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POWERING THE SMART GRID

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The case for the defence

A reprieve for lead in ESS is needed

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Lead, not guilty as charged… the case for the accused

For the last five years energy storage systems have increasingly turned to lithium ion batteries as their chemistry of choice. The logic hasn't been perfect — but the hype around the subject has! But given rapid and massive improvements in lead battery technology perhaps it's time to re-evaluate what should go where.

It's been one of the most abrupt turnarounds in the history of science. The lead battery — workhorse of the modern world for more than a century — has become the least favoured battery for the new and rapidly expanding world of energy storage systems.

According to recent US Department of Energy figures lead acid batteries were used in just over 2% of new large scale energy storage deployments in the past year. A couple of years ago that figure stood at around 10%.

Quite why this has happened is puzzling given that lead batteries continue to be the chemistry of choice for heavy duty energy storage such as large scale battery deployments in UPS and telecoms applications.

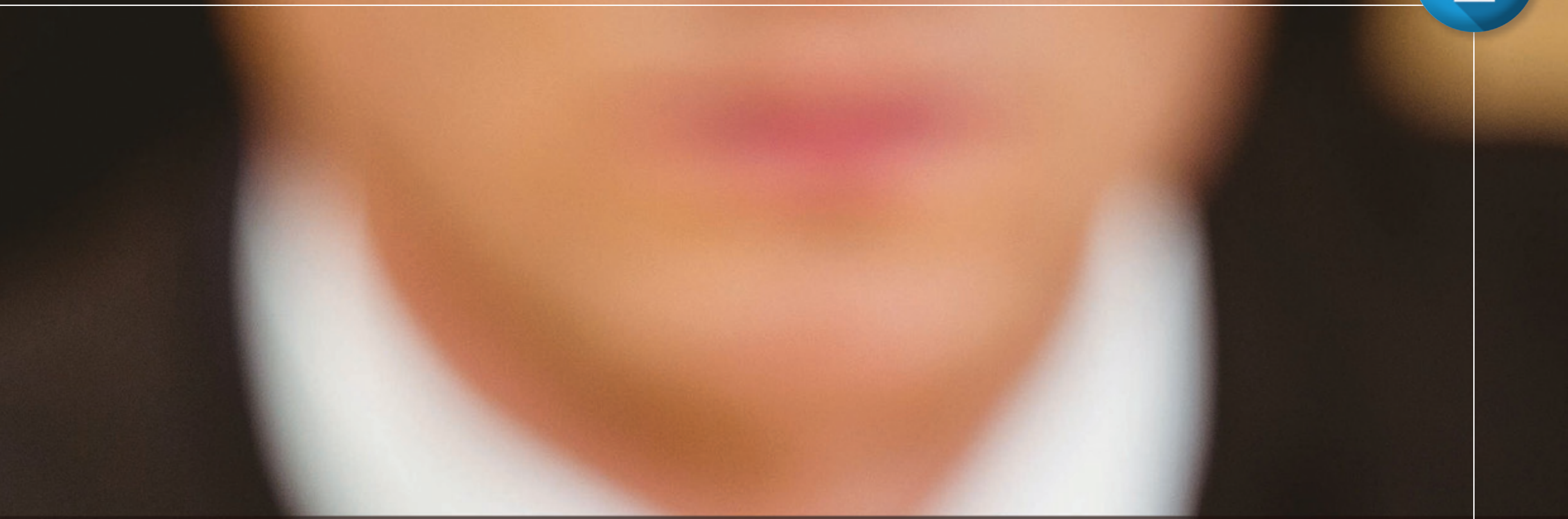
There is no denying, however, that lithium ion batteries have many advantages over lead acid batteries. Their energy density is higher, they have superior performance in fast recycling. In particular, they are better suited in coping with some of the more sophisticated grid management functions — such as load levelling, frequency regulation and the like.

These functions are nowadays more important than ever as utilities need to balance a grid that has to deal with the intermittency of renewables and the more subtle needs of the smarter grid.

But what they gain in one direction they lose in another.

"There's a kind of blindness that's overtaken our industry in the past couple of years," says one systems integrator. "In that lead batteries can be used for the heavy lifting — cheap bulk energy storage is where it excels — while the higher grid functions can be dealt with using lithium.

Cost savings: bipolar firm ABC says its batteries can reach three times the cycle life but with half the lead content.



"Also some of the advanced lead batteries that are entering the market nowadays can compete with lithium for many of these higher grid functions.

"The idea of hybrid systems — mixing everything from flywheels and supercaps with lithium has been around for a long time. But lead batteries have stopped being a contender. I don't really know why. It's as if the whole industry has upped sticks and said any chemistry but lead."

This is perhaps the oddest phenomenon of all. Lead stands head and shoulders above every other chemistry in being the most affordable at around $150/kWh. And, though lithium has made inroads in moving towards this figure, it still requires a leap of faith that it can prove as cost-effective within the next decade.

But any realistic defence of lead needs to be judged on hard facts. And that is whether proven data from existing products can match up to large scale ESS requirements.

Bipolar — success at last

On paper, bipolar offers a new way of constructing a lead-acid battery, one that has the potential to make batteries cheaper to manufacture, and more importantly deliver better performance than traditional lead-acid batteries or even lithium batteries in some applications.

The key to realizing the technology's potential lies in the biplate, specifically making it non-corrosive, lightweight, conductive and cheap. Several companies have tried to make a viable, marketable biplate, but so far the difficulty has always been taking the concept through to commercialization.

But that is no longer the case. Two firms stand out at the moment — Advanced Battery Concepts (ABC), which has now a commercial line in operation, and Gridtential, which is close to commercialization of its product.

Both firms have attracted investment from major lead battery firms in the US and abroad and the first mass-produced bi-polar batteries could be rolling off the factory production lines soon.

So why are big companies looking at bipolar? There are two reasons why the technology is important, says Ray Kubis, an industry veteran who, two years ago, became a director and latterly chairman of Gridtential.

The first is the market demand for higher voltage products with unique capabilities.

"Either it's going to be lithium-ion or the deployment of bi-polar, because they are the only types of solutions that can offer the opportunity to scale up to higher voltage," he says.

The existing infrastructure of leadacid batteries is adaptable and well done at the 12V level. However, when non-bipolar (or monopolar) batteries are scaled up it is hard to reach the higher voltage demanded by new applications such as 48V systems for micro and mild-hybrid cars.

Bipolar offers a viable, theoretical way for companies to achieve those demands.

Gridtential has a sheet of silicon that replaces the traditional metal grid in current lead acid battery designs with a silicon substrate.

In January last year Gridtential raised $6 million from Crown Battery, Leoch, Power-Sonic and East Penn. These firms are conducting trials of inserting the new technology into their existing lines.

Elsewhere, ABC is using a lead sheet that has an "excellent technological chance of being successful", says one consultant. "Its conductivity is good and I've seen results from ABC, and some of those are very good. The issue there, however, is durability under corrosion, but technically their results are very good."

