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Batteries & Energy Storage Technology

No. 46
Autumn 2014

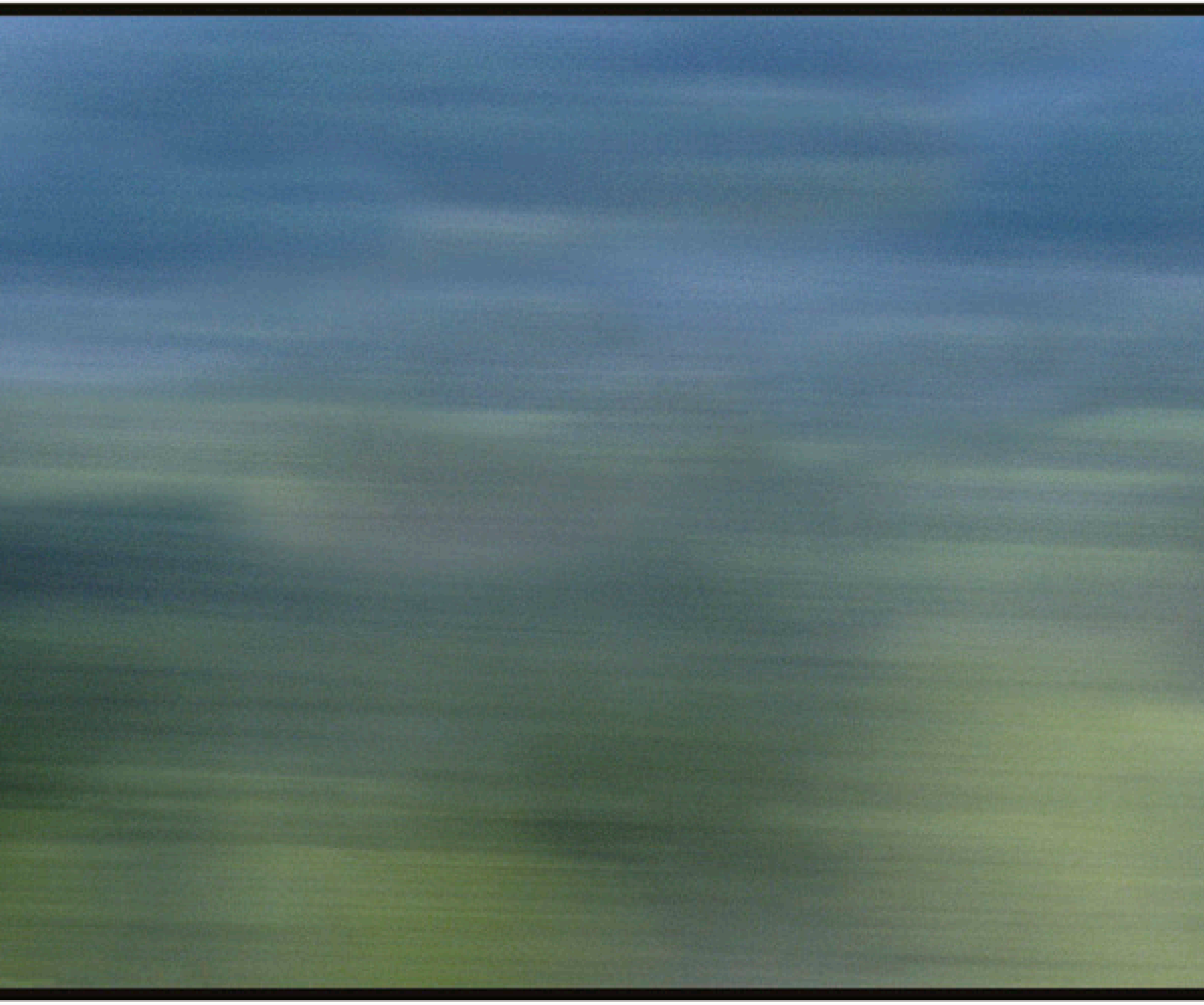
Old dogs, new tricks

Inside:

Hi-temp VRLA – Can lead take the heat?
Sodium-ion – The best of British
Lithium silicon anodes

And so much more

Rise Above The Marketplace.



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EDITORIAL OFFICE
Energy Storage Publishing Ltd
70 Goring Road
Worthing BN12 4AB
ENGLAND
TEL +44 (0) 845 194 7338
FAX +44 (0) 845 194 7339
E-mail: gerry@bestmag.co.uk

EDITOR AND PUBLISHER
Tim Probert
tim@energystoragepublishing.com

ASSISTANT EDITOR
Laura Varriale
laura@energystoragepublishing.com

ADVERTISING
Les Hawkins
advertising@bestmag.co.uk
+44 7885 910 187

CHINA AND EAST ASIA ASSOCIATE
Liang Yunchao
lyunchao@vip.sohu.com
+86 136 0324 2669

SOUTH ASIA ASSOCIATE
Dipak Sen Chaudhuri
dipaksc@yahoo.co.in
+91 98314 37792

OFFICE ADMINISTRATION
Sonya Upton
sonya@energystoragepublishing.com

PRODUCTION
Ben Osborne
ben@energystoragepublishing.com

SUBSCRIPTIONS
Angela Crowe
angela@energystoragepublishing.com

PRINTED IN ENGLAND

Tim Probert
Editor

If that was a trade show, where were the products?

Welcome to the Autumn issue. Many of you will have attended the recent European Lead Battery Conference (ELBC) in Edinburgh and, no doubt, enjoyed what was a pleasant show in a great city.

Away from the convivial atmosphere of the evening festivities, BEST had been hoping to learn more in the conference hall about the advances in lead-acid battery technology, but came away disappointed with what were relatively rudimentary research presentations. As more than one person commented, “If this is a trade show, then where are the products?”

For all the fluffy talk about climate change and the usual refrains about sustainability – do customers or the wider world really care all that much that can be lead recycled and lithium can’t? – what the customer really wants from lead is improved performance, be it automotive, industrial, stationary or standby power. As Tim Ellis said during his maiden ELBC speech, for the first time in 150 years, lead has got real competition.

As our feature on page 53 about high-temperature VRLAs clearly demonstrates, there has been some very important progress with lead-acid batteries, be it grid alloys, expanders, organic additives, as well as mechanical components. And there continues to be good work, not least from the ALABC, which shows the industry can rise to meet customers’ demands.

But there were relatively few products launched at ELBC, and this is symptomatic of the lack of market savvy of the lead-acid battery industry. OK, Entek launched its new separator and offered a tour of its factory (as reported on page 36), Digatron and Bitrode launched equipment and a few others in general, but the industry seems to be missing a trick.

If you are developing groundbreaking new products, tell the big wide world, don't keep it a secret, and launch them at a trade show. At the very least drop us a line so that we can tell the world about it via our weekly BEST Battery Briefing newsletter and within these pages.

Elsewhere, we keep you abreast of developments in lithium silicon anodes, Germany and Britain’s struggling effort to meets ambitions to become a lithium-ion battery weltmeister/world leader, and a visit to sodium-ion developer Faradion. Not forgetting our unrivalled series of in-depth articles on lead-acid manufacturing by Mike McDonagh and market developments in supercapacitors by Peter Harrop.

Enjoy the issue.

Tim

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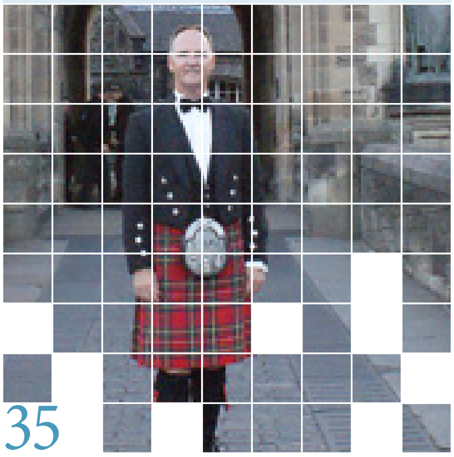

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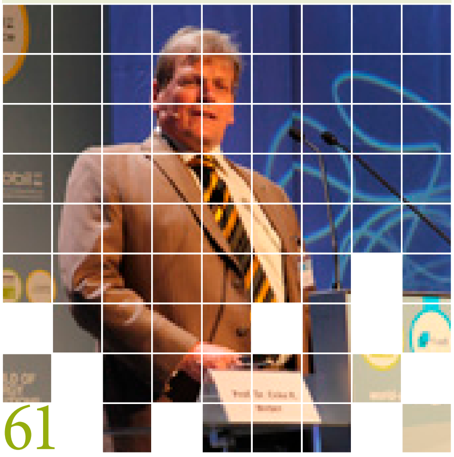

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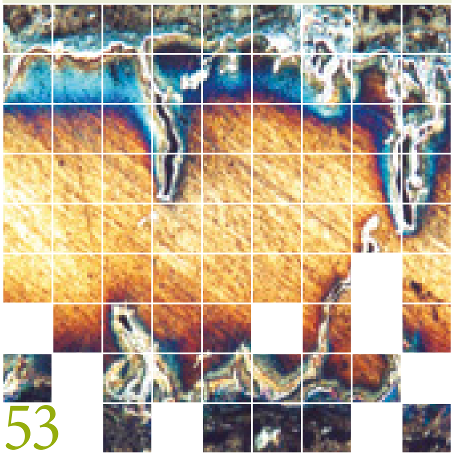
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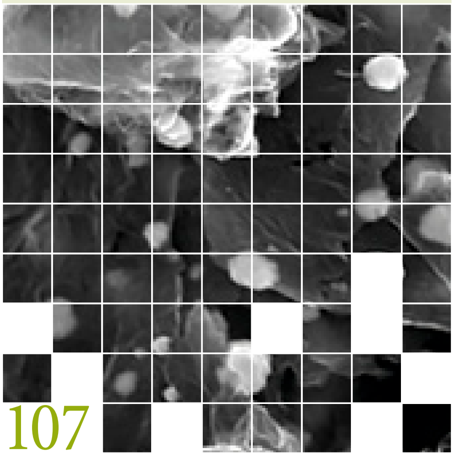
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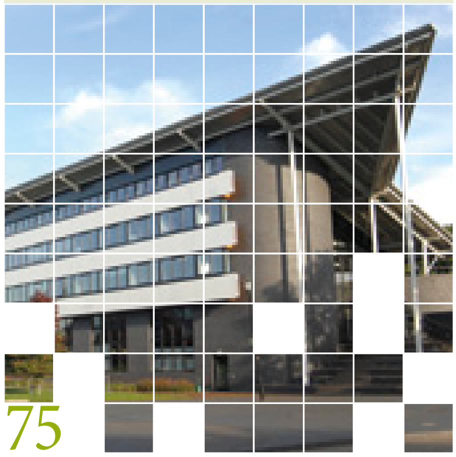
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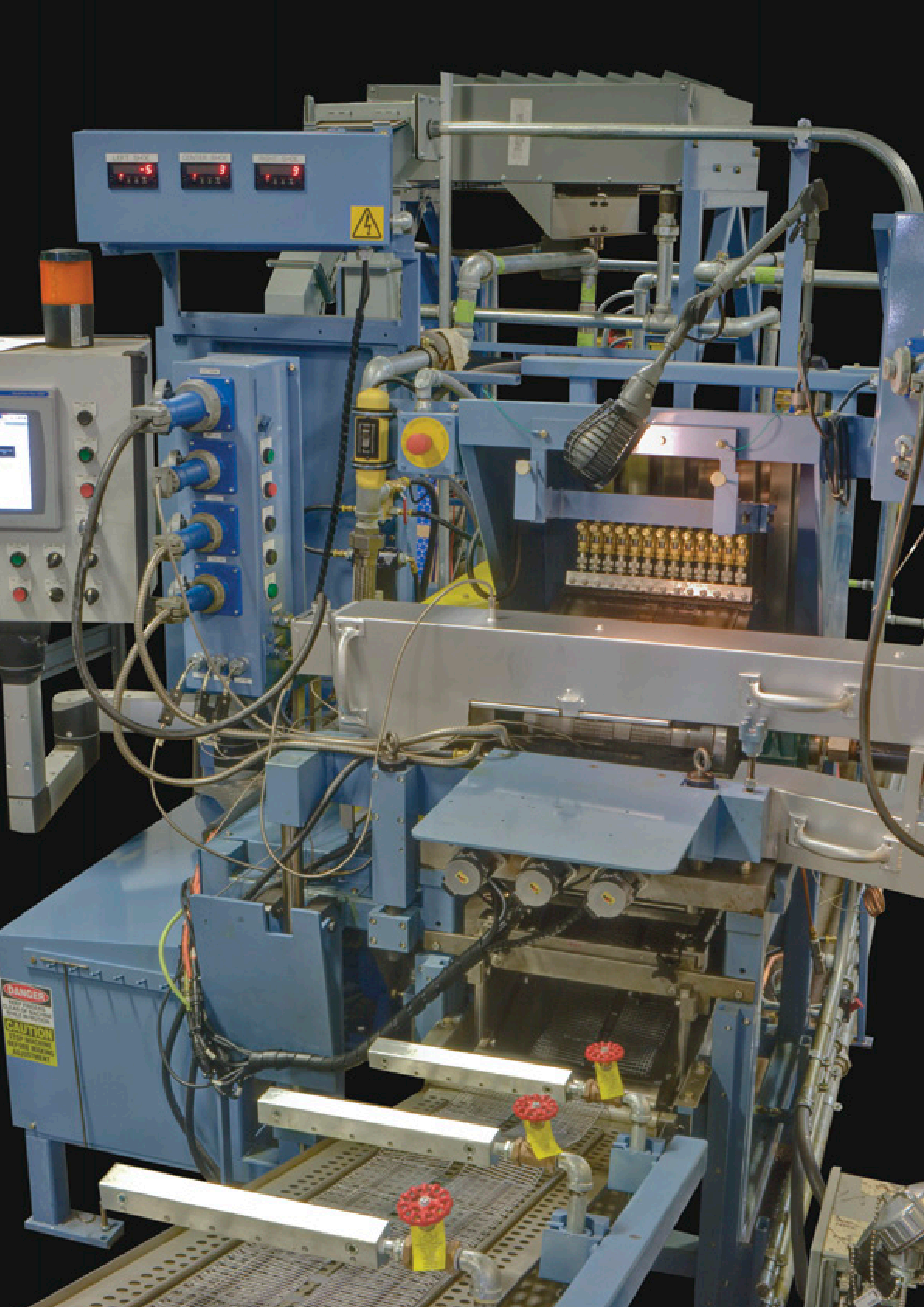
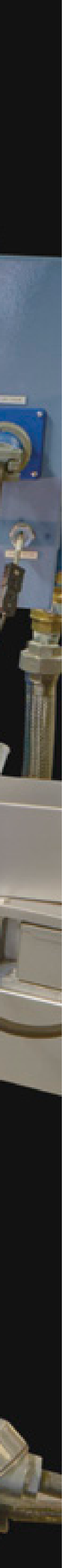




Gearing up for tomorrow

Another conference, another self-congratulatory pat on the back for the battery industry.

Aren't we great? Aren't we green? Let's strike another medal and smile!

By and large, the lead-acid market continues to show, overall, reasonably healthy growth globally, while in some regions notably parts of Asia, the figures are still exceptional.

Traditional markets for these products aren't going away but they will be increasingly eroded by alternative chemistries. It will be years before this erosion is a serious threat to viability.

The lithium-ion market continues to flourish, mainly in the small cell area thanks to our global love affair with smartphones and tablet devices. In large format sizes aimed at hybrids, EVs and to a lesser extent, stationary energy storage, it is a little disappointing. Technical success for lithium-ion here largely comes where the battery business is integrated into a larger electronics giant, e.g. Samsung, LG and Panasonic. Collectively these companies have massive R&D departments not just developing new consumer products, but new materials and new ways of fabricating them, from printing circuitry in thin films to lithographic deposition of battery electrodes.

The know-how and expertise in materials is shared within the companies. That's not to say great ideas don't come from the smaller battery players but being on the inside track of product development gives an advantage.

The big names in lead-acid, however, are out on their own. Enersys, Exide, East Penn and even giants in China like Camel are solely engaged in the manufacture of lead-acid batteries and not part of any large-scale industrial conglomerates.

There simply isn't a cutting edge technology division closely linked to the respective battery business making 'something else' that is potentially applicable to lead-acid.

What makes these companies a success (or failure) are sound manufacturing and business skills, cost control, good supply chain management, competitive pricing and in all honesty, not too much more science.

And that, I think, is why some of the names in the world of lead are easing off in their support of ALABC, alluded to by chairman Tim Ellis in Edinburgh. All the science they need to make 'good enough' lead-acid batteries is out there and to a greater or lesser extent, published.

What the big names in lead need now need are joint ventures or even mergers and acquisitions with PV and other alternative energy generators to make 'off grid in a box products' of the kind this writer saw at Intersolar in Germany this summer.

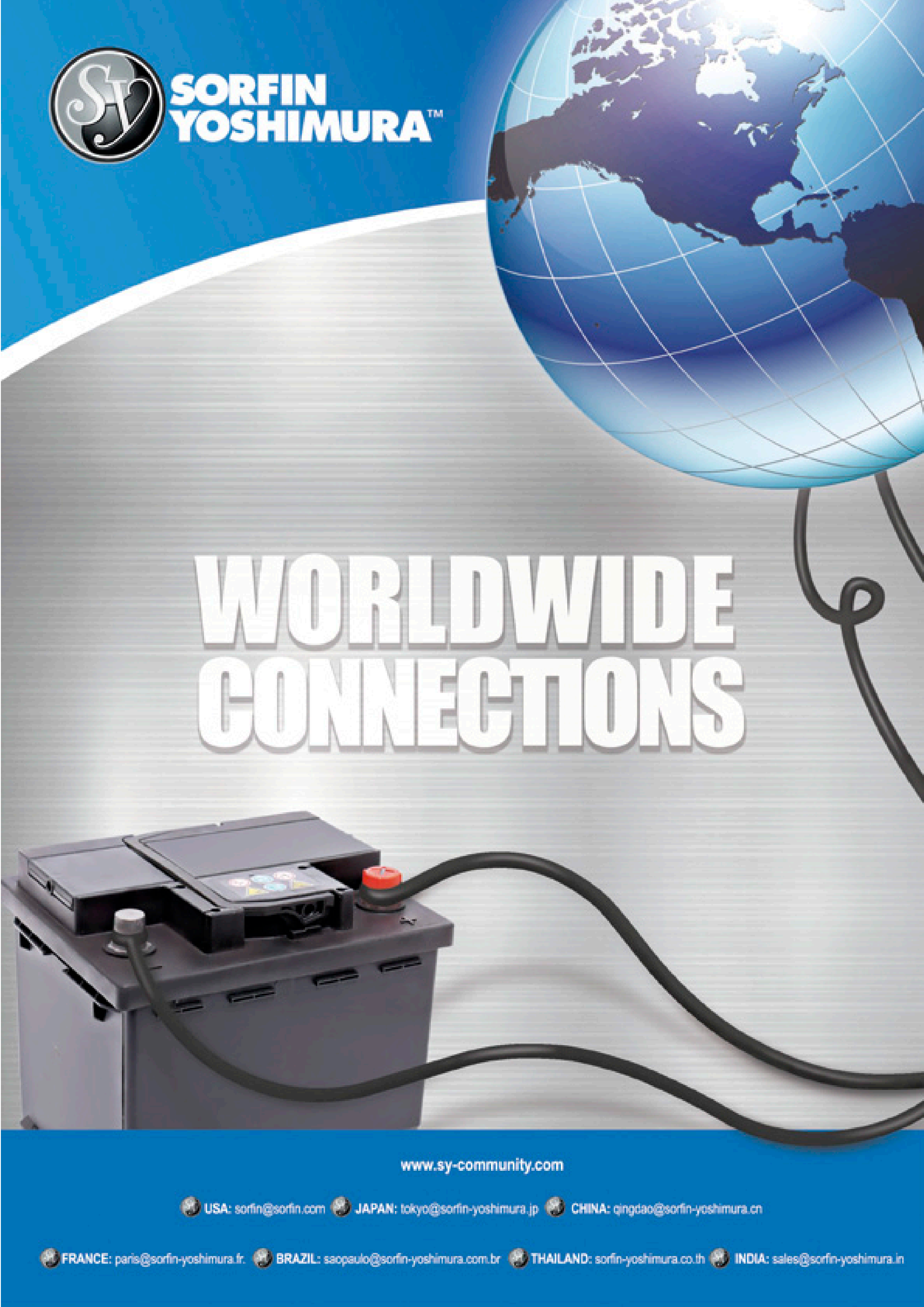
Too much of what I saw from the lead-acid world was less than joined-up thinking.

Simple batteries in a box won't cut it with specifiers, but total solutions will. Lead still has the big advantage on price. In a world where climate change is now provoking widespread protests all around the world, surely that's a big enough signal to start making the products (with batteries included) the world needs?

Let's hear from you

Got an opinion on the above or anything else? Then share it. If it's battery standards or the answer to the ultimate question in the universe, BEST's readers would like to know.

Contact: tim@energystoragepublishing.com



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Tesla selects Nevada for 'Gigafactory'

Automaker Tesla has chosen US state Nevada as the site for its planned $5 billion lithium-ion battery factory.

Californian Tesla is to build the factory in partnership with Japan's Panasonic and expects to produce 35GWh of packs per year by 2020 for Tesla's upcoming electric vehicle. The plant is aimed to generate more than 6,500 jobs and build 500,000 cars per year.

Tesla will purchase the land, buildings and utilities required for the battery-producing factory and Panasonic will manufacture and supply cylindrical lithium-ion cells, as well as invest funds in equipment, machinery and tools. The possibly 10m sq. ft. site is aimed to be ready for production in 2017.

It is still unclear if Tesla will build a second factory as possible backup for the Nevada plant in case it will not deliver as expected.

Tesla announced in July that it had broken ground in Reno, Nevada, but stopped the construction. Reno has a four-hour proximity to Silver Peak, North America's only commercially active lithium mine in Nevada.

"It really gives them a big advantage, because if you have to ship it, you have to ship it by rail, and that's a hazardous product," said Reno county judge Nelson Wolff.

First stage of California energy storage target to be "all procured" – Commissioner

The first stage of California Public Utilities Commission's (CPUC) flagship energy storage target will be fully procured, according to the Commissioner responsible for its implementation.

In October 2013 CPUC approved a mandate requiring the state's three large investor-owned utilities – Southern California Edison, Pacific Gas & Electric and San Diego Gas & Electric - to procure 1.325GW of energy storage by 2020. CPUC will issue in December its first competitive solicitation for the scheme, and with 136MW up for grabs demand is expected to be strong.

However, the responses are subject to cost-benefit methodologies devised by the utilities and stakeholders. If utilities do not have enough successful bids that pass the methodologies, they have the option to defer until the next solicitation in 2016.

"I expect all [136MW] to be procured," CPUC Commissioner Carla Peterman told BEST. "The market seems ready to respond to the solicitation at competitive prices.

"The anecdotal evidence is there will be a wealth of products that will be able to come in under the methodology," she added, noting Southern California Edison's solicitation earlier this year for 50MW of energy storage projects to cover reliability issues drew 500 responses.

Peterman expects the majority of the 136MW, which would be deployed in 2015, to be short-duration battery energy storage for grid reinforcement, mostly lithium-ion, deployed close to load centres and in places with network constraints.

"I expect a large share of batteries but we're also going to need some longer duration storage projects," she added.

Peterman said CPUC would evaluate the 1.325GW energy storage target in 2016. "We'll look at whether we need to raise the target or lower it, and also whether we need more grid-level storage or behind-the-meter, customer storage," she said.

The total cost of the programme is estimated at $1-3 billion.

Patent applications for stationary energy storage batteries doubled – study

Patent family applications for batteries suitable for stationary energy storage have doubled. From 2006 to 2011, the number of patents increased from 2,800 to 5,900, according to a study, 'Monitoring innovation in electrochemical energy storage technologies: A patent-based approach', by Technical University Munich.

The lithium segment is most dynamic with a steep upward trend since 2008 and 4,900 patent family applications in 2011. Simon Müller, physicist and economist at TUM told BEST: "A lot of companies have high market expectations for lithium batteries that result in extensive research development. As soon as the techno-economic data are good enough, research and development activities will attract more investments, which will generate an even stronger lead". The growing EV industry is also a factor that increases the patents, he added.

In second place in terms of the number of patent applications filed are lead batteries with only around 580 new patent families in 2011. The scientists noted, however, a recent marked increase, albeit to a low level, for redox flow batteries, in which the energy-storing chemical compounds are used in liquid form: From 2009 until 2011, the number of applications more than doubled from 90 to 200. The number of new patent families for alkaline batteries dropped slightly to 240 and sodium-sulphur technologies played a consistently marginal roll with 20 applications.

Asian countries submitted almost four times as many patent applications as European battery developers. In 2011, 2,100 Asian applications were noted, 530 European and 410 US. "If you look at the EV industry, the big car makers Audi, Tesla and BMW have Asian battery suppliers. The success drives research and development at the companies and patent applications already reflect that and will in the future," said Müller. The top ten lithium battery developers consists of eight Japanese companies, Korea's Fuji and Valence from the US.

The study researched the worldwide annual number of patent applications for energy storage systems between 1991 and 2011.

ALABC seeks participants for DOE lead carbon stop-start research programme

The Advanced Lead Acid Battery Consortium is seeking participants for a $300,000 US Department of Energy (DOE) funded lead carbon battery research programme.

The programme will include six lead carbon batteries to be tested in 12V stop-start automotive applications. The DOE is to put up $150,000 for the one-year research programme, which is expected to commence in early 2015, with the six participants stumping up $25,000 apiece.

Electric Applications' Don Karner, who has been spearheading the programme on behalf of the ALABC, said the batteries could be 'pure' lead carbon anode batteries or lead-acid batteries featuring carbon additives in active material.

"We're calling for production batteries or at least near-production batteries," he said. "Let us benchmark you".

Initial performance tests of lead carbon batteries would be conducted for two months, while cycle life testing would take place over a year. Quarterly reports are also expected.

The ALABC will finalise the participants by the end of September, and expects to submit its final proposals to the DOE by 10 October. A DOE contract is expected to be signed by the end of 2014.

Karner said the programme could be the first step in a plan to work with the US Advanced Battery Consortium, which excluded lead-acid batteries from its research, to design new research programmes and develop further their work with the automotive industry.

International air safety officials consider limiting number of lithium batteries on planes

The United Nations International Civil Aviation Organization (ICAO) has discussed potential limits on the number of rechargeable, lithium-ion batteries carried by a single passenger aircraft, according to newspaper reports.

The discussions, which took place during an ICAO conference in Cologne on 9 September, involve bulk shipments of batteries, rather than batteries carried by individual travelers, reported the Wall Street Journal.

The ICAO aims to place the "least possible burden" on battery manufacturers while still providing "the international aviation community with "an acceptable risk" level. Nancy Graham, ICAO's top safety official, highlighted "concerns with the risks all lithium batteries present...on both passenger and cargo aircraft."

Meanwhile, the Air Line Pilots Association, the largest North American pilot union, is stepping up its campaign for more-stringent standards and regulations.

ALPA wants to outlaw bulk shipments of lithium metal batteries for all cargo carriers. In the meantime, it wants to ensure pilots have detailed information about the precise location and size of any battery shipments on a plane, and that cargo crews can get access to certain areas in the event of a blaze.

Battery manufacturers will seek to head off any new restrictions that might be imposed by the ICAO, believing that existing packaging and labeling requirements —combined with ICAO-mandated quality controls at factories - provide adequate safeguards.

"Rules for what you ship and how you ship it are bound to get tougher," according to Brian Morin, chief operating officer of lithium separator maker Dreamwater International.

David Shaffer replaces John Craig as Enersys president

David Shaffer has replaced John Craig as the president of Enersys effective 1 November but Craig will remain with the company as chairman and CEO.

With this move, Shaffer has been appointed to the newly created position of president and chief operating officer. Shaffer was appointed president of the battery manufacturer's Europe, Middle East and Africa business in January 2013 and prior to that was president of Enersys' Asia and Australia business.

49 year-old Shaffer, who has over 24 years experience in the battery industry, joined Enersys in 2005.

Shaffer will continue to report to John Craig. "Dave is an experienced executive recognized for his accomplishments at Enersys, I want to congratulate him

on his new position and look forward to continuing to work with him," he said.

"As Enersys continues to grow towards our goal of $4 billion in revenue by 2018 this new position is one more element that will help ensure we achieve this objective."

ABC launches and starts commercial production of AGM VRLA battery

US battery company Advanced Battey Concepts (ABC) has commenced commercial production of its patented valve regulated lead-acid battery (VRLA).

The company launched the large format, bipolar, sealed absorbed glass mat (AGM) VRLA battery at 14 ELBC in Edinburgh.

According to ABC, the battery uses 45% less lead than standard VRLA batteries and reduces manufacturing costs as well as cost of ownership. It is designed to charge in around half the time than other VRLA batteries.

“It has been a significant challenge to develop a commercial battery in such a large format that delivers consistently high performance results and combines the additional benefits that come with a sealed unit and AGM technology,“ said Edward Shaffer, CEO and founder of ABC.

The patented battery is 100% compatible with existing charging and recycling systems. "As we move into commercial production, we felt that the time was right for Advanced Battery Concepts to make a valuable contribution to ALABC's programs,“ said Shaffer.

Michigan-based ABC recently joined the Advanced Lead Acid Battery Consortium (ALABC). The company is also currently developing a low cost and high voltage partial state of charge advanced lead-acid battery for automotive applications.

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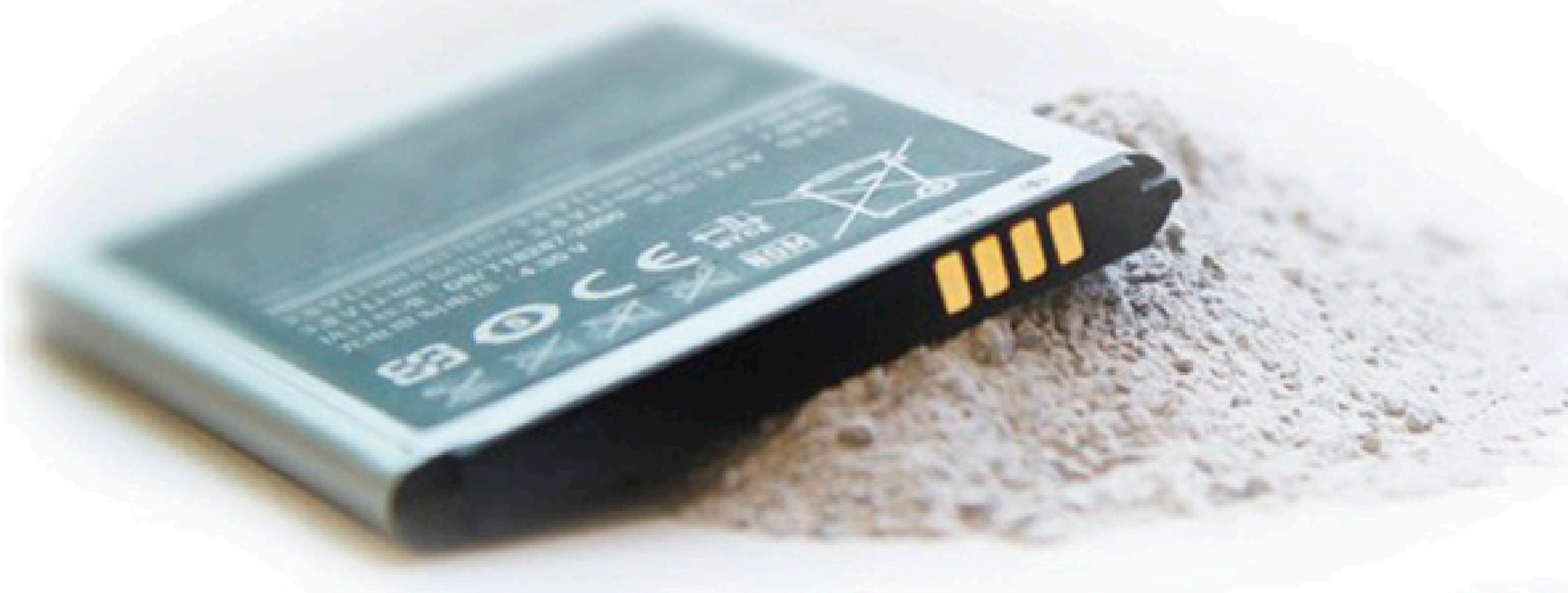

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Southern California Edison commissions 32MWh lithium energy storage system

Southern California Edison (SCE) commissioned the largest lithium-ion battery storage system in North America on 24 September at its Monolith substation in Tehachapi, California.

The utility plans on running the 8MW/32MWh facility for the next two year to test the performance of the batteries in real-world conditions. It will also test how to automate and integrate the operations of the storage facility and its power onto the grid.

The project is located in the Tehachapi wind resource area, which should have 4.5GW in installed wind capacity by 2016.

The system cost $50m, with the costs split by SCE and the US Energy Department.

California's investor-owned utilities are facing mandates from the Public Utilities Commission to add 1,325MW of energy storage by 2024. The requirement for energy storage is being driven by the state's need to integrate increasing amounts of variable renewable generation under the state's climate policies.

The 32MWh of battery capacity represents 604 racks that collectively hold more than 10,000 battery modules supplied LG Chem.

Younicos and WEMAG open 5MW battery park in Germany

Berlin-based renewables company Younicos and green electricity provider WEMAG have launched Europe's biggest commercial battery park in Schwerin, Germany.

The lithium-ion battery pack has a capacity of 5MWh. The battery storage is designed to stabilise grid-frequency and to integrate wind and solar power into the grid. The energy storage system (ESS) also comprises of Younicos' software. According to the company, the ESS provides as much control power as a conventional 50MW turbine.

Samsung SDI supplied the lithium-ion cells with guarantee of 20 years performance.

"High power intelligent storage such as the Wemag Battery Park is the key to a more efficient, greener and more economic energy system. They make the grid more intelligent, flexible and resilient and allow us to shrink the old, fossil-nuclear system as the new, renewable and decentralized system grows", said Clemens Triebel, CTO of Younicos.

The German government aims to increase the use of renewable energy to lessen the dependence on fossil fuel and nuclear-generated electricity.

Younicos' software is also integrated in a commercial energy storage trial in Leighton Buzzard, UK and on parts of Italian grid operator Terna's storage lab on Sardinia, Italy.

The opening ceremony took place on September 16 with Germany's vice chancellor Sigmar Gabriel.

ABB and BYD team up for energy storage solutions

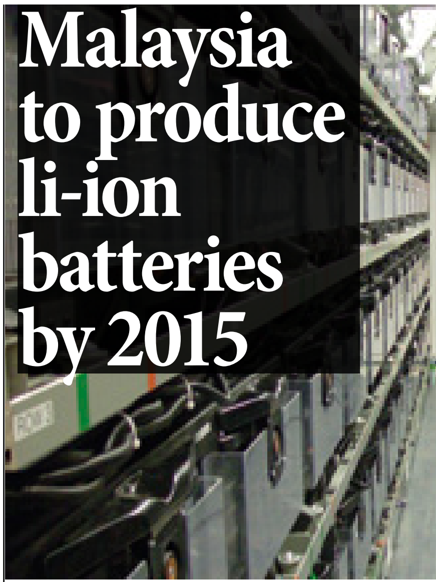
Switzerland's automation technology group ABB and China's battery maker BYD are to jointly develop energy storage solutions.

