability and long duration of zinc.

The energy transition is underway and rechargeable, renewable zinc batteries are poised to provide a greener, cleaner alternative in energy storage. The need for more energy storage options is clear: The newly released BloombergNEF's 2022 Energy Storage Market Outlook forecasts that energy storage capacity will reach 411GW by 2030, 15 times the storage available last year with a cumulative capacity of 1,194GWh installed. Competitive, scalable, and sustainable batteries of all types are needed to meet the high demand for energy storage. Zinc batteries are ready to provide stationary storage and are on the threshold of developing e-mobility applications, all thanks to zinc's abundance, secure and stable supply, recyclability, and competitive advantages.

Zinc is naturally plentiful around the world, with an estimated 63,000 million tonnes of zinc in the earth's crust available for extraction. Moreover, zinc has strong supply chains in all major regions, with high production in North America, Europe, and Asia. Given this abundance and supply, zinc can ease the untenable demands placed on lithium, which is limited in supply and sourced largely from China. Given the energy transition's growing demand for energy storage, alternatives to lithium, including abundant and secure zinc, must be a part of the equation.

Beyond zinc's abundance and secure supply chain, most zinc batteries recycle well, and the zinc can be repurposed for batteries or other zinc products. According to a global stock and flow analysis by the International Zinc Association (IZA) and the Fraunhofer ISI Institute of 2022, zinc recycling has doubled while zinc mining remained constant and the end-of-life recycling rate for zinc has reached 34%. This zinc can be recovered without deteriorating and 39% of zinc going into use came from recycled sources in 2019. Zinc's recycling and reuse rates are expected to increase as recycling techniques improve and more policies encouraging recycling are implemented.

Zinc is a natural contributor in the clean energy space, as zinc is non-toxic and a truly clean element. In addition, zinc batteries are non-flammable. And unlike lithium-ion batteries, they do not run the risk of thermal runaway or off gassing, so there is no need to invest in thermal management or fire suppression systems.

Non-flammable zinc batteries are a popular choice for powering military jets and submarines. The US Navy has been a leader in promoting nickel-zinc batteries as the "clear frontrunner" to power the next generation of submarines. It has partnered with US-based ZAF Energy, developer of nickel-zinc batteries, to develop its technology to meet the most exacting standards. ZincFive, another US-based developer of nickel-zinc batteries, is focusing on mission-critical data centre deployments where immediate high power is essential. Hybridising different chemistries, such as nickel-zinc for immediate power and zinc-air, zinc-bromine, or other technologies for long duration energy storage, is another new approach to maximise the benefits of deployment.

Safe, sustainable zinc batteries also outperform competitors, providing a long cycle life, high specific energy, and maintenance-free operations. The average life of zinc batteries is nearly 20 years, more than 25% higher than lithium-ion batteries under the same conditions. This longer life lowers overall cost through reduced maintenance, replacement costs and more reliable performance. Zinc batteries do not sulfate or contain hazardous materials, so they do not require continuous monitoring for cell balance and safety while charging. Additionally, zinc batteries operate within a wide temperature range (-30C to 75C), significantly better than most other battery chemistries.

The energy transition, as well as the incentivising policies and funding surrounding it, are accelerating the development and manufacture of numerous zinc battery technologies. California company EnZinc, which has created a novel 3D zinc micro-sponge electrode, has expedited its battery development thanks to a $1.8 million award from the California Energy Commission to build a pilot anode manufacturing line. Once completed, EnZinc will build batteries for stationary storage in homes and commercial buildings as well as mobility applications including e-bikes, e-scooters and e-delivery vehicles.

In lieu of state or federal funding, developers of promising zinc batteries often partner with complementary companies. This summer, Canadian Salient Energy, developer of zinc-ion batteries, announced its partnership with sustainable homebuilder Horton World Solutions. It will qualify and install Salient's system in more than 200,000 homes. Alternatively, New York-based Urban Electric Power, developer of zinc-manganese batteries, is working with Pine Gate Renewables to supply 4,550MW of power for a number of solar-coupled and stand-alone energy storage projects. The partnership enables Pine Gate's large customer base to access Urban Electric Power's batteries for five years under preferential terms.

The most recent incentives are provided by clean energy policies, such as the European Union's REPowerEU plan, which sets clean energy targets to reduce reliance on Russian gas; and the US Inflation Reduction Act (IRA); an unprecedented legislation providing nearly $370 billion in federal funding for cleantech. Canada's Zinc8, developer of zinc-air-flow technology, is the first zinc battery developer to take advantage of this landmark legislation.

IRA's manufacturing production credits prompted Zinc8 to select Hudson Valley, New York, as the site of its first manufacturing plant. It will produce scalable zinc batteries with residential, commercial, and industrial applications.

Even without the benefit of a supporting partner or policy, zinc battery developers are fast-tracking their progress through increasing access

Let's hear from you

Got an opinion on the above or anything else? Then share it. We welcome views from all sectors of the battery industry— whatever the chemistry.

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to financing opportunities. Canadian e-Zinc, developer of a zinc-air battery, recently closed a $7 million venture debt facility with Silicon Valley Bank. The financing enables e-Zinc to expand and expedite commercialisation of its new Ontario facility and advance its work with Toyota Tsusho Canada and the California Energy Commission.

Whether through partnerships, policy incentives or more accessible financing, zinc battery developers are leveraging their many assets to accelerate their role in the clean energy transition.

Zinc's performance, coupled with its secure supply, safety and sustainability empowers this promising technology to meet the very large demands of the energy transition.

The Zinc Battery Initiative (ZBI) is the voice of the zinc battery industry and a programme of the International Zinc Association. ZBI was formed in 2020 to promote the story of rechargeable zinc batteries and encourage further adoption of these products. Its members are the leading companies in the industry.