The key area where bipolar has the potential to trump legacy lead acid batteries is in the architecture of the

"if you can reconfigure existing factories and the bipolar product coming out of that factory can compete with lithium-ion, and at only 5%-10% of the capital outlay you would otherwise spend, then to me it makes sense to rapidly develop the alternative bipolar."

battery. In a typical prismatic design, a grid is connected to the cast-on strap at the lug. This means the active material for a standard grid is being worked non-uniformly during cycling because the current flow is high near the lug, and low away from the lug.

In a bipolar design, the current flow is extremely uniform across the active material. "As a result," says Ed Shaffer, CEO and co-founder of ABC, "you have higher utilization of the active material or more energy.

"Additionally, the design is very suitable for thin layers so higher power can be achieved as well with much better charge acceptance."

The simplified construction and uniform current flow also results in higher cycle life, up to three times, ABC says, "as long as you can maintain the edge seal".

Interest in ABC has mounted this year. In January the company signed a non-exclusive agreement with Johnson Controls. In April this was extended as Hal Hawk, the president and owner of Crown Battery, took a stake in the firm. Hawk, a former head of BCI who has spent a lifetime in the lead battery industry, is a widely respected figure. His investment is seen by many in the lead industry as a more powerful endorsement than that of Johnson Controls.

> "Either it's going to be lithium-ion or the deployment of bi-polar, because they are the only types of solutions that can offer the opportunity to scale up to higher voltages"

In April, ABC announced it had chosen Wirtz Manufacturing to install production-scale paste lines for its prototype production facility. "This equipment will allow us to demonstrate run at rate throughput and assist our licensees in their adoption of our GreenSeal bipolar technology," Shaffer said at the time.

John Wirtz — who has also spent a lifetime working and designing battery manufacturing equipment — said: "ABC has been able to demonstrate precision pasting of bipolar electrodes repeatedly and successfully. Theirs is easily scalable, innovative, and simple. We look forward to the broad adoption by licensees of their bipolar lead battery technology."

In another endorsement, Bob Galyen, chief technology officer of China's CATL (and the largest lithium cell producer in the world), became chairman in May of a technology advisory board set up by the company to help its development.

Galyen, who is also the current president of NAATBatt, has a long history in the automotive battery sector and worked on the original General Motors EV1 project in the 1990s. He knows both lead and lithium well.

In May, the Trojan Battery Company became the third battery manufacturer to take a licence in ABC's technology. The participation of Trojan is particularly interesting in that its speciality has always been deep cycle batteries. Many in the lithium sector are unaware that Trojan, for example, offers a lead battery with a guaranteed 17 year life.

It is also no secret that it sees its

BIPOLAR IN BRIEF

For years most batteries have been made with conventional monopolar technology that uses two plates per cell and then connects those cells in a series of metallic connectors outside the cells or through a wall. (Figure 1) This design results in ohmic losses within the plates, leading to unsymmetrical distribution of the current density during operation. Furthermore, these grid and cell connectors increase the total weight of the battery.

While bipolar and monopolar designs share the same lead acid chemistry, they differ in that in bipolar batteries, the cells are stacked in a sandwich construction so that the negative plate of one cell becomes the positive plate of the next cell. The cells are separated from each other by the bipolar plate, which allows each cell to operate in isolation from its neighbour.

Stacking these cells next to one another (Figure 2) allows the potential of the battery to be built up in two-volt increments.

Since the cell wall becomes the connection element between cells, bipolar plates have a shorter current path and a larger surface area compared with connections in conventional cells. This construction reduces the power loss that is normally caused by the internal resistance of the cells.

At each end of the stack, single plates act as the final anode and cathode. This simpler construction leads to reduced weight since there are fewer plates and bus bars are not needed to join cells together. The net result is a battery design with higher power than conventional monopolar lead acid batteries.

Until recently, the main problem limiting the commercialization of bipolar lead acid batteries was the availability of a lightweight, inexpensive and corrosion resistant material for the bipolar plate, and the technology to properly seal each cell against electrolyte leakage.

Source: Advanced Lead Acid Battery Consortium

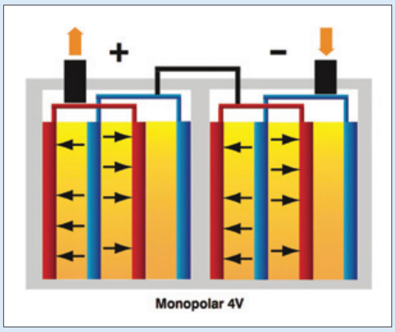


Figure 1

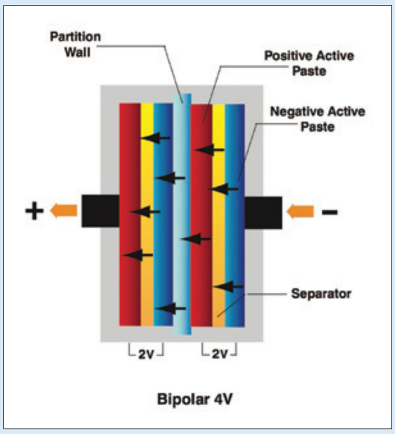


Figure 2

future — as its CEO Jeff Elder once told *Energy Storage Journal* — as an energy solutions company rather than just as a battery manufacturer.

From ABC's perspective, the true benefit of its technology will be in the 20%-30% lower production costs based mostly on bill of materials reduction. "That is huge," says Shaffer.

Data from ABC shows that using its technology, a battery can reach three times the cycle life but with half the lead. "That means that every pound of lead mined can be used six times longer… or put another way there is six times less lead needed for the same amount of energy. That is fantastic," says Shaffer.

Kubis believes that Gridtential's bipolar construction helps improve active material utilization to breakthrough levels, while improving charge acceptance and life at Partial State-of Charge.

Looking beyond regular lead

The kind of performance changes demanded by users — especially if lead battery manufacturers can offer utilities and power companies the huge storage and energy management capabilities that they are purchasing from lithium suppliers — is why it's important that companies improve their paste recipes and concurrently implement fundamental architecture changes, such as the bipolar architecture.

This could yield advanced lead-based batteries with overall performance of three to four times that of legacy lead acid batteries. Our existing batteries are simply not good enough against the performance required by today's demanding and growing range of applications, says Kubis.

In many applications, where there is a need for very high power, such as in backup power for cloud computing or for frequency regulation for grid-scale services, bipolar batteries will work, says Kubis. However, with consumer electronics — or long duration, say four to eight hours where there's a need for a steady energy release across a few hours and not high power — it is harder for advanced lead batteries to compete.

But Kubis believes advanced bipolar batteries can compete across high power or mixed power/medium energy applications.

Having better PSoC means the battery is a potential game changer in 48V systems. At the energy storage

side of the market, Geoffrey May, principal of FOCUS Consulting, says bipolar's future will probably lie in its ability to be used in domestic or small commercial installations.

"At that end you'll probably see systems with 48V modules bringing it up to a reasonable capacity because of the need for systems at domestic level to be a few kWh to start being viable," he says.