The collaboration will focus on the development of electric vehicle (EV) charging, micro-grid as well as off-grid energy storage systems, PV storage and applications for the fast-growing marine segment. Financial details were not disclosed.

The companies aim to combine ABB's experiences in EV charging and grid storage with BYD's expertise in battery technology in order to accelerate the introduction of new energy storage products.

"We are pleased to build on our achieved joint success and broaden our excellent cooperation with BYD. This next step will bring two leading companies with highly complementary expertise and market access for electric energy storage closer together," said ABB Chief Executive Officer Ulrich Spiesshofer.

Malaysia to produce li-ion batteries by 2015



The Malaysia Automotive Institute (MAI) is to start producing lithium-ion battery prototypes for electric vehicles (EV) and energy storage by 2015.

"There are only a handful of lithium-ion battery manufacturers on a global level. We're currently conducting research on producing a prototype for the local market and possibly export," said MAI chief executive officer Madani Sahari.

The MAI will produce the batteries in collaboration with Malaysia's transport logistics firm ARCA and Australia's EV researcher AutoCRC and Swinburne University of Technology.

The first battery will be designed for an electric bus prototype developed by ARCA. The first test runs are scheduled for the second quarter of 2015. "Once we have successfully tested the prototype battery, we want to then produce them locally on a wider scale," said Sahari.

ARCA is to invest $63.45m over a period of four years into development and production.

ABB to install flywheel storage system in Alaska

ABB is to deploy an integrated commercial flywheel system on Kodiak Island in Alaska, US.

The flywheel system, integrated with a battery, is aimed to enable the integration of renewable energy from an expanded wind farm to its microgrid and to address stability challenges.

The system comprises of two 1MW grid stabilisation generators based on a spinning flywheel with inverters to store short term energy to absorb or inject real and reactive power onto the grid.

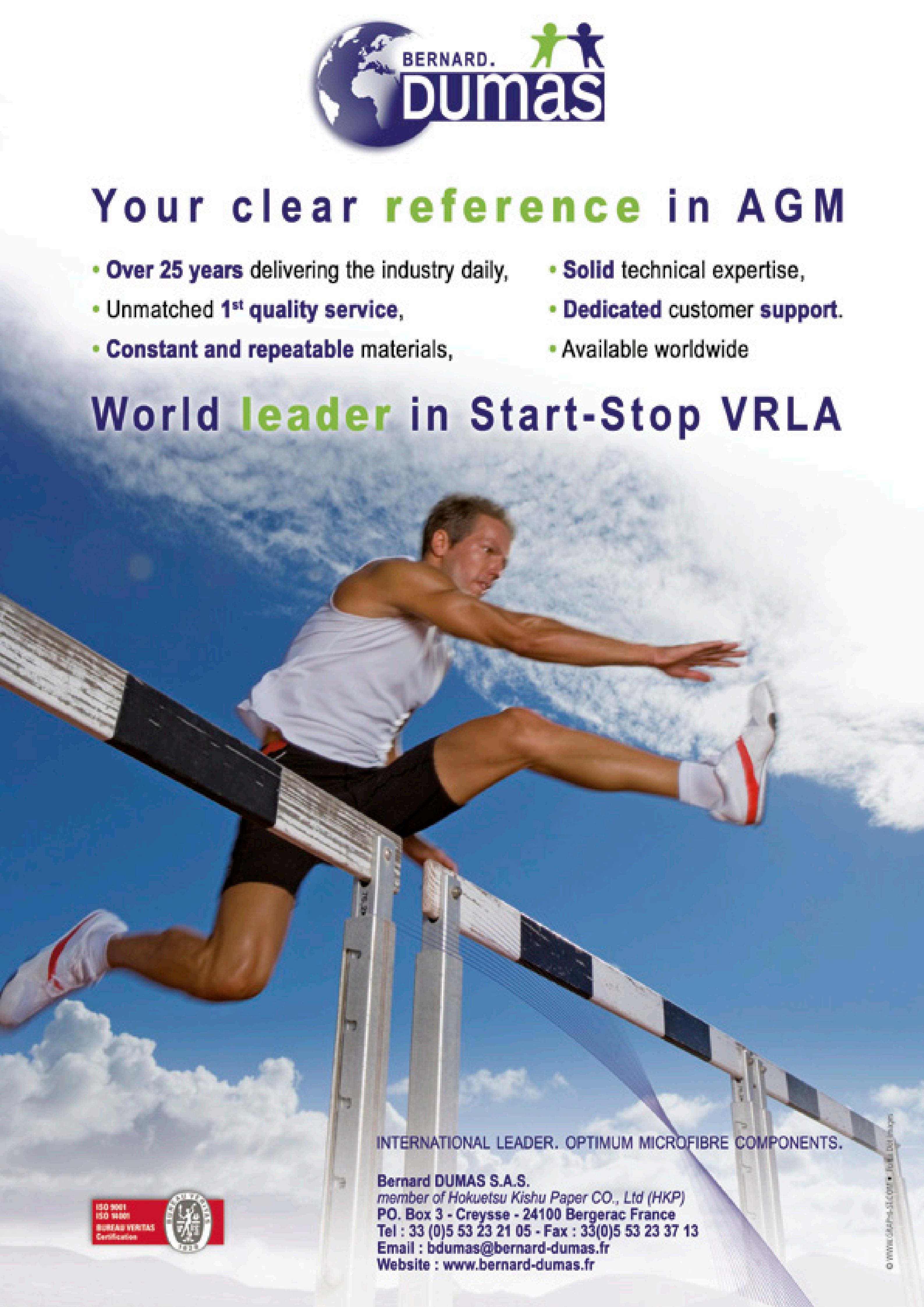
The flywheel will help the 3 MW of batteries already installed to manage the fluctuation of power induced by the 9 MW wind farm and of the to-be installed electric port crane, the current one being smaller and running on diesel.

According to the Swiss-Swedish power electronics giant, the system can switch from a full-power charge to a full-power discharge in less than 5ms.

Kodiak Electric Association (KEA), an electric cooperative owned by residents of the island, commissioned ABB. KEA operates a microgrid that generates 28MW of electricity capacity from hydropower and wind. The island is populated by 15,000 people.

"Remote locations like islands may be rich in renewable energy sources, but the intermittent nature makes their integration into the power grid a challenge," said Claudio Facchin, head of ABB's power systems business.

"ABB's innovative microgrid solution as in this case includes grid stabilization technology that enables high penetration of renewable power generation, and distributed control systems that provide intelligent power management and efficient hybrid power plant operation," he added.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Audi to introduce 48V electrical system to future cars

German carmaker Audi is to introduce a dual 12V/48V electrical architecture to future ICE (internal combustion engine) vehicles.

The 48V system features a lithium-ion battery and a DC/DC converter to integrate the 12V electrical system. The alternator achieves an energy recovery output of 10kW, adding up to a saving of up to 10g/km CO2, according to Audi.

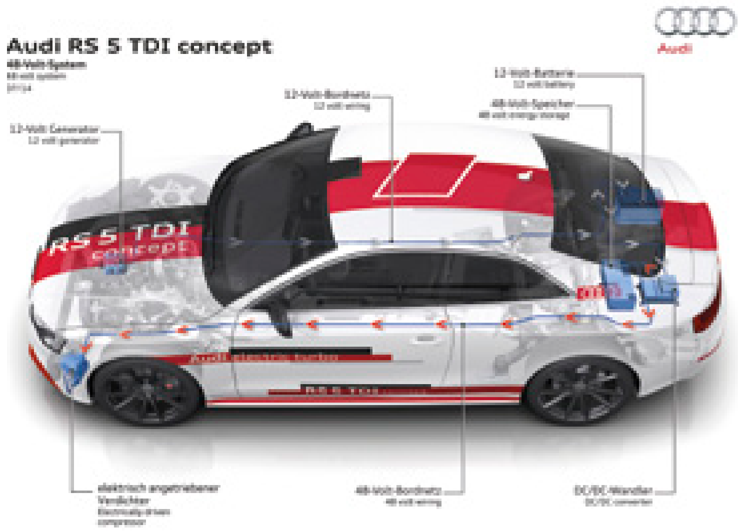
Current 12V systems incorporating lead-acid batteries are at the limits of their capability. 'Hotel' load components can account for the entire power generated by the alternator – up to 3kW.

According to Audi, the 48V system can make more energy available than the 12V system and allows the carmaker to integrate new features such as e-boost technology that make vehicles more "sporty" and efficient.

"The lithium-ion battery operates in conjunction with a new alternator. Within this concept there are diverse ways of starting, controlling and deactivating the combustion engine as needed," said Ulrich Hackenberg, member of the board for technical development at Audi.

The automaker has not revealed the timeframe for the 48V launch. Audi's next-generation SQ7 electrically-turbocharged diesel SUV, which will feature a 48V electrical system, is to be launched in 2016.

The news came at the same time with LG Chem's announcement that it has struck a deal with Audi to supply its 48V lithium-ion batteries.



Grafoid acquires li-ion battery maker Braille Battery

Canada's graphene products developer Grafoid has bought lithium-ion automotive battery maker Braille Battery.

Grafoid acquired 75% ownership interest in US-based Braille Battery, which produces lightweight lithium-ion batteries and AGM lead-acid batteries for IndyCar, NASCAR, Formula 1 racing cars, motorcycles and batteries for the marine industry. Braille Battery's founder Blake Fuller will remain president and chief operating officer.

Financial details on the deal were not disclosed. Grafoid aims to commercialise its graphene technology, the so-called MesoGraf products, with the acquisition. "Grafoid's high-energy performing MesoGraf graphene combined with Braille's cutting edge engineering and manufacturing capabilities create a perfect fit for adapting a novel power source to the needs of our future electric vehicle manufacturing customers," said Grafoid CEO Gary Economo.

"The diverse capabilities of MesoGraf graphene will enable Braille Battery to improve not only lithium ion batteries, but other transportation power technologies," said Blake Fuller, who founded its firm 2002 next to his involvement in racecar driving.

According to the company, its products are cheaper, because the company managed to simplify the production process from raw graphite to the final product.

In 2013, Grafoid launched a commercial platform with Focus Graphite, owner of Quebec's graphite deposit and he National University of Singapore's Graphene Research Centre, the IP holder of the MesoGraf production process.

EnerVault adds Denis Giorno to board of directors

California-based energy storage firm EnerVault has appointed Denis Giorno to its board of directors.

Giorno currently works as CEO and president for Total Gas & Power New Energies USA. He joined the company 1975 and has held numerous, international management positions within the Total group.

He also serves as one of the directors of Californian solar company SunPower.

"His in-depth knowledge and experience in utilities, renewable energy, and international markets will help guide EnerVault as we continue to pursue utility scale energy storage," said Jim Pape, CEO of EnerVault.

EnerVault manufactures long-duration, grid-scale energy storage systems based on iron-chromium redox flow battery technology.

The company is currently working on a redox flow battery storage project in California's Central Valley. According to EnerVault, the system is designed to deliver 1MWh of energy from a 250kW battery performing for four at that rated level.

Camel acquires Apollo Battery

Chinese battery company Camel Group has bought Yangzhou-based Apollo Battery for Rmb220m ($355.98m).

The company acquired 100% of the company from two Australian shareholders, Oriental Technologies and Indeveno Industrial Supply.

Apollo Battery develops and produces lead-acid batteries for the automotive and shipbuilding industry. The company has an annual production capacity of 3m units and has an international customer base.

Camel produces lead-acid, lithium-ion and battery materials. The company is also involved in battery recycling through its subsidiaries. Camel mainly provides batteries for automobile engines and e-bikes.

The deal enables Camel to expand in east China. Camel has now production facilities in east, west, north and central China.

A preliminary stake acquisition agreement was signed in April this year.

Amara Raja Batteries to enter solar and motive power markets

Indian Amara Raja Batteries (Amara) is to expand into the solar and motive power markets and plans to open a second manufacturing plant in Chitoor, India.

Amara aims to target the solar storage market with its lead-acid batteries. Its motive power batteries are aimed to be supplied to a wide variety of electric powered transportation systems, including the railway market.

The battery manufacturer has commissioned an additional manufacturing plant in January in Chitoor, India and is to open another battery factory in the same region in December this year in order to increase its exports.

Amara is currently supplying lead-acid batteries to the industrial and automotive market. Amara's focus has been on Indian Ocean rim countries, especially in the African continent. Its batteries are now marketed in Nigeria, Uganda, Tanzania and Egypt.

"We will also continue to explore the possibilities for forging strategic alliances in the industrial batteries business and cater to dynamic technology changes in the storage power sector globally," said Jaydev Galla, managing director at Amara.

In 2013, Amara and Exide Industries have dominated the Indian lead-acid battery market with a 90% market share.

Lockheed Martin buys Sun Catalytix assets

US aerospace firm Lockheed Martin has acquired assets from flow battery energy storage firm Sun Catalytix.

Sun Catalytix, an MIT spinout startup, will become a wholly-owned subsidiary and operate under the name of Lockheed Martin Advanced Energy Storage in the future. 25 employees along with patents and the company's business plan will become part of Lockheed Martin. The financial terms of the acquisition were not disclosed.

Sun Catalytix was founded in 2008 and funded with $4m by the US Departement of Energy's Advanced Research Projects Agency-Energy in 2010 and won more than $10m in funding from Polaris, Tata and others.

One of the company's major interests was to produce flow batteries for grid-scale and commercial-scale storage after switching from its initial interest, the development of an artificial form of photosynthesis to harvest hydrogen from solar energy.

Unlike vanadium redox or other established flow batteries, Sun Catalyst's electrolytes are made from metals combined with ligands, which are molecules that bind to metal atoms. The company says using metal-ligand compounds allows this active material to be dissolved in a near-neutral aqueous solution - rather than a strong acid - which is safe in the case of a spillage and is not corrosive to pumps and valves.

According to Sun Catalytix, it's developed storage system can deliver 1MW of power for up to four to six hours using a battery roughly the size of a shipping container at a cost lower than the current long-lasting batteries used in public power grids.

Ador Digatron India appoints director for Pune facility

Ador Digatron India appoints director for Pune facility

Ador Powertron and Digatron Power Electronics have hired Somnath Singha as director for the companies's Indo-German joint venture (JV) Ador Digatron India in Pune, India.

Singha has worked for critical power supplier Emerson and was, before joining the JV, CEO of Adino Telecom where he restructured the company. He has more than 20 years of experience in the uninterruptible power supplier and battery industry.

Singha will be responsible for strengthening the JV's operations as well as entering new markets with new power electronic test equipment and managing the corporate culture.

He holds an engineering degree in electronics and telecommunication.

Saft chairman John Searle dies

John Searle, the British-born battery executive who helped take French battery maker Saft to the stock market, has died suddenly at 60.

Searle joined Saft in 1990 and helped make the firm a significant international player, work colleagues stated. The company was spun out of the French telecom giant Alcatel in 2004 and under Searle's management, the company established operations in 18 countries and became a leader in the deployment of lithium battery technology.

Searle has been succeeded by Bruno Dathis, CFO of the Group since 2008.

Navitas promotes Mil Ovan to president

US-based energy storage company Navitas Systems has appointed Mil Ovan as the company's new president.

Ovan was previously Navitas Systems' as chief marketing officer. Before joining three years ago, he was a principal of Nova Associates and senior vice president as well as co-founder of battery developer Firefly Energy. In his new role he as president of Navitas Systems, he will be responsible for overseeing all functional areas of the company.

"Mil's leadership in the last eighteen months as Navitas Chief Marketing Officer has continued to positively impact all areas of our products, business divisions, and served markets. So it was only natural to install Mil into this new role and to position our company for the next level of growth and profitability," said chairman and founder Alan ElShafei.

"Over the next few months, we're going to be unveiling a number of significant new products which will demonstrate our growth strategy of delivering the most innovative and robust energy storage and power electronics solutions in several high growth markets," Ovan said.

Navitas also appointed David VanAssche as vice president of operations and strategic programs, located at Navitas Advanced Solutions Group in Ann Arbor, Michigan, US.

Entek reveals lead-acid PE separator at ELBC

Lead-acid separator company Entek has launched the LR (low resistance) separator for lead-acid automotive batteries at the European Lead Battery Conference in Edinburgh.

The PE separator is designed for extended flooded battery applications and aims to offer high porosity and low electrical resistance. The initial product launch is for separators with 0.20 and 0.25mm backwebs.

'What everybody has learnt is that we can't have both, you can have high punctural resistance, but you are suffering on the electrical resistance or vice versa. But our new separators can have both," David Trueba, vice president sales and marketing at Entek told BEST.

Trueba said Entek's LR separator results in 30% lower electrical resistance and 20% higher puncture strength compared to a standard separator with the same backweb and overall thickness.

Entek worked over two years on the product and carried out commercial trials. As BEST understands, Entek will supply the separators to a Western European lead-acid firm in Q4 2014.

The production of the Entek LR separator production will start this week at Entek's plant in Newcastle, UK and later on as well at the company's facility in Oregon, US.

The company has invested $17m to develop its next generation lead-acid separator materials at its Newcastle manufacturing plant, which celebrates 25 years of production this week.

Digatron launches silicon carbide based battery test equipment

Germany's Digatron Power Electronics has launched its next-generation battery/cell testers with silicon carbide (SiC) technology.

The universal battery tester is designed to test batteries ranging from 0-20V, the cell tester to test cells from 0-6V. The charging/discharging rate is up to 150A per 1.8kW circuit.

According to the Aachen-based company, the SiC technology enables the test equipment to be cooler and quieter than other testing equipment in the industry. "The SiC technology is very exciting, but rarely used until now," Ralf Beckers, Digatron Power Electronics' head of marketing, told BEST.

"SiC devices have lower losses and higher voltage," he added. The company's products use SiC junction gate field-effect transistors that are more efficient at high reverse voltages than Si insulated-gate bipolar transistors.

Both systems comprise of six independent circuits and have a packing density of up to 48 circuits per cabinet. The system can utilise two different kinds of energy regeneration. A so-called 'Biconditional Energy Supply' balances the energy flow between the circuits and tracks the energy balance of the DC link either to generate energy or to feed excess energy back to the three-phase grid.

Oxis Energy to supply lithium sulphur batteries for marine applications in 2015

Britain's Oxis Energy, in conjunction with compatriot MSP Technologies, is to market lithium sulphur battery packs for marine applications in spring 2015.

Launched as part of MSP Technologies' Ghost – Power range of diesel/battery hybrid power systems for motorboats, Oxis Energy's lithium sulphur packs will be scalable from 20 kWh to 50 kWh upwards. The battery will be designed for Lloyd's Register approval, which Oxis Energy claims will give safety assurance to customers while helping to lower insurance premiums.

Ainsworth told BEST: "We are currently achieving 265Wh/kg on prototype Li – S pouch cells and around 300Wh/kg in R&D cells.

"Other companies have publicised higher energy densities than this, but they have achieved them using volatile electrolyte systems that are unsafe. We have been able to achieve our energy density figures using electrolyte systems that show a high degree of safety.

"In terms of cost the cathode cost for our Li-S cells will be significantly cheaper than for Li – ion chemistries where the cathode material typically accounts for over 25% of the material cost of the cell. Additionally, all other material and processing costs in our Li-S cells are comparable to Li-ion chemistries, so at volume cell costs should be lower."

Industry veterans share 2014 International Lead Award

Dick Amistadi and Michael Mayer shared the 2014 International Lead Award at the 14th European Lead Battery Conference (ELBC) in Edinburgh.

The International Lead Award is presented on behalf of the International Lead Association to recognise lead industry stalwarts for their contributions.

Amistadi has worked in the lead battery industry for 47 years, working 37 years at Doe Run, which he joined in 1968. In 1992 he became the first chairman of the Advanced Lead Acid Battery Consortium, standing down in 2005.

Amistadi retired in 2005 and immediately established a consultancy, Amistadi Associates. Pennsylvanian Amistadi was nominated chairman and president of the Association of Battery Recyclers in 2012.

"Lead air pollution and employee blood lead levels are at an all-time low," he said. "The industry has been highly successful, and we need to publicise this more.

"I'm proud to be part of the lead acid battery and recycling industry. It feels like being part of an extended family, it has a closeness not seen in other industries."

80 year-old Michael Mayer, who launched the European Lead Battery Conference in 1988, has worked for the lead acid battery industry for most of his life. He spent many years with battery companies in the

UK and the USA and joined the Lead Development Association (now the International Lead Association) in 1979. Mayer formed the Electric Boat Association in 1985.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Varta launches EFB battery with 'unique' acid circulator

Varta has launched an EFB battery for heavy commercial vehicles featuring a 'unique' acid circulator to reduce stratification.

The battery is specifically designed for high-performance commercial vehicles with large power demands and intense vibration resistance requirements, including end-of-frame installation.

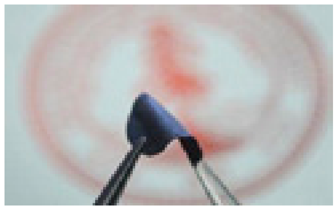
The German battery maker, owned by Johnson Controls, claims the innovative circulator effectively prevents the acid stratification effect. Florence Bailleul, Vice President & General Manager Aftermarket EMEA, said: "The unique acid circulator is a Varta benchmark' technology that guarantees better acid circulation and keeps charge acceptance at the

Stanford University reveals carbon-coated lithium anode technique

Researchers at Stanford University have created a carbon-coated lithium anode, which has performed 150 charge/discharge cycles without forming dendritic spines at 99% Columbic efficiency.

The team placed layers of amorphous carbon to form a protective coat around the lithium anode, thus allowing it to expand and contract without causing dendritic growth at the electrolyte-electrode interface, claimed the Stanford team in a research paper published in Nature Nanotechnology.

To build the coat, the researchers placed a layer of polystyrene spheres 500 nanometers across. A layer of amorphous carbon was deposited on top of the spheres. The polystyrene spheres were then ablated with heat, leaving the layer of carbon sitting on top of a copper backing. Lithium was



then electrodeposited onto the copper, filling in the space below the carbon cap to form the electrode.

The researches claimed they managed to increase the efficiency of a lithium anode battery from 96% to 99%. But more research needs to be done to get the anode's efficiency up to 99.9% over a long period of charging cycles, the team said. The test run ended after 150 cycles and the batteries were not tested at very high charging rates.

A stable performance at high charging rates is necessary if the anode is to be commercially available and integrated in an EV or consumer electronics battery.

highest levels. The battery will last much longer and the risk of failure is reduced significantly."

Meanwhile, Varta has added its Blue Dynamic EFB and Silver Dynamic AGM batteries to its range of automotive batteries. In a statement, Varta said both batteries come with a longer cycle life performance and stand for reliability and high starting power.

UK to fund research for energy storage device materials

Energy storage device materials are among the low carbon vehicle technologies given £6m ($10m) funding by a UK research council.

The UK Engineering and Physical Sciences Research Council (EPSRC) is funding two new research projects - ELEVATE (ELEctrochemical Vehicle Advanced Technology) and Ultra Efficient Engines and Fuels – involving academics from eight UK universities.

ELEVATE, led by Professor Rob Thring at Loughborough University, will develop better materials for energy storage devices such as fuel cells and batteries and improve integration between devices, vehicles and power grids.

It will draw on expertise in departments of Chemistry, Chemical Engineering, Materials and Manufacturing and be informed by an Industrial Advisory Committee that includes companies such as Jaguar Land Rover, Johnson Matthey and Intelligent Energy.

While Ultra Efficient Engines and Fuels, led by Dr Robert Morgan at the University of Brighton, will investigate how to improve the operation of internal combustion engines by as much as one third efficiency and how new fuels' performance can be used in future engines to bring emissions close to zero.

It will involve academics from departments of Computing, Engineering & Maths, Engineering & Design, Physics, and Mechanical Engineering. Industrial partners include Delphi Diesel Systems Ltd, Jaguar Land Rover, BP British Petroleum, Ricardo UK.

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Ambitious Northern Ireland compressed air energy storage project set to be online by mid-2018

An ambitious 268MW compressed air energy storage (CAES) project in Northern Ireland could be online by mid-2018, according to developer Gaelectric.

Wind energy developer Gaelectric wants to build the approximately £300m ($491m) CAES project on the outskirts of the Northern Ireland port of Larne. The project would require the development of three 230,000 m3 salt caverns to store compressed air and provide up to six hours of energy for peak-time use.

Electricity from the nearby Ballylumford gas-fired power station fed via a new 5km cable would be used to power an electrical motor, which would drive a 300 bar compressor that stores air in the salt cavern. When electricity demand increases, this air would be released and used to run a turbine to generate electricity.

To improve the power output of the turbine, some natural gas is used in the combustion cycle. This will require the construction of a 1.8km pipeline.

Gaelectric's programme manager Conall Haughey said the final submission to Northern Ireland's planning authorities was imminent. "We would hope to receive planning consent in July 2015, and have the three caverns operational by June/July 2018," he told BEST.

Navitas reveals drop-in lead-acid replacement

US-based Navitas Systems has launched a lithium battery family for commercial, industrial and military applications.

The Ultanium line, designed to directly replace lead-acid batteries,come in three versions; a 24V version for electrical systems of military vehicles, a 12V type for military or commercial starting/deep cycle applications and a 12V version for deep cycle applications.

"Commercial and military vehicles contain 21st century electronics, but they still are saddled with using 19th century lead-acid batteries," said Navitas Systems' president Mil Ovan.

The batteries are the same size as most military, commercial and industrial lead-acid batteries and work with existing lead-acid chargers. The company improved cycle life, runtime of the Ultanium line, which work nearly 50% faster in ampere-hours to full state-of-charge than traditional lead-acid batteries.

The new batteries will be undergoing testing by the US Army later this year.

14th ELBC: So much to do, so little time

BEST visits the 14th ELBC in Edinburgh and was underwhelmed by the technical prowess on display. Good parties, though...

Digatron's Kevin Campbell aka 'Kevin of Scotland'

Edinburgh in mid-September 2014 was a place of wonder. It felt like the centre of the universe. Was this anything to do with the International Lead Association's (ILA) 14th European Lead Battery Conference (ELBC) taking place in 'Auld Reekie'?

Er, no. With the referendum just one week away, there was a vibe in Scotland's capital like the Berlin Wall was about to come down. Or go up. A hoarding promoting redevelopment in Edinburgh's Haymarket district that read 'SOMETHING EXTRAORDINARY IS HAPPENING' had it dead right.

But there was little extraordinary at the 14th ELBC. The show kicked off with a scene-setting opening session that attempted to place lead-acid batteries in the forefront of the battle against climate change.

Julian Allwood, professor of engineering and the environment at the University of Cambridge gave a worthy presentation, 'Climate Change Mitigation, Lead and Energy Storage'. Sadly, by his own admission, Allwood's knowledge about batteries is minimal, and lead-acid batteries even less.

This 'Climate Change for Dummies' presentation was a good introduction to the work of the UN's Intergovernmental Panel on Climate Change but whether ELBC delegates were convinced that, in fact, they are doing God's work by helping to the save the planet with lead batteries is moot. Some of the ELBC crowd will be dead in 2020, let alone 2050, so making them worry about global temperatures in 2100 is a challenge.

On the whole, however, it was a smart move to try to make lead battery guys feel good about themselves, as the industry can often feel under attack from all sides.

Allwood was highly sceptical about the green credentials of EVs, and people have been "sold a lie", noting the Toyota Prius has the same fuel consumption as the original Mini. Drive a small car to save the planet? Sure, but you can't get golf clubs in a 25-year old Mini...

The lead-acid battery industry is not making enough noise about the high recyclability and low energy intensity of the battery production cycle, said Allwood. But is recyclability of lead-acid a sexy thing? You decide, dear reader.

Industry stalwart Patrick Moseley of the Advanced Lead Acid Battery Consortium (ALABC) gave another dummy's guide to climate change (but not quite as good) before moving on to present the results of an energy storage project in Peru – Padre Cocha – which the International Lead Zinc Research Organization and CSIRO launched in, wait for it, 1997.

This was an attempt to show how current lead-acid batteries are in a pain in the ar*e for energy storage projects and stop-start applications, using graphs

Technical Tour: Entek

Lead-acid separator maker Entek celebrated 25 years of production at its Newcastle plant by organising a tour for ELBC delegates.

The bus trip started at prestigious Waldorf Astoria in Edinburgh's city to Entek's facility in slightly less fancy Newcastle suburbs. To lighten things up, the trip included a visit of the 'Harry Potter Castle' aka Alnwick Castle at the end of the trip, too.

Entek was not only celebrating its Newcastle facility, it also revealed its new LR (low resistance) PE separator.

On the way to Newcastle, Entek set the rules for the factory visit. Sales manager Steve Gerts warned that anyone who attempts to take a picture inside the factory would be thrown into the dungeon of Hogwarts.

He also took the opportunity to call attention to the predominant Yes signs in Edinburgh of the independence supporters, to the No signs on the fields of Southern Scotland and included the Scottish bus driver who was quite reluctant to unveil his political viewpoint on the microphone.

Tour members were welcomed in a marquee next to the facility, set up for the Newcastle birthday celebrations. Entek has invested $17m to develop its next generation lead-acid separator materials at its Newcastle manufacturing plant. The company worked over two years on the product and carried out commercial trials. Like a lot of lead-acid companies when it comes to publicise new products, Entek was shy about its new PE separators during the tour.

Only during lunch over shrimps and humus, between factory visit and castle tour, did David Trueba, vice president sales and marketing, answers nosy questions from **BEST.**

The roughly 70 tourists were guided in three groups through the manufacturing plant. The Newcastle plant comprises of eight production lanes. As we walk past the calendaring lanes, the packaging lanes and the quality lab, some people missed "the fun stuff". Hearing complaints by German tour members that there wasn't much to see, Trueba explained chemical gases being released during the process of making the separator material is poisonous and they couldn't take the risk of exposing them to the tour members. ...

That's why we had to watch how separators are put into boxes. Good move to take everyone to Hogwarts afterwards as the guided tour through the personal living room of the Duke and Duchess of Northumberland eliminated any prior complaints.

Next to chemical exposure, one of the main reasons is probably that Entek doesn't want to reveal the secrets of the new technology to curious industry members from other separator companies by accident.

Entek also has an Oregon plant that will eventually produce the new LE separators, too. The company tries to standardise its plants, meaning that the manufacturing process and the workflow should be the same as in England.

Trueba wants to "change the way that separators are integrated into lead-acid cell designs". The new separators have high punctual resistance and low electrical resistance at the same time. Entek says it's possible without the magic of Harry Potter.

Newcastle staff left to right: Brian Clough, Colin Byrne, Marek Kuran, Dennis Merritt

produced by Ford to demonstrate their lack of dynamic charge acceptance. As Moseley rightly acknowledged, "the same".

In what was to be a recurring theme at 14th ELBC, the lead-acid battery industry needs to up its game. "There will only be long-term prospects for lead-acid if rapid recharge and long cycle life is attainable," said Moseley. So what's the solution? The UltraBattery, stupid!

Then there were some downbeat presentations about lithium-ion's prospects. Avicienne Energy's Christophe Pillot's message was EVs were overhyped and said lithium batteries "are kind of a bomb" in terms of safety, albeit in a way suggesting he was told to say it.

Linda Gaines of Argonne National Laboratory was also brought into be bashed up about lithium battery recycling, or the lack of it. When Gaines briefly touched on the issue of dumped lead batteries being disassembled by children she was given a most frosty stare by session chair Andy Bush, the managing director of the International Lead Association.

Apart from the lack of material to be recycled, one of the problems is that there is no danger of demand for lithium outstripping supply by 2050, even if there was no recycling at all. And only the cathodic material of certain lithium-ion batteries using cobalt and nickel is actually worth recycling, unlike iron and phosphate, and even that is marginal.

But, perhaps most importantly, there is no regulation driving lithium battery recycling. The US Environmental Protection Agency (EPA) is not pushing for lithium recycling.

No regulations, no bother? Well, the EPA has not been entirely inactive regarding lithium and, Gaines suggested, the industry may be wise to come up with its own regulations to pre-empt any official moves.

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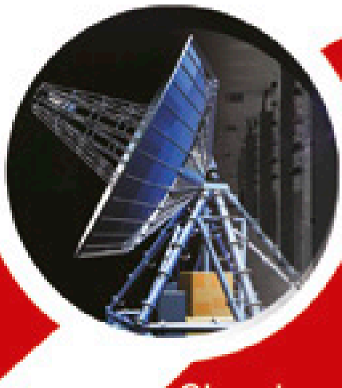


Hollingsworth & Vose's Mitch Bregman once again delivered his industry projections, which are formulated using input from 25 lead-acid battery companies. Bregman's main point was there is far too much focus on automotive batteries and hand-wringing about 'lead could be dead'.

The message is any sales lost to other battery chemistries for industrial and automotive batteries would be compensated by new and/or growing markets such as UPS and grid energy storage.

Noting that 150m photographs are "stored forever" every day on Facebook and predictions for 25 billion connected devices by the end of the decade will contribute to a tenfold increase in mobile data traffic, Bregman expects 7-8% annual growth in battery sales for the communications market to $3.25 billion in 2016.

In total, Bregman expects the global market for stationary and motive power lead-acid batteries to hit $10.2 billion in 2016, up from $8.6 billion in 2013.

Despite the optimism, Bregman was careful not to appear too complacent. Fuel cells have begun to gain market traction at distribution centres, including at Wal-Mart.

Despite the cost of fuel cell systems, Wal-Mart has worked it hard enough to make the numbers work (just) and repeat orders are expected. And while the Dreamliner incident is the toast of the lead-acid industry, it should be remembered that Boeing stuck with lithium-ion batteries.

Former Doe Run VP Dick Amistadi receives award from former room-mate David Prengaman

Eurobat president Johannes Dempwolff put up a sterling defence for lead-acid batteries in vehicles – nothing else is as cheap, and switching to other chemistries is technically challenging – but he voiced concern that the European Commission would not extend the exemption for lead batteries from the End of Life Vehicles (ELV) Directive by another five years.

"The five-year exemption was unusually long," Dempwolff said. "It's hard to predict but the next one may only be two or three years." All will be revealed when the Commission decides on the exemption length for lead batteries by the end of this year.

For the first time the ILA's International Lead Award was given to two recipients. Dick Amistadi, who retired from Doe Run almost ten years ago and 80 year-old Michael Mayer, who launched the European Lead Battery Conference in 1988, were the lucky winners. Will there be a posthumous award in 2016, we wonder?

ALABC – Admission of failure

In his first speech to the ELBC as chair of ALABC, Tim Ellis of RSR pulled no punches in what was a highly critical rant. It was almost as if Ellis didn't really want to be chairman of the ALABC, such was his spiky condemnation of some aspects of the lead battery industry.

This was a radical speech aimed at shaking the industry from its complacency and take it forward to the 21st century, or at least the 20th century. Only time will tell if it will be effective, but it certainly woke up the old-timers hitherto snoring loudly in the conference hall.

Warning that "being big didn't save the dinosaurs", Ellis bemoaned the industry's lot in a world where "for the first time in 150 years, lead-acid has competition". Worse, the lead-acid industry "hasn't invested enough in fundamental research" but "doesn't even have the coffee budget of lithium-ion battery organisations."

Having recently lost BHP Billiton as a member, Ellis attacked lead traders for not dipping into their pockets and joining the ALABC. The new chairman is clearly concerned about losing more members, who were said to be voicing doubts about the validity and relevance of the organization.

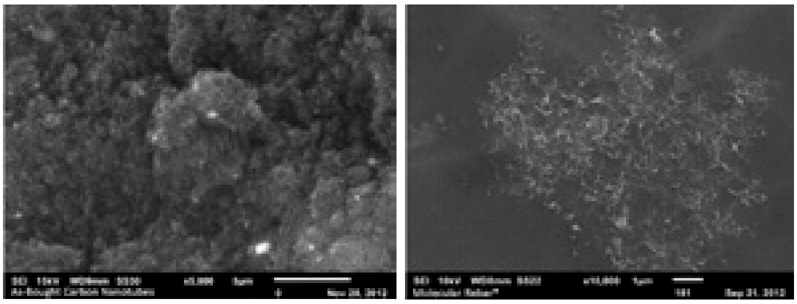
No shibboleth was deemed too sacred. Forty year-old data around since the days of the Soviet era no longer cuts the mustard as credible research for batteries. Battery manufacturers were also condemned for not using the ALABC's research project vehicles, which are sitting in garages at significant cost – will they be binned?

Only by changing attitudes to lead, "second only to plutonium" in terms of bad press, will the industry improve its small funding base. Rather than reinvent the wheel, heard delegates, ALABC should partner with other industries, such as biotech and semiconductors, who have already conducted similar materials research, to give lead-acid batteries some cutting edge.

Ellis said the ALABC's next three-year programme, which commences in 2016, gives an opportunity to have a "very deep rethink" about its purpose. No more school science car projects?

Carbon additives: So much work to do

Ellis, as did others, pointed to carbon additives, one of the major themes of the show, as the future of lead-acid, but this author was distinctly underwhelmed by the



Left: 'As-Bought' CNT Right: Molecular Rebar 'discrete' carbon nanotubes.

session entitled 'The Influence of Carbon on Battery Design'.

Cabot's Paolina Atanassova gave a dummy's guide to carbon additives for advanced lead-acid batteries. This was quite negative on carbon additives.

There are fundamental issues with carbon additives. The increase in NAM depolarizes the negative plate and causes increased gassing and water loss. Conversely, mitigating water loss with lower carbon loading, but this reduces NAM surface area and DCA.

This is no miracle cure, there needs to be a trade-off between higher DCA and water loss. Getting the right recipe is crucial – 1% carbon black is seen as the rule of thumb – but this isn't enough to be 'advanced lead-acid'.

Atanassova gave the impression carbon additives are still very much on the drawing board, and if not an afterthought, it seems rather peripheral rather than its core focus. But, at least, it is encouraging that a major chemicals firm like Cabot is taking it seriously.

Then came a paper by Jusef Hassoun of Rome's Sapienza University of Rome, who has switched from lithium battery to lead-acid. And, judging by his presentation, he seems to having difficulty letting lithium go.

Hassoun made a lithium-style lead pouch cell using a glass fibre separator designed for lithium electrodes. By adding 1.5% carbon black to the anode, Hassoun recorded a capacity of 350 mAh compared to 250 mAh for a similar cell with 0.1% carbon black.

The carbon had lowered impedance. Yep, we knew that already. This caused muttering about whether ELBC is a trade show or an opportunity for academics to show off their pet projects, possibly done in their lunch hour?

It was not until the final paper in the session did delegates learn about purely commercial efforts to develop so-called 'advanced carbon' additives and actually sell them.

And, in fairness, the paper by Molecular Rebar's Paul Everill – 'Discrete Carbon Nanotubes as a Game-Changing Advancement in Lead-Acid Battery Performance' was worth the wait, despite the corny title.

Of course, carbon nanotubes (CNTs) for lead-acid batteries are not new, but hitherto attempts have largely failed because of the impact of high carbon content on reserve capacity, cold cranking and water loss, not to mention paste rheology during formation. In what Everill characterized as a "coming out party" for Molecular Rebar, the firm claims to have cracked the problems of "store bought" CNTs.

Everill said that, rather the using bundled, entwined CNTs, Molecular Rebar uses "individualized entities" largely free from impurities. These "detangled" CNTs were claimed to increase charge acceptance by 150% and cycle life by 300%.

The secret lies in using the right concentration of these 'discrete' CNTs (dCNTs) as a liquid and requests battery manufacturers to reduce the amount of pasting liquid it uses.

The Austin, Texas firm has been working with Fijian lead-acid manufacturer Pacific Batteries in Fiji to test 12V automotive batteries rated with 45 min reserve capacity, 35Ah C20 rate, and 280s cold-crank performance.

After curing, the negative plate contained a final 'dCNT' concentration of 0.16%, a final barium sulfate concentration of 0.24 – 0.37%, a final sodium lignosulfonate concentration of 0.15 – 0.24%, and a final carbon black concentration of 0.06 – 0.12%.

Data generated by third-party tester JBI of Ohio is promising. Reserve capacity tests (25A discharge until voltage ‹10.5V) showed slightly increased capacity in batteries containing dCNT over CNT-free control batteries.

Contrary to other carbon additives, dCNT did not negatively impact reserve capacity or cold-cranking performance. Cold-cranking, durational tests (270 A discharge until voltage ‹6V at 18 degrees C showed that batteries with dCNT persisted 10% longer than CNT-free controls.

Cold-cranking, voltage tests (270A discharge at 18 degrees C, voltage read at 30s) showed marginal increases in voltage from batteries containing dCNT.

The cumulative charge factor - the total charge passing in and out of the batteries during three cycles of recharging, reserve capacity, and cold-cranking studies - showed the Pacific batteries containing dCNT absorbed 15% and passed 3% more charge than CNT-free controls.

Everill noted Molecular Rebar separator issues causing premature failures due to their brittle consistency, probably caused by extra cycles.

The company is confident about the future and is talking to a dozen battery manufacturers about offering samples.

Marketing dCNTs as a premium product, Everill expects it will add 10-20% to the cost of the battery.

Molecular Rebar is considering connecting batteries to solar arrays to benchmark energy storage applications. By the end of the year it expects to be making batteries with dCNTs and is planning a 200 tonnes/year manufacturing facility in Houston, Texas.

Another 'additive' worthy of note was Tim McNally of Borregaard Lignotech, whose paper 'Innovations in Vanisperse Manufacture Dramatically Improve Cold Crank Performance' focused on its next-generation Vanisperse AT. A commercial trial conducted in tandem with Superior Battery demonstrated the use of Vanisperse AT led to a cold cranking discharge time of 53 seconds to 7.2V compared to 44 seconds for Vanisperse A at -18 degrees C.

McNally said these results suggested an 8% potential reduction in NAM, equivalent to savings of $0.65/battery.

Ford: Lose some weight

Ford's Eckhard Karden served up some lessons learned from the usage of lead-acid batteries in stop-start applications. And the message was there are surprisingly few issues, much less than he anticipated a few years ago.

EFBs last for two years of robust service life – good enough – and AGMs are really only necessary for commercial vehicles. When stop-start vehicle thinks the battery is not charged, it probably is, it's usually just an electronic calibration issue.

And while poor DCA means no cycling, this is actually a positive because the battery is effectively protecting itself.

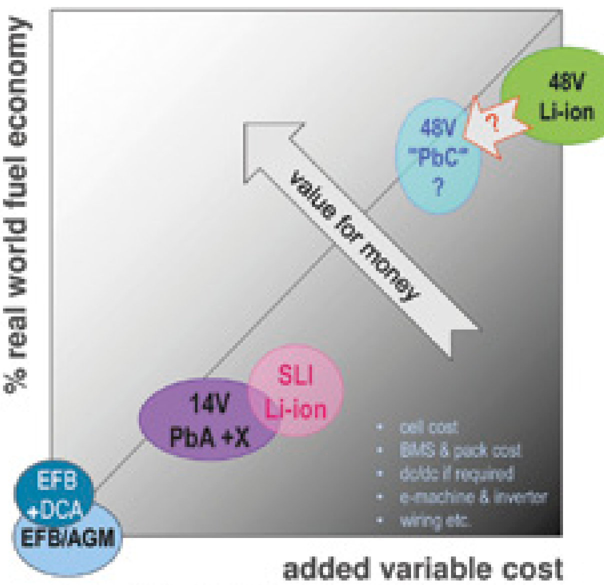
What Karden was more concerned with weight. Stop-start batteries with a capacity of 60Ah have added 1-3kg; if the size was reduced it would offer similar weight savings.

So carbon has a role to reduce weight by getting rid of excess lead. It also would improve real world fuel economy and improve robustness as the electrical load of vehicles increases ever higher. But at some point the industry will run into problems and Ford really doesn't want to use an even bigger battery and add yet more weight.

Yet carbon additives are "not all equal". Some accelerate water consumption more than other, so choosing the right one is critical. Karden said OEMs will not put anything that put hot climate reliability at risk, noting degradation of existing field stop-start battery reliability due to water consumption is already "unacceptable".

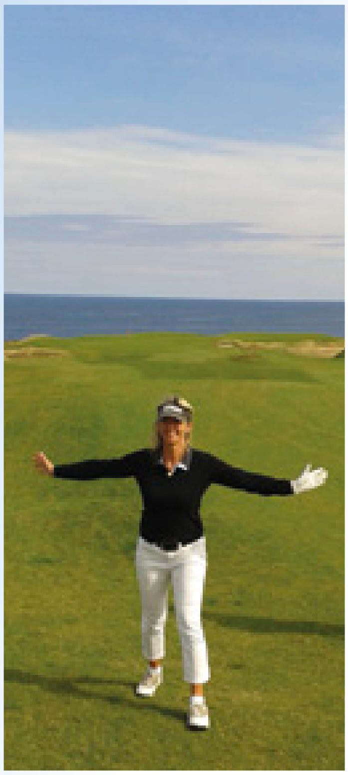
However, water loss due to carbon is at least stable over battery lifetime, unlike the use of antimony in positive plates. A side effect of partial negative polarization is grid corrosion, another issue it wants to get rid of.

DCA is the next challenge. Ford would like to 0.5A/Ah in its own test to allow up to three times more real road fuel economy benefit. Even so, Ford would still be limited by the battery and not the alternator, which gives it reason to look to improved performance from other technologies.



The diagram shows a qualitative representation of fundamental trends. Quantitative results vary with vehicle type, powertrain, driving conditions, etc.

Ellen van Beers crowned champion golfer



Ellen van Beers took the glory at the **BEST**-sponsored golf tournament at St Andrew's.

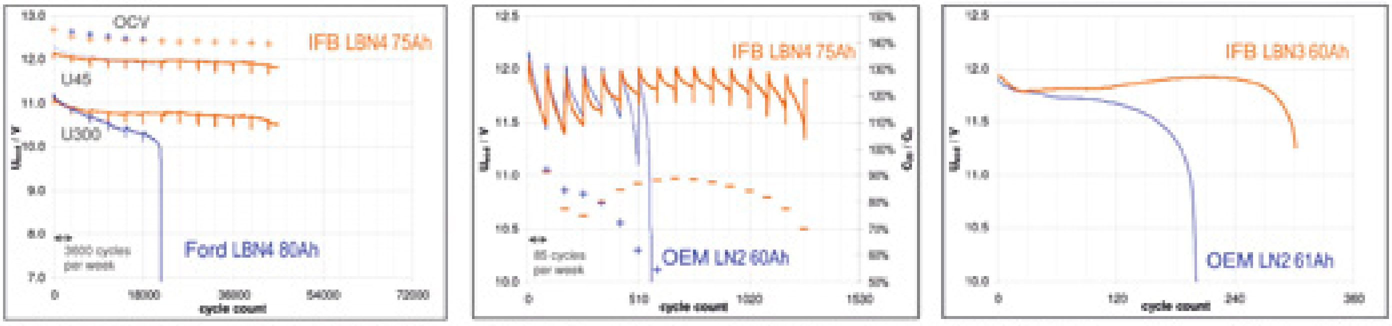
While Ray Kubis of Eco-Bat comfortably shot the lowest total at St Andrew's Jubilee course with a highly commendable round of 78, Ellen van Beers, wife of Luxembourg metals trading firm's Nizi International's Theodoor van Beers, secured the overall honours via the Stableford scoring scheme, which takes handicaps into account, on the Castle course.

John O. Wirtz, president and CEO of Wirtz Manufacturing, was the winner on the Jubilee course. Other Jubilee course winners were Axion Power's Mike Romeo, who bagged the nearest-the-pin award, while Nate Deem of Pyrotek took home the longest drive gong.

Other winners on the Castle course were Mark Yingling of Doe Run, who snagged the nearest-the-pin trophy, while Nate Deem pocketed the longest drive accolade for a second time.

WE FORM YOUR BATTERIES
we have the technology
Excellent
Good
Average
Poor
we form quality
made in germany
>200
MODULES
IN OPERATION
we have the experience
F A Q
we give you support
sophistication
we are highly specialised

cycle life: Over 500·C_n turnover with EFB is possible (2010 data).



SBA S0101 in 25°C water bath (~1.1% DOD) — 17.5% DOD with stratification (25°C water bath) — 50% DOD after deep discharge (40°C water bath)

The challenge is when stop-start is no longer enough to achieve sufficient fleet emissions reduction while being able to manage high loads.

Next generation EFBs should be able to offer up to three times more recuperative power – a big improvement - but much less than the alternator can provide, which is up to 3kW, and it is unrealistic to dump 150-200A consistently into a lead-acid battery.

A cheap option would be to upsize the alternator to 14V with 3.5kW recuperative power. This would require a secondary energy storage device, likely to be a lithium LFP or LTO battery, and not a supercapacitor, which would require an expensive DC-DC converter. Karden also warned that the threat from 12V lithium batteries should not be underestimated.

But, the moment, Ford wants an EFB with higher DCA offering a cheap, durable solution at lower weight without increased internal resistance. Easy? Apparently not.

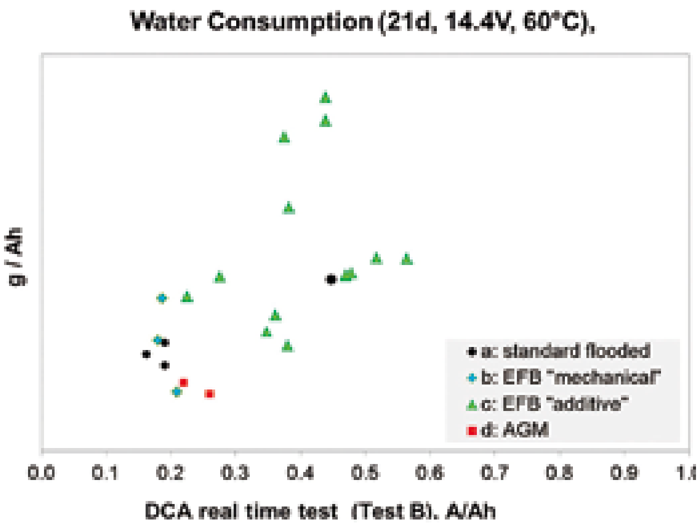
Manfred Gelbke of Moll Batterien said it had seen "remarkable" improvements in so-called 'next gen' EFBs featuring carbon additives, i.e. its latest series product, due to more uniform current discharge through the plates, thus reducing acid stratification and therefore premature aging.

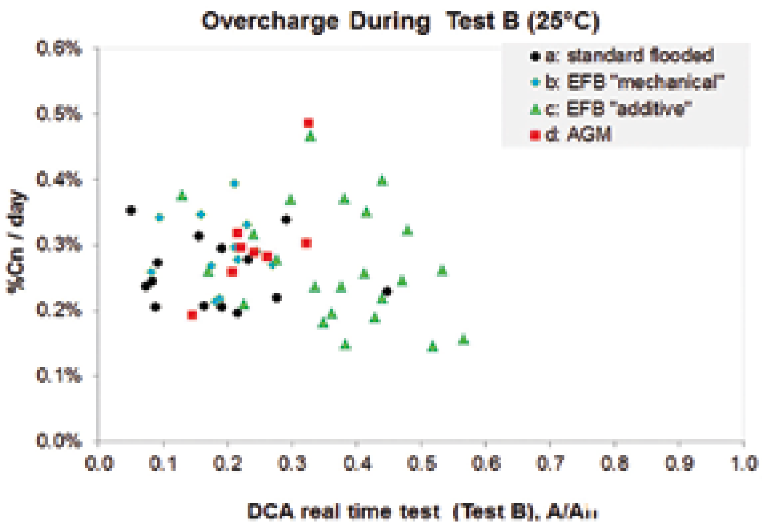
But the main message was EFB (and AGM) had significant improvement potential but there is an urgent requirement for detailed research into how carbon additives affect pore size and therefore stratification and, ultimately, DCA. This was one of several papers calling for urgent research. Over to you, guys.

Saving the polar bears: Lead-acid batteries for grid energy storage

The lead-acid batteries for energy storage session was a mixed bag. Ecoult's John Wood almost had a tear in his eye remembering East Penn's tragically deceased Sally Miksiewicz, but he has plenty to be happy about with the progress of the UltraBattery.

By the end of the year, Ecoult will launch an updated large format UltraBattery, which is claimed to have double the power





output for half the lead, with a PSoC range of 40-50%. Watch this space.

The numbers seem to stack up, at least for batteries installed at East Penn's manufacturing facility in Pennsylvania. Wood claimed an IRR of 14% for a 3MW system to provide frequency response for the PJM market, with multipurposing – demand response and UPS back-up as well as FR – this rises to an IRR of 43%.

Time will tell whether UltraBattery economics are so impressive at installations not belonging to the manufacturer, but Wood was very upbeat about Ecoult's prospects.

Enersys' Steve Vechy gave a terrifically cynical reality check, reminding the audience that most projects thus far have been reliant on some form of public money, Thomas Edison thought it was a boondoggle over 100 years ago, and, in any case, if battery energy storage was so good then why isn't it already ubiquitous?

The level of skepticism was not surprising from Vechy, but Enersys does supposedly have a business unit – OptiGrid – which offers a turnkey lead-acid battery energy storage installation.

Exide has hopes for its Tensor Solar branded gel lead-acid battery, aimed at German householders with domestic solar PV, replete with fancy casing. While it looks a 21st century product, in truth Tensor Solar – marketed under its Sonnenschein@home domestic energy storage brand, is little more than a battery in a box costing around €2-4000 for up to four 8kWh modules.

Inverters and a BMS are not included in this package and if you want IUIa charging it will need a €5000 converter. Will Sonnenschein@home take Germany by storm? Don't hold your breath.

The next ELBC takes place in Malta's capital city Valletta. When this was unveiled at the gala dinner this drew gasps of delight from the wives. Great parties! But the conference...?

Faradion:

Boosting the industry's capacity to make sodium-ion batteries

The Editor visits Faradion and a finds a small British sodium-ion battery developer with, potentially, a big future.

They say that an organisation is only as good its people. That augurs well for a British startup, Faradion, one of the few companies trying to bring sodium-ion batteries to market.

Faradion is the brainchild of a trinity of distinguished battery professionals. They include Faradion's chairman Chris Wright, former group operations director of AEA Technology and responsible for licensing of the highly successful lithium cobalt oxide (LCO) in the 1980s.

Chief technology officer Jerry Barker is a former chief scientist of US-based Valence Technology, and is claimed to have invented more lithium-ion electrode patents than anyone. The last of the trinity is chairman Andrew Dixey, former CEO of bipolar lead-acid battery developer Atraverda. In July, Dixey departed, with CEO Wright moving to chairman and replaced by Lawrence Berns, the former CEO of battery module maker Axeon, which was acquired by Johnson Matthey in 2012. Quite a team.

Lawrence Berns, former CEO of battery module maker Axeon. Top: Chris Wright chair of Faradion.

Faradion is somewhat unusual in the sense it was formed by a venture capital firm, rather than by a University spin-out or another form of R&D spin-off. Ashwin Kumaraswamy of Enterprise Ventures, an early stage venture capital fund manager, had prior experience of assessing investment opportunities in this sector and was keen to invest in reducing the cost of energy storage.

Kumaraswamy approached Wright and Barker. Wright, who had been CEO of IP2IPO (now known as IP Group), an early stage technology investor in mostly University spin-out companies, was invited to lead operations.

Jerry Barker, who was running his own battery consultancy, as well as in the employ of Culham as chief technical officer, UK-based Surion Energy, a now defunct developer of proprietary Li_2FeS_2 cathode technology, was invited to be CTO. Andrew Dixey also came on board at this time.

Faradion is born

Finance Yorkshire Seedcorn Fund became the founder investor in Faradion and remains the largest shareholder. Prompted by Barker, Finance Yorkshire Seedcorn Fund decided to invest in sodium-ion, deemed to be "most ripe for development", says Wright. Faradion swiftly started work in labs at the University of Sheffield in 2011.

"We wanted to grow the company quickly," says chairman Chris Wright, "which meant the company used facilities and resources wherever they were available. Hence we decided to work in the University of Sheffield, which also housed the company headquarters in the early days, and also in Witney in Oxfordshire, sharing the facility with Caterham Formula One team.

Having access to more than one facility in the early days has proved a successful strategy."

Work on sodium-ion technology progressed sufficiently well to secure three UK government grants: an initial £100,000($160841.5) from the Technology Strategy Board (TSB) to produce a demonstrator, which led to a further TSB demonstrator grant of £479,000. Faradion has also secured from the UK Department of Energy and Climate Change a £396,000 grant for a collaborative project with Sharp Laboratories to develop and scale up a 'new' large format battery for residential and community energy storage systems.

With help from Finance Yorkshire, this money has been used to move out of the University of Sheffield and establish its own prototype sodium-ion battery line in rented facilities at its headquarters at the Sheffield Innovation Centre, within a stone's throw from its former base at the University.

The prototype line is end-to-end, including cathode making, coating, electrode punching, cell building, electrolyte fill, degas, testing, the whole caboodle. Faradion is now at a stage of making cells and packs for deployment in trials, with the ultimate intention of licensing the technology to battery manufacturers.

But, first things first, why sodium? "When we started, the sodium-ion intellectual property field was very, very sparse and there were very few patents compared to lithium," says Wright. "We saw an opportunity for a fleet-of-foot company like ourselves to command a great deal of intellectual property.

"One of our first missions was to synthesise very large numbers of sodium-ion materials - we've since looked at over 2,000 - and we've so far identified 14 'patent families' covering thousands of materials."

Once Faradion started looking into sodium, it quickly realised not only sodium carbonate for the cathode is cheaper than lithium carbonate, but also sodium electrolyte is less expensive than lithium electrolyte and sodium salts are more soluble than lithium salts, requiring a lower concentration for the same conductivity. And, whereas in a lithium cell you have to use one copper current collector and one aluminium current collector, in a sodium cell you can use two aluminium current collectors, says Wright.

"Sodium-ion does everything lithium-ion does, but cheaper," he says. "If a manufacturer already has a lithium-ion plant, there is no incremental capital cost because it uses the same equipment. According to Argonne National Lab's BatPaC data model, a 16kWh sodium-ion pack is 30% cheaper."

Characteristics of sodium-ion

Of course, as the ionic radius of sodium is 30% greater than lithium, graphite cannot be used at the anode because its interlayer space is too narrow; it simply does not go in. The obvious alternative is hard carbon.

Hard carbons have a wide interlayer space. As the interlayer space is slightly disordered, the average space between the carbon layers is wider than of graphite, allowing sodium ions to be inserted, explains chief technology officer Jerry Barker.

"If you heat most carbons high enough they will crystallise into graphite," he says. "Hard carbons, on the other hard, can be turbostratically disordered, which means the layers are rigidly held apart rather than 'graphitize' no matter how high the temperature."

While hard carbons are commercially available, they tend to be optimised for lithium-ion. Although they work perfectly well for sodium-ion cells, Faradion makes its own grades, which Barker claims outperform commercial grades.

To create suitable hard carbons, Faradion dewaters the carbohydrate source, be it sugar or coconut shell or another suitable substance, leaving a precursor of a pre-carbon to be heated in a particular range and particular atmosphere. The desired result is for Faradion to optimise its own hard carbons to be in a position where a third party would be able to pick it up and run with the technology.

Sodium-ion vs lithium-ion energy density

While sodium is a heavier metal than lithium, it does not make a huge difference between a sodium-ion and lithium-ion battery, says Barker.

"Take lithium cobalt oxide," he

says. "The lithium constitutes only ~5% of the mass. If you replace sodium with lithium, there's a negligible difference in terms of the formula mass. When you work the sums it doesn't make a lot of difference by going from an atomic weight of 7 to 23 because it is the rest of the cell that makes most of the difference."

Faradion is currently claiming an energy density of 140Wh/kg, compared to 150-180Wh/kg for an LCO $_{1}$8650 cell, and 100-110Wh/kg for lithium iron phosphate. Wright says Faradion`s 'roadmap' targets an energy density of 200Wh/kg within three years.

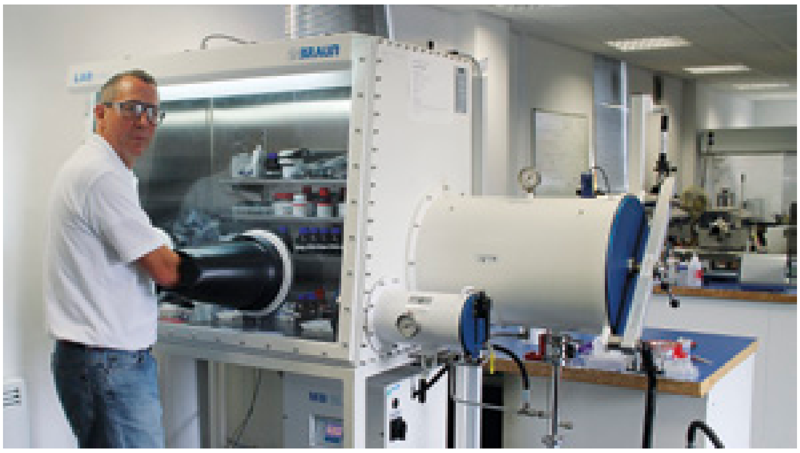
At a cost per kilowatt-hour basis, which is crucial, energy capacity will be cheaper than lithium-ion, says Wright. "There is a prejudice about lithium because it was the first high energy density cathode. Changing the ion doesn't make much difference to energy density or rate characteristics.

"Conventional thinking was too simplistic. It is not necessarily the case that because sodium-ion is bigger than lithium it will diffuse more slowly. What determines the rate of diffusion is how the ion moves in a very complex lattice, and if you pick a lattice with big channels or tunnels then it will have rapid diffusion.

"Because sodium is larger it can occupy different positions in the interlayer space, making them faster diffusers and therefore higher rate materials than their lithium equivalents."

"In terms of voltage, we are also at similar levels to lithium-ion, we're not taking a big hit," adds Barker. "We can get it to work and it works well, and we've performed 1,000 cycles and beyond. The fade rate, mainly due to gradual cell impedance, is similar to lithium-ion. We see a little bit of active loss, but the fade rate characteristics are very similar."

Jerry Barker and Whitney.



Easy peasy, lemon squeezy?
Faradion makes it sound easy. Is it? "It has been surprisingly easy," says Barker. "I published one of the original sodium-ion papers over a decade ago and at the time I thought there would be major challenges to make it a commercial reality: cycle life, rate, impedance, solubility, instability and so on. But it's been easier than anticipated to make a good performing sodium-ion cell. There are no fundamental barriers."

If it is so easy, then why isn't everyone doing it? "There are lot of groups who have published papers on research but only one or two commercial operators are manufacturing prototype cells and packs," says Wright.

"Sumitomo Electric and Sumitomo Chemical started a few years before us and the former recently announced it would launch a sodium-ion cell in 2016. Sumitomo Chemical has taken a different approach at the cathode. Sumitomo Chemical`s approach appears to have been focused on taking out the lithium from a lithium-ion battery and replacing it with sodium, e.g. sodium iron phosphate. We feel that's the wrong way round, we've started from a bottom-up level and what is required for a sodium-ion cathode material."

Deployment in the field
During its first three years of existence, Faradion believes it has demonstrated to its satisfaction that sodium-ion technology could deliver the same kind of performance at the individual cell level as lithium-ion. The next stage is building small, 1kWh demonstrators in order to generate data and materials to potential partners.

By the end of 2014, Faradion will have demonstrated sodium-ion modules in small-scale applications with Williams Advanced Engineering, as stipulated by its larger TSB grant. The sodium-ion packs will be demonstrated in an ebike application.

Faradion is currently making pouch cells, but it is agnostic about the format. One of the greatest strengths of sodium-ion batteries, says Barker, is that they can be manufactured on lithium-ion production lines as the production process is so similar.

"If someone wanted to convert a line to sodium-ion there is literally nothing that needs to be changed apart from the materials used," says Barker. "The technicians running the line wouldn't notice any difference.

"We double-side coat the anode and cathode; layer the materials step-by-step with a separator, we electrolyte-fill for the porosity in the electrodes and separator; there are two or three formation cycles; we degas; then we make the final seal.

"We could jelly-roll for 18650 cells or use a Z-fold arrangement of a continuous layer of separator instead of individual stacks with a square separator, but whichever process we would choose it is exactly the same process as for lithium-ion."

Route to commercialisation

Faradion's commercial strategy, of course, is not to be a manufacturer of sodium-ion packs but commercialise the technology in partnership, preferably via licensing. Wright's experience with LCO should come in handy with what Faradion wants to achieve.

Wright was heavily involved with the licensing of LCO at AEA Technology, the privatised arm of the UK Atomic Energy Authority that owned the IP, having first been developed by Professor John Goodenough at the University of Oxford in the late 1970s.

AEA licensed LCO technology all over the world, most famously to Sony to develop its 18650 cells. This made AEA Technology pots of money, although perhaps not as much as hoped given mobile phones were the size of bricks and PCs were the size of sewing machines, and small consumer electronics did not take off until the 1990s.

Later, in conjunction with Japan Storage and Mitsubishi Materials, Wright helped establish lithium battery maker ABSL in northern Scotland, later acquired by Enersys, to manufacture D-cells and bespoke cells.

Faradion has held initial talks with Asia-Pacific, European and US lithium-ion manufacturers, but it will only commence firmer discussions with prospective licensees at the end of 2014 when happy with the performance of the cells supplied to Williams Advanced Engineering in the TSB project. "Taking a starting point of 1 January 2015, we think licenses will be taken up by 2017," says Wright, who sees the most likely applications as those which are particularly cost-sensitive, such as transport and stationary storage.

"The automotive sector has all sorts of regulatory hurdles, so it would take a long time to enter. The markets with the lowest barrier to entry and most cost-sensitivity are small-scale transport like ebikes and stationary storage coupled with domestic or community solar power."

Faradion's Dickensian incentive scheme, harsh but effective.

Haldor Topsøe investment boost

Faradion received a major boost in January 2014 when Danish catalysts firm Haldor Topsøe took an 18% stake. The investment marked Haldor Topsøe's first ever equity investment aimed at broadening its technology portfolio and is closely linked to its '30 in 25' growth strategy, which aims to reach revenues of DKK30 billion ($5,091,075,300) in 2025.

The investment is Haldor Topsøe's first equity step on the road to building its battery materials business, says Wright. "They wanted to commit resources because they are a materials specialist.

"Their ambition is to build a business manufacturing battery materials and secure a unique, attractive position as a supplier of sodium-ion materials; Johnson Matthey bought Axeon and BASF is building its battery materials business." Having a well-known investor like Haldor Topsøe will undoubtedly add clout when negotiating licenses, says a chipper Wright.

"When we talk to prospective licensees they are interested in having a total package, not only the intellectual property but also the materials. The attraction of a partnership with Haldor Topsøe is their manufacturing skill and our ability to put our prospective licensees in contact with them and, as far as we're concerned, having access to their knowhow about battery material manufacturing in large quantities is fantastic."

The future looks bright for Faradion and that is reflected in its ambition to increase its ten-strong headcount by 50% in the near future. Most of all, however, it believes it has a good sodium-ion battery product which the market will want to buy.

"We don't know of anybody doing as well as us, or as close to us," says Wright. "We're throwing down the challenge. If anyone else out there thinks they can out-perform us, tell us."

Shandong Jinkeli Power Sources Technology Co., Ltd was founded in 1982 and is currently member of Lead-Acid Battery Industry Standard Board in China. Shandong Jinkeli has close relationship with many Chinese Lead-Acid battery producers with more than 70% market share in Lead-Acid battery additives supply.Shandong Jinkeli is a strategic partner of Borregaard AS in China.Borregaard AS is a Norwegian base company and global leading Lignosulphonate producer.

There is a professional team of engineers equipped with advanced testing equipments in Shandong Jinkeli's technical center to provide technical services to the Lead-Acid battery industry. The company of Jinkeli was accredited by ISO9001:2008 certification.

To be global leading suppliers of Lead-Acid battery additives is Shandong Jinkeli's goal.

Jinkeli Expanders (Composite additive available by the customer request)

- CuringBon® (4BS Crystal Seed)
- Humic Acid
- Sodium Humate
- Ultrafine Barium Sulfate
- Short Fiber (Polyester Staple Fiber)
- Sodium Lignosulphonate
- Carbon Black
- Graphite
- Oak Powder
- Cork Powder

Borregaard

Add: No.8 Malianshan Shengchuan Road, Zichuan Economic Development Zone, Zibo City, Shandong China.
P.C. 255130 Tel: +86 533 5310399, 5316599 Fax:+86 533 5313399 E-mail: jkl@jinkeli.com qinda@jinkeli.com
www.jinkeli.com

If you can't stand the heat…

VRLAs able to cope for long periods operating at elevated temperatures are somewhat of a Holy Grail. Tim Probert explores efforts to improve lifetime of 'high temperature' VRLAs.

As almost everyone reading this will well understand, one of the major drawbacks of lead-acid batteries is they do not perform terribly well at high temperatures.

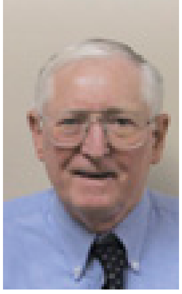
Typically, lead-acid batteries will have a ten-year design life at 25°C. If you increase the temperature to 35°C you would theoretically halve the life of the product, meaning five years, 2.5 years at 45°C and so forth.

Operating at 40°C is generally not a problem for VRLAs. When you get above 60°C, more than possible when operating in hot climates without cooling, you start to run into big problems and the battery design has to be specially adapted in order to prevent failure within days.

At these temperatures there are so many components in the battery that are under stress. It is a demanding architecture in a demanding environment, and just about the worst environment for a product containing acid.

Everybody is trying to improve their components, be they grids, pastes, oxides, containers or valves and so on, but the typical failure mechanism of the battery is almost exclusively positive grid corrosion and dry-out. Therefore, the challenges are to increase corrosion resistance of the positive grid and to decrease water loss.

David Prengaman, RSR Technologies



Positive grid problems

In simple terms, the first thing is to add silver to the alloy and increase the volume of tin to dramatically reduce the rate of corrosion of lead calcium alloys, as is essential for stop-start automotive batteries to pass high-temperature testing at 60°C or 75°C.

The standard alloy for VRLAs is lead calcium, with calcium at 0.7%, and tin at 1.2-1.4%. Silver is useful primarily for high-temperature cycling, 0.3% is usually sufficient for corrosion protection.

The original high temperature alloy for positive grids for SLI's was GNB's AG9 alloy, which had 0.6% tin and 300ppm silver, introduced in the late 1990s.

This problem all started with the Ford Taurus, a car designed to be highly aerodynamic. The airflow no longer flowed through a grille in the bonnet but over the car, and the engine compartment got hot. This meant the batteries lasted only a few months.

Ford came with a diabolical test called the 'Hot J240', which tested reserve capacity cycling at 75°C. Ford demanded their suppliers met their requirements, but no-one could do until GNB came up with a low-silver alloy.

The genius of it, says lead-acid battery industry stalwart Bob Nelson, was GNB realised that "When you put a small amount of silver into a positive grid alloy the silver would tend to enrich in the grain boundaries and it creates a hard grain boundary which is much more difficult to corrode".