"Both 48V and energy storage systems are possible applications. If you look at ABC and the stage where they have got to — with data in the public domain — you can look at reasonable cell production within a few years." May says he cannot make a judgment of Electriplast or Gridtential because they have yet to go public with their results.

The other factor is energy density, at around 38Wh/kg for legacy lead acid and the potential for bi-polar to reach 50Wh/kg-63Wh/kg. Theoretically the technology could double from these claimed levels today. Companies such as Gridtential know bipolar is going to beat traditional lead acid for energy density, but they have yet to validate that.

"There's talk about the very high theoretical capacity of advanced lead," says Kubis. "Yet we believe we can realistically reach much higher than 50Wh/kg."

And he thinks the timescale to achieving this target will be much smaller than five to 10 years because of the progress that his company's partners have made.

"We expect there will be products in the field from our manufacturing partners and investors by the end of this year and developing further in the next year."

A lot of alternative battery systems

"Both 48V and energy storage systems are possible applications. If you look at ABC and the stage where they have got to — with data in the public domain — you can look at reasonable cell production within a few years." — Geoffrey May, principal of FOCUS Consulting

use unique new materials that come from small-scale industry but Kubis says Gridtential's solution is integrating treated silicon wafers that comes from the high volume, low cost solar industry.

And at higher volumes, they can see the cost of silicon they use dropping as low as lead at $1 per pound, while enabling the much higher performance concurrently with at least a third less weight.

"In addition, to adapt Gridtential's technology, you also don't have to spend billions of dollars on a gigafactory, you only need to adapt the assembly process, and integrate a silicon biplate supply chain to change the factories from being able to manufacture traditional lead acid batteries to bipolar. You can continue with your existing oxide manufacture, curing and charging infrastructure," says Kubis.

"Some claim lithium ion is a better investment at scale, yet you just need to look at the recalls within the industry along with the scale of new factory investments. If you invest $5 billion in a battery factory then have periodic recalls such as we've seen with cellphones, laptops, or with Boeing, what's the return on investment then?

"If you can reconfigure existing factories and the bipolar product coming out of that factory can compete with lithium ion, and at only 5%-10% of the capital outlay you would otherwise spend, then to me it makes sense to rapidly develop the alternative bipolar."

Kubis says existing battery manufacturers are under threat. "The lithium ion industry is coming out of China, Korea and Japan. If this trend were to continue then European, US

From Advanced Battery Concept's perspective, the true benefit of its GreenSeal technology will be in the 20%-30% lower production costs based mostly on the reduction in the bill of materials. That is huge" — Ed Shaffer, CEO and co-founder of ABC

and Indian battery makers will be reduced to being assemblers of cells."

"So bipolar offers the opportunity for the non-Asian battery industry to not become obsolete, and bipolar is a way to add value to your region and continue to offer a strong supply chain."

Paste glorious paste

One of the critical phases in the development of a good lead acid battery is adding the lead paste to the grid. How it attaches — with the use of a so-called 'expander' — and the way crystal structures that develop form make a huge difference in battery performance.

In the past four years Hammond Group has made extraordinary progress in the development of expanders. It now has a range of 120 customizable expanders under a generic brand called SureCure.

"The nub of the problem between lead and lithium is mostly a question of price and recyclability," says Terry Murphy, chief executive of Hammond, who has refocused the firm to concentrate on the battery sector.

"For advanced energy storage lithium ion batteries meet most of the technical requirements, but are too expensive. By contrast lead acid batteries are inexpensive and 100% recyclable, but don't have the necessary cycle life. The challenge has been to extend that life."

"SureCure expanders provide lead acid batteries with dramatically improved dynamic charge acceptance while our lab, which is open to the industry, is dedicated to all of our technical development. Its goal is to enable lead acid batteries to achieve 80% of lithium ion's technical performance. But at just 20% of its cost," says the firm.

Dynamic charge acceptance — the way batteries can accept and rapidly store large influxes of energy — is the next big thing for the lead acid business. It opens up two worlds — that of microhybrids in the automotive sector and the huge new areas of business opening up with grid scale storage.

In laboratory testing and now in production batteries, Hammond has achieved an order-of-magnitude increase in dynamic charge acceptance while simultaneously increasing cycle life show relative comparisons to our control samples.

The innovation does not require a change in other battery paste ingredients, grids, or plates. No change in any other material component or process. No new tooling, production technique, distribution, use, scrap characterization, or recycling. SureCure represents a new expander family, with no safety concerns or known adverse effect

Moreover, SureCure is customizable according to the needs of the batteries being made and the operating conditions that they will run in.

Perhaps one of the most interesting facets of Hammond's new expander range is the fact that, for example, the extended cycle life that can be added to a battery can be multiplied when paired with say a bipolar battery.

Enter the UltraBattery

The UltraBattery is a hybrid, long-life lead-acid energy storage device. It combines the fast charging rates of an ultracapacitor technology with the energy storage potential of a lead acid battery technology in a hybrid device with a single common electrolyte.

Combining these two technologies in one cell means that UltraBattery works efficiently in a Partial State of Charge (PSoC).

Compared with conventional VRLA batteries, UltraBattery provides more energy and costs less over its lifetime when used in variable power applications. The technology is more efficient, and is equally as

HOW INEVITABLE ARE FURTHER ADVANCES OF TECHNOLOGY?

A lesson from history. Perhaps.

In 1965 legendary Boeing designer Joe Sutter set up a special team to develop a new airplane — "we're calling it a jumbo jet," he said. "The hump in the middle will convert it into a cargo plane. Technology is racing so fast that by the 1970s they'll soon be obsolescent for passengers. Supersonic airlines are the future."

Half a century on, The 747 remains the workhorse of the skies. Technology marched on. But not at the pace that the 1960s and 1970s visionaries or designers thought would be the future of aviation.

"The trouble with large sectors of the energy storage business is they believe that something approaching Moore's law — where computer processing power was predicted to double every two years — applies to our industry," says one commentator.

"Basically that means the challenges of today will be mastered by the technologies of the future. Unfortunately that's not necessarily true. There are physical limitations to what can or can't be done. And battery chemistry in terms of energy density, say, is one of them."

Recycling of spent lithium batteries is one such example.

The difficulty here is a simple one — recycling is perfectly feasible but is the technology ever going to be in place to do this in a commercially attractive way?

Moreover, at a certain point limitations will necessarily arrive — a Carnegie Mellon report pointed out just two years ago, economies of scale in lithium battery production are fast approaching their end point.

safe and recyclable, as conventional lead batteries.

Although this technology has been found in the advanced lead acid battery world has been around for the past five years, it is only now becoming commercially more available. Two firms make the battery — Ecoult, a subsidiary of East Penn Manufacturing, and Furukuwa Battery.

This May, Ecoult signed an agreement with Exide Industries, one of the top two battery firms in India, which is now going to manufacture them. Market expectations are that they will change the face of the energy storage market in the country.

UltraBattery technology is already successfully deployed in automotive and stationary energy applications. *(In the conference in print section following these pages in this magazine, full details of one such grid management scheme are given.)*

An Ecoult spokesperson said: "UltraBattery technology is well suited to a large number of industry sectors including: grid/microgrid support, including frequency regulation, power quality, spinning reserve, energy shifting and demand management and smoothing and ramp-rate control (particularly for renewables); micro and medium HEVs; dual-use for data centres and buildings; diesel efficiencies; residential energy management; and other transportation (particularly railways).

"We are very excited about the possibilities for dual-use applications. These exploit UltraBattery's ability to provide grid and UPS support in a single installation (ie selling grid support services while the grid is available, but switching to UPS for any grid-outage event).

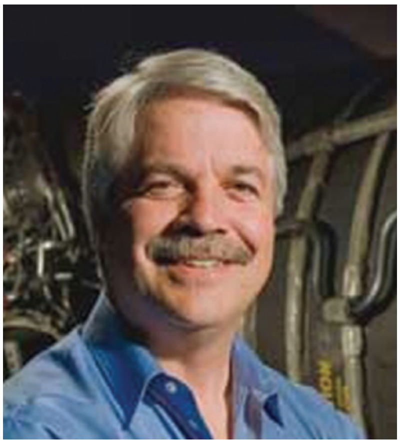
"The cost for such applications suggests that businesses such as data centres could gain an attractive return on their battery investment."

Other improvements

There are at least three other mainstream directions that the lead market is moving in to earn the title of being considered as an advanced lead battery and a cheaper rival to lithium as an industry standard.

Carbon additives Pioneering research carried out through the use of carbon additives in negative lead battery electrodes started well over a decade ago but a whole new generation of products is just emerging.

The latest studies from ABC suggest that the combination of a bipolar battery and carbon additives is an immensely powerful combination.



"Our goal is to enable lead acid batteries to achieve 80% of lithium-ion's technical performance. But at just 20% of its cost. I believe it's a target that's already in our sights" — Terry Murphy, chief executive of Hammond Group

Carbon additives as such don't change the basic electrochemistry of the battery but they do increase specific power and reduce sulfation, the principal cause of lead battery failure.

A good example of a new additive comes from Heraeus Battery Technology which launched its Porocarb carbon powders in September. These increase charge acceptance by up to 20% and life cycle by 100%.

"Porocarb is a product family of synthetic porous carbon powders tailored specifically for demanding electrochemical applications in which the needs for a designed porosity intersect good kinetic accessibility," says the firm, which claims its product is the first conductive additive that ensures electronic connectivity within the electrode and enhances ionic conductivity.

"Even at the highest levels of electrode compression and loading, Porocarb ascertains open pathways within the electrode that help with electrolyte supply and distribution during filling and operation. It enables advanced electrochemical systems that were previously not achievable using standard carbon conductive additives."

Developed in 2014, the additives have been tested with actual customer pilots, says the firm, and have demonstrated increased charge acceptance of up to 120%; faster recharging rates; increased cycle life of up to 100%, and nearly 50% greater capacity at deep-discharge operations for longer power supply.

Separators A new generation of separators is emerging — the largest players at the moment are ENTEK and Daramic, both of which have developed separators that allow lead batteries to be customized for use in varying climates and locations.

Most importantly, however, this customization means that step changes in terms of greater cycle life are being achieved.

TPPL Two lead battery firms in particular, EnerSys and Northstar ,have been pushing this technology further. Thin Plate Pure Lead batteries have a higher energy density, fast charging capabilities and eliminate topping up of the batteries. TPPL essentially is a simple idea though complicated to achieve.

TPPL batteries have a manufacturing process to create thin plate pure lead (99.99%) grids that measure 1mm compared with the conventional 2mm-4mm plates. Using thin plates improves power density as more plates can be fitted into the same-sized cell. Using a stronger acid in the battery further enhances power density.

TPPL also lowers energy consumption. EnerSys says it has measured up to a 40% reduction in the energy required to maintain a battery fully charged, compared to a traditional lead-calcium battery with the same power.

Advanced TPPL batteries are virtually maintenance-free during their anticipated design life which contributes to their low total cost of ownership. Northstar says that one of its battery ranges has a design life of more than 15 years at 20°C.

Moreover because of their advanced casings the batteries can withstand operating temperatures of -40°C to -65°C. The low self-discharge rates means that TPPL batteries also store well. Their shelf life is up to 24 months between refresh charges.

The latest research work by the ALABC — the Advanced Lead Acid Battery Consortium — is seeking to find yet higher energy densities for lead batteries and claims its researches are very positive. ■

Nobody can deny the huge strides made in developing lithium batteries over the last decade. But some of the questions of its future — at least in terms of universal adoption and the rate it happens, refuse to go away.

And the case against lithium...

It would be foolish to knock lithium batteries from a point of view of technology — huge progress has been made in recent years in creating top-class, best-of-breed lithium batteries.

But there are question marks hanging over them which refuse to go away. Broadly they come down to four areas.

- Lack of recyclability, at least from an economic viewpoint.
- Possible shortages of supply in any run-up to mass adoption. The main concerns are cobalt, nickel and refined lithium carbonate.
- When things go wrong, they do so in a spectacular and highly expensive way
- Price. The cost of lithium battery packs continue to come down but still — despite many wild claims — not to a level approaching lead acid.

The true costs of recycling

There's a rough rule of thumb that's been used about recycling large format lithium batteries for the past few years. The cost of recycling is roughly a tenth of the cost of the new battery. So, a $7,000 EV battery will cost around $700 to dispose of.

One lead smelting veteran puts it simply: "For the dollars of smelting you have to put in, you only retrieve a few cents of metal that have any value from recycling lithium batteries. That's the difference with lead recycling — lead is worth something and justifies the cost of processing it."

As a rough rule of thumb it's useful, but all lithium batteries aren't created equal. There are six basic chemistry types and three of these contain cobalt, a metal for which there is a demand, though the cost of retrieval is still greater than the metals retrieved.

In various parts of the world, most particularly in the European Union, recycling is the only legal method of disposal. Landfill is not an option.

But in the generality recycling is difficult to justify economically. Recent estimates suggest that just 3% of lithium batteries are being recycled. The processing costs are around $4,000 per tonne — with anecdotal evidence that lithium batteries are being discharged and stored in warehouses.

For the most part, however, those lithium ion batteries reaching end of life are consumer batteries from portable electronics.

It will be at least 15 years before sizeable flows of lithium batteries will need to be recycled from electric vehicles and stationary storage.

Maarten Quix, who heads up the recycling business unit of metals refining and recycling specialist Umicore, says: "In comparison with lead acid batteries, which consist of lead, acid and plastic, the complexity of rechargeable lithium ion batteries is much greater, with a variety of cell formats, and metals used to make these batteries for the portable electronics, automotive and stationary storage markets.

To date there are not enough volumes of lithium ion batteries needing to be recycled to create economies of scale reducing the costs of collection and smelting.

Shortages ahead?

The upcoming shortage of cobalt is reasonably well known in the lithium ion battery markets — three of the basic lithium batteries contain cobalt — and as *Energy Storage Journal* went to press cobalt had reached $75,000 a tonne — a 20% jump in the month.