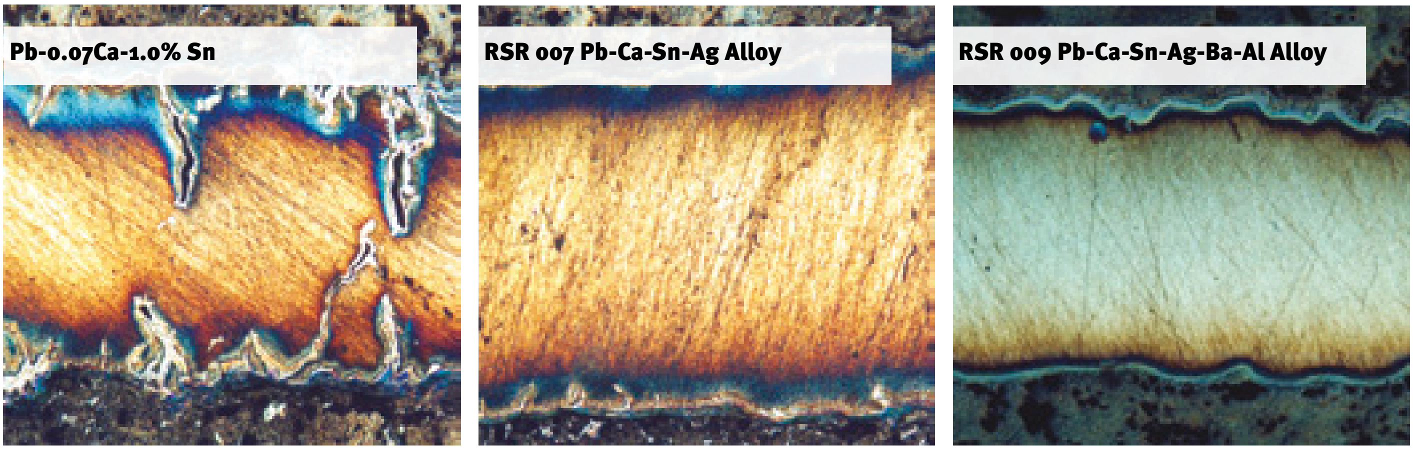
The drawback with AG9, says RSR Technology's David Prengaman, was that the silver content made it very difficult to stick active material on to it. As a workaround, the grids were placed into curing chambers at high humidity and 100°C to form a corrosion layer and paste the active material on to it.

However, this resulted in extremely low calcium content and the resulting weak grids were slow in ageing. Furthermore, due to the low tin content, recharging was problematic.

Newer alloys, including RSR's 007 and later 009 alloy had higher calcium content allowing for quicker aging and higher tin content in order to improve recharge through the grid active material interface, as well as slightly lower silver content to avoid ternary eutectic cracking of the calcium.

"If you don't control the silver and tin content the grids would crack when gassed," says Prengaman. "Cracking never occurred in calcium alloys before, this was a brand new phenomenon which had to be overcome — you have to balance the silver content with the tin content."

Added to the RSR009 mix is



RSR Technologies' '00' Series of positive grid alloys versus standard.

aluminium to prevent calcium loss, and there's a little more calcium than normal than in the AG9 alloy to allow better aging and handling. Yet, even with these improvements, VRLAs will still suffer from corrosion at the grain boundaries.

The next thing added was a small amount of barium, which segregates to the same areas as the tin and silver. The barium gives a very uniform corrosion on the surface of the grid and does not cause penetrating corrosion, which can cause potential problems.

"This took care of the grid corrosion problems", says Prengaman. Be they book cast, rolled-punched, rolled-expanded, cast-expanded or cast-punched."

While grid corrosion is very important, there are many other components which need modification from the standard kit. There has to be higher positive paste density than normal, even though the higher the density, the better the resistance to elevated temperatures, says Prengaman.

This can seem counter-intuitive because conventional wisdom states lower paste density improves active material utilization. But higher density leads to extended lifetime and this is the name of the game.

Another issue is the higher the temperature, the higher the likelihood of gassing on float service. Adding bismuth in the active material has been shown to reduce gassing under float service. Adding zinc, either as zinc sulphate in the electrolyte, or to the negative active material, can also reduce gassing by as much as 15-20%, notes Prengaman.

For cycling batteries, carbon additives in the negative material improve recharge at elevated temperatures, but most carbons increase the rate of gassing. That is where the aforementioned addition of zinc comes in to offset the effects of the carbon.

Among the many other possible additives are tetrabasic lead sulphate crystals in the positive active material, which allow higher cycling ability and life cycle, as the active material does not fall apart.

Prengaman also notes high density separators with a high volume of fine fibres are necessary to prevent the electrolyte from stratifying. If the electrolyte stratifies just a little, you slowly sulphate both the positive and negative plates due to the higher concentration of acid, thus shortening life.

Expanding role of expanders

Normal expanders do not work effectively at elevated temperatures due to degradation. Newer expanders from manufacturers like Penox, Hammond, Addenda and so on perform better at high temperatures, but some firms are currently testing materials offering the promise of improved high temperature stability, as Hammond's chief technical officer Achim Lulsdorf explains.

"Over the past 18 months we have focused our R&D efforts almost entirely on partial state of charge applications like stop-start, microhybrid and renewable energy storage," he says. "As an initial result we released our Hammond K2 expander line for PSoC applications at the 2013 Asian Battery Conference in Singapore.

"Ever since we have performed extensive work to investigate possible interaction effects of various expander materials, mainly advanced carbons and advanced organic additives. We were able to find materials and interaction mechanisms that allow for exceptional dynamic charge acceptance, increased PSoC cycling life, and reduced water consumption.

"A by-product of our efforts was the identification of organic materials with a high level of temperature stability. However, currently these materials are still in test to evaluate whether they cannot only withstand elevated

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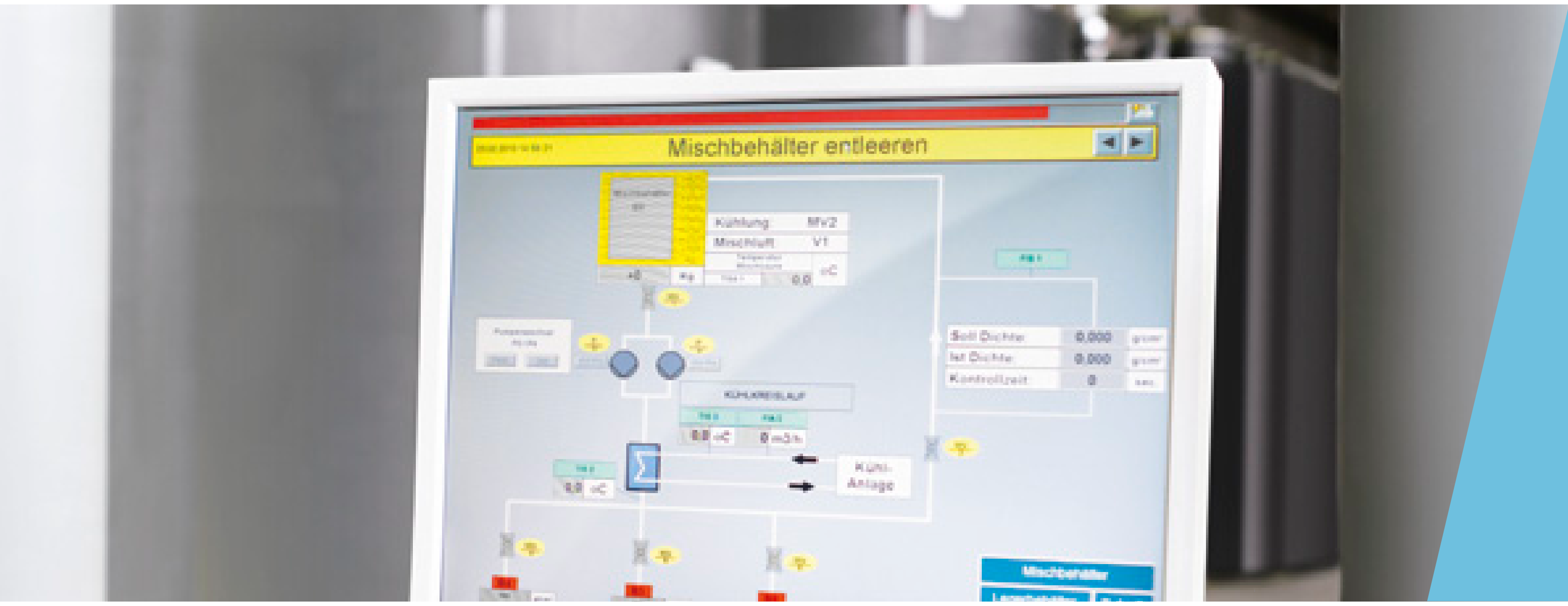

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temperatures but also survive under high overcharge potentials at the same time.

"A high temperature VRLA Hammond expander is not commercially available yet, but depending on the outcome of our current tests may become reality soon."

Meanwhile, Borregaard Lignotech is testing its Vanisperse HT organic additives for the negative paste, hitherto largely targeted at improving cold crank for automotive batteries, for high-temperature VRLAs, with an eye on standby power applications in hot countries like India.

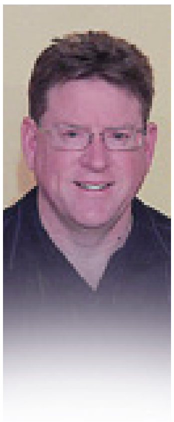
"We've evaluated it for VRLAs and we've found that you need not only high-temperature stability but also high charge acceptance," says senior research associate Tim McNally. "In countries with very unreliable power grids like India, these batteries are not so much standby as cycling.

"They are cycled so regularly they are not necessarily being fully charged, so we find charge acceptance becomes paramount. The more efficient the charge, the more complete the charging.

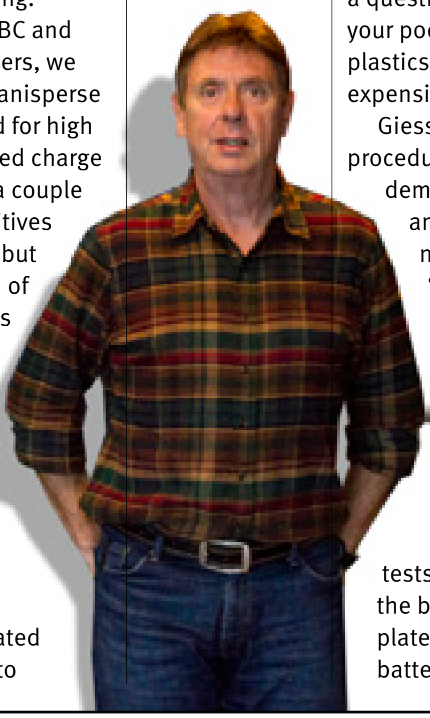
"Working with the ALABC and our suppliers and customers, we are working on a line of Vanisperse additives being evaluated for high temperatures and improved charge acceptance. We do have a couple of promising organic additives based on lignosulfonate, but at this point they are kind of hush-hush, as the process of getting from the raw material to the final product is novel."

A design for life

Despite all the electrochemical work, it is the mechanical design that is most crucial for extended lifetime at elevated temperatures, according to Herbert Giess of Pyramid Vision Consulting, who has worked with Chinese high-temperature VRLA manufacturer Narada.



Tim McNally, senior research associate, Borregaard Lignotech.



Frank Fleming, chief technical officer of Northstar.

"Grid corrosion is important but the most critical issue is the battery container," he says. The killer for lead-acid batteries is short-term excursion to higher temperatures, for example when a cooling system fails.

A thermal excursion to 60°C to 65°C will result in standard VRLAs failing within a week, says Giess. "With high-temperature excursion above 60°C, the container will lose mechanical strength and compression will be lost. If the battery case is too soft, the plate core is not sufficiently compressed and you will lose capacity. The loss of compression also changes recombination behaviour and may cause thermal runaway.

"So you need special high-temperature plastics or some special reinforcement allowing high temperature operation. Such plastics which allow operation up to 100°C without deformation are available, allowing batteries to survive two months up to 70°C. It's a question of reaching deep into your pocket to pay for these exotic plastics, which are 30 to 50% more expensive."

Giess questions standard test procedures for VRLAs, which demonstrate grid corrosion and water loss levels, but not mechanical strength. "People may be wondering how it's possible to do high-temperature accelerated life testing at 60°C or 65°C and demonstrate 16 weeks or even a year of operation.

"This is because these tests are performed by clamping the battery between two steel plates or vice which keep the battery box stable. This is standard procedure for testing grid corrosion and water loss, but not the failure of the battery case. So, in order to get long life without having a steel vice clamping the monoblock in position, you need high-temperature plastics."

Frank Fleming, chief technical officer of NorthStar, agrees the mechanical stability of the battery is very important. "If you operate batteries at elevated temperatures then you need to look very carefully at the valve. Will the valve last for a prolonged period at these temperatures or will it leak?

"If you have a leakage it can allow water to escape which increases the dry-out rate and also allow oxygen back into the battery, which would cause the negative electrode to run down."

Bob Nelson notes some other construction features that can be important for high-temperature VRLAs, particularly those on float. "15-20 years ago VRLAs had terrible problems with unregulated 'hots' where temperatures would reach 60-65°C.

"Manufacturers started using temperature compensation (TC), a small device which senses the ambient temperature and lowers the charging voltage to compensate. You might be floating at 2.3V or 2.35V per cell at ambient temperature, but without TC and the installation heats up to 60°C it's as if you're floating at 2.55V or 2.6V per cell."

TC is now standard tech. Using a micro-catalyst developed by Philadelphia Scientific can also mitigate thermal build-up and water loss by correcting the imbalance in the chemical reactions caused by impurities in the active material.

A small catalyst valve is inserted into the cell and gasses, which would normally be vented out of the battery, are diffused out the plate stack. Nelson notes this method is expensive and not without problems.

"It's a platinium or palladium catalyst, which means hydrogen and oxygen will be converted to water which is good, but is problematic. If too much gas comes out of the battery, the catalyst plug can overheat, and over time the platinium or palladium can leach into the cells and significantly increase gassing."

Nelson also notes NorthStar has published papers exploring a technique called intermittent charging for float applications where batteries are taken offline periodically and then charged with a short, high current when the battery voltage drops to a critical level, then rests.

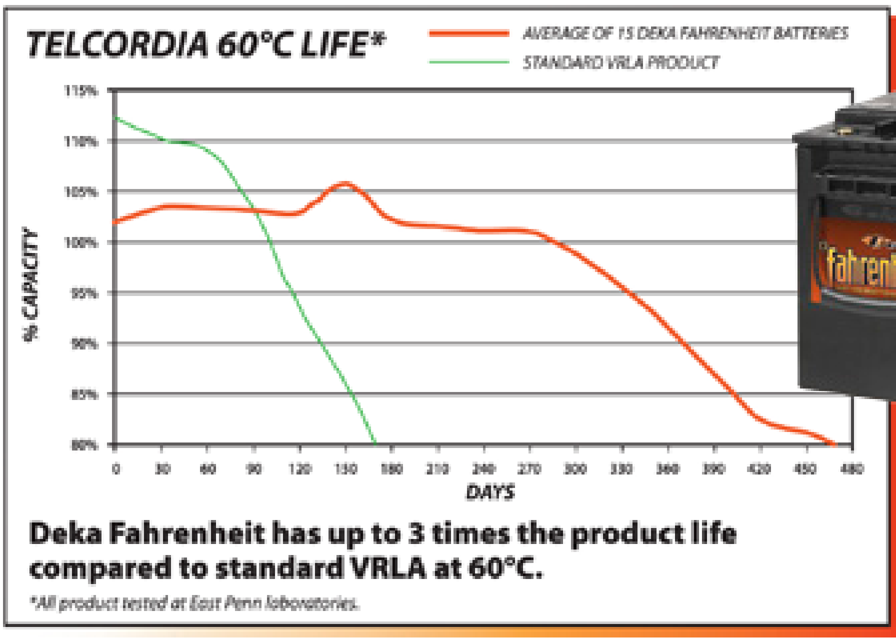
"It's a cycle, but then so is a regular use of float batteries. The main thing is the battery isn't nearly as stressed by high temperatures and over a year you may only put in 15% of the overcharge into a float battery installation compared to continuous float charging, so it's very attractive.

"NorthStar tried it a few years ago and it didn't really work. But it could be part of the package to make high temperatures much less abusive to VRLAs."

Doing what it says on the box?

East Penn's Deka Fahrenheit range incorporates its proprietary Microcat catalyst, Helios negative plate additive, TempX corrosion inhibitor grid alloy and THT composite plastic of the outer case to produce a battery that its lab tests have shown to last three times longer than standard VRLA telecom float product at 60°C. The warranty for the Fahrenheit telecom battery is six years full at 35°C, an improvement from its standard VRLA product warranty, which is four years full at 25°C.

Does Bob Nelson believe East Penn's Fahrenheit battery does what it says on the box? "I'm always suspicious when a new product is claimed to have three times the float life at 60°C in lab testing because in the field they may not see anything close to lab testing conditions," he says. East Penn told BEST it is "confident that our lab results will translate to field applications as this product has been under development for five years", but "field testing has only just begun with interested customers and prospects" and "results will take years".



Deka Farenheit heat tolerant VLRA battery.

Future research

NorthStar's Frank Fleming says it is conducting a high-temperature battery research programme of its own. "A lot of applications would be preferred to run at high temperatures particularly for outdoor BTS (base transceiver stations), for example.

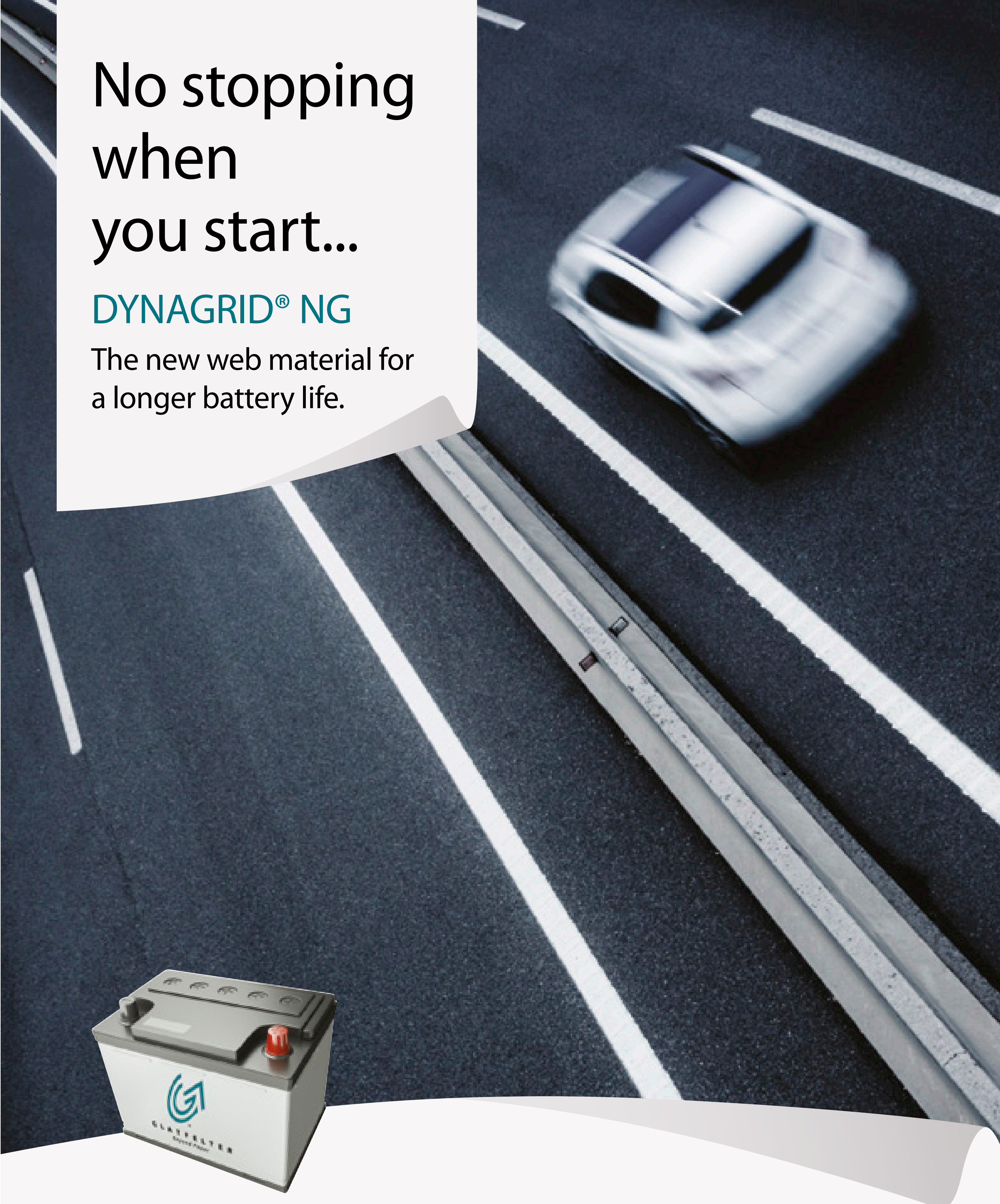
"If somebody can increase durability of the product at these temperatures then it would be a significant breakthrough. If you were able to make a 20-year product at 25°C then theoretically durability at higher temperatures will increase."

Fleming says NorthStar's research programme is not focused on a single issue, but is looking at components in the round. "We've isolated five or six components, be it electrochemical or mechanical, and we are exploring each one.

"Of the areas we are considering, I have the most confidence that we've solved the positive grid corrosion problem. That's the one that gives me least concern, getting the correct grain structure etc. has been pretty well addressed.

"I have concerns about the valve being able to operate at elevated temperatures for a long time. Obviously the role of the negative expander is critical, you have to maintain a healthy negative, and there's a lot of understanding required there."

Fleming says NorthStar has been working on it for two years. "It will be a while yet before we get to the product development stage simply because the testing is so protracted. If you develop a long-life product, then in order to ascertain whether you've made an improvement you typically have to test it for one year. This is one of the big problems we face."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Germany's lithium-ion *weltmeister* ambitions: A reality check

Laura Varriale visits Stuttgart's World of Energy Solutions and finds the reality about Germany's lithium-ion manufacturing ambitions fall far short of the rhetoric.

After being football *weltmeister* and export *weltmeister*, Germany wants to be a world leader in lithium-ion battery production. While Germany is an eager beaver and has done its homework thoroughly, this looks to be a bridge too far.

The World of Energy Solutions trade fair and conference with its parallel Battery+Storage, e-mobil Baden-Württemberg and f-cell (fuel cell) events aim to provide, as the name suggests, solutions. Taking place in Stuttgart, in Germany's wealthiest region, with BMW, Daimler, Porsche, Bosch and many more as major employers, the growing trade show and conference was attended by 2,700 people from 35 nations.

The international World of Energy Solutions trade show and conference attracted 2,700 industry visitors.

Of course there were a lot of mentions about the *Energiewende*, or energy turnaround, which is Germany's self-imposed task to be an energy, yes, *weltmeister*. But a solution is not that easy. The German government's long-term goal is to replace fossil fuels with renewables as her primary power source, but the *Energiewende* is more than that. It needs a turnaround in energy as well as mobility.

In fact, there are several possible solutions for mobility, power and energy. Energy storage is one of them and possibly the most promising, was the consensus view among the delegates.

The technology, it seems, is also set. Lithium-ion. The Battery+Storage conference part was almost entirely dedicated to lithium batteries. There were a few presentations about flow batteries and none for lead-acid.

A recurring refrain was that lithium-ion mass production should take place as soon as possible. Eric Maiser, managing director productronic from German mechanical engineering association *Verband Deutscher Maschinen- and Anlagenbauer* (VDMA), said that nickel-cadmium and redox batteries will have a future, but lithium-ion batteries is "the first and only choice" for xEVs and will completely replace lead-acid in stationary energy storage systems.

The global lithium-ion battery business is expected to be worth €30 billion ($38 billion) by 2020 with a 15% annual growth rate, according to Werner Tillmetz, head of the electrochemical energy technologies division at ZSW *(Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg)* in Ulm.

But there is one problem with lithium. It is too expensive. This is nothing new, but it is puzzling the industry to find out how to decrease the costs. Battery costs are €1,000 ($1,266) per kWh in Germany, whereas cell packs in the US, manufactured in China, cost $200 per kWh.

"You are preventing the introduction of lithium-ion storage with these prices," said Professor Eicke Weber, director of the Fraunhofer Institute for Solar Energy Systems. "That doesn't make sense. Why not buy the $200 batteries, test them, certify them and then sell them for $500 here?"

There is no big German mass production project for lithium-ion in sight. So far, there are only pilot lines in Germany. The VDMA, the Fraunhofer Institute and RWTH Aachen University have published a roadmap to lead the way for scale-up. But the roadmap has identified 15 so-called 'red brick walls' that have to be broken through.

Professor Eicke Weber, director of Fraunhofer Institute for Solar Energy Systems.

Prices will decrease when the cells are mass-produced, says the roadmap. Good old economies of scale. With big deals comes the scale-up. No big deals, no scale-up. How to kick off mass production, then?

"You have to stick to one technology," says VDMA's Maiser, "to achieve better quality while increasing costs". Yet the German battery industry itself is not ready to invest millions in production facilities, let alone billions like Tesla. Germany lacks big consortia that can afford these sums or an enfant terrible like Elon Musk.

Tesla was mentioned in almost every session about batteries. The speakers admired the unconventional business model, but there will not be a Tesla-like project in Germany any time soon.

Turning Japanese

The good news is that the know-how is there. But the access to international-scale projects and the ability to offer complete line production are important requirements for the competitiveness, especially for German battery machinery suppliers, is not.

The ZSW inaugurated a large-scale pilot line for lithium-ion production in September with German equipment only. Under real industrial conditions, the battery research centre aims to assure that the quality of the equipment is good enough for scale-up. "When we started everything, many battery experts told us: 'If you want to build a state-of-the-art production line, you have to use Asian machines'," said ZSW's Tillmann.

The ZSW followed the advice and ordered equipment from Japan. "When we conducted tests and looked at specifications, we found out that we already have excellent equipment in Germany. We don't have to hide behind Asian companies. German engineering knows how to do things".

BASF, BMW, Daimler, Rockwood Lithium, SGL Carbon and Siemens will start using the Ulm research platform for the first projects in January 2015. Initial tests are already underway.

German engineering giant Siemens has developed an operating data and automation programme for production control and documentation in order to standardise the production process, a procedure common in other industries. The company is testing it at ZSW.

Although Germany is jealous of Asia's lead in lithium-ion cell manufacturing for consumer, automotive and industrial applications, the industry and research speakers were fairly optimistic in the ability to catch up. But Pierre Blanc from Swiss lithum-ion battery company Leclanché offered the German optimists a strong dose of reality.

It is simply too late to catch up, he said. But, in fairness, Blanc said there were opportunities for European and US battery makers to enter the market for new cell formats and niche markets, thanks to a strong research tradition, especially in Europe.

The market for industrial applications might be easier to access for the expensive German batteries, because it is not as price sensitive as automotive. Whereas cell manufacturing is predominantly done in Asia, module manufacturing for stationary, industrial or automotive applications is done locally in Europe. This is also due to the market demand.

Blanc also challenged popular misconceptions about Germany's perceived high labour costs. For battery manufacturing, these are not the costs that play a major role for the cell price, he said. The materials are too expensive and the only solution for that is scale-up, he thinks. And a scale-up has to come with an optimised production process.

"Reduction of the dry room area means reductions of running costs. We don't set up a production line in a dry room, that's simply too costly," he said. A production line takes up about 6,000 square metres, and that is impossible to put that in a dry room.

Blanc suggested in-line drying processes to cut production costs. "This will save you a few percent that can make you profitable." The reason why Europe lags behind, lies also in the standards, Blanc explained. Europe has high industry standards, which sets the entry barrier high.

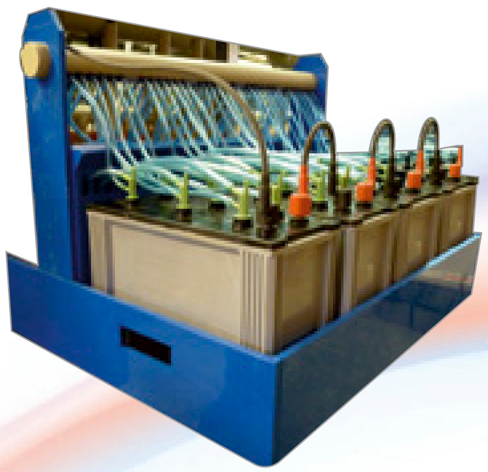
All the speakers, independent of where they come from, had something in common. They want governments to continue their financial and regulatory support, whether for emission-free cities, research programmes like the ZSW or building infrastructure for EV mobility. "Especially cell manufacturing and machinery have to be supported," said Blanc. "Continuing supports will give the whole industry the chance to grow and take a part in the overall growing market."

In a discussion about next-gen automotive batteries, chaired by Jörg Huslage, group leader for electrochemistry at Volkswagen, a member of the audience asked why Volkswagen is not producing lithium-ion batteries in a similar partnership like Tesla with Panasonic, especially as it wants to focus on lithium-ion for EVs and thinks lithium batteries are needed as soon as possible. Huslage replied: "If someone would tell me that you can earn actual money from producing them, then we would." So no 'Gigafactory' from Volkswagen!

The industry has to pay upfront costs, there is no way out of that. And return on investments will be years away. Who will be willing to financially take the risk of building up this industry to volumes that allow it to be competitive and enable the entire value chain to gain a similar level of experience and a track record that the Asian-based companies have reached?

There's a need for speed. Germany has to speed up if it wants to be a star. The country and its *weltmeister* dreams of football, exports and lithium-ion mass production could be achievable. But someone has to have the guts to spend upfront costs.

Peter Haan, spokesperson of VDMA battery production & head of business development OEM industries at Siemens.



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Energy storage: Regulation, regulation, regulation

The Editor attended the UK Institution of Mechanical Engineers' one-day energy storage conference and finds some optimism, despite concerns over costs.

Distribution networks are widely seen as a sweetspot for energy storage. Why build a new substation, install a transformer, or erect a new overhead line, when batteries in a container can reinforce grids with real and reactive power and be installed in a matter of a few days?

And if those same battery systems can also provide balancing services such as frequency response, voltage control and peak shaving on top, you would have a very useful asset. This is what several distribution network operators (DNOs) told delegates at the UK Institution of Mechanical Engineers' excellent energy storage conference in Birmingham on 23 September.

DNOs such as Scottish & Southern Energy (SSE), UK Power Networks, Western Power Distribution and Northern Power Grid all presented results from various projects funded under the UK's LCNF. The results were mixed. Not so much from a technical perspective - the benefits of battery energy storage are real and they are generating useful benchmark data – but speaker after speaker said the business case for storage – even with full subsidy – are challenging.

SSE's head of future networks Nigel Bessant spoke on its 'community energy storage' project on a new housing development near Slough in the county of Berkshire. Here, SSE installed three 25kW single-phase Dow Kokam lithium-ion storage systems for 100 customers, many with rooftop PV. The batteries avert the need for more cables further down the network from a substation and offer peak shaving.

Bessant was particularly impressed with the reactive power capability of the inverter, which can help manage voltage by injecting reactive currents. This seems to bear about all those ideas about energy storage systems being able to import/export wind power with storage while modifying voltage using reactive power.

SSE has also worked on a larger, three-phase project in down the road in Bracknell. The Thames Valley Vision project comprises twenty-five 12.5kWh three-phase energy storage units and three 12kVA power electronic units.

Bessant highlighted a challenge that does not typically confront utilities is partial state of charge. Energy storage systems need to be optimized to charge/discharge, which needs forecasting and very good algorithms, which were developed by the University of Oxford and the University of Reading.

SSE found only need to use

Left to right: Nigel Bessant, SSE, Ben Godfrey, WPD, Nick Winser, National Grid.

storage 5% of the time to get a 25% reduction in peak. This opens the door to making use of the batteries for other services. Bessant also noted that 80% of the cost is battery, 20% power electronics, so if you get away with using fewer batteries, will help to make numbers stack up.

However, the project was "just about feasible" with Low Carbon Network Fund money. Bessant says that although Three Valleys was a £30m bespoke installation with bespoke algorithms, the aim is for it to be "repeatable" across their networks. "Let's see how it goes," he says. Yes, let's.

Northern Power Grid has installed six A123 lithium ion 'nano'-phosphate battery storage systems across its networks, equivalent to 7.4MWh. At a combined cost of £54m, these systems are used to bolster weak areas of its network.

The largest of these, a 2.5MW/5MWh facility at its Rise Carr high voltage substation near Darlington in County Durham, is used for peak shifting and reduce thermal constraints on the transformer.

While this was a technical success, Northern Power Grid is less than enthused with the economics of energy storage. "It's nowhere near economic," says network technology project manager Ian Lloyd. "The cost of the 5MWh system was £4m, or £800/kW, a very high figure for network assets.

"To cover even the inherent technical losses of a storage system [battery storage systems are net consumers and have a round-trip efficiency of around 85%], it needs to buy and sell the full range of services, but cannot due to electricity trading restrictions imposed on DNOs."

> "DNOs seem less than keen to own storage assets"

Western Power Distribution (WPD) low-carbon engineer Ben Godfrey said installing its Project Falcon energy storage systems in Milton Keynes was a steep learning curve. DNOs are used to cramming in copper wires in substations; cramming in batteries is not wise.

WPD has had to learn about ventilation, safety (thermal runaway, of course), interfacing DC with AC, and noise pollution. As Godfrey said, these are not things you want sat next to a block of flats operating at 1am...

Lessons learnt: Many functions/simple footprint

- 3ph Inverter
- Modular Design for scalability
- Rapid installation (3 days)
- Minor civil works

	Voltage				Thermal		Efficiency		
	Regulation	Harmonic Distortion	Balance	Flicker	Phase	Neutral	Utilisation	Losses	CI/CML and Emergency response
Balancing load between phases (without storage)	M		M		H	H	M	M	
Storage to balance peaks and troughs	M				H	H	H	H	
Balancing load between phases (with storage)	M		M		H	H	H	H	
Reactive voltage support (without storage)	H		H					M	
Reactive voltage support (with storage)	H		H					M	
Improve power quality & harmonics		H		H					
Demand reduction									H
Frequency response									H

Hypothesis *"use of forecasted demand ... [to] provide a coordinated response to address ... voltage and thermal performance in the most efficient manner possible."*

Source: *Smart Control of ESMUs (Energy Storage and Management Units) by Nigel Bessant, Scottish and Southern Energy Power Distribution*

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So was Project Falcon useful? For WPD the usefulness lies in being able to sweat its assets by increasing utilization from 80% to above 90%. Godfrey was also keen on the advanced inverters improving harmonics.

But, as always, it comes down to costs and even if a positive case can be found by stacking up all the revenue streams from balancing services and cost savings from investment deferral, DNOs seem less than keen to own storage assets.

Godfrey said an ideal solution would be to rent mobile storage systems mounted on trailers, which could be plugged in for a few weeks at a time at times of system stress. Alternatively, it could buy a small fleet of mobile systems to moved around its network as needed or, perhaps, “share” them with third parties, who would aggregate them and trade electricity/grid services.

UK Power Networks is now in the final stages of commissioning of its flagship battery energy storage project – the 6MW/10MWh Leighton Buzzard system featuring Samsung SDI lithium-ion. The rationale for Leighton Buzzard is to use storage as an alternative to building a third overhead line to cope with peak demand.