But it's impact on the energy stor-

"Though lithium-based batteries have achieved impressive, higher standards in energy density over the last 25 years, their safety hazards remain very real, with huge consequences when something goes wrong in design, assembly, controls, usage, or collection and return after use. Think Samsung and a $5 billion recall" — Ray Kubis, Gridtential

age industry will be limited given that most grid storage systems are using lithium iron phosphate.

Perhaps more worrying, in a more subdued fashion, is that lithium carbonate prices are also heading upwards — from $6,100 per tonne two years ago to above $20,000 a tonne in November.

Demand pressure is intensifying. BMW said its needs for car battery raw materials such as cobalt and lithium will grow 10-fold by 2025 and that it was in the middle of signing five and 10-year supply contracts.

Other car companies such as VW, which has a $40 billion five year investment in electric vehicles, are trying to cut similar deals. Media chatter is that most automotive firms are finding supply problematic in closing deals given China has secured most of its own market needs.

The problem for large scale ESS projects is a simple one — much of their planning is not even in the pipeline.

Securing long term supply contracts will only be available for a few utilities and grid projects. Meaning, at the most basic, that the cost of ESS using lithium as the base battery chemistry is now open to the vagaries of a potentially roller-coaster market three to five years down the line.

Farid Ahmed, principal analyst for lead markets with Wood Mackenzie, says: "While there is an abundance of lithium in terms of a global resource, the rate at which production needs to expand to meet projected demand over the next decade outstrips anything previously achieved for a mined commodity.

"That's not to say it can't be done, but it won't be easy."

Ahmed also said there was an absence of any meaningful new supply of metallic nickel powder in the coming years, essential for Li-ion batteries. Possibly an even greater concern is the lack of forecast production capacity of Li-ion batteries, whether or not the raw materials are available.

"This means that the availability of Li-ion batteries will remain constrained for the next decade or so, limiting the rate at which battery prices can fall," said Ahmed. "The likely outcome will be that in the short to medium term, Li-ion batteries output will go preferentially to the application most demanding of light weight and high energy density — electric vehicles and hybrids.

"Unlike lithium, there is ample future supply of refined lead, with over half of global production coming from recycling. This opens a window of opportunity for lead batteries to become established as the best option for deployment as the energy storage battery chemistry of choice, both in terms of performance and cost."

When things go bang …

And when things go wrong on the lithium side of things they have gone spectacularly wrong.

The cost of the Samsung recall of its batteries this year has been estimated in the region of $5 billion. The recall of Sony laptops — 2006 and 2016 and other firms in between — also makes the point that even the best run technology firms have encountered difficulties in the past. And expensive ones too.

"Though lithium-based batteries have achieved impressive, higher standards in energy density over the last 25 years, their safety hazards remain very real, with huge consequences when something goes wrong in design, assembly, controls, usage, or collection and return after use," says battery veteran Ray Kubis.

"Long after recalls for Sony laptops, a fleet of cars dramatically burning in New Jersey and the grounding of a whole fleet of new Dreamliner jets design from Boeing, we've just seen a global recall of Samsung phones.

"Samsung is not a struggling startup from an emerging country with developing management, supply chains, and controls — rather, it is one of the three largest and best producers globally of lithium based batteries."

The price of everything

The arguments over price comparisons between lithium ion and lead acid batteries installed in ESS continue to rage — mainly because a whole range of different comparisons are made. Lead acid batteries are known to be cheaper than lithium by as much as half, but the average lifetime cost is never so clear and possibly misrepresented as such by lead distractors.

A recent report by Navigant suggests that the installation costs of ESS for lithium batteries will drop by 54% by 2030. The same report said lead acid batteries would drop by around 50%.

One neutral industry commentator said: "With so much money pouring into a sector, it is perhaps inevitable that not all deals will complete smoothly and not all investors will realise the return they were hoping for.

"But in some cases investors could misunderstand or even be misled — deliberately or otherwise — by the way in which energy storage units detail their project return on investment and detail key elements such as pricing per kilowatt hour.

"The reality is that the basis of the figures varies.

"Sometimes figures are given for a whole installation; sometimes calculations are offered per cell or per pack. But these differences can make a big and important difference to the relative attraction of an energy storage project to investors and its commercial viability.

"The multiple variables present in any energy storage project make it extremely difficult to accurately calculate the cost of energy storage, never mind the 'value' of it or the pricing per kilowatt hour." ■

The demonization of lead: a short history

Thomas Midgley Junior isn't so well known now.

But, until his death in 1944, he was reckoned to be one of the most brilliant men of his day.

Midgley's fame rests on his two great contributions to mankind — dichlorodifluoromethane (better known to us as CFC, the chemical that destroys the ozone layer) and tetra-ethyl-lead, the anti-knocking additive to petrol that was universally accepted as poisonous some 50 years after its discovery.

To be fair, Midgley's immediate contribution to the planet was, at first, a beneficent one.

The first CFCs were a boon to air cooling systems and saved many lives. The alternatives, such as propane or chloromethane, were toxic, explosive or highly flammable. Oddly enough in the 1920s and 30s every year people died at the hands of their fridges.

And tetra-ethyl-lead provided the automotive industry the push that made the internal combustion engine the workhorse of the planet and the troubled dream of an entire nation.

But — 70 years after his death — with CFCs phased out and TEL only found in the poorest nations of the world, Midgley's legacy lingers on.

And in a totally unexpected way.

By putting TEL into our cars, Midgley put lead into the atmosphere. Or rather General Motors did (which to its shame knew from very early on that it was dangerous following deaths, madness and hallucinations in its workforce).

Rather like the anti-smoking campaign, public awareness of TEL took time to build up. As did the growing accumulation of lead in the air.

The trigger for it becoming an issue came from an unexpected direction: cheap paint and timber frame houses in the US. For the very poor in America, their cheap wood-built houses could be spruced up nicely with the judicious use of paint — whose principal pigment within it was lead oxide.

And the mix of cheap wood and cheap paint?

The result: flakes of peeling lead which entered people's lungs.

The resulting US (and then later worldwide) legislation turned attention to finding lead anywhere and everywhere.

So in the 1960s and early 1970s a seemingly powerful case for getting rid of the lead in petrol emerged. News that the high levels of lead in US and European inner city children caused by petrol fumes created a ripple effect — from the world of the tabloid to seats of government. In the event, legislation to enforce a ban of lead in petrol was inevitable.

At this point, Robert Merton's Law of Unforeseen Consequences kicked in.

In the public mind by the end of the 1970s lead had now become as dangerous as, say, arsenic or strychnine. Probably even looking at the metal would make you blind or send you into spasms.

The fact that it was not just fit for purpose — and maybe the only thing that would easily and cheaply work within a car, or a power back up system — was left by the door … neatly sitting next to the open-toed sandals.

Even congressmen and MPs are human and jump with the lemmings.

The result? We now have a generation of misinformed politicians who, with admirable thoroughness, are trying to legislate lead out of existence.

The lead community has been fighting back for a generation and more. But with little impact on a media that doesn't want to hear a good news story.

So, for example, arguments about the recyclability of lead continue to have little impact on a general public that believes recycling of, say, tins or wine bottles is probably worthwhile — but interesting?

Yet the recycling story is an important one to remember — even if the arguments don't touch the heart. It shows a responsible, mature industry that can point with ample justification to a defence that its core product is safe. And can be proven so.

The trouble is that changing public perceptions only seems to work best when sensationalism occurs.

In Europe, for example, a thoroughly worthwhile book *'E' is for Additives*, written in 1987, persuaded an

Thomas Midgley Jr: "the man who inadvertentlyhad more impact on the atmosphere than any other single organism in earth's history"

In the public mind by the end of the 1970s lead had now become as dangerous as, say, arsenic or strychnine. Probably even looking at the metal would make you blind or send you into fits.

entire continent of people who didn't read the book that an 'E' number (the European food code for a permissible food additive) was not just a bad thing but a terrible one.

(Forgetting of course that E948, for example, is the code for oxygen, or that herbs such as oregano would nowadays be coded as too dangerous to be assigned an 'E' number.)

Lead trade organizations such as the International Lead Association, EUROBAT, BCI and various others continue to try and fight back. But they have an enormous challenge on their hands. And, being respectable bodies, rightly enough would not stoop to underhand media trickery.

But ill-informed politicians — or even informed ones either — don't necessarily want to go against the views of their electorates: "It's hard to get political people, let alone ordinary ones, to understand what an inconsistent view they have on lead. They want to ban it from the European Union but still drive cars," one battery veteran told *Batteries International* recently.

"They worry about infinitesimal levels of lead in the blood while the battery itself powers the most remorseless killing machine on the planet — the motor car."

And in yet another twist in the Law of Unforeseen Consequences, removing lead from petrol gave rise to the wider use of diesel, which now causes some 38,000 premature deaths, according to the World Health Organization. WHO predicts this will rise to 174,000 a year by 2040.

Tetra-ethyl-lead provided the automotive industry with the push that made the internal combustion engine the workhorse of the planet and the troubled dream of an entire nation.

The full demonization of lead would not be complete, however, without the blessing of the media which, during the US presidential campaign last year cheerfully conflated a lead scare in Flint, Michigan, a scandal around a recycling plant in Vernon, California, and the idea that perhaps now was the time for all cars to be electric.

In the public imagination, historically which was the more evil: lead or Saddam Hussein?

Indeed the problem for lead goes back to image rather than substance.

Lead can be toxic — so can pure oxygen — but the chances of lead batteries finding their way into the environment in any meaningful way is virtually non-existent.

Perhaps the issue of demonization is about to take a new twist.

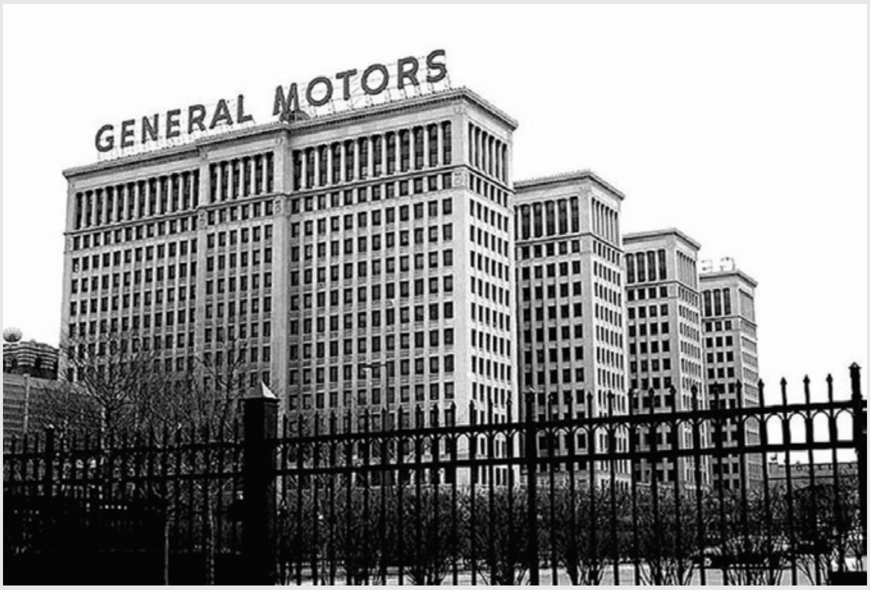
The Dreamliner scare of three years ago hit the headlines but was quickly forgotten, so too were the hoverboard scandals last Christmas and even the $5 billion recall of Samsung mobile phones this spring.

But now there are rising fears — some of them even credible — of laptops, tablets and mobile phones exploding and going into thermal runaway on passenger planes. Could this be a wake-up call to the New Enemy of Humanity? The 18650 battery and the lithium coin cell?

If that's the case it'll be another unexpected consequence of the kind poor Tom Midgley suffered.

In his instance, he was unlucky to the end — "the man who inadvertently had more impact on the atmosphere than any other single organism in earth's history," according to one historian — met a sorry fate.

Crippled by polio in his 50s he invented an elaborate system of pulleys to make himself mobile. He died from strangulation in his invention's strings. ■



By putting TEL into our cars, Midgley put lead into the air. Or rather General Motors did (which to its shame knew from very early on that it was dangerous following deaths, madness and hallucinations in its workforce).

This extract from a paper written by **Geoffrey May** *(principal, Focus Consulting)*, **Alistair Davidson** *(director, International Lead Association)* and **Boris Monahov** *(program director Advanced Lead Acid Battery Consortium)* demonstrates how lead acid batteries provide a viable, sustainable and cheaper resource for large scale static energy storage systems,

The whole paper provides an overview of the performance of lead batteries in energy storage applications and highlights how they have been adapted for this application in recent developments.

Lead batteries for utility energy storage: a review

Lead acid batteries have been used for energy storage in utility applications for many years but it has only been in recent years that the demand for battery energy storage has increased. It is useful to look at a small number of older installations to learn how they can be usefully deployed and a small number of more recent installations to see how battery technology has moved forward and the directions for the future.

BEWAG, Germany

The BEWAG BESS facility was installed in 1986 to provide spinning reserve and frequency regulation for the electricity network in West Berlin when it was an isolated network not interconnected with the then East Germany.

The battery had a capacity of 14MWh and comprised 12 parallel strings each with 590 cells with a capacity of 1000Ah. The cells were tubular flooded cells with negative grids made from lead plated expanded copper mesh and pasted in a normal manner.

The increased conductivity of the negative plates in tall tubular cells leads to a more uniform current distribution between the top and bottom of the plates and better performance.

The battery ran for nine years from installation until 1995 although in the last two years of operation, Germany had been re-united. The battery was inter-connected to the grid and the need for battery support was reduced.

In the first seven years of operation, it had a capacity turnover of 7,000 times the nominal capacity and there were no reported problems.

The battery supported a 30kV distribution system and the power delivered for frequency control was limited to 8.5MW but for spinning reserve this was increased to 17MW. The system fully satisfied the technical requirements for maintaining the stability of an island network and showed a high level of reliability.