The 765m2 facility - the size of three tennis courts – is a mini-power station, featuring 50,000 cells (12 x 264 strings) and 230 tonnes of equipment inside a cladded building raised two metres off the ground.

The plant is heavily insulated with thick foam and features double acoustic louvers. Needless to say this required a full planning process, always a headache for any developer.

While this is very much gold-plated project from a technical standpoint, it is perhaps of most interest for its commercial, or at least semi-commercial, trading arrangements. London-based electricity trader Smartest Energy is providing UK Power Network's indirect route to the wholesale market and dictate the operating profile according to their trading positions.

Meanwhile, third party demand response provider KiWi Power will aggregate capacity from the system to provide balancing services such as Short Term Operating Reserve to help National Grid cope at times of high demand.

One drawback of using batteries to provide these services, as opposed to say, a diesel generator, is the difficulty in guaranteeing continual responses due to lower state of charge. Further, as UKPN is consuming power to charge the batteries, it is liable for renewable energy feed-in tariffs levies on that power even though it is being used to timeshift consumption at a cheaper period. Something for the regulator to remedy.

As was pointed out, DNOs are used to fix-and-forget copper cables and transformers, which require little maintenance and may last 40-80 years. Battery energy storage systems require annual maintenance checks - which require downtime – and could last only 20 years at best.

The immediate prospects for energy storage are not great. The LCNF money has been spent and DNOs expect little if any investment in similar projects for the rest of the decade.

Prospects for other forms of energy storage, such as pumped hydro, seem similarly dim. SSE has proposed building a 600MW pumped hydro facility, Coire Glas, to the northwest of Loch Lochy near Lochaber at an estimated cost of £600m. However, building pumped hydro plants is likely to be extremely challenging from a planning point of view due to their location in protected areas and engineering characteristics.

But despite the cost-benefit worries there was plenty of hope in Birmingham. What is clear is it needs strong political support, as seen from that centre of the energy storage universe, California.

The Sunshine State has mandated its three large investor-owned utilities – Southern California Edison, Pacific Gas & Electric and San Diego Gas & Electric - to procure 1.325GW of energy storage by 2020.

Towards the end of the conference, California Public Utilities Commissioner Carla Peterman - via Skype - showed the way: get the regulator to set a big fat target and get electricity consumers to stump up the cost.

The UK Electricity Storage Network wants to see a 2GW target for 2020. While the UK Department of Energy Climate Change is unlikely to adopt a target this side of next May's General Election, there was hope the next Government might be interested.

Despite the cost concerns, delegates went away thinking that, with a firm push from the centre, grid energy storage in the UK might just have a future.

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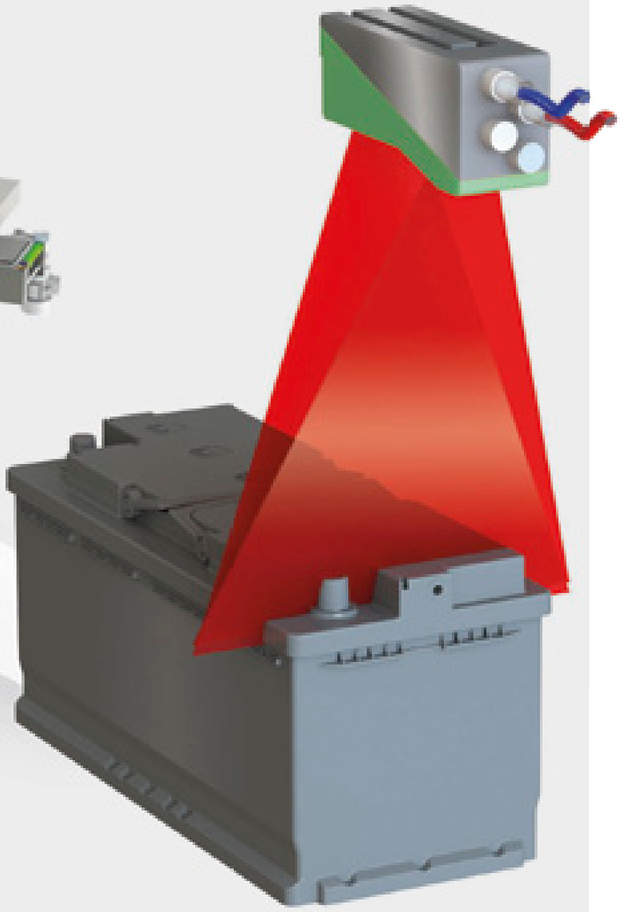

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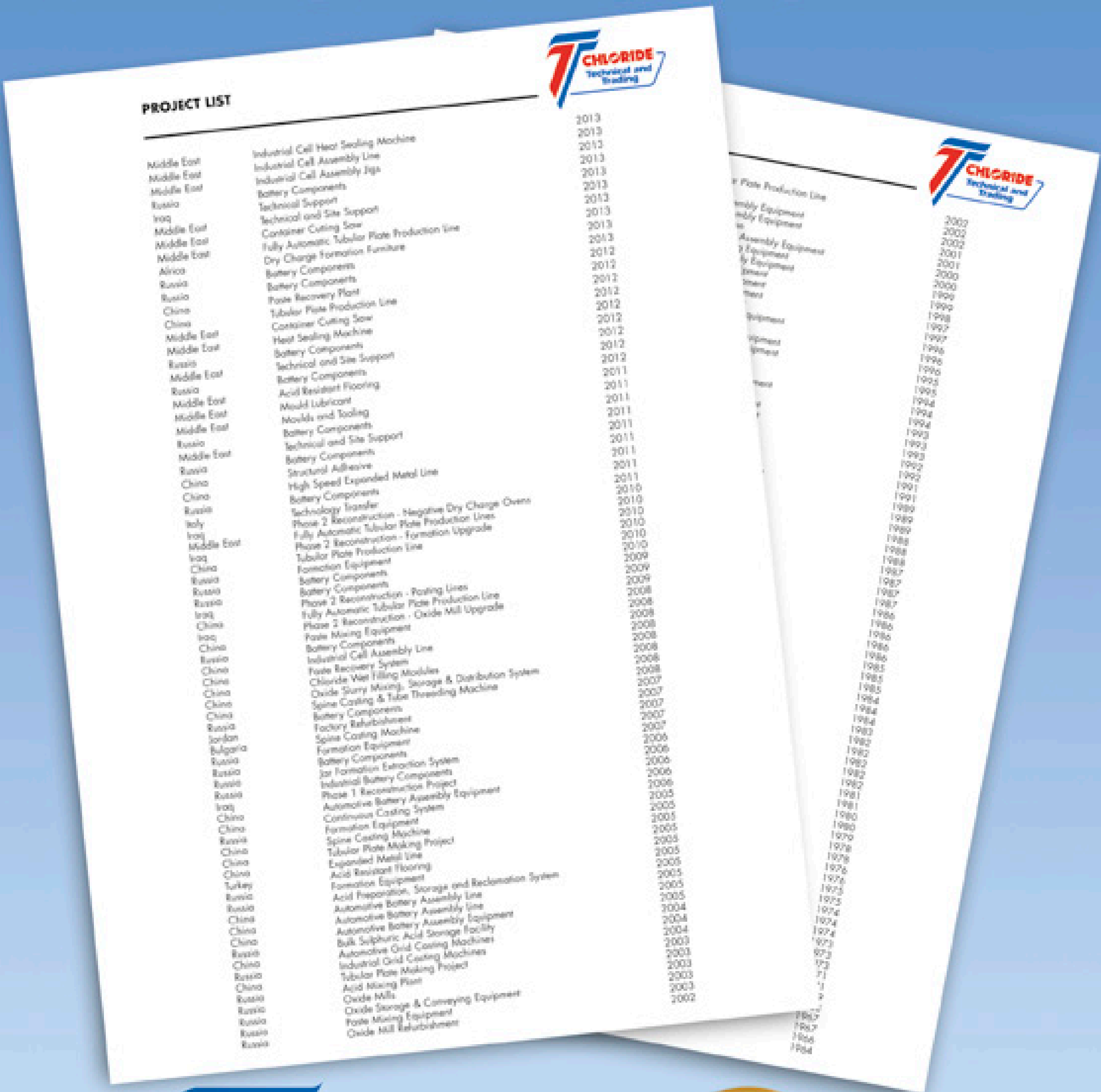

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It's all gone now. Hasn't it?

The UK's Warwickshire was once a world-class centre of automotive engineering but its former glory is a distant memory. Laura Varriale visits the High Value Manufacturing Catapult at the University of Warwick to learn of attempts to capitalize on the opportunity offered by electric vehicles.

Above: (left) Paul Blackmore, project manager at WMG and (right) Mark Amor-Segan, principal engineer at WMG.

The British motor industry was born in Coventry in the county of Warwickshire. In 1897 a clever man named Harry Lawson saw the potential of the car and converted a cotton spinning and weaving factory to produce the Coventry Daimler, Britain's first motor car.

Many of Britain's famous carmakers originate from this city in the English West Midlands. Jaguar, Rover, Land Rover, Austin, Triumph, Healey and more had roots in Coventry.

In its pre-war golden era, Coventry was UK's version of Motown, but much of it has long gone. Jaguar Land Rover (JLR), now owned by India's Tata Motors, continues to be a major global force, but in general the area's golden era is a fast fading memory.

Like Detroit, it is not like it used to be. But efforts are underway to refresh the area's automotive market, and these efforts include battery technology for electric and hybrid vehicles.

Perhaps the most eye-catching of the UK government's initiatives is the £1 billion ($1.6 billion) Advanced Propulsion Centre (APC), a 50:50 public-private project to "research, develop and commercialise technologies for the vehicles of the future". The APC, which has the backing of Bentley, BMW, JLR, Nissan, Ford and 22

Project engineer Philip Hallam describes the small-scale electrode slurry mixing equipment to research fellows Stefania Ferrari and Melanie Loveridge.

other firms, is aimed at maintaining and expanding Britain's automotive engineering base and securing the 30,000 jobs linked to producing engines.

The home of the APC will be the Warwick Manufacturing Group (WMG) at Warwick University, three miles from Coventry city centre. Back to Coventry, back to the roots. WMG has research-to-industry driven work programmes to help new technologies to cross the crucial point from academic research driven work to industrial system development.

WMG is home to another UK government initiative – the Technology Strategy Board's network of High Value Manufacturing (HVM) Catapult centres, of which there are seven across the country. The idea of the Catapult centres is to fund a sector where Britain is or was "world class", but has slipped back and find an outstanding research centre that already – or still – has the connections, know-how and is innovative.

Catapult centres research risky technology that otherwise may be too costly, but they also have to create self-sustaining income and balance research ideas with commercial potential, while having industry requirements in mind.

Lithium pilot line

WMG's HVM Catapult focuses on low carbon mobility and it features an Energy Innovation Centre, which identifies as well as demonstrates lithium batteries with higher energy densities and improved safety while reducing costs.

Fully operational since spring 2014, the Energy Innovation Centre provides a complete battery material pilot line, where full-size prototype battery cells can be created, without relying on industrial battery manufacturers to produce them. The laboratory is equipped with mixing and milling equipment designed to cope with different battery chemistries.

A reel-to-reel electrode coating machine, where battery slurries can be coated onto aluminum or copper foil, works like an industrial large-scale coating machine. The machine can coat in stripes or patches of double-sided electrode material to close tolerances. The lab also provides a calendaring machine that compacts the coating to improve the energy density of the battery electrodes.

The dry room has less than 1% relative humidity.

After being slit, anode and cathode cutting machines cut out the electrodes to a wanted profile in the dry room. The dry room itself has less than 1% relative humidity to prevent the electrode materials reacting with moisture during the manufacturing.

Once the electrodes are vacuum dried, they are stacked into multi-layer cell packs and put into the stacking machine that places alternate layers of anodes, cathodes and interleaves separators between each layer. Tab, cut and welding machines as well as a pouch cell-forming machine are also located in the dry room. Tab welding machines and pouch sealing machine are also located in the dry room. An electrolyte filler injects the desired volume of electrolyte into the cell pack.

In the chemistry laboratory, small prototype cells can be made in ultra-dry gloveboxes to test small amounts of the developed battery materials. Offline analysis such as particle size analysis, surface area measurement, scanning electron microscopy and rheological characterisation all provide additional data for making next generation battery chemistries.

A battery abuse centre challenges the systems to the utmost; batteries can be subjected to high temperatures, crush and nail penetration to characterise their failure modes. WMG offers a comprehensive service to industry including testing cells over a wide range of temperatures and pressures, and benchmarking commercial packs both physically and electrochemically.

"It is unique to have everything in one place," says Paul Blackmore,

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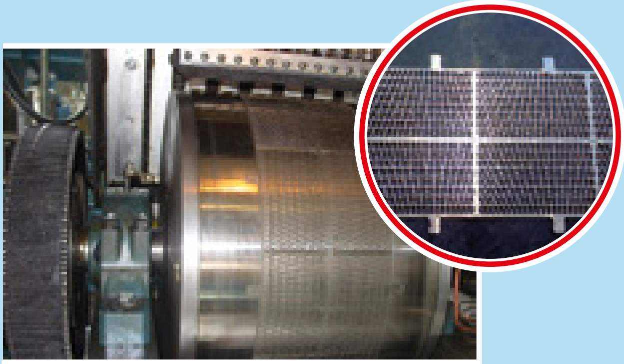
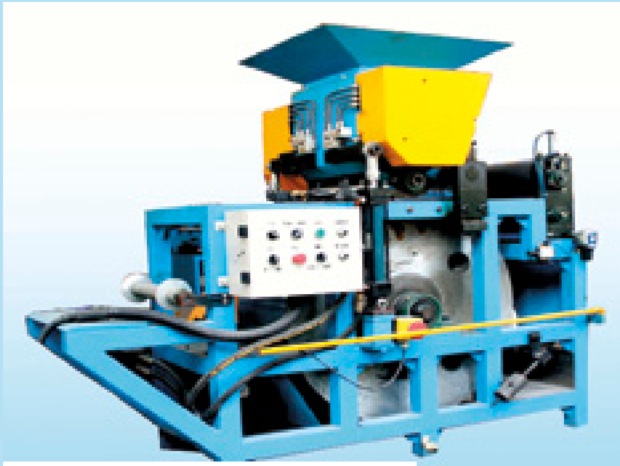

Continuous grid casting mold


HZ vacuum paste mixer


TW no-belt pasting machine


QF oxide mill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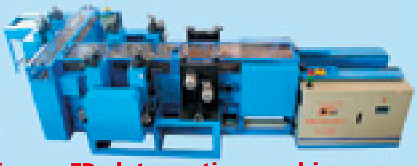
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project manager at WMG. "There are other businesses in the UK that can do these individual tests, but not in a one-stop-shop fashion."

Testing, testing

WMG also has extensive performance testing capabilities for evaluating lithium batteries and other energy storage technologies that companies might want to use. WMG can evaluate all aspects of performance encompassing electrical, thermal and mechanical behaviour.

A chemistry laboratory is located at the mezzanine floor.

"We can test special requirements and under real conditions," says Mark Amor-Segan, principal engineer at WMG.

"Some universities are application-oriented, some do fundamental research," he says. "We are sort of sitting in the middle. We are specialised in the integration side. We bring both sides together and do the performance evaluation and system optimisation.

"The key message is small to large. For example, universities come in, work out all processes with us, all small scale materials and move over to large scale, so we can produce four reels of material, which are representative of what you would find in the industry."

The most important tests are related to battery thermal behaviour, says Amor-Segan. "Temperature management is a key factor," he says. "Poor thermal management can have a dramatic impact on reliability and life-span. We are able to evaluate the effectiveness of battery thermal management and cooling strategies."

WMG is currently working with its close partner Tata to study thermal effects on battery cells and systems. "We're working on a battery project for cell chemistries in hot environments, such as India," says Blackmore. "Tata's interest is in batteries for hot places and all the challenges that that brings with it: higher energy densities and safer batteries in hot climates."

WMG's Vehicle Energy Facility, funded by the European Regional Development Fund, comprises two linked dynamometers for hybrid powertrain testing, battery cyclers and thermal chambers that enable to test in a controlled environment.

The dynamic lithium battery industry brings new technologies and creates the need for testing procedures. Lithium-ion cells' different ageing mechanisms demand more equipment to monitor precise evaluation of the effects of temperature, low state-of-charge charge, high state-of-charge, compression that affects the AC ripple and so on.

"When you look at the research, there are probably 15 or 20 different mechanisms from which only four or five are well understood and documented. What we need to do, is to understand the remaining mechanisms," says Amor-Segan.

"We have a lot of equipment that allows us parallel testing of up to 18 months so we can achieve in 18 months or two years what would otherwise take many years. We are starting different ageing tests soon, which will occupy a lot of our testing devices. That's also why we have so much equipment, which is unusual for an academic facility. We are at our capacity now. I'm looking to double our capacity, the equipment and put another mezzanine in," he adds.

Most of the temperature test equipment was purchased through Catapult funding.

Coventry: The new EV Motown?

Blackmore is all too aware Britain has to catch up in the electric vehicle (EV) battery market. "The Japanese, Koreans and Chinese are in the lead for lithium-cell materials for 20 years now," he says.

Will Coventry become the new EV Motown? "There is so much potential just because of the traction and the size of the automotive industry here."

While there are very few British lithium-ion battery manufacturers of note, there are signs of progress. Two years ago, Jaguar moved its Battery R&D activities to the WMG centre HVM Catapult in Warwick.

Paul Blackmore at the electrolyte filling unit for pouch cells.

"It's not an exclusive relationship, " says Blackmore. "We have other customers that are interested in battery design, cells and the actual chemistry of it.

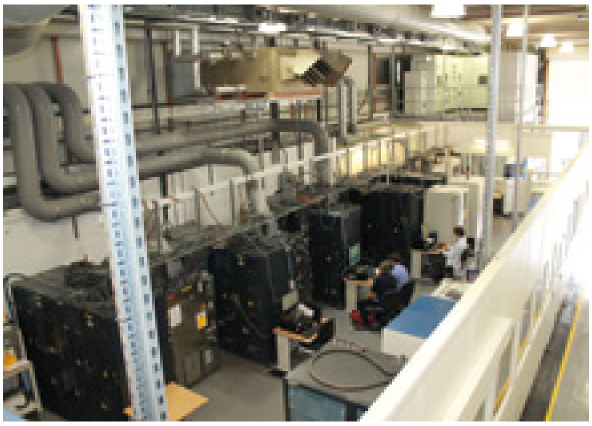
"Car manufacturers have begun to be more and more interested in battery design and what they actually want from the battery. They don't have to rely on the data sheets of the battery producers anymore. In one sense, we increase the value chain of the UK and Europe, because we are looking at every component."

"It is actually quite interesting to look at the mindset of the car makers," says James Marco, associate professor vehicle electrification and energy storage at WMG. "One side is completely dominated by cost, quality and precision, but what they have been used to was okay, it's interesting to get their perspective on it"

"There is some element of holistic design, but you have to look at the vehicle, look at this big lump of cost and value that you currently have no understanding of. And the risk exposure – not only the battery – and uncertainty is driving a lot of the R&D," he adds.

Other projects at WMG's impressive facilities include battery testing for new London hybrid buses, remanufacturing end-of-life batteries and research for the Drayson Formula E car. In 2013, Drayson set a new world electric land speed record of 205.139mph in the sub-1,000kg class.

The WMG team sees motorsport as one of the main driver for new battery technologies. "With Formula E and the new electric Le Mans Garage 56 races, we are getting a lot more interest from the high-performance companies



The battery testing and characterisation lab comprises of storage chambers, battery cycling equipment and climatic chambers and battery cycling equipment.

to use our facilities to test and characterise," says Amor-Segan.

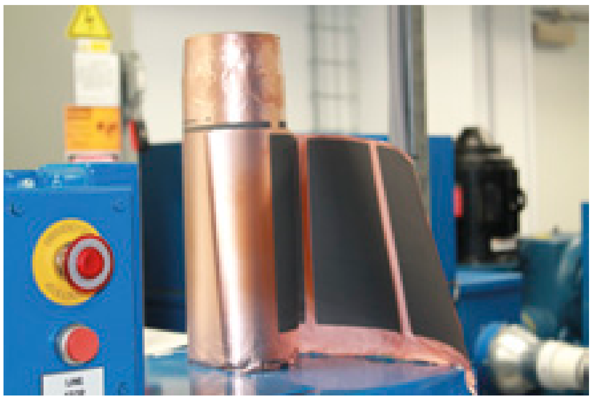
But WMG does not only work for the EV industry. The centre also researches grid-scale energy storage, thinking that the time for energy storage has come. "We've just started another vehicle-to-grid applications project where we try to bring grid storage and batteries together to use them for vehicles.

"That's with Senex Energy and Cardiff University. The Engineering and Physicals Sciences Research Council, which supports fundamental research, funds this project."

The need for speed

The EU target is to cut carbon emissions by 20% by 2020 in every member state. To reach the 2020 reduction targets, emission cuts will be needed not only in sectors covered by the EU Emissions Trading System, but also in other sectors, such as buildings, agriculture, waste

Calendring compacts the coating to improve the energy density of the battery electrodes.



Paul Blackmore and project engineer Marcus Jahn at the pouch cell stacking machine.

management and, last but not least, transport (except aviation).

Of course, it is not the car manufacturers' fault that Britain is behind of a lot of Asian countries in the EV industry. It is a problem that you can see all over Europe.

Money and legislation are the key factors for the success of new technologies in mass production. Something that the British government is now trying to achieve and has to, if it wants to stick to the rules of the European Union.

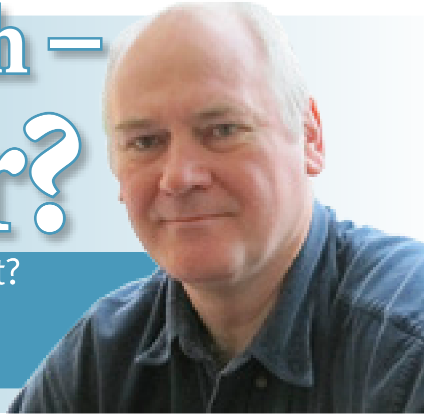
With a battery scale-up line, including a battery characterisation laboratory and an electric/hybrid test facility to enable industrial-scale testing at its Energy Innovation Centre, the WMG facility seems ideal. The connections are there and almost more important: the location has its great history that the government now wants to reenact.

Bringing R&D and industry together is nothing new but it is essential for success. But can the government catch up 20 years with funding? There is a chance, because the APC and Catapult centres are thinking in the long term.

But will it be enough; will billions of funding paid by taxpayers be justified?, Asian governments, especially China, are also funding their R&D centres, in order to bring its technology centres further and extend the lead, if you want to see it as a race.

It is good when new inventions conquer the valley of death. But it is still uncertain how the market response, which is so crucial, will be. This is something that the government cannot influence. But it is worth a try.

Finishing, storage and dispatch – The final frontier?



So, you've finishing making your perfect lead-acid battery. What's next? Quite a lot, actually, as lead-acid battery expert Dr. Mike McDonagh explains in the 11th part of his step-by-step guide.

We have now reached the stage when production of carefully crafted, well-designed lead-acid batteries is finished. They have just rolled off the assembly line; they have passed all the quality tests for every component and are being prepared for storage or dispatch. The hard work is finished and you can now confidently relax in the knowledge that there is very little that can now go wrong. Ha!

But the problems just don't end there. In many ways they are just beginning. There is still the small matter of finishing and cleaning, which should be simple and straightforward, but if not done correctly can give rise to massive problems. The finishing process should ensure that all traces of the chemical processes are removed, from the external surface that is. There are still checks and tests to be completed and organization of stock to ensure that the batteries are fit for purpose and will remain so, even if stored for long periods before dispatch.

The main areas for attention are cleaning; wrapping for storage and dispatch; storage conditions; identification of the batteries, stock rotation; refresh charging policy and methods; cosmetic damage from handling; acid leaks resulting from incorrect filling practices or lid designs incompatible with formation and filling methods. All this before it is even out of the door.

To all producers and distributers of batteries, I say this. Take a trip to a customer's premises to be present when a delivery from your facility is made. It could completely change the perception of your self-image and certainly that of your customers.

There are a lot of considerations for battery storage that rely on the properties and design of the battery. Some properties for consideration are: self-discharge rate; state of charge (SOC) required for delivery; impedance values for parallel connections; final destination requirements, particularly for public sale or further storage; refresh charge frequency, the method of transport and stability of the batteries or cells on the pallet being transported and so on.

The conditions in which the battery is being stored can also determine whether or not refresh charging is required or special packaging and/or layout of the stored batteries is to be considered. Self-discharge rates and the effect of temperature for different lead acid battery technologies is an important factor in deciding how to equip a warehouse. ***Figure 1*** shows the effect of temperature on the self-discharge of different battery technologies. It is also important to understand the requirements and conditions placed on batteries in service. The margin between a warranty complaint and a personal injury lawsuit can be the result of small differences in the batteries' condition on dispatch.

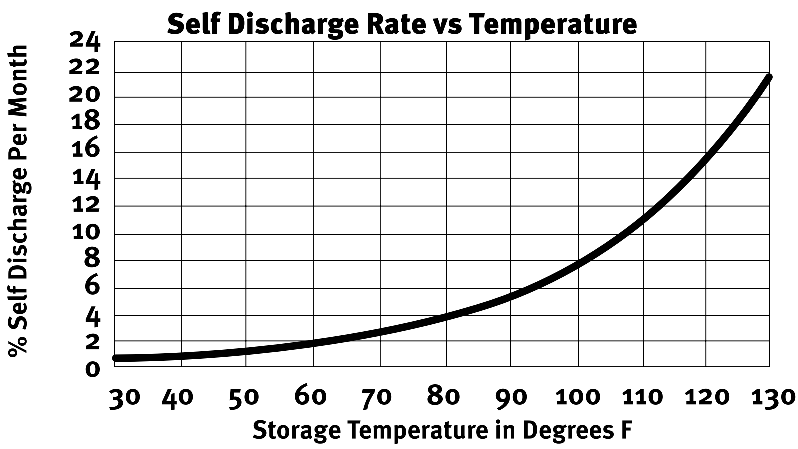


Figure 1: *Effect of temperature on self-discharge rate of VRLA lead-acid batteries.*

Battery finishing

One of the most important aspects of finishing the battery is to ensure that it is fit for purpose so that it meets market requirements. That market can be the public for automotive or leisure batteries, or the engineers and trading companies who have to store or fit the batteries into vehicles or installations. In all of these situations, not only the battery output and performance have to be considered but also the ergonomic and safety aspects of the finished product. From the member of the public fitting a 12V monobloc into his caravan for lighting, TV etc., to the traction battery engineer who has to manhandle 70Kg 2V cells into the corroded tank of a 20 year-old fork lift truck, there has to be a consideration for safety. Most of the problems relate to dealing with acid, both inside and outside of the battery or cell.

Looking at the acid inside the cell, this is a deliberate addition which plays a key role in determining the performance and life of the battery. In most cases the specific gravity (SG) and quantity are carefully controlled, deliberate additions. Acid on the outside however, is a mistake and the result of poor equipment and/or working practices. For the purposes of understanding the causes of external acid and proposing solutions, we can separate out the monobloc style batteries from the 2V cells as groups with similar characteristics.

For both groups the level or height of the internal acid in the battery or cell is achieved through a controlled process as both a technical and a practical requirement. The external acid should be entirely removed. However, aspects of the design, the finishing equipment or procedures used, along with the formation and acid filling processes can result in acid being retained either directly on the outside, or contained in pockets inside the lid to come out later during use or handling.

Monobloc finishing, flooded cells

Modern, flooded, monobloc batteries have a variety of uses - mostly SLI and leisure applications. Many manufacturers are now adopting a two-part lid with an explosion-proof vent. One of the consequences of this design is the introduction of a labyrinth into the upper part of the lid to prevent acid from reaching the vent hole. However, this, and some single piece lid designs have to allow acid that reaches this area to return to the bulk electrolyte of the cell and to be evacuated from the lid.

Superficially, this seems to be a simple matter that can be achieved by good design, however, in practice, this simple requirement has proved difficult to achieve. The cause of the problem is basically that acid trapped in the labyrinth can reach the vent area at the side of the battery. It can then be ejected out of the battery on charge.

Figure 2 shows the results of this, which resulted in a warranty claim from a customer. In this particular case, there was a lawsuit resulting from damage to the vehicle but thankfully not to the customer's person. The cause was the result of several factors in combination: the level of acid in the battery, the design of the vent plug and lid along with the two-shot acid filling process.

Looking at each of these factors in turn a picture emerges, which is not obvious when they are all considered separately. Overfilling a battery is clearly an incorrect procedure, but it can happen and the manufacturer should be aware of this in the final stages before washing. A levelling device to remove acid after the final filling point should be mandatory. This can be incorporated into the filling device but it is best if it is achieved by removal of electrolyte rather than by inputting the correct amount. For the purpose of preventing acid ingress into the lid, the level of acid, rather than the quantity, is a critical factor in equipment choice.

It is also important to consider the level of acid when the battery is on charge. Both the production of gas and the increase in temperature will increase the volume of the contained electrolyte. This volume increase will inevitably cause a rise in the acid level. It is possible that this increase will be sufficient to allow ingress into the lid space. This is more likely if the battery is installed into a moving vehicle.

Acid trapped in the lid from the production processes, or from excessive movement in use, should fall back into the battery compartment. Examination of several lid designs where this problem has shown the acid should fall back into the cell compartment and not reach the exit port of the lid. Additionally, electrolyte levels were not high enough to push

Figure 2:
Acid which is leaking from the vent hole of an automotive battery. This was returned under warranty with a claim for damage to the vehicle.

Acid clearly visible being pushed out of the vent hole under internal gas pressure resulting from normal alternator charging voltage.

Acid spillage after less than 15 minutes charge at 14.4 volts.

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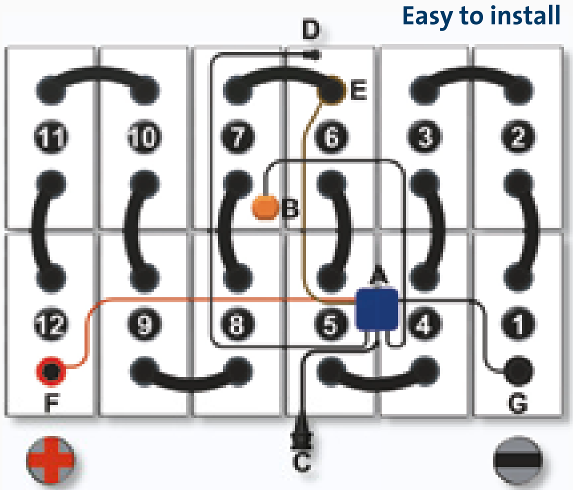

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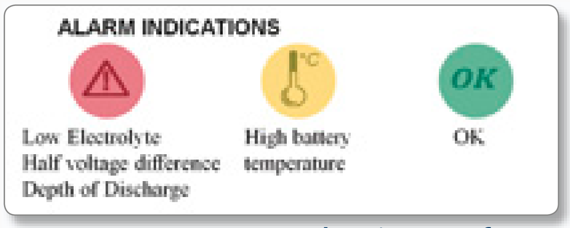

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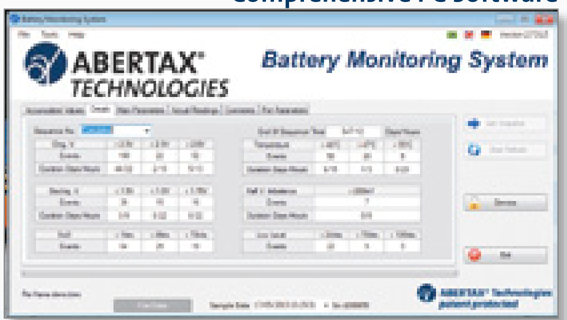

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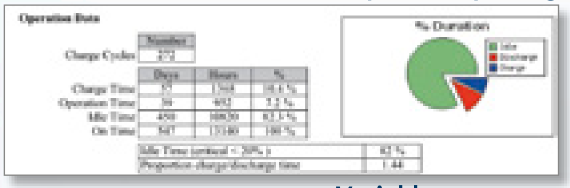
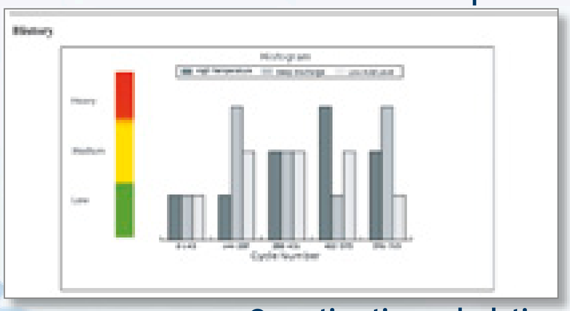
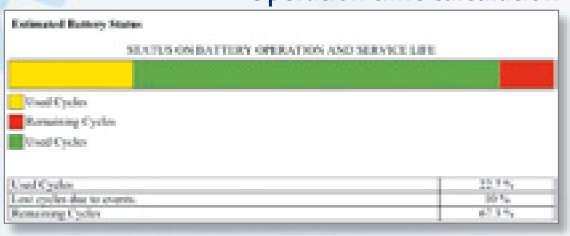


Variable sequences



Operation time calculation



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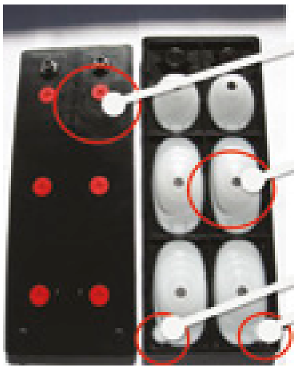


Figure 3: *Example of a lid with an improved design to prevent acid traps and eliminate acid spillage from the vent holes. (Picture provided by Biasin).*

electrolyte into the lid even with normal vehicle movement. There must be a reason why the acid in this case was able to be retained in the lid and reach the exit port of the explosion proof vent.

A mechanism for this, whereby acid could reach the lid exit port, was investigated by checking various conditions of operation. This included examination of various electrolyte levels, charging conditions and the temperature of the battery. It was found that if acid was deposited in the lid, for a variety of reasons, which include the manufacturing process, pressure from gas evolution at charging voltages of 14.4V for several hours could cause droplets of acid to be pushed along the labyrinth towards the exit port. These droplets can accumulate at this point, and dependent upon the lid design and temperature, can ingress into the explosion proof vent plug and then, under the pressure of gas evolved during charging, be ejected out of the battery.

The way to prevent this is for the battery manufacturers to understand the limits of the labyrinth design and for the lid manufacturers to appreciate the processes whereby the acid can reach and be ejected from the battery lid. Careful control over the filling processes, elimination of the entrapment during formation and ensuring that, during charging, the levels of electrolyte do not reach a critical height. Specification of the charger parameters is also required to guarantee acid will not be ejected from the battery. All this is the responsibility of the battery producer.

Equally, the lid manufacturer should invest the time and resources to fully appreciate the conditions under which this acid entrapment can occur and design lids that minimize the possibility of acid reaching the exit ports. One example of this commitment to improve lid design is the newly patented lid design of the Italian company, Biasin. Figure 3 shows the design and operating principle.

Dealing with the residual external acid is a different matter. This is almost entirely a process-related phenomenon, although design improvements to the monobloc box and lid cannot be ruled out. In nine out of ten cases of external acid being found on the battery after finishing, the causes are the formation and filling processes. While it is difficult to prevent acid contamination from a two-shot formation schedule, it should be possible to minimize acid spillage from the filling processes both before and after the batteries are formed.

This is important, particularly as modern batteries have so many features to improve the ease of use. There are many areas that can hold acid and make it difficult for automatic battery washing machines to reach these parts. The critical points are the undersides of the battery parts that form projections, such as the handles, or lid projections with holes for rope handles. This is further complicated by batteries being different heights, widths, lengths and configurations.

The other important aspect for battery finishing is the drying method. It is not good to store or transport wet batteries, particularly if they are to be shrink or stretch wrapped individually or on a pallet. There can be cosmetic effects such as watermarks, or hydrated lead layers on the terminals, as well as possible tracking across terminals, particularly with batteries on pallets covered with plastic shrink wrap or stretch wrap. This is more likely where there are significant temperature variations between night and day. Water evaporating in the day will be held in the pallet pack by the plastic wrap sheet then condense at night and drip onto the surface of the batteries.

Wet batteries can cause in-service problems with tracking particularly in the case where there is some acid contamination and high voltages and currents are required. Likely candidate areas for problems are high voltage series parallel installations, such as UPS and standby power. Further down the commercial chain, batteries sold to the public as leisure or SLI demand that no surface acid is found on the outside of the battery, for obvious reasons.

Batteries delivered in boxes with damp edges have been known to be rejected. I have even been called to a UK port where a container of batteries was impounded because a worker saw acid leaking from under the door of the container. Thankfully, I had pH paper and demonstrated it was neutral and therefore water. Where did the water come from? The container was loaded in India during the rainy season.

A list of post finishing quality checks is presented in ***Table 1***. Normal test equipment would include: multimeter, hydrometer, pH indicator or paper, impedance meter and high rate discharge tester.

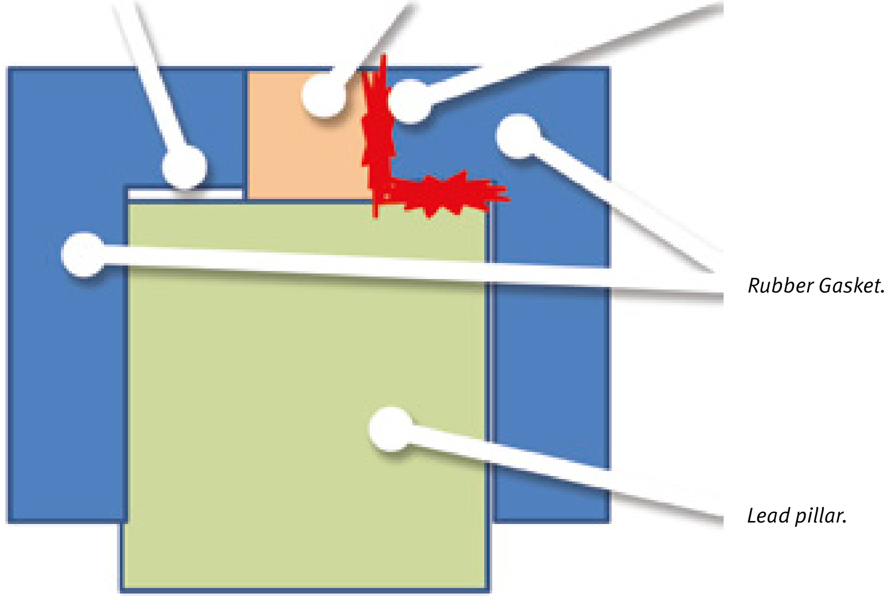


Figure 4: *Schematic of cross section of a threaded traction pillar with rubber grommet, showing location of acid.*

Finishing for monoblocs with immobilsed electrolyte

The main difference between flooded batteries and those with immobilized electrolyte is the inability to measure the electrolyte strength and make adjustments after final filling of batteries with immobilized electrolyte. However, the surface cleanliness and washing methods are identical. Additionally, it is very unlikely to find acid leaking from the lid as the system is completely sealed. Problems can occur in-service if the electrolyte strength is incorrect and the filling process not consistent.

For VRLA batteries the charging method is always voltage limited to prevent excessive gassing. It is not possible under these conditions to equalize cells that are out of step due to differences in SG or quantity of acid. Great care has to be taken to ensure that both AGM and gel batteries have the same amount and strength of acid in each cell of a monobloc.

Of course it goes without saying that the amount of active material in each cell should be equally consistent. Cells that go out of step, particularly in cyclic duty batteries, are common causes of battery failure. The more consistent the capacities and SOC of each cell, the longer the battery will last. This highly important parameter will be discussed in more detail in the next article looking at battery applications and design.

2V cells

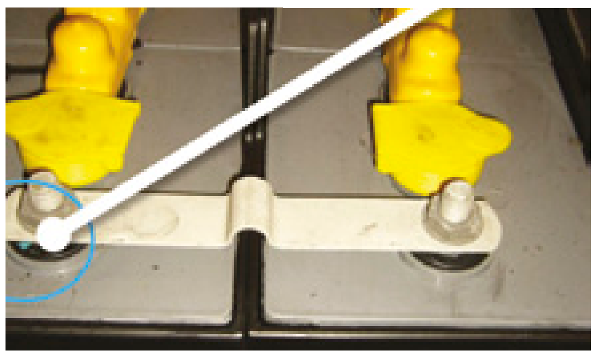
There is a distinct difference between the cleaning problems for monobloc batteries and those of 2V cells. The lid and box construction for 2V cells is a lot simpler than those of monobloc designs. 2V cells are made to fit into containers or limited spaces, usually by lowering into a tight gap; they need to have smooth sides and no lid projections. The lid does not have to contain a handle, as they are not carried or moved individually once in place. They almost always form part of a battery and are fixed into a vehicle or installation.

Although the plastic lid and container are a simple construction, the majority of cells have a grommet seal for the pillars and in some cases there is a bolted connection system. The bolt on system generally has a brass insert into a lead pillar, which may or may not be coated with another metal such as tin, lead or a lead tin alloy. This, of course, in the presence of acid, is a recipe similar to that of the Japanese puffer fish meal. It is safe if you know what you are doing and are aware of where the danger areas are. However, one small error can be fatal.

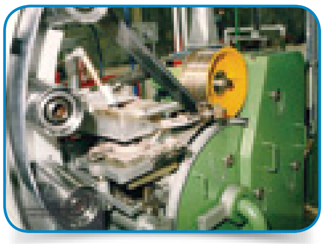
Figure 4 shows a schematic of a typical bolted cell pillar and grommet arrangement. As you can see there are areas where the acid can be trapped. Acid can and will enter these areas if conventional charging methods and inadequate connectors are used. ***Figure 5*** shows a typical poor arrangement for the formation of 2V traction cells. The connections are not sealed and the vents are open allowing acid spray to reach the terminals.

It does not take any real knowledge of electrochemistry to see the dangers of having dissimilar metals in contact with acid. However, it is interesting to note the additional factors inherent in this design, which make the problem more insidious than is first perceived. Again, taking ***Figure 4***, it is obvious that an electrochemical cell will be set up between lead and ANY other metal when acid is present. An acid proof coating such as tin or solder will still form an electrochemical cell with lead in the presence of acid. The

Figure 5: *Inadequate pre-dispatch condition for bolted two volt cells.*



PUNCHED GRIDS FROM WIDE LEAD STRIP FOR BATTERIES PRODUCTION



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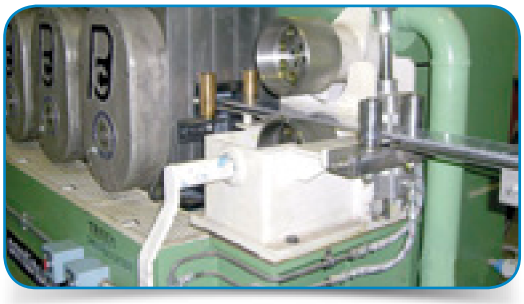

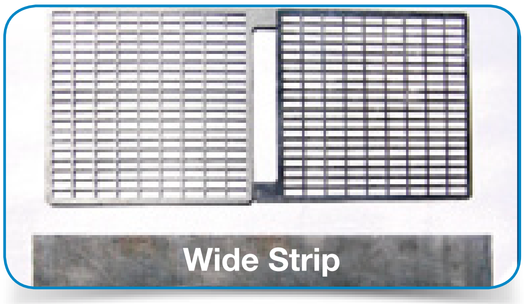

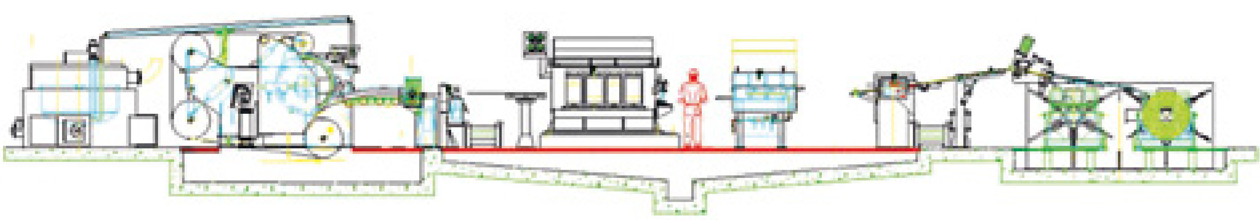

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straightforward galvanic corrosion for any metal (M) is as follows:

Galvanic corrosion

$$M + 2H^+ + SO_4^- + Pb^+ = MSO_4 + Pb + 2H^+$$

Equation 1

This reaction should go to completion once the sulphuric acid runs out and there should be a limit to how much corrosion occurs. This is not the case, however, and pillar corrosion can be extensive. In this case the corrosion product is not simply metal sulphate. It is a complex hydrate and sulphate with a much greater volume than the original metal. The reactions behind this are driven by two additional factors: the oxygen concentration gradient and the cell voltage. It almost invariably occurs on the positive pole and, as it is a process that removes electrons, it is clearly corrosive and driven by the cell electrochemistry.

Differential aeration corrosion occurs when a metal surface is exposed to differential air concentrations or oxygen concentrations. The part of the metal exposed to higher oxygen concentration acts as cathodic region. The part of the metal not exposed with a lower oxygen concentration, acts as an anodic region. Consequently, poorly oxygenated region undergoes corrosion.

Differential oxygen concentration corrosion

At the anode

(low O_2 concentration),

$$M = Mn^+ + ne$$

Equation 2

At the cathode

(high O_2 concentration),

$$H_2O + ½ O2 + 2e- = 2OH^-$$

Equation 3

Because we also have sulphuric acid present, producing H+ ions from the galvanic corrosion, we have a source to replenish the water when equations 1 and 3 are combined as follows:

$$2OH^- + 2H^+ = 2H_2O$$

Equation 4

There is some confusion within the industry as to why traction pillars with bolted inserts suffer from corrosion. In some quarters and certainly going back to the late 1980s and early 1990s, it was believed that the acid would creep up the pole, through the grommet seal and end up in the top of the pillar in contact with the brass insert. Many weird and wonderful designs involving screw fit inserts and compressed grommets found their way into the market, all of which were designed to prevent acid coming up from underneath the lid. The use of the push fit grommet shown in ***Figure 4*** still has the problem of external acid ingress and subsequent corrosion.

The best washing method is water, preferably a water jet to get underneath the top of the grommet seal and ensure that acid is removed from the brass/lead interface. However, it is also useful to remove the water, commonly with a compressed air jet. This is an expedient and not good practice due to the potential hazard of the spray and the inability to completely remove an aqueous medium, which can promote corrosion reactions through differential aeration.

The best, and in my view, the only solution is to ensure that the acid does not get access to the inside of the grommet or any part of the brass insert. This requires proper connectors with rubber seals, which are thoroughly washed with water after every formation cycle. Not only will the cell be safe in storage, but the connector life will be greatly extended. This is a procedural and control issue rather than a technical matter. However, if you can afford to invest in a recirculating acid system as described in a previous article, this is a very good technical solution.

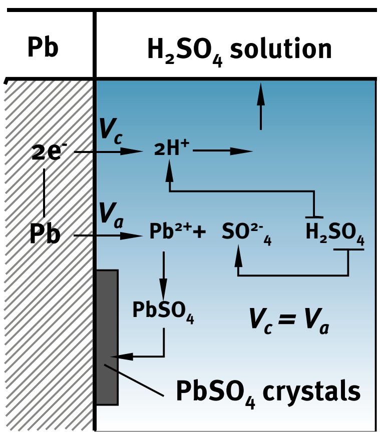


Figure 6: *Self-discharge mechanism on the negative plate according to Pavlov. Source: Lead-Acid Batteries: Science and Technology, Science and Technology.*

Storage: Self-discharge rates for different technologies

Figure 1 shows the reliance of self-discharge rates on storage temperature. The discharge rate is a function of the plate chemistry, electrolyte density and physical state (immobilized or free acid), separator material and design and the concentration of impurities in the electrolyte. All these factors result in a rate of self-discharge or coefficient of self-discharge, which is characteristic of a particular battery design.

This can be ascertained by measurement of capacity loss over a period of time. Since it is an electrochemical process it is likely to be temperature dependent and non-linear. However, considering an isothermal case, the self-discharge coefficient can be defined as SD where:

$$SD = \frac{1}{co} \times \frac{\Delta C}{\Delta t}$$

Co is the starting capacity, ΔC is the

change in capacity over time Δt

The result of this after differentiation and assuming isothermal conditions is:

$Ct = Co \exp (1\text{-}SD * \Delta t)$

This gives an asymptotic curve approaching 0 as Δt approaches large values of years or more. The effect of temperature, as shown in ***Figure 1***, is based on an AGM battery and is supplied by C&D Technologies. It is real data and a practical guideline.

So what are the causes of self-discharge and how is it affected by battery design and storage conditions? As the name implies it is the conversion of the active masses PbO2 and Pb to lead sulphate PbSO4 with no applied load. Taking the positive and negative plates in turn:

Positive:

$$PbO_2 + 4H^+ + SO_4^{2-} + 2e = PbSO_4 + 2H_2O$$

$$H_2O = 1/2O_2 + 2H^+ + 2e$$

Negative:

$$Pb + SO_4^{2-} = PbSO4 + 2e$$

$$2H^+ + 2e = H_2$$

Figure 6 shows a schematic representation of the negative self-discharge phenomenon. Evidently, these reactions will dilute the acid and also create gas. So for flooded batteries it is possible to measure acid density and also the amount of gas evolved as a measure of self-discharge.

Additionally, the cell or battery voltage will also be dependent upon the SG of the electrolyte and is also used as a measure of state of charge. This is the most common method for flooded, sealed flooded and VRLA cells and batteries. So looking at these discharge mechanisms how does battery design and plate chemistry affect the rate of self-discharge.

Plate chemistry

The grid alloy and additives to the plates can affect the rate at which the sulfation reaction occurs. There is also the added effect of M+ ions migrating to the negative and plating out by reduction. This consumes electrons and effectively transfers the charge from the positive plate to the negative plate.

Shelf-life of lead-acid batteries has increased substantially over the last 20 years principally as a result of reducing or eliminating antimony from the grid alloy. It is thought that antimony has the dual effect of creating a porous interface structure between the active mass and the grid as well as migrating from the positive to the negative plate and causing self-discharge as described above.

There are long standing candidates that are often accused of increasing stand losses for lead-acid batteries. However, as pointed out in a previous article on grid alloys, new evidence from ALABC suggests that we may have been wrong in some of our assumptions. However, taking as an example iron, this element can discharge both positive and negative plate when in the divalent and trivalent states respectively.

$$PbO_2 + 3H^+ + HSO_4^- + 2Fe^{2+} = PbSO_4 + 2H_2O + 2Fe^{3+}$$

$$Pb + HSO_4- + 2Fe^{3+} = PbSO_4 + + 2Fe^{2+} + H^+$$

As is evident, there is a type of shuttle process with the same ions being transported back and forth between the plates, probably driven by diffusion, or perhaps they hitch a ride to the positive plate on larger oppositely charged particles. The obvious conclusion is that a small concentration can have a big effect.

Apart from metallic ions there are also present organic and non-metallic additives, predominantly in the negative

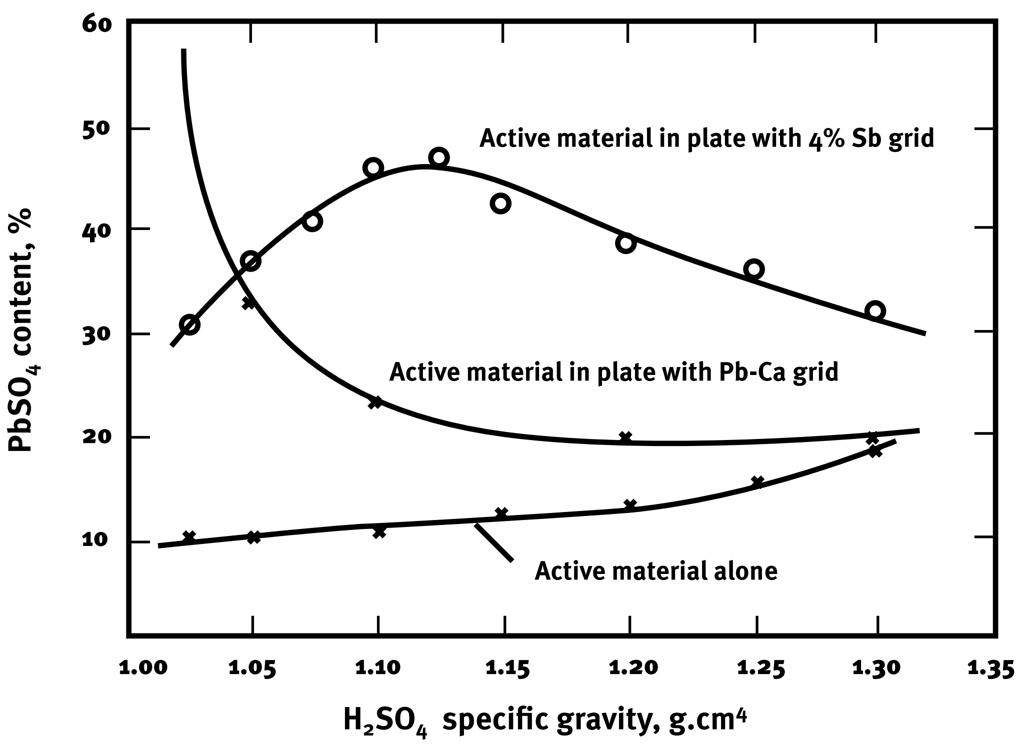


Figure 7: *Effect of acid concentration and conducting grid material on the self-discharge rate of lead-acid battery plates.*

plate. The effect of these additives is to raise the hydrogen over-potential above the single electrode potential of -0.12V. Generally they are beneficial.

The separator can also affect the self-discharge process by providing organics, which can be oxidized on the positive electrode. This is not significant and the contact area is usually small due to the rib construction, or even non-existent due to the use of glass mat. The distance between the plates and the concentration of the electrolyte are also factors. The greater the plate spacing, the lower the self-discharge rate.

The effect of acid concentration, however, is less obvious. ***Figure 7*** shows the results of a study carried out by Pavlov showing the effect of acid SG on the self-discharge rate of lead acid batteries. Three situations were examined: plates made with grids fabricated with an antimony alloy, plates made from a lead alloy grid and just active material without a grid support.

While the active material alone behaves predictably, that is, increasing acid concentration leads to increased plate sulfation, the plates containing the lead alloys show very different behaviour. There is insufficient space within this article to discuss the possible mechanisms behind these results. However, it can be said that in both cases it is best to keep the SG as high as possible and as close to the fully charged state as possible.

Manufacturing batteries is similar to having children: they may have grown up and left home, but that does not mean you can forget about them or expect your responsibilities to be over. Even if you make 'perfect' batteries, there are so many ways and so many reasons why non-performance or damage can be laid at the manufacturers doorstep that it is imperative that you remove as many reasons as possible from the long list of standard complaints which are used to claim warranties. Just remember: nothing is idiot proof, they will just invent better idiots.

TABLE 1: *Recommended quality checks to be performed after final cleaning and testing and before wrapping and storage or dispatch.*

Check	Limits	Reason	Potential problem	Cause	Remedy
Terminal acid	PH 6-8	Terminal Corrosion	Complete loss of connection before delivery	Acid ingress into grommet seal from production processes	Wash thoroughly with water and dry with compressed air.
Acid SG (flooded)	0.005 above or below specification	Stand losses and final application requirements	Low capacity, excessive stand loss, low CCA, in service corrosion, possible charging problems.	Incorrect formation, incorrect filling acid before or after formation.	Initially charge until no SG changes occur then adjust cell SG by partially removing electrolyte and refilling with 1.4 SG acid or demineralised water. Keep charging to thoroughly mix the components.
Acid level (flooded)	Max height 1 cm from underside of the lid	To prevent easy ingress into the lid cavities and	Acid leaks from the battery causing property and equipment damage with public health risk	Acid reaching the exit port of the lid labyrinth and venting system through internal gas pressure during charge	There is very little to remedy this situation if it has already occurred, if possible, remove any flame arrestors and try to clear the acid out using low pressure compressed air. Ensuring that any acid spray from the opposite side is safely contained is an essential requirement. Care must be taken!
Cell or battery voltage	0.05 Volts above or below the nominal fully charged rest voltage.	To ensure that the battery is in a good state of charge and has the correct SG/voltage before storage/shipping.	May not perform on delivery. May be under-formed and self-discharge rapidly. It is an indication of SOC and acid SG. Low SG will give low capacities, High SG will give charging problems and charge acceptance.	Low SG from second filling. Under-formed due to rectifier malfunction, low SG and high plate sulphate level.	Make a high rate discharge test to check the SOC. If under-formed, continue formation. If wrong SG acid, then adjust SG.
Pressure test	No leaks at 0.2mb	To ensure that lid seal is undamaged from handling processes	Acid leaks and danger of damage or personal injury	Inadequate heat sealing or handling damage	Reject the battery.

Panasonic's Indian ambitions

South Asian correspondent Dipak Sen Choudhury explores the potentially significant decision by Panasonic to set up a lead-acid battery hub in India.

In July, Panasonic formally announced the setting up a plant in India for the manufacture of lead-acid batteries to be mainly used for automobiles and also in data centres. This is a part of their overall plan to use India as one of their strategic hubs and aggressively expand the range of products it offers, both on the consumer side as well as on the business-to-business side.

Though present in India for four decades, with a clutch of seven companies manufacturing an entire range of electric equipment, the battery interest has been rather sporadic.

Manish Sharma, managing director of Panasonic India & South Asia, said a feasibility study is underway as to where the battery making factory should be located. According to Sharma, it will be a standalone greenfield project and the target is to have it up and running by 2016. At a planned investment of 2 billion rupees ($33 million) the operation, as envisaged now, does not seem to be in a very large scale but should nevertheless be enough to take care of current Indian automobile OE makers.

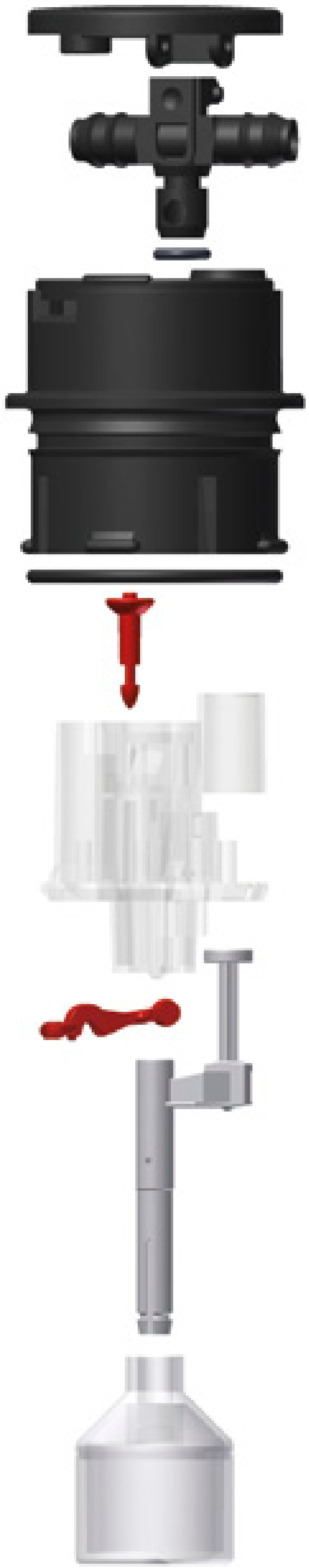
Japanese car makers have traditionally asked their ancillary suppliers to move along with them whenever they have moved out their manufacturing facilities to other countries. With Suzuki, Toyota, Honda and Nissan all having major production units in India, with each having ambitious plans to ramp up export of their cars to different parts of the world, it is imperative for critical Japanese OE suppliers like battery makers to set shop in the country.

Until now Panasonic had been bringing in some limited supplies to India from their Thailand and China units, mainly for automotive applications. For the Indian car battery manufacturers this will be a major wake-up call because Panasonic as a brand name is enormously strong in the mind of the Indian populace. the advent of this brand in the aftermarket could well cause a major shift in user preference.

There is also a huge and growing market for UPS batteries particularly in the large data centres that have come about all over the country. These centres are to necessarily operate with 'zero down time' mode and in a country like India that has hugely unreliable mains power supply, major companies have preferred to procure their battery supplies from European and American manufacturers.

Indian manufacturers of UPS batteries have failed to generate, in the mind of the procurement teams of the critical users, the level of confidence that say, a Deka or a Panasonic battery are typically associated with. This is an opportunity that Panasonic has sensed where its top-of-the-range technology products can come in and fill the niche. The fact that this segment is not particularly price sensitive also helps.

Overall, the entry of Panasonic in the Indian market is welcome as it is bound to trigger a flurry of activity amongst existing players in the country. Advanced technology, consistent quality and better price is what eventually the country is going to benefit from.



Is graphene the magic sauce for supercapacitors and batteries?

IDTechEx's Peter Harrop takes a detailed look at recent advances in functional materials for supercapacitors, including graphene.

As we all know, graphene is an allotrope of carbon in the form of a very thin, nearly transparent sheet, one atom thick. It is remarkably strong and electrically conductive for its very low weight and its surface area is unrivalled. It has been shown to improve lithium-ion batteries but it is not yet attracting major attention here.

Lithium metal rechargeable batteries involve metallic lithium and therefore potentially safety hazards and short operating life. Chinese researchers have commented on their fundamentally new strategy for reviving rechargeable lithium (Li) metal batteries and enabling the emergence of next-generation 'safe' batteries featuring a graphene-supported Li-metal anode, including the highly promising Li-sulfur, Li-air, and Li-graphene cells with exceptionally high energy or power densities.

All the Li metal anode-based batteries suffer from a high propensity to form Li dendrites at the anode upon repeated discharges/charges. A dendrite could eventually penetrate through the separator to reach the cathode, causing internal short-circuiting and even explosion, the main reason the battery industry abandoned rechargeable lithium metal batteries in the early 1990s.

By implementing graphene sheets to increase the anode surface areas, one can significantly reduce the anode current density, thereby dramatically prolonging the dendrite initiation time and decreasing the growth rate of a dendrite, if ever initiated, possibly by a factor of up to 10^{10} and 10^{5}, respectively.

Improving supercapacitors

On the other hand, graphene electrodes are one of the best prospects for enabling supercapacitors and the intermediate devices 'supercabatteries' (notably lithium-ion capacitors) to possibly take as much as half of the lithium-ion battery market in 15 years – amounting to tens of billions of dollars a year.

Yes, that is an outrageous statement. However, consider how they have already replaced lithium-ion batteries in most hybrid buses, the Toyota and Renault Formula One cars and the Toyota Auris concept hybrid car. Something like that happens every month now, even with one-twentieth of the energy density or worse, something graphene looks set to greatly improve.

In addition, their use across lithium-ion batteries is now commonplace because it means you can manage with a smaller, simpler, cheaper battery while improving life, performance and overall cost. Only a few years ago, most experts preached that supercapacitors are power components and nothing to do with batteries and their markets but now these components are colluding and colliding. How wrong can you get?

Graphene may also be key to AC supercapacitors, taking much of the multibillion dollar aluminium electrolytic capacitor business. That will make supercapacitors and maybe supercabatteries one of the largest applications for graphene, so it is now appropriate to look in some depth at the research and technical considerations in this respect.

The basic options are shown in ***Figure 1*** but, in reality, it is a continuum of options and compromises that get designed in as the research gets more sophisticated.

Actually, AEDLC is misleading because some of the options from companies such as Yunasko are faradaic but symmetrical, and therefore are sometimes called hybrid supercapacitors, although we prefer the term supercabattery to avoid confusion with hybrid cars.

Traditionally, supercapacitors are improved in the manner shown in ***Figure 2***.

Source: IDTechEx report, Functional Materials for

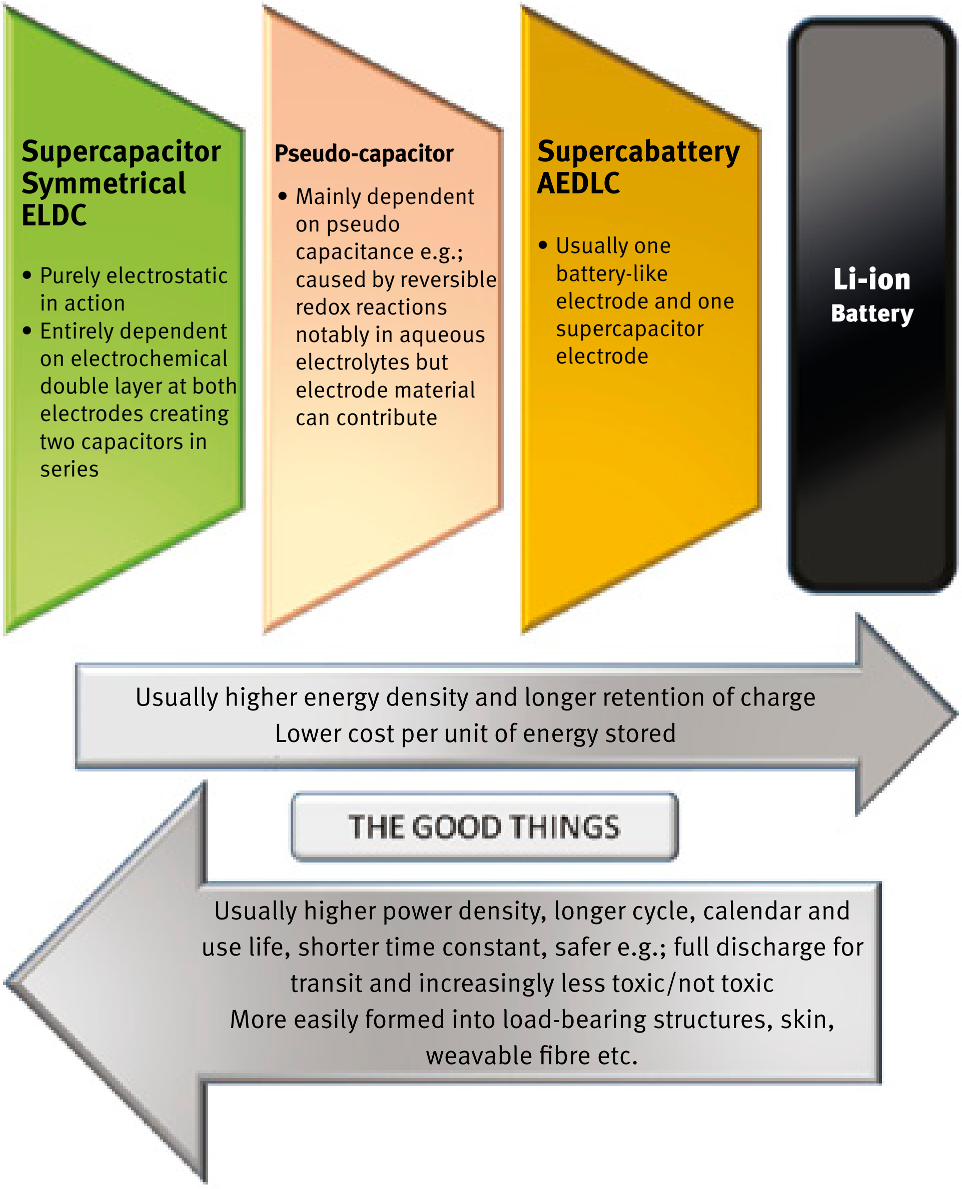


Figure 1: *Three basic options for supercapacitor technology. EDLC=Electrochemical Double Layer Capacitor; AEDLC=Asymmetric Electrochemical Double Layer Capacitor. Source: IDTechEx report, Functional Materials for Supercapacitors/ Ultracapacitors EDLC 2015-2025*

Supercapacitors/ Ultracapacitors EDLC 2015-2025

However, even the methodology top-centre in ***Figure 2*** is being usurped. In research, today's 'hierarchical' electrode structures with an ever smaller hierarchy of pore structure – letting ions further into monolithic masses of carbon – is giving way to often, but not always, better results from 'exohedral' structures meaning ones where the large functional area is created by allotropes of carbon often only one atom thick such as graphene, carbon nanotubes and nano-onions (spheres within spheres). Added to these are newer aerogels with uniform particles a few nanometers across.

It is not simply an area game. The structure must be optimally matched to the electrolyte, then the pair assessed not just for specific capacitance (capacitance density) but voltage increase, because that also increases the commercially important energy density. Then again, at least initially, exohedral structures like graphene tend to improve gravimetric but not volumetric energy density. That will cut off many applications if it is not solved or there is no work-round.

The best example of the latter is planned structural supercapacitors where the device replaces dumb structures like car bodies and laptop casing, taking effectively no volume, regardless of measured volumetric energy density. Of course cost, stability, temperature performance and many other parameters must also be appropriate in all potential applications of graphene in supercapacitors and supercabatteries.

Indeed, for replacing electrolytic capacitors, working at 120Hz is key and in other applications, increased power density may be valuable but energy density improvement is the big one for sharply increasing the addressable market – probably around 2025 or later.

Graphene: A strong focus

Recent developments by industrial companies demonstrate that graphene supercabattery as opposed to supercapacitor systems can operate up to 3.7V with a very high cycle life and excellent power performance. They tend to be biased towards supercapacitor performance because there are no longer two capacitors (double layers) in series. Chemical balancing is needed.