In the first seven years of operation, it had a capacity turnover of 7,000 times the nominal capacity and there were no reported problems.

Southern California Edison, Chino, California

Southern California Edison (SCE) installed a 10MW, 40MWh battery at a sub-station in Chino which became operational in 1988.

The battery consisted of eight parallel strings of 1,032 cells with a capacity of 2,600Ah.

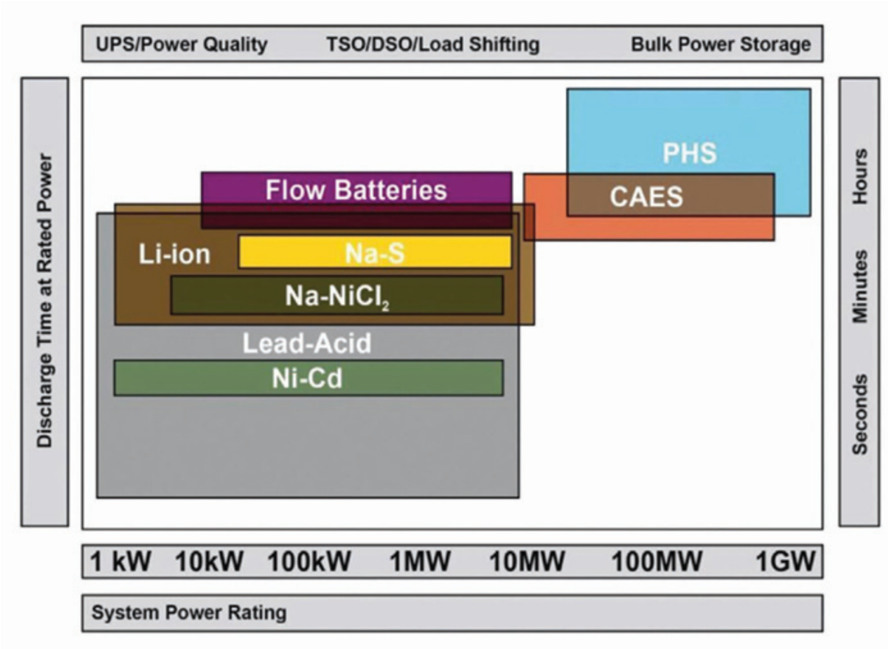
The cells were pasted plate cells with antimonial grids and used compressed air for electrolyte agitation to avoid stratification. There were systems for water addition, acid-level indicators, temperature measurement and overall battery management.

The battery had a design life of 2,000 cycles over an eight year period and in fact operated for nine years.

The power conversion system was connected to a 12.5kV line that in turn fed into a 69kV line from the sub-station. Battery efficiency was measured as 81% and the power conversion efficiency was 97%.

Since this was an experimental facility, it was used to demonstrate capabilities for peak shaving, load levelling, load following, spinning reserve, transmission line support, frequency control, voltage control, VAR control and black-starts.

One particular feature of the battery was its use to damp low frequency oscillations which can occur on long transmission lines.



Type, power rating and discharge time for different energy storage systems

This experimental facility was used to demonstrate capabilities for peak shaving, load levelling, load following, spinning reserve, transmission line support, frequency control, voltage control, VAR control and black-starts.

It was shown that by modulating battery power output, these fluctuations could be reduced although this was limited by the power output available.

Switching from idle to full charge or discharge could be achieved in <20ms.

The project was successful in demonstrating that a large lead acid battery could perform a wide range of duty cycles reliably over an extended period of time.

Metlakatla, Alaska

Metlakatla is a small community on an island off the coast of Alaska and its power needs are supplied by a hydroelectric generator and a diesel powered generator. The demand is variable and had high peaks because of the operation of a commercial sawmill.

Before a BESS was installed, diesel generation was used for peak demand and the hydroelectric generator was not used to full capacity. This also resulted in inefficient use of the diesel generator to follow the load.

An analysis of the system showed that a battery could stabilize and improve power quality by reducing voltage and frequency variations and reduce reliance on diesel generation which would result in savings in fuel costs that were high because of the remote location.

A 1.6MW peak, 1.0MW continuous battery was commissioned in 1997 and has operated successfully since then. The battery consists of a single string of 378 2V modules each with a low rate capacity of 3,600Ah.

Each module consists of three VRLA AGM 1,200Ah cells in parallel. The battery is connected through a power conversion system to a 12.5kV distribution network. In 2000 the sawmill was closed because of environmental concerns regarding deforestation but the system continues to operate with reduced demand.

The system operates in a PSoC mode using excess hydroelectric power to charge the batteries and is charged and discharged to maintain frequency and voltage within prescribed limits.

A physical examination and electrical tests on cells removed after a period in service showed that they were in good condition, and were likely to exceed its design life

Equalization charges are required at six-monthly intervals. A physical examination and electrical tests on cells removed after a period in service showed that they were in good condition, and were likely to exceed its design life. The level of overcharge reported after three years in operation was only 0.8% which is a strong factor in reducing the degradation of the battery.

Lerwick, Shetland Isles, Scotland

The Shetland Isles in Scotland has an electricity supply network with a 66MW diesel generating plant and 11MW of wind power. There is some thermal storage in use and a BESS with 3MWh of capacity and a 1MW peak output has been installed to reduce the demand on the diesel generation and increase the proportion of wind power that can be used.

The system was installed in 2013 and has operated successfully since that time providing a 20% reduction in peak demand for diesel generation with savings in fuel costs and improvements in power quality.

The battery consists of 12 parallel strings of 264 cells with a nominal voltage of 528V and a capacity of 1,000Ah. The cells are VRLA AGM types with carbon loaded negative active materials and high density positive active materials mounted horizontally in steel enclosures. The charging parameters are carefully regulated and a recharge factor of 5% is specified.

Detailed monitoring of the battery is carried out locally and remotely by the battery supplier. Thermal management is important

The lessons learned from this installation are that current sharing between strings and recharge factor uniformity are useful parameters to identify the proper functioning of the battery

for uniform operation of the battery. Safety systems include hydrogen detection and dispersion as well as conventional fire suppression equipment.

Power conversion is through two 500 kW inverters to a transformer to an 11kV grid connection.

The lessons learned from this installation are that current sharing between strings and recharge factor uniformity are useful parameters to identify the proper functioning of the battery and that a high level of measurement of voltage and temperatures is useful to ensure efficient maintenance activity. Heat output from the battery needs to be managed.

Equalization charges may be applied as necessary. The overall efficiency of the installation was measured as 84%. This is a round trip efficiency based on the energy input for charging and the energy output on discharge.

The recharge factor was 105%.

PUTTING THE WHOLE PAPER TOGETHER

The competitive position between lead batteries and other types of battery indicates that lead batteries are competitive in technical performance in static installations.

Table 2 provides a summary of the key parameters for lead acid and Li-ion batteries.

Lead batteries cover a range of different types of battery which may be flooded and require maintenance watering or valve-regulated batteries and only require inspection.