There are far fewer companies making these AEDLCs than EDLCs or lithium-ion batteries, and the market that lithium-ion capacitors has established so far is only at the $10m level. As they improve that may change, but a power engineer designing, say, a car may say the compromise is locked in with a supercabattery, so they may prefer a discrete supercapacitor across the traction battery. Nonetheless, supercabatteries are improving

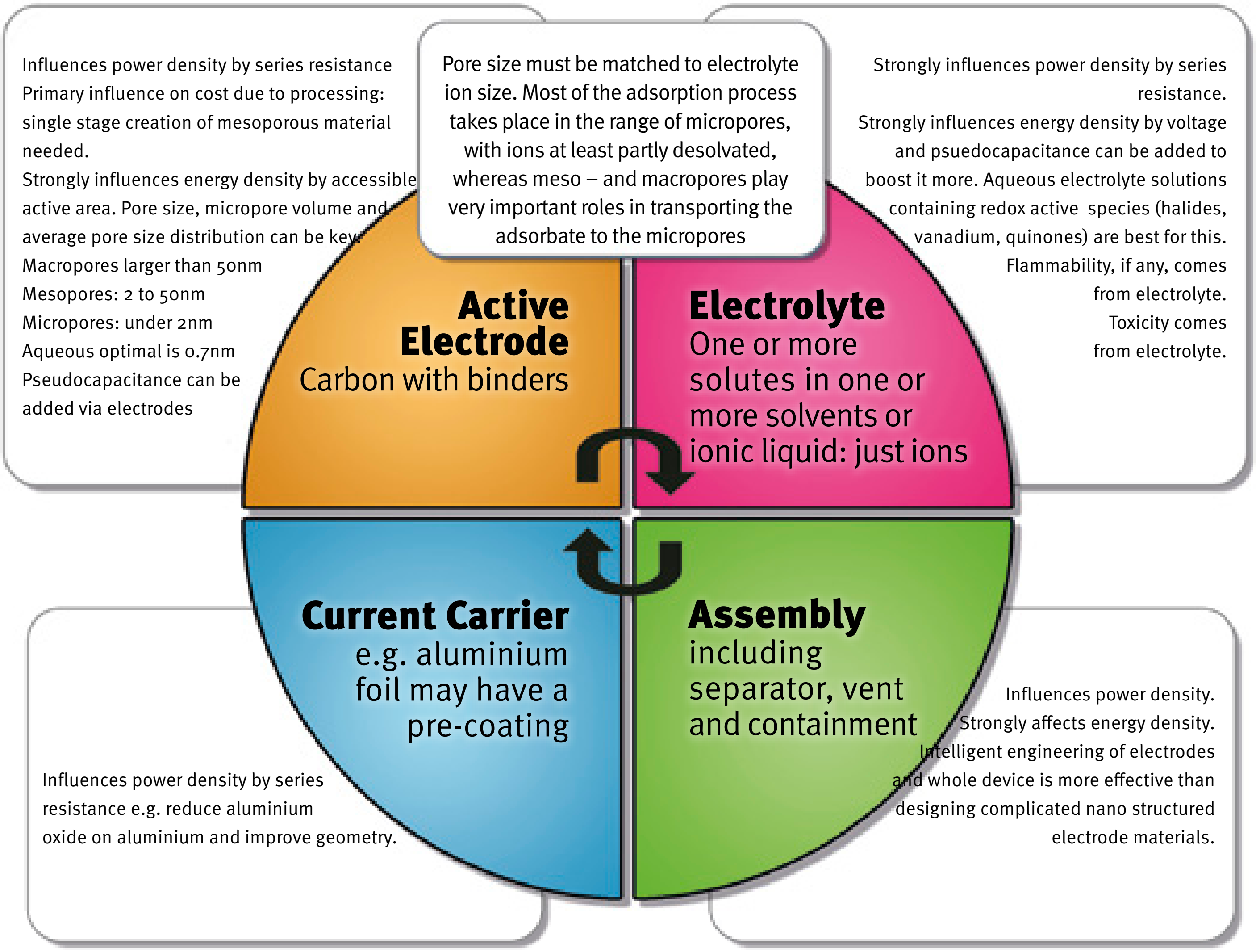


Figure 2: *Options for improving traditional supercapacitors.*

Figure 3: Some of the better advances in experimental capacitance density primarily achieved by improved electrode materials.

and this combined product should be the low-cost approach where supercapacitor energy density is inadequate.

Graphene gives some of the highest energy densities in the laboratory and it is particularly effective in exhibiting high specific capacitance with the new electrolytes – aqueous, with desirable low cost and non-flammability and ionic with desirable simplified manufacturing, high voltage, non-flammability and exceptional temperature range.

With aqueous electrolytes, graphene's large accessible area offsets the low voltage to give good energy density. With ionic electrolytes such as N-butyl-N-methylpyrrolidinium bis (trifluoromethanesulfonyl) imide (PYR14TFSI), graphene works despite the high viscosity that makes them ineffective in hierarchical electrodes. In contrast, graphene does not exhibit good specific capacitance with the old acetonitrile and propylene carbonate organic solvent electrolytes as shown below.

Replacing electrolytic capacitors

Potentially, inverters in such things as electric vehicles could be made smaller, lighter and lower cost by supercapacitors replacing the large aluminium electrolytic capacitors. So far, it is only with vertically stacked graphene that a time constant of 200 microseconds has been demonstrated suitable for 120Hz filtering, potentially replacing electrolytic capacitors ion the big inverter market. Vertically aligned graphene was used in KOH.

The energy density merits of graphene are more theoretical than real as yet

A disproportionate amount of work on increasing the energy density and reducing the cost per Wh of supercapacitors is

Group	Type	Example of the best capacitance density values achieved F/g	Formulation	Challenges
HIERARCHICAL Solid carbon with large holes leading to small ones	Activated carbon AC i.e. that has been heated or otherwise treated(e.g. HOH) to increase it's adsorptive power.	100	Examples are those from coconut shells or charcoal.	Difficult to tailor to purpose. Confused morphology.
	Carbide derived carbon.	140	TiC-CDC in 1m TEA-BF4 in AN.	Difficult to tailor to purpose.
	Templated carbon.	190	Zeolites or silica as a sacrificial scaffold.	Low yield, high cost.
	Activated carbon fibres ACF.	175	Phenotic resin based fibres etc.	Limited ability to tailor to purpose.
THIN FILM	CDC printed thin film.	250	Synthesised on carbon paper.	Confined to micro devices
	Graphene	276	Chemically modified or derived from reducing graphene oxide.	High cost, limited ability to tailor to purpose. Confined to micro devices.
EXOHEDRAL Wide carbon structures usually one atom thick.	The positive curvature of tubes or spheres of the exohedral carbon family (carbon onions and CNT's) facilitates double layer formation, and the reduced electrical field near spherical or cylindrical surfaces decreases the driving force for counter-ion adsorption and co-ion desorption. The effect is more pronounced for spheres compared to tubes, and increases as the curvature increases.			
	Carbon nanotube CNT	100	End sealed (capped)	High cost, limited ability to tailor to purpose, cost.
	Carbon aerogel	90		High cost. Poor volumetric energy density.
	Onion like carbon (OLC)	100	Nano-onions from detonation diamond then thermal annealing.	High cost, limited ability to tailor to purpose.
	Graphene	276 but some much higher figures quoted e.g. 550	Chemically modified or derived from reducing graphene oxide.	High cost, limited ability to tailor to purpose.

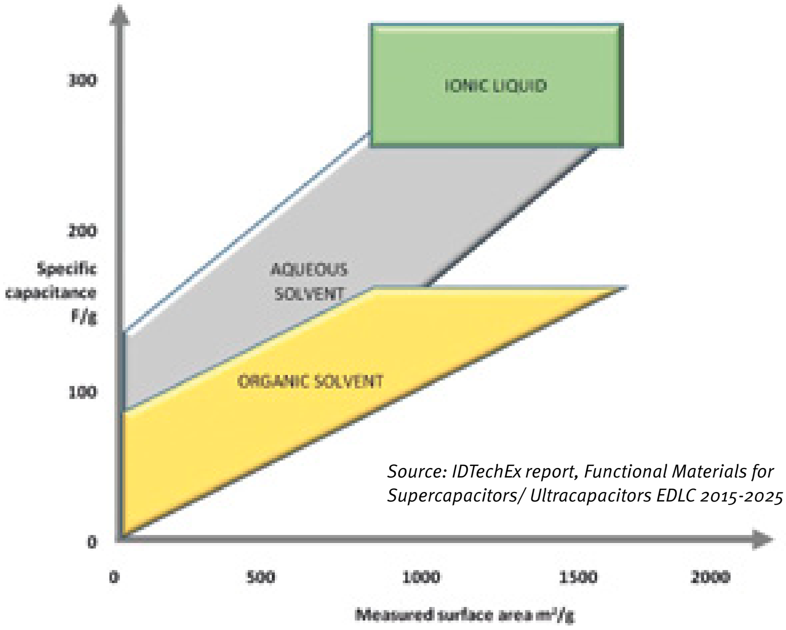
Source: IDTechEx report, Functional Materials for Supercapacitors/ Ultracapacitors EDLC 2015-2025

dedicated to graphene because of its exceptionally large area and excellent conductivity. However, there is no guarantee that that area can be fully or even largely utilised in production of supercapacitors people will buy in volume. The jury is out.

For example, vanadium-based electrolytes have unusually high redox activity to boost supercapacitance at the negative electrode. The pseudocapacitive effects of iodide in electrolytes have been combined with those of vanadium using activated carbon electrodes sometimes with 10%wt of carbon nanotubes.

A huge 300-1000 F/g results and useful but not remarkable energy density of 20 Wh/kg. For comparison, ***Figure 5*** shows graphene results that mainly apply to useful 1-100 kW/kg power density, but again only in the laboratory with no guarantee that they can form the basis of a useful volume product with all parameters appealing.

Graphene has much further to go and supercapacitors using it optimally, combined with the newer electrolytes and intelligently exploiting pseudocapacitance without resorting to expensive and toxic materials, could get to 50-100 Wh/kg in ten years and more in 15 years. If that happens, lithium-ion batteries will be under serious threat on grounds of safety, power density, life, reliability and more, even if they have improved the predicted twofold in energy density in ten years.



Source: IDTechEx report, Functional Materials for Supercapacitors/ Ultracapacitors EDLC 2015-2025

Figure 4: *Specific capacitance vs identified electrode area per unit of weight (e.g. measured by nitrogen adsorption) for graphene-based supercapacitors and lithium-ion capacitors in the laboratory, showing how graphene particularly leverages the newer electrolytes.*

Take one example of scope for improvement using graphene. The newcomer may think of 'curved graphene' as a nano forest of near-identical corrugated sheets, gripped vertically by some super pre-coating on the current-carrier metal foil. Nothing could be further from the truth. Today, curved graphene looks like crushed paper under the microscope: nothing optimal about that.

Toyota's head of R&D, Mitsuhisa Kato recently said that the technology to make pure electric cars a viable replacement for internal combustion has not been invented yet. "The cruising distance is so short for EVs, and the charging time is so long. At the current level of technology, somebody needs to invent a Nobel Prize-winning type battery," he says.

Well, supercapacitors can charge in minutes, and improved supercapacitors replacing bodywork in a car can store a large amount of energy yet take no noticeable space. Volvo, working with Imperial College London, has already demonstrated an experimental car trunk lid that is a supercapacitor. Supercapacitors have even been made into stretchable woven fibres and smart skin so they can literally 'disappear into the fabric of society'. The new energy harvesting of heat, light and movement – regenerative braking and shock absorbers – can only help more. Supercapacitors grab more harvested energy than is the case with batteries.

Figure 5: *Graphene supercapacitor and supercabattery research results. Red equivalent to present or future lithium-ion batteries. Yellow equivalent to lead-acid and nickel-cadmium batteries.*

Structure	Energy density Wh/kg	Specific capacitance F/g
Laser scribed graphene	>600	276
Curved graphene with 5% wt Super P acetylene black and 10% wt PTFE binder	160	
3D porous, curved activated to create macro/meso pores, capillary compression, etc	60-98	206-550
Graphene composite		500
Theoretical limit of EDLC without pseudocapacitance	200*	550

**Not certain but suitable electrolytes and structure may give 200*

Source IDTechEx report, Functional Materials for Supercapacitors/ Ultracapacitors EDLC 2015-2025

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Silicon anodes: The future of lithium-ion?

Rick Howards presents the case for silicon anodes, and describes some of the many ways this material might be utilized in tomorrow's lithium-ion cells.

For over two decades, graphite has been *the* anode material for Li-ion manufacturers. In the ever-improving world of rechargeable batteries, however, graphite is looking more and more like Stone Age technology. Due to escalating consumer demand for extended run time between recharges, major research efforts into improved electrode materials are ubiquitous, but only in recent years has significant attention been paid to the anode.

Why silicon? The short answer is its extraordinary ability to alloy with lithium, providing (in theory) gravimetric and volumetric capacities of 4200mAh/g and 9786mAh/cc respectively, 10-30 times the capabilities of graphite. Unfortunately, this silver cloud has a very dark lining: as Li diffuses into Si during cell charging, the anode material expands dramatically, up to 400% at the end point where crystalline Si is transformed into amorphous $Li_{15}Si_4$.

Besides warping the metal cell casing and potentially allowing electrolyte leakage, the repeated expansion and contraction of this anode material during charging and discharging causes fragmentation ***(see Figure 1 (a))***. The result is small, electronically isolated particles of Si and partially lithiated Si, and ionic conductivity throughout the electrode is rapidly diminished. This is the major cause of unacceptable capacity fade observed with anodes of Si film and micron-sized particles.

A side note: germanium, in the same chemical family as Si, exhibits healthy gravimetric and volumetric capacities of 1384mAh/g and 7366 mAh/cc respectively for Li storage, but, in addition to identical physical shortcomings, it is much more expensive than Si. Tin, another Group IV element that forms Li alloys, is the least expensive but has even lower capacity and greater fade.

A comment for academic and government researchers: gravimetric energy densities have little value for cell manufacturers. Far more important is the volumetric energy density, mAh/cc, which provides an estimation of how much anode material must be fitted into each cell, and is a variable used extensively in cell modeling.

There is no benefit in a 1000mAh/g Si composite if the density is 0.4 g/cc, because the resultant anode capacity (and cost) does not improve on a conventional graphite electrode.

The highest-capacity cathode material – non-stoichiometric NCM, in early pilot stage – produces roughly 250mAh/g, just a fraction of silicon's Li storage capability. Is it possible to have too much of a good thing? Yoshio et al realized a mathematical relationship between anode and cathode capacities in electrochemically balanced cells,

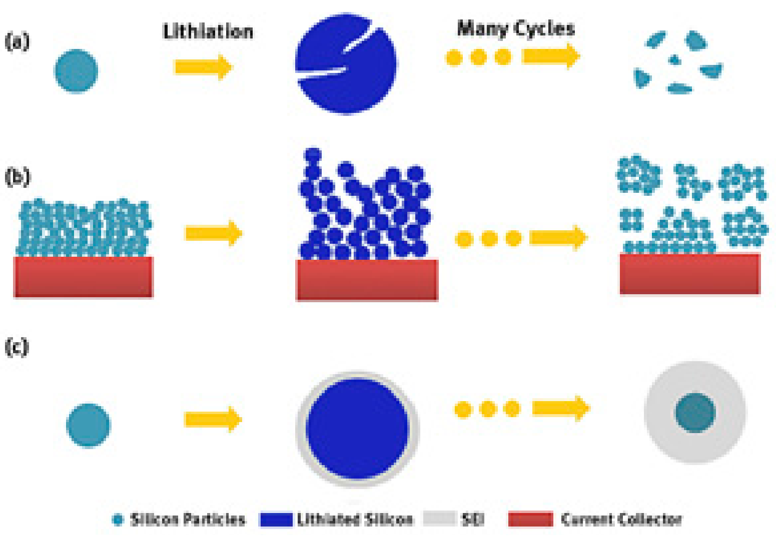
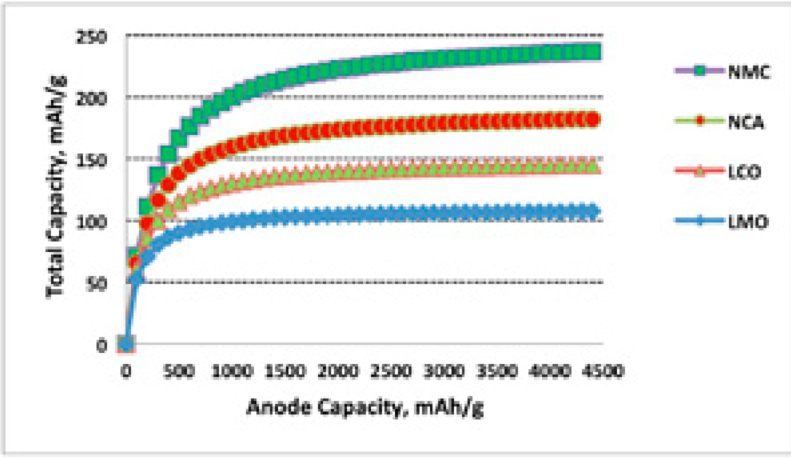


Figure 1.
Silicon anode degradation processes: a) particle fragmentation from repeated expansion and contraction; b) agglomerate separation from binder during cell cycling; c) continuous buildup of SEI layer. From Wu and Cui, Nano Today 7, 414 (2012).

and presented their calculations in graphical form ***(Figure 2)***.

What this plot tells us is that each cathode material has a asymptotic relationship with total cell capacity, and at some point, there is little benefit in increasing the efficacy of the anode. If an 80% cutoff for total specific capacity relative to cathode capacity is used, then optimum anode capacity will be roughly as follows: 450mAh/g for spinel (LMO), 600mAh/g for LCO, 750mAh/g for NCA, and 1000mAh/g for NS-NCM. Unless a strikingly novel, ultra-high performance cathode material is discovered, anode materials with capacity exceeding 1500mAh/g are probably overkill, from a practical viewpoint.

Figure 2. *Graph of anode Li storage capacity vs total cell capacity, as a function of cathode materials, substantiating the law of diminishing returns. Derived from M. Yoshio et al, J. Power Sources 146 (2005), 10.*



The challenge for scientists was obvious: control Si volume changes during Li alloying and de-alloying. Secondary goals included low first-cycle irreversible capacity loss (<10%, usually attributed to SEI formation) and <0.02% capacity fade per cycle for hundreds of cycles.

Of course, this is easier said

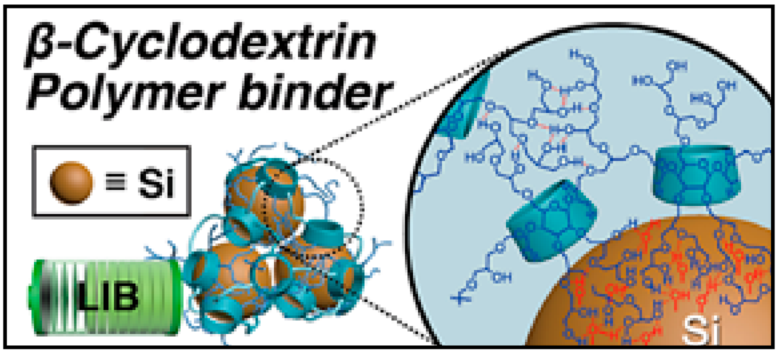


Figure 3. *Hyperbranched β-cyclodextrin polymer binder for Si nanoparticles. From Jeong et al, Nano Lett., 2014, 14, pp 864–870.*

than done, and lurking in the background was the bane of all process technologies: cost-benefit analyses. Even with a reasonable but substantial advance to 3X the capacity of graphite, there is no way Si technology will command x3 graphite's market price – a 10-20% increase is more likely. That means scientific success will shift a heavy burden to engineers: design a cost-efficient process delivering structurally-stable silicon anodes.

Pacific Northwest National Lab (PNNL) is developing a compromise Si anode using so-called 'spongy' material riddled with mesopores that absorb lithium without gross expansion. By limiting the Li storage to roughly 750mAh/g, still greater than twice that of graphite, volume growth is only 30%, not great but likely to be acceptable for Li-ion cells without rigid expansion constraints. A prototype cell retained >80% of its original capacity after 1000 cycles – definitely a worthwhile achievement.

Despite PNNL's advancement, the most probable pathway to Si-based anodes is constructed of nanoparticles, which resist breakage and exhibit electrochemistry approaching theoretical limits of capacity with exceptional rate capability. Further, nanoparticles will not endure SEI fracturing from mechanical deformation and subsequent 'repair' to untenable thicknesses, as found with larger particles, as depicted in ***Figure 1 (c)***.

Researchers determined that above 150nm, Si grains will pulverize with Li alloying and extraction ***(Figure 1(a))***, which limited early Si anode efforts. Attention turned to vapour deposition, a well-known technique controllable down to coatings just a few atoms thick. Alas, lithium uptake caused these films to buckle and lose contact with the current collector (substrate); cell impedance skyrocketed and capacity plunged.

Another approach, good in theory but a failure in practice, was the mechanical preparation, e.g. high energy ball milling, of Si nanoparticles. The extreme surface area of these species makes controlling anode slurry viscosities very difficult, and particles agglomerate easily in the slurry, negating the nano advantage ***(Figure 1(b))***. However, nanoparticle surface energy is sufficient to stall the propagation of surface cracks leading to fragmentation, and the benefits of nanotechnology are compelling. Clearly, more sophisticated methods and morphologies were needed to achieve commercial success.

With nanosizing a given, the quest focused on ways to prevent nano-Si from migrating and reassembling into microparticles (or larger), a weakness observed after only modest cycling. Aggregation results in a poor conduction network and loss of particle connectivity, thus increasing the resistance between the anode and current collector after long-time cycling. There were numerous creative fixes proposed, although only a few with marketable potential.

A complete review of all the methods is beyond the scope of this article, but three approaches deserve greater description: matrix-isolated nanoparticles, alloys, and substrate-grown or free-standing nanofibers. These technology segments have

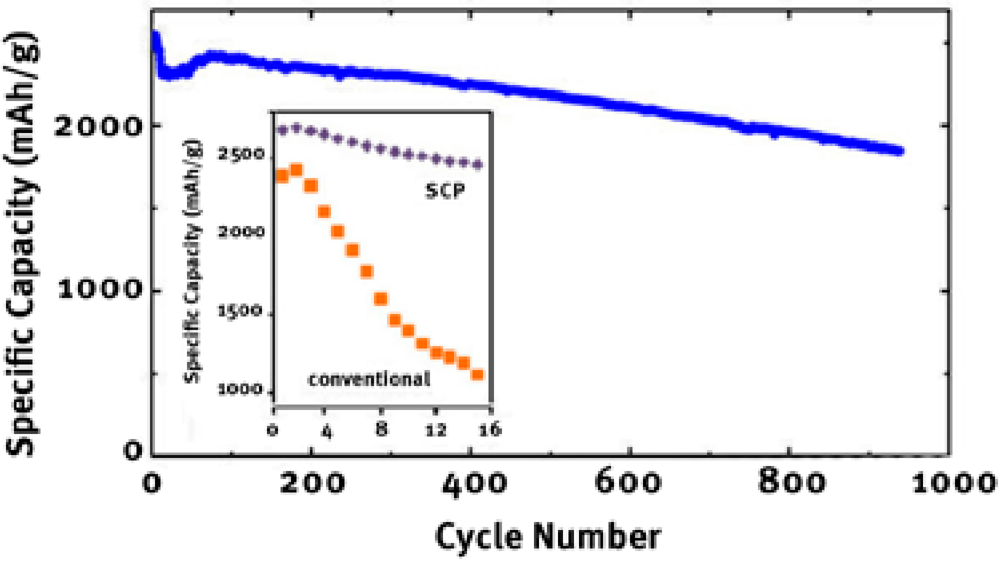


Figure 4: *Electrochemical cycling performance of a conductive polymer-Si (SCP) elec-trode. Inset shows the advantage of SCP over a conventional Si electrode during the first 15 cycles. From Gu et al, Scientific Reports 4, Article #3684, 2014.*

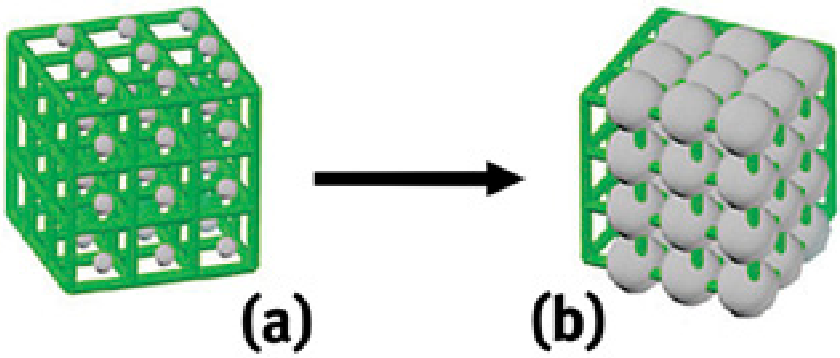


Figure 5. *Si bound in a carbon scaffold before (a) and after (b) Li storage. The structure, derived from pyrolyzed CMC-Si, accommodates Si expansion without breakage. From Wang et al, Chem. Commun., 2010, 46, pp 1428–1430.*

sufficient promise to encourage government and private investor funding for start-up companies pursuing the dream.

Silicon particles can be sequestered in a polymer or as one component of an alloy, with the underlying assumption that lithium will readily diffuse through the composite. ***Figure 3*** provides an example; Si nanoparticles trapped in highly branched poly(ß-cyclo-dextrin), held in place by H-Si bonds. The multitude of bonding sites in each polymer unit provides a 'self-healing' effect after particles' volume changes during Li insertion and extraction, ensuring anode conductivity is not diminished, thereby extending cycle life.

A similar rationale holds for conductive polymers and salts of carboxymethylcellulose and poly(acrylic acid), but more linear species less able to form bonds to Li+, such as polyacrylates, poly(alcohols), and polyesters, are not as adept at holding their guests in place. Lithium storage capacities as high as 3200mAh/g have been reported, or roughly 4200mAh/g relative to Si content, by this method; Si particle sizes are usually ‹150nm, averaging about 50nm. Si-polymer composites with good linkage to the Si particles buffer against expansion, thus are an effective response to Wu et al's anode degradation mechanism shown in ***Figure 1(b)***.

Positive results from a conductive polymer-Si composite were obtained by Gu et al, a joint effort from several national labs and General Motors ***(Figure 4)***. The authors cite the polymer's ability to reversibly adjust to Si volume changes during cell operation, therefore maintaining electrical contacts within the anode, as the reason for slow capacity fade, although maximum expansion of the composite was estimated at 100% from TEM images.

Further, Si nanoparticles remained dispersed throughout the composite, without agglomeration, and energy density was greater than from conventional Si-PVDF-carbon black anodes. Gu's conductive polymer, poly(9,9-dioctylfluorene-co-fluorenone-co-methylbenzoic ester), established proof-of-concept: related composites with fluorine-fluorenone structural units are described in a Berkeley National Lab patent application, WO2013116711A1.

Other researchers working with conductive polymers have employed ball-milled silicon with polyparaphenylene, acidic polymers with sulfate and carbonyl substituents, and a pre-commercial hydrogel with a polyaniline network (from Bao Research). This last material obtained 5000 cycles with ›90% capacity retention at 6000 mA/g current density, and had a calculated volumetric capacity exceeding 1000mAh/cc.

A less-costly cousin of these materials is pyrolyzed polyacrylonitrile-macroporous silicon, which retained ›1000mAh/g capacity after 600 cycles. The process, which involves spraying a PAN-silicon slurry onto a heated Cu current collector, yields a stable scaffold structure and is applicable to other polymers ***(Figure 5)***.

The cited examples are, at best, in early development stages, and appear three to five years removed from commercialization. Highly complex polymers and nano-sized silicon are not inexpensive, and efficient production processes must be developed to insure marketable pricing. Still, there is great potential with such composites, with many eminent scientists and well-endowed companies joining in the stampede toward commercialization.

Silicon alloy anodes seem closer to fruition than polymer composites. For example, 3M has invested considerable effort into the development of this genre, with an extensive intellectual portfolio to its credit. A recent patent –USP 8,071,238 – serves to illustrate the complexities and requirements of such materials, prepared by sequential melting and high energy ball-milling steps.

The alloy comprises three critical phases: amorphous Si (limited expansion with Li up-take), electrochemically inactive nanoparticles of metal silicide (generally 3rd or 4th row elements, for strength and homogeneity), and carbon, in the form of silicon carbide. Some combinations included amorphous Sn (flux aide and Li alloying). The rigidity of the alloy prevents damaging volume expansion during Li uptake, thereby maintaining anode integrity.

Twenty examples were provided in 3M's patent, with capacities at the 40th cycle ranging from 479mAh/g ($Si_{66}Co_{22}C_{12}$) to 1184mAh/g ($Si_{224}Fe_{35}Ti_{35}C_{12}$),

although all but two of the materials tested yielded more than 700mAh/g. Coulombic efficiencies were marginally acceptable, most at 99.7 or 99.8% (some improvement needed, to ›99.9%). The highest capacity material was comprised of Si, $FeSi_2$, and $TiSi_2$ phases, all with 10-20nm grain sizes, plus some amorphous $FeSi_2$.

Key properties of these alloys are their densities (›4g/cc versus ≤1.5g/cc for graphite) and volumetric capacities (›1500mAh/cc, ›x3 graphite's ~500mAh/cc). Not all of these combinations are winners, however: a NiTiSi alloy (described elsewhere), capable of ›1100mAh/g Li storage with first-cycle efficiency ›90%, lost capacity faster than 2%/cycle – a fatal flaw. A rule of thumb in these systems is that higher percentages of the host element(s) lengthen cycle life at the expense of reversible capacity and (usually) rate capability.

The theory behind 3M's (and similar) materials depends on the combination of active and inactive phases, relative to Li alloying. Transition metal components, which are not miscible with Li, form a rigid network that holds the alloying portion in place and minimizes volume changes.

Since lithium is less than a universal alloy, such matrices must contain a lithium acceptor: the common (inexpensive and environmentally friendly) partners are Si, Sn, Sb, Al, and Mg, while other (workable but less accommodating) elements from Groups IB, IIB, IIIA, and IVA are rarely used except to substantiate theory. Note that Si has the highest energy densities of the preferred elements: while Mg is close (3350mAh/g), its low density and high reactivity make it a second-string candidate, Sn was previously down-played, and Al and Sb exhibit even lesser performances.

If all the elements in the storage material combine with lithium, expansion-contraction cycles are relatively unfettered, reversible Li cycling is rapidly diminished, and the anode quickly crumbles away into non-conducting pieces. This matrix concept is also found in various non-silicon alloys, such as Cu_2Sb, TiNbSnSb, and GeFeC, among many others: capacity and fade are typically of lesser performance relative to Si-containing species.

Beneficial mechanical properties for Li storage alloys include low ductility and elastic modulus, to relieve high tensile stress during delithiation that can lead to fragmentation, as proposed by Tarascon and co-workers. In general, alloy matrices exhibit high conductivity, restrict Si expansion, and have reduced reactivity with electrolyte solvents, but production costs likely will push commercialization out three to four years.

The third group of emerging Si-based anodes features nanoparticles isolated on a conductive surface, which facilitates electron transfer and therefore boosts rate (power) capability. Examples include nanopillars or nanowhiskers grown on a metal substrate, which also serves as the current collector, and nanodots decorating a thin plate or film, especially graphene and its analogs.

This method is not exclusive to Si: it includes the alloys mentioned above, as well as a plethora of metal oxides, cermets, and other species capable of hosting lithium via a conversion or redox mechanism. An example is depicted in ***Figure 6***. Vapour deposition techniques created carbon nanopillars on Cu foil, which were then coated with Si.

Expansion with Li uptake was almost exclusively axial (typical of these nanostructures), and with the proper spacing of the nanopillars, there was ample room for volume expansion without degradation from overcrowding. Initial capacity exceeded 3000mAh/gSi, with 89% retention after 100 cycles at 1C, and there was little diminution of capacity between 0.1C and 2C, boding well for power applications.

Nickel and titanium are useful substrates, more electrochemically robust than their transition metal brethren. A Korean team (Lee et al., J. Electrochem. Soc. 2014, 161, A1480) demonstrated modest success via a combination of nanolithography, chemical vapour deposition, and electroforming onto Ni. Although first cycle discharge capacity was an encouraging 2550mAh/g at 1C rate, charge capacity after 100 cycles was a mere 732mAh/g (412mAh/g at 10C), meaning a lot of lithium had been lost in the anode.

The high rate capability is typical of such species, but the capacity fade in this instance is less than desirable. A related system, also mounted on Ni, incorporated Ni_3Si_2/Si nanorod arrays with ›2000mAh/g Li storage, and irreversible first cycle capacity

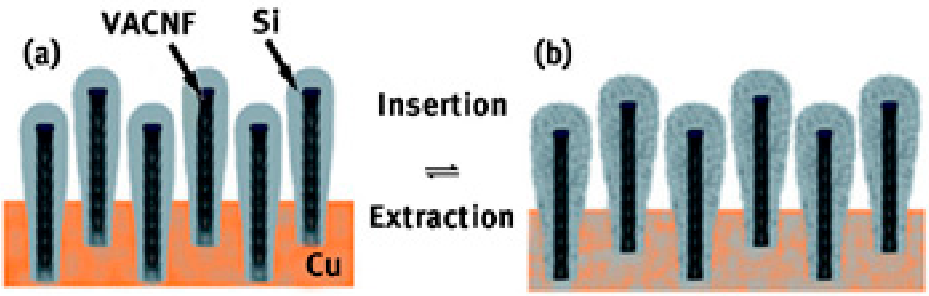


Figure 6. *Vapour-deposited Si on vertically aligned carbon nanofibers, with sufficient separation to allow Li insertion without impinging on neighbouring structures. The Si coating is equivalent to 1.5 µm films. From Klankowski et al, J. Mater. Chem. A, 2013, 1, pp 1055-1064.*

loss was a competitive 12-13%. Unfortunately, the requirement of three demanding process steps will make it difficult to reach manufacturing cost objectives.

A precursor to this approach features Si either electro – or chemical vapour deposited onto Ni or Ti foam, which also serve as current collectors. The open structures had more than adequate space for LiSi alloy expansion, but volumetric energy densities suffered from low Si content.

Earliest attempts at Si composites utilized graphite or carbon black, low-cost choices, and that has not been overlooked. Yushin's Georgia Tech squad produced the spherical Si-C nanocomposite shown in ***Figure 7*** from Si-coated carbon black via a "bottom-up" self-assembly technique.

Fabrication was described as low-cost and readily scalable with existing manufacturing hardware; anode preparation is nearly identical to current practices. The micron-sized nano-composites generated 1950mAh/g, while longevity was attributed to internal interconnected pores able to accommodate Si expansion.

More recently, EnerG2 and Battery Innovation Center (BIC) announced a collaboration to produce prototype portable devices powered by cells based on high-voltage lithium metal oxide cathodes and silicon-carbon composite anodes. The companies project cell capacities greater than 200mAh/g and 350Wh/kg, improving outputs 20% over present state-of-the-art, with claims of enhanced stability, safety and cycle life.

In a previous **BEST** article *(Next-Gen Materials Make EV Dream a Distinct Possibility, Winter 2014 page 119)*, I wrote about the potential of decorated graphene anodes, especially their ability to boost both energy and power

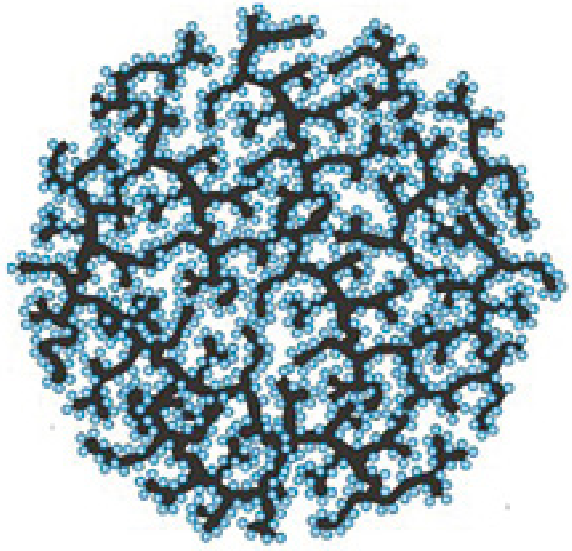


Figure 7.
Si-C granule (ca 20 µm sphere of branched carbon with <30 nm Si "fruit"), showing the pore structure that allows electrolyte entry for fast Li+ transport and low-stress Si expansion. From Magasinski et al, Nature Materials 9, 353–358 (2010).

ratings of Li-ion cells. Mounting high capacity Si on graphene flakes seems an obvious path to enhanced performance, an opinion shared by many in the industry.

There is a caveat: too much Si negates the graphene advantage, as a single-layer composite with c.65% Si started with 1100mAh/g storage capacity, which faded to 512mAh/g after only 40 cycles. Without flogging a dead horse, a few examples should suffice to describe efforts in this arena.