For many energy storage applications with intermittent charging input and output requirements, especially with solar PV input, batteries are not routinely returned to a fully charged condition and where the battery is required to absorb power as well as deliver power to the network, PSoC operation becomes the normal mode.

There have been substantial improvements in lead acid batteries in this area especially with the use of carbon additives to the negative plate but this continues to be an area of active development and further improvements in performance should be achieved.

There are also other types of lead batteries, particularly batteries with a hybrid construction with supercapacitor elements combined with a conventional negative plate.

These offer further improvements in shallow cycle performance.

Safety needs to be considered for all energy storage installations. Lead batteries provide a safe system with an aqueous electrolyte and active materials that are not flammable. In a fire, the battery cases will burn but the risk of this is low, especially if flame retardant materials are specified.

Li-ion batteries have a much higher energy density, highly reactive component materials and a flammable electrolyte. Safety engineering needs to be to a very

Table 1: Comparison of key parameters for energy storage systems

System	Life (years)	Cycles	Energy efficiency (%)	Installed system cost ($/kWh)
PHS	50	20,000	80	250–350
CAES	25	10,000	65	200–250
Lead acid	15	2,000	85	400–600
Ni-Cd	20	2,000	85	1,200–1,500
Li-ion	15	2,500	90	1,250–1,500
Na-S	10	4,000	75	600–800
$Na\text{-}NiCl_2$	10	4,000	75	750–1000
VRB	15	10,000	70	750–850
$Zn\text{-}Br_2$	7	3,000	70	600–800
$Na\text{-}NiCl_2$	10	4,000	75	750–1000
VRB	15	10,000	70	750–850
$Zn\text{-}Br_2$	7	3,000	70	600–800

King Island, Tasmania, Australia

Hydro Tasmania, an electricity utility in Australia has integrated a 3MW UltraBattery BESS from Ecoult as part of an island microgrid it has implemented on King Island in Bass Strait.

The island grid supports the residential and commercial electricity needs of the island which has a population of around 1700 people. The BESS complements other components of the microgrid such that the system often runs for continuous periods of more than 24 hours using electricity generated from renewable sources (wind and solar) alone with the BESS shifting energy from periods of excess generation to periods where extra energy is needed to match load as well as contributing to ancillary services like frequency management.

The Hydro Tasmania solution

The BESS complements other components of the microgrid such that the system often runs for continuous periods of more than 24 hours using electricity generated from renewable sources

high standard to ensure the risk of thermal runaway, fire and explosion is managed. Other battery systems also have safety issues that need to be controlled.

An issue with all battery technologies is sustainability. There are strict regulations regarding collection and recycling of all types of battery and mandated efficiency targets irrespective of the broader societal needs to ensure that all goods form part of a circular economy.

For lead batteries, there is an established recycling infrastructure in place that operates economically in full compliance with all environmental regulations. For Li-ion and other chemistries used for battery energy storage, recycling processes do not recover significant value and will need to be substantially improved to meet current and future requirements.

Lead batteries have a long history of use in utility energy storage and their capabilities and limitations have been carefully researched. Their reliability is well established and they can be adapted for a wide range of duty cycles within this sector which will continue to ensure they provide a good solution that is competitive to other approaches.

Table 2: Comparison of technical and other features of lead acid and Li-ion batteries for energy storage service

System	Lead acid	Li-ion
Energy density	35–40 Wh/kg *	150–180 Wh/kg
	80–90 Wh/l	300–350 Wh/l
Power density	250 W/kg*	800 W/kg
	500 W/l	800 W/l
High temperature performance	to 40°C	to 50 °C
Low temperature performance	to -30 °C	to -20 °C
Charge acceptance	Good	Better
Cycle life	1,500–5,000	1,000–5,000
Overall service life	15 years	10–15 years
Reliability	Proven	Needs to be assessed for longer
Sustainability	Excellent	Recovery methods uneconomical
Safety	Excellent	Issues to be resolved
Cost (battery system only)	$150–200/kWh	$600–$800/kWh
Cost (battery system only)	$150–200/kWh	$600–$800/kWh

Note *: Bipolar lead-acid batteries are being developed which have energy densities in the range from 55 to 60 Wh/kg (120–130 Wh/l) and power densities of up to 1,100 W/ kg (2,000 W/l) has significantly reduced the amount of fossil fuel (diesel) consumed to meet the island's energy needs and the UltraBattery batteries in the BESS which has been operated for a number of years continue to operate reliably.

UltraBattery batteries have now been used in many grid and renewable integration projects and recent projects include the integration of reserve power functions and the ability to move seamlessly from grid ancillary support to full islanded microgrid modes for power continuity during times of grid failure.

Aachen, Germany

A large battery system was commissioned in Aachen in Germany in 2016 as a pilot plant to evaluate various battery technologies for energy storage applications.

The behaviour of Li-ion and lead acid batteries is different and there are likely to be duty cycles where one technology is favoured but in a network with a variety of requirements it is likely that batteries with different technologies may be used to achieve the optimum balance between short and longer term storage needs.

This has five different battery types, two lead acid batteries and three Li-ion batteries and the intention is to compare their operation under similar conditions.

Each battery is grid connected through a dedicated 630 kW inverter. The lead acid batteries are both tubular types, one flooded with lead plated expanded copper mesh negative grids and the other a VRLA battery with gelled electrolyte.

The flooded battery has a power capability of 1.2MW and a capacity of 1.4MWh and the VRLA battery a power capability of 0.8MW and a capacity of 0.8MWh.

The Li-ion batteries are lithium-manganese dioxide, lithium iron phosphate and lithium titanate.

The experience from this project to date is that battery energy storage can control reactive power in a network, maintain stability and provide useful support to the network. It is intended to evaluate the economic aspects of different methods of operation as the work proceeds.

It has been confirmed that batteries can be installed and put into service quickly close to consumers.

The behaviour of Li-ion and lead acid batteries is different and there are likely to be duty cycles where one technology is favoured but in a network with a variety of requirements it is likely that batteries with different technologies may be used to achieve the optimum balance between short and longer term storage needs.

Lyon Station, Pennsylvania, US

The DSO for a large part of the Eastern part of the US has installed a large hybrid lead battery/ supercapacitor (UltraBattery) in Lyon Station, Pennsylvania for frequency regulation.

This was installed in 2012 and has been shown to be highly effective in stabilizing the network. There are four batteries each feeding into 900kW inverters which in turn feed into a 13.8kV line continuously to provide frequency regulation. Each string consissts of 480 2V VRLA cells.

The hybrid batteries have a total of 3.6MW of power capability and 3MW of power can be exchanged either as output or input. The system has been shown to be 92%-95% DC/DC efficient and in performing regulation services has an average AC to AC efficiency of 80%.

The original cells are performing well and one string has been replaced with a higher performing UltraBattery variant. ■

This was installed in 2012 and has been shown to be highly effective in stabilizing the network. There are four batteries each feeding into 900kW inverters which in turn feed into a 13.8kV line continuously to provide frequency regulation.

Lead-based Ultrabattery® used for frequency regulation at Lyon Station, Pennsylvania