XG Sciences was among the first market entrants, hydrothermally producing Si-graphene nanoplatelet composites. These are short stacks with up to 10 graphene layers held apart by Si nanodots, providing 600-2000mAh/g gravimetric and 500-1700mAh/cc volumetric capacities, up to 200% improvement over graphite, depending on Si content, which is controllable to customer specifications. Irreversible capacity loss during the formation cycle is a workable 10-15%, and capacity fade is described as "minor." A separate study on a similar composite claimed that capacity loss due to SEI formation can be mitigated by judicious choice of electrolyte solvents.

This author interviewed Samir Mayekar, CEO of SiNode Systems, for details about his company and their Si-graphene composite. As expected, some of the in-progress information is still proprietary, but one comment stood out. Silicon in Li-ion requires three pillars to support market viability: volume expansion control, extended cycle life, and competitive material/ processing costs.

Mayekar's team is successfully developing all three, in contrast to many academic groups and some startups who overlook that critical third leg. Because it can take ten years to sell new technology batteries into the automotive supply chain, SiNode is approaching smaller markets, such as the military, to generate early cash flow. Mayekar cited partnerships with Merck, to facilitate their composite scale-up, and Motorola Mobility, to gain rapid exposure to consumer electronics markets. Sounds like deserved optimism grounded in strong scientific and engineering bases, with a controlled business approach.

SiNode is in advanced development of a Si-graphene anode ***(Figure 8)***, produced in multi-layer sheets, with the added attributes of extreme flexibility and strength. Initial capacity from half cells is 3200mAh/g, with long cycle life (300-500+ cycles, depending on Si loading) and excellent rate capability: 2000mAh/g at 0.5C and >1100mAh/g at 7C.

While too early to release full-cell data – tests by an independent lab are underway – indications are that performance will be competitive with graphite anode cells. The most compelling aspect of SiNode's material is their claim that processing is accomplished with off-the-shelf production equipment and is highly

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scalable. Almost as important, their Si-graphene sheets require no binder or slurry preparation. These factors translate into a major cost advantage in manufacturing: will it be enough to bring SiNode's cells into the mainstream? DoE thinks so, to the tune of a $1m Phase II SBIR grant, and other seed moneys are substantially greater.

California Lithium Battery (CalBattery) is another startup seeking to make a big splash in the Li-ion pool. Their Si-graphene composite ***(Figure 9)***, based on technology developed at Argonne National Lab, is prepared using silane via a gas deposition process. The product is structurally stable, with no degradation from Si volume changes, exhibits 1250mAh/g capacity, nearly four times that of graphite, and has an energy density of 525mWh/g. CalBattery, partnering with CALEB Technology, is working hard on process development, currently with a third-generation reactor capable of continuous flow operation. They project commercial volumes, in the thousands of tonnes, in less than four years.

Angstron Materials, a manufacturer of graphene nanoplatelets, recently announced a graphene-silicon product specifically for Li-ion, which should be available by the end of 2014. Initial claims include 1200mAh/g (720mAh/cc) capacity, 87% first-cycle efficiency, 0.60g/cc tap density, and "hundreds of charge-discharge cycles." Materials are available in gram quantities, hardly enough to support the industry; Angstron is currently seeking up to $10m funding for production scale-up, to facilitate market entry.

A Korean team from KAIST has utilized the enhanced qualities of N-doped graphene and carbon nanotubes to spontaneously encapsulate Si, yielding an anode material with high rate capability (914mAh/g at 10C) and good capacity retention (>79% after 200 cycles). From a theoretical viewpoint, carbon-coatings foster single-cycle SEI formation rather than continuous build-up of salt strata on Si surfaces, and the coating also lends compressive strength to the composite, preventing breakage. Usually the protective layer results in better capacity retention, but tends to create higher irreversible capacity loss during the formation cycle while lowering the Li storage capability. This approach is highly dependent on the type of carbon (or other coverings, such as SiO) and the coating method, and it is difficult to project competitive process costs.

While Si nanostructures are more commonly placed on metal or graphene, several groups have prepared stand-alone nanowires, where the major obstacle to scale-up is process cost. An academic team from the University of Southern California utilized low-cost ball milling and stain etching to produce nanoporous Si with >1100 mAh/g after 600 cycles, claiming its method is both low-cost and eminently scalable. Another group varied this theme, preparing a "soft" Si coating on Ni/PVDF nanofibers in 3-D networks, with claims of high capacity and long cycle life. The nanofibrous composite served as the current collector and exhibited good flexibility. Note that nanowhisker technology is not limited to silicon: a number of companies are developing similar anodes based on Li-alloying materials, such as Ge, CuSb, and other combinations.

Amprius, a Silicon Valley startup, presently makes silicon nanowires in a small-scale batch process using chemical vapour deposition (CVD), a process borrowed from the semiconductor industry. Laboratory tests on cell prototypes showed energy densities approaching 800mWh/cc, a step up from conventional Li-ion output of 400-530mWh/cc; Amprius claims 6000 cycles

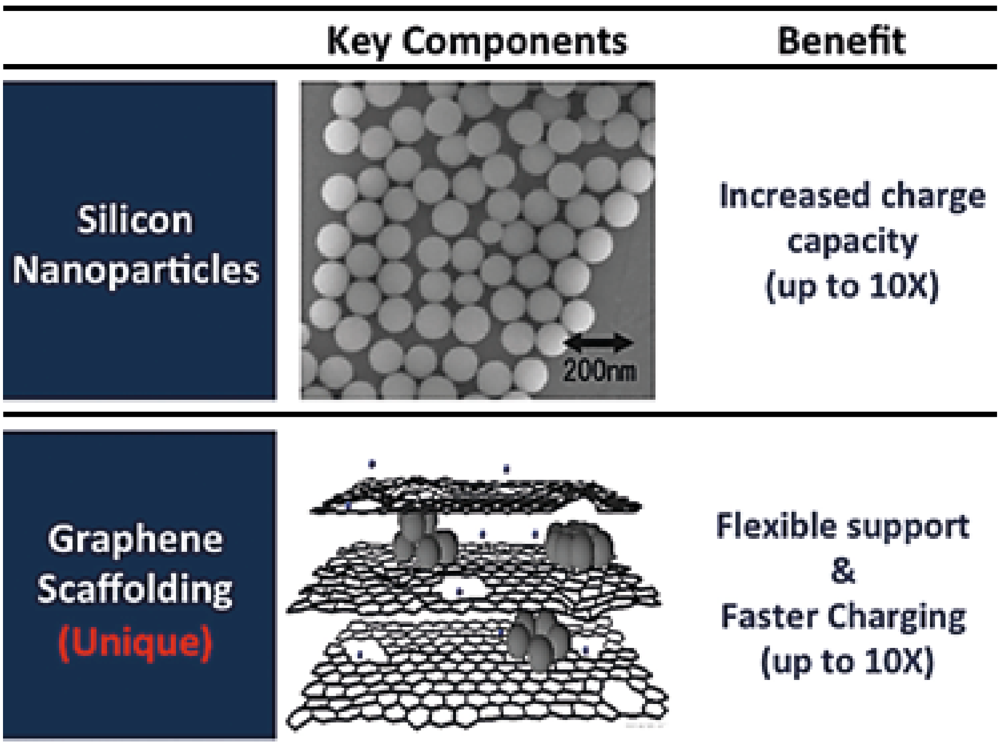


Figure 8. *Schematic of SiNode Systems' anode material, a multilayer Si-graphene compo-site prepared by low-cost manufacturing methods.*

without anode structural damage. Funding has been ample: a recently completed C-round added $30m to the coffers, although full production is estimated at 5 years and >$100m in the future.

Mass consumer applications would require a far more efficient and low-cost manufacturing technique than CVD. The company development plans target a thousandfold scale up in manufacturing capability, building on their Chinese pilot operation with initial production in 2015. Amprius will enter the fray with batteries for consumer electronics, including mobile phones, laptops, and tablets.

The high-reward target for Si-based anodes is electric vehicle batteries, to counter the dreaded range anxiety over the possibility of running out of electrons in the middle of rush hour. Navitas, the company that won the auction for A123's government research contracts, was awarded a $1m Phase II grant from DoE for the development of an economical Si-based anode material for EV/HEV use. During Phase I, Navitas established key innovations utilizing low-cost raw materials (μ-sized Si and commercial graphite), scalable processes (water-based slurries and slot-die coating), and electrode fabrication methods already used for high volume output.

A company datasheet claims >600mAh/g of reversible capacity, >80% capacity retention after 300 cycles at C/2 rate, and <15% capacity loss during the formation cycle, thanks to a proprietary artificial SEI coating. As noted earlier, more is not necessarily better: Navitas' power anode contains only one-quarter the Si as their high-energy composite, and retains 80% of baseline capacity at 5C.

The use of S-composite anodes for automotive usage is probably closer than we think: industry pundits speculate that Tesla will use Si-based anodes in their Reno, Nevada 'gigafactory, to double its cars' 240-mile ranges. Don't wager against Elon Musk! And the potential market may be better for EVs rather than hybrids, even though the latter far outsell all electrics (so far). Based on present-day technology, the average ratio of battery capacities in these two types is 17:1-24kWh for the Nissan Leaf versus 1.4kWh for the Toyota Prius. When affordable EVs attain consumer-comfortable ranges on the order of or exceeding that of a Tesla, the demand will accelerate at a frightening pace.

Analysts' projections for EV/HEV growth support this contention: Navigant Research expects an 11X growth in lithium-ion energy needs just for vehicles within six years. This will be accompanied by falling prices, possibly as low as $150/kWh in 2025, compared to about $500/kWh today. Similarly, Frost & Sullivan project Asian LIB sales to double in only three years, led by the EV/HEV sector.

Meeting these expectations depends on technology advances as described above, else automotive industry demand for LIBs will stagnate. Range anxiety is a major concern in the US, which drives the vehicle market, so the minimum between charge target for EVs is 200 miles (325km). To be fair, European and Asian drivers do not have America's wide open spaces, and such a lengthy trip capability without recharging will be a nice but not mandatory option.

Silicon-based anodes will provide greater cell capacities, increased power capabilities, and improved safety characteristics: what's not to like? As with any disruptive technology, new manufacturing processes and materials will require different or modified equipment, and must be cost-competitive relative to the overall benefits. Users of battery-powered devices, up to and including EVs, can expect longer working periods between recharging and shorter downtimes to refill the electron reservoir.

It does not appear necessary to have high-loaded Si anodes, which at best are difficult to prepare, and, to date, exhibit cycle lives considerably shorter than graphite anodes. Results cited above point to anode capacities in the range 500-1500mAh/g as providing the improvements OEMs and consumers are seeking. Whether the big winner will be Si-polymer composites, Si-containing alloys, or nano-Si fibers/islets (stand-alone or as substrate decoration), expect major performance enhancements from Li-ion batteries in the next three to five years.

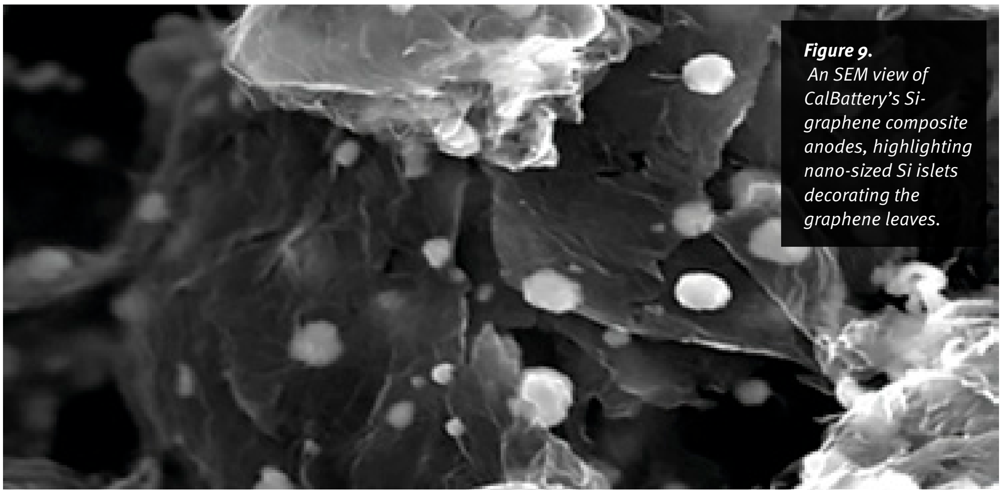
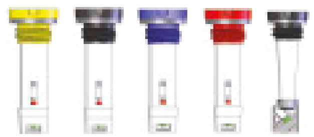
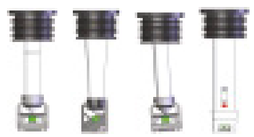
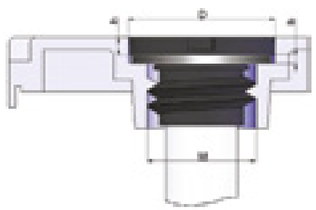
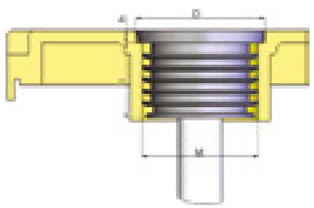
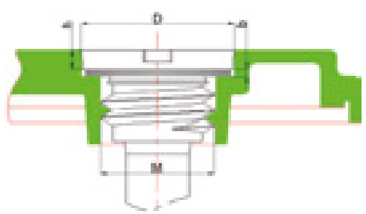
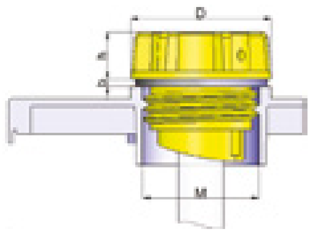
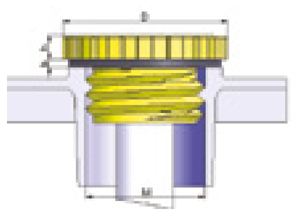
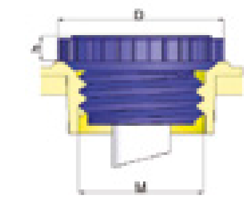


Figure 9. *An SEM view of CalBattery's Si-graphene composite anodes, highlighting nano-sized Si islets decorating the graphene leaves.*

Products Catalogue

Serial	S1 Plastic Head with Screw		S2 Push-In Type		S3 Plastic Head with Screw		S4 Transparent Head with Screw		S5 Vent Plug Indicator	
Sketch										
Specification	S1-A1	Φ20×M16×P2.0	S2-A1	D21.30/M19.16	S3-A1	Φ20×M16×P2.0	S4-A1	Φ20.5×M16×P2.0	S5-A1	Φ24×M18×P2.5
	S1-A2	Φ20×M15×P1.5	S2-A2	D22.90/M20.77	S3-A2	Φ20×M15×P1.5	S4-B1	Φ20.5×M16×P2.0	S5-B1	Φ25.5×M18×P2.5
	S1-B1	Φ23×M16×P2.0	S2-B1	D21.30/M19.16	S3-A3	Φ20.5×M16×P2.0	S4-B2	Φ20.5×M15×P1.5	S5-B2	Φ25.5×M18×P2.5
	S1-B2	Φ23×M15×P1.5	S2-B2	D22.90/M20.77	S3-B1	Φ23×M16×P2.0	S4-C1	Φ23×M16×P2.0	S5-C1	Φ28×M22×P2.5
	S1-C1	Φ24×M18×P2.5	S2-C1	D21.30/M19.16	S3-B2	Φ23×M15×P1.5	S4-C2	Φ23×M15×P1.5	S5-C2	Φ28×M22×P2.5
	S1-D1	Φ20×M16×P2.0	S2-C2	D22.90/M20.77	S3-C1	Φ24×M18×P2.5	S4-D1	Φ23×M16×P2.0	S5-D1	Φ36×M28×P2.5
	S1-D2	Φ20×M15×P1.5	S2-D1	D21.30/M19.16	S3-D1	Φ27×M20×P2.0	S4-D2	Φ25×M16×P2.0	S5-D2	Φ36×M30×P2.5
	S1-E1	Φ23×M16×P2.0	S2-D2	D22.90/M20.77	S3-E1	Φ20×M16×P2.0	S4-E1	Φ23×M15×P1.5	S5-E1	Φ34.5×M25×P3.0
	S1-E2	Φ23×M15×P1.5			S3-E2	Φ20×M15×P1.5	S4-F1	Φ20.5×M16×P2.0	S5-E2	Φ34.5×M25×P3.0
					S3-F1	Φ23×M16×P2.0	S4-F2	Φ20.5×M15×P1.5	S5-F1	Φ34.5×M26×P3.0
					S3-F2	Φ23×M15×P1.5	S4-G1	Φ20.5×M15×P1.5	S5-F2	Φ37.5×M26×P3.0
							S4-G2	Φ23×M16×P2.0	S5-H1	Φ25×M20×P2.5

Assembly Instruction

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	● - Blue Ball	1.150 & 1.160 & 1.170 & 1.180 & 1.190 & 1.195	60 / 62.5 / 65 / 68 / 70 / 72 / 75 / 77 / 80
	● - Green Ball	1.200 & 1.210 & 1.220 & 1.228 & 1.235 & 1.250	

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Transformers: The US leads the way

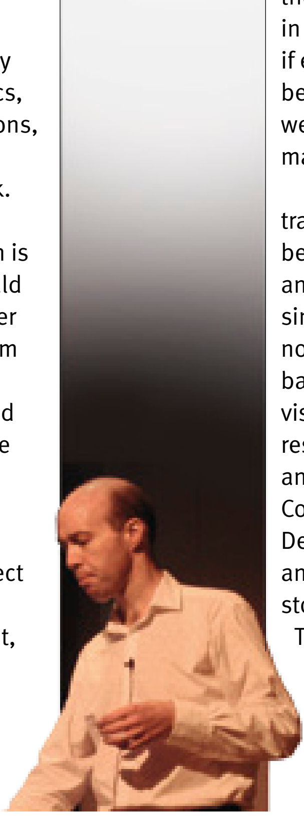
Anthony Price, director of the UK Electricity Storage Network, attends the annual US DoE's Energy Storage Systems Program review and is impressed.

The US Department of Energy (DOE) is steaming ahead with a comprehensive programme of storage development, both within its own Energy Storage Systems Program and under the aegis of the ARPA-E and the ARRA programs.

Each year, the US DOE invites delegates to attend their peer review of publicly-funded projects. Some years ago, the projects were limited very much by a tiny budget, and so the review was but a few short presentations. This year, the review extended over three days, and included not only presentations for the major topics, but some intensive poster sessions, each with 30 presenters talking enthusiastically about their work.

The scale of research, development and demonstration is impressive, and is one that should be noted by policymakers in other countries. If you want to transform your power industry, you need innovation, you need funding and you need the will to make change happen.

Enervault are high on the list of top transformers. Their demonstration flow battery project is a showcase example of good design and product development, beautifully executed. SustainX, developers of the isothermal compressed air system should also be included as a company that has produced storage in a game-changing manner.



Jonathan Radcliff, Senior Research Fellow, Energy Storage at the University of Birmingham.

On the other end of the spectrum, it was fascinating to see just how much effort is being directed towards solving some of the fundamental issues with electricity storage, typically related to bringing down costs. This has given birth to more innovation, with new types of electrolytes, ranging from organics, including quinones, ionic liquids, and more abundant resources such as low-cost salts.

Membranes and separators are the focus of some very clever people in academia who are conscious that if energy storage solutions are to be manufactured on a mass scale, we need to find cheap alternative materials.

Is there a difference between the transformation of energy storage between my own country, the UK, and the USA? There are some strong similarities: both countries have now organised a strong research base. In the UK, this is most visible in the funding for academic research through the Engineering and Physical Sciences Research Council (EPRSC) initiatives and the Department for Business Innovation and Skills (BIS) declaring energy storage to be one of 'Eight Great Technologies' that will propel the UK to future growth.

Industry is playing its part, with a number of smaller and larger companies both quietly and publically developing their own ideas. InnovateUK, the newly-renamed Technology Strategy Board, is directing effort towards new energy technologies, including storage.

The UK Department of Energy and Climate Change (DECC) has supported a number of energy storage demonstrations, but UK government expenditure on these storage demonstrations is nearly two orders of magnitude lower than in the USA, and we could say that it is several years behind. DECC and regulator OFGEM have a major programme in place to discuss the introduction of the smart grid, but we still find that there are more problems to be solved than there are solutions. We all believe that storage is essential, but there is no plan as to how it will be introduced and paid for.

To support change, it is important that we look at how other industries have progressed and moved forward in the past and the answer could be transformers – not the lumps of metal and coils of wires that change voltage, but people with the ability to see the need for change and to make change happen.

In September, I attended the Institution of Engineering and Technology's (IET) 'Power in Unity' conference, where Professor Roger Kemp from Lancaster University presented his findings on research he had conducted on a number of

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other well-known industries and sectors. These included, London's Docklands Light Railway, the GPS system, the Internet, air traffic control and the water system.

In each case, the infrastructure had been set up using a methodology based on system architecture. In former times, an architect designed buildings, but now, almost every industry has a role for a system architect. This applies across sectors, where for example in the design of light rail systems, joint venture companies were set up using design build transfer models. The model works well for greenfield projects, but not so useful when redesigning legacy systems.

The 'System of Systems Approach', used by the UK's Ministry of Defence, requires a systems architect to review assets that are connected to its data networks. Similar procedures are used in air traffic control to allow safer interoperation between all the data systems that control aircraft within a given airspace.

The IET maintains the spotlight needs to be on the British electricity sector. The nature of the changes that are expected in the industry are so vast, complicated and inter-related, that it is only by adopting a system architect function, that change to a modern, efficient, decentralised and sustainable network will be achieved. The only oversight currently provided comes through DECC and its role is adoption by default and not design.

The IET is very careful not to promote the resurrection of the Central Electricity Generating Board, but it does point out that the grid code and distribution code panels have a narrow technical remit and do not consider a comprehensive view of the industry, taking into account operational and commercial interests as well. Smart loads, such as EV charging, Internet-connected white goods, and heat pumps are not represented on the panels.

During his presentation, Professor Kemp also listed many of the new participants in the electricity system. If we were to also include community energy groups and electricity storage operators, we can begin to see the scale of the problem – and like an iceberg, most of the problem is not yet visible.

The transformation is under way in the USA. National and State initiatives have put storage on the grid. Roadmaps have been published. Plans are in place. The UK now needs to read 'Transforming the Electricity System', the IET's recent report, and realise that its own electrical infrastructure needs transformation.

And if the IET is right, and we do need a systems architect, let's have one, but they must understand the fundamental need for electricity storage.

Ali Nourai of DNV KEMA talking about flywheels at the USDOE review.

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18-20 November

Automative 48v Power Supply Systems

Düsseldorf, Germany

This international conference will give an insight into latest developments of automotive 48V onboard power supply in mild hybrids. This includes innovations on 48V batteries, advanced 48V topologies, EMC, LV 148 Specification and E/E components. The automotive 48V power supply system enables the improvement of the electrification to reach the strict emission targets by 2020. Experts of international OEMs and Tier1s will give an insight in their latest 48V solutions.

Info: www.48v-vehicles.com

12-15 December

Energia 2014

Greater Noida, India

Energia 2014 focuses on the research & development and latest emerging technologies in lead-acid battery and lithium batteries. The technical conference, seminar, workshops will provide the technical knowledge to put up battery manufacturing units in micro, small and medium enterprises.

Info: www.ssepcon.com

13-15 January

5th Electric Energy Storage Conference

San Diego, US

The 5th Electric Energy Storage Conference will focus on the technology successes when implementing new changes into existing storage systems, how companies are overcoming financial barriers and what it is they need in order to succeed and advance even more with energy storage. The conference will discuss how to meet storage levels for 2020 and beyond.

Info: www.marcusevans-conferences.com

16-19 February

NAATBatt

Phoenix, US

The title of the National Alliance for Advanced Technology Batteries meeting is Energy Storage: Electrifying the Future. The programme will focus on innovation in the technology, manufacture and applications of electrochemical energy storage.

Info: www.naatbatt.org

2-5 December

European Electric Vehicle Congress 2014

Brussels, Belgium

The European Electric Vehicle Congress addresses the challenges, opportunities and the outlook for battery, hybrid and fuel cell vehicles. A series of presentations covering politics, industry, R&D, user experiences and NGOs aims to find synergies to get the cars on the roads. Feedback from past and current experiences will also be discussed and analyzed so that best practices & best ways for a daily introduction of eMobility could be identified.

Info: www.eevc.eu

9-11 January

Power-on India

Pune, India

The international conference and exhibition focuses on batteries and the solar market. The event is India's largest and pioneer battery exhibition and conference. It will display manufacturers, policy makers and industry leaders of the lead-acid battery industry and PV as well as EV industry.

Info: www.batteryfair.co.in

26 - 29 January

AABC Europe 2015

Mainz, Germany

At the 2015 European Advanced Automotive & Stationary Battery Conference European automakers and energy-storage system developers will discuss the emerging programs and the prospects of the upcoming designs to meet the needs of the European market. AABC Europe 2015 will offer two technology-focused symposia and two application-focused symposia

Info: www.advancedautobat.com

25-27 February

Battery Japan

Tokyo, Japan

The Battery Japan in Tokyo is one of the largest trade fairs for the production and development of rechargeable batteries worldwide. Visitors will find all kinds of materials, production technologies, test and analysis equipment and batteries. This exhibition is a communication and information platform in the industry and offers the exhibiting companies the opportunity to present to an audience of experts.

Info: www.batteryjapan.jp/en

3-5 March

7th International Battery Expo & Recycling 2015

Goa, India

The event will bring together world leading battery manufacturers interested in technology and business cooperation, battery equipment and component manufacturers, experts in waste management and in environmentally sound technologies for recycling of batteries, recycling equipment manufacturers and recyclers.

Info:
www.bfi.org.in

3-6 May

BCI 2015

Savannah, US

Battery Council International presents its 127th Convention and Power Mart Trade Fair - a convention to learn about the latest technologies, environmental issues and the impact of global economy on the battery. Topics include critical regulatory activities affecting the lead acid battery industry throughout the world; other issues facing the industry such as emission levels, blood lead levels, and health care reform. From sourcing to transport to recycling, the Convention will give you the most up-to-date and comprehensive perspective on the various authorities that govern our industry.

Info:
www.batterycouncil.org

3-6 May

EVS28

Goyang, South Korea

Under the theme of "e-Motional Technology for Humans," EVS28 will serve as a venue to share and discuss the next steps of electro mobility as a key to making the automobile industry "Green" and "Sustainable." The event features lectures as well as a poster exhibition for delegates to present and discuss their own work related to electric vehicles. Within the topics discussed are batteries, fuel cells, propulsion systems (motors and power electronics) and BMS.

Info:
www.evs28.org

12-14 May

Battcon 2015

Orlando, US

The Battcon International Stationary Battery Conference features a non-commercial conference for users, manufacturers and developers of all types of stationary batteries. All chemistries and applications feature on the comprehensive schedule. Alongside the conference is a two-day trade fair. Featuring leading stationary battery experts, the conference presents papers by users and manufacturers that relate to everyday battery applications, technical advances, and the diverse concerns of the battery industry.

Info:
www.battcon.com

9-12 March

International Battery Seminar

Fort Lauderdale, USA

In its 32nd year, this seminar provides industry speakers to discuss worldwide energy storage technology developments for portable, automotive and stationary power applications. This meeting provides informed insights into significant advances in materials, product development and application for all battery systems and enabling technologies.

Info: www.international batteryseminar.com

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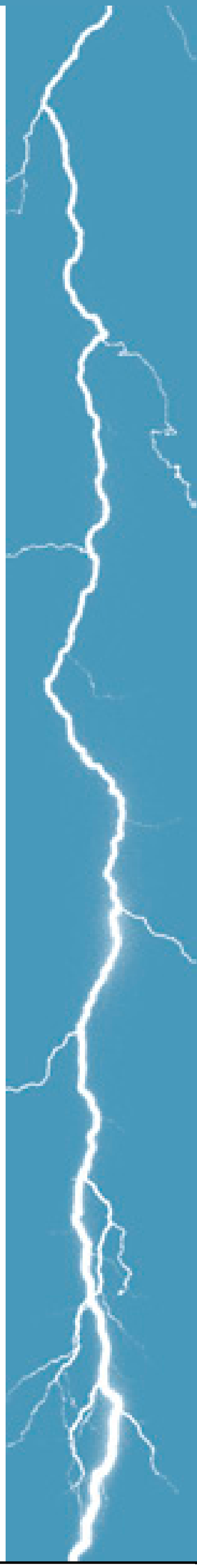
International Thermal Systems	sales@itsllcusa.com	internationalthermalsystems.com	69
JBI Corporation	joe@jbicorp.com	jbicorp.com	100
Jinfan Power Technology	public@jsjf.com.cn	jsjf.com.cn	123
Kustan	geku@kustan.de	kustan.de	56
La Pneumatica	info@lapneumatica.com	lapneumatica.com	108
Lap GmbH Laser Applikationen		lap-laser.com	20
Mac Engineering	maceng@mac-eng.com	mac-eng.com	IBC/BC
Maccor	sales@maccor.com	maccor.com	103
Microporous		microporous.net	46
Oak Press Solutions	sales@oakpresses.com	oak-battery.com	51
OM Impianti	info@omi-nbe.com	omi-nbe.com	64/65
Oxis Energy Ltd	info@oxisenergy.com	oxisenergy.com	30
PC di Pompeo Catelli	info@pompeocatelli.com	pompeocatelli.com	116
Penox Engineering	engineering@penox.de	penoxgroup.com	126/127
Polyworld Sendirian	info@polyworld.com.my	polyworld.com.my	119
SE.R.I. S.p.A	info@serihg.com	serihg.com	23
Shandong Jinkeli Power	jkl@jinkeli.com	jinkeli.com	52
Shandong Sacred Sun	weizengliang@sacredsun.cn	sacredsun.com	38
Sorfin Yoshimura	sorfin@sorfin.com	sorfin.com	11
Sovema	stella.fermo@sovema.it	sovema.it	28/29
STS Instruments	info@stsinstruments.com	stsinstruments.com	25
Superior Graphite	customerserviceUSA@superiorgraphite.com	superiorgraphite.com	18
Unikor Industry Company Ltd	ukb@ukbkorea.com	ukbkorea.com	90
Water Gremlin	steve.mende@watergrem.com	watergrem.com	4
Wirtz	sales@wirtzusa.com	wirtzusa.com	8/9
Wuhan Hilans Automation M Co	sales.hilans@163.com	hilans.cn	125
Yucry Traffic Appliances Co. Ltd	yucry@yucry.com	yucry.com	120

Where lethal voltages and rhetoric pass harmlessly to earth

Hydrogen: In or out?



Visitors to Edinburgh and the 14th European Lead Acid Battery Conference could hardly have failed to notice that the people of Scotland were energised by the Yes/No question as to whether Scotland would remain in a union with England and remain part of the United Kingdom.

Well, the Scribe assumes most of you know the result by now: the Union held and quite an achievement it was for democracy, with an estimated 85% voter turnout of those who were eligible to vote.

But the United Kingdom is not the only alignment under stress: as borders shift periodically in continental Europe, the Scribe - under the influence of very strong painkillers - began to hear rumblings from other quarters.

The constituents of the Periodic Table of the Elements are also showing signs of discontent. Forced into an organisation since 1869 by a self-appointed Russian, Dmitri Mendeleev, who allegedly saw the order of elements in a dream, the Scribe has heard rumblings from a number of elements.

There has always been trouble with some of the elements in periods 7 and 8 of the transuranic elements. They just don't want to hang around long enough to be part of anything.

And there's always been a problem with hydrogen and helium. Hydrogen and helium are often placed in different places than their electron configurations would indicate. In the world of physics, your status is really about your atomic weight and the number of electron shells you have— a bit like wealth in the everyday world?

Hydrogen is usually placed above lithium, in accordance with its electron configuration, but is sometimes placed above fluorine (or even carbon) as it also behaves somewhat similarly to them. Hydrogen is also sometimes placed in its own group, as it does not behave similarly enough to any element to be placed in a group with another.

Its relationship with the other groups is like the UK's relationship with the European Union. It wants to be both in and out at the same time. So maybe we should be holding a referendum over hydrogen? Should hydrogen remain in or out of the periodic table?

What would the Better Together lobby have said about this? Vocal proponents of hydrogen staying in would have been oxygen and carbon surely, for the sake of organic chemistry?

And, of course, once you let the genie out the bottle, well all kind of arguments start to surface. Rest assured lead is happy where it is: eight and two, 82.

The ultra-conservatives might ask for a return to the simple days of Lavoisier with gases, metals, non-metals and earths. And that would keep out any new elements we haven't discovered yet. Indeed this might be the approach of the British UKIP party... no more immigration! Or would we spend another 100 years trying to reorganize what we already have?

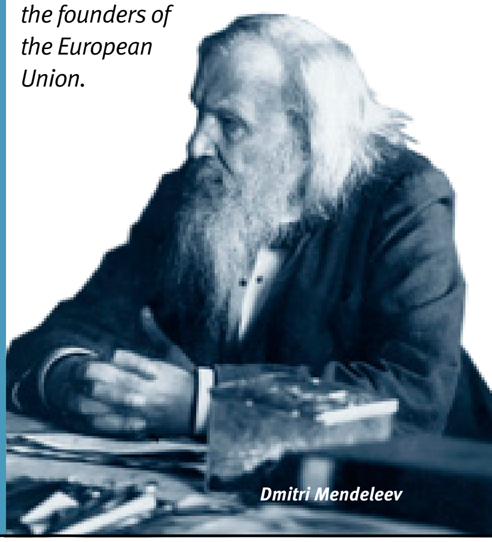
Further digging by the Scribe reveals that there are many, many representations of how the elements relate to one another but one way or another, they are jolly hard to put in a book, especially when three-dimensional and even four-dimensional (where one dimension is colour, and damn hard to explain).

So perhaps we should give thanks to Horace Groves Deming, the American chemist who gave us the short form periodic table that adorns the walls of many a high school chemistry lab, in the same way that we remember the founding fathers, the Duke of Queensberry* and French foreign minister Robert Schuman**.

The political and chemical unions we have are not perfect, but, at least, they are better than the chaos we might have without them.

** James Douglas, 2nd Duke of Queensberry was largely responsible for the successful passage of the Union Act by the Scottish Parliament.*

***Robert Schuman, France's Foreign Minister 1948-53, was instrumental in building post-war European and trans-Atlantic institutions and is regarded as one of the founders of the European Union.*



Dmitri Mendeleev

Lead: In rude health

The ILA picked a winner in Edinburgh. There was no shortage of venues for the great and the good to celebrate and Messrs Gardiner & Beckers of TBS and Digatron lived up to their reputations of being super hosts for friends and customers alike.

The Scribe found himself on the former Royal Yacht Britannia with team TBS. Over dinner, guests indulged in a game to find the staggering number of man-years the assembled company had put into the lead battery industry.

The effect of fine wines and conversation means the precise number never registered for long but it was great enough (possibly) to have redesigned the space shuttle, solved the issues of climate change and found a vaccine for Ebola. And it begs the question that if lead is so harmful to health, why do so many of its former employees work in the business for so long, never fully retire and look so damn healthy?

ESPL— The UK's new leading tour company?

Having ESPL's Chinese team in the UK gave the Scribe a taste of next possible career as a tour guide. Indeed, showing foreigners around Britain's historical sites is both a quick brush up on 1000 years of history and a reality check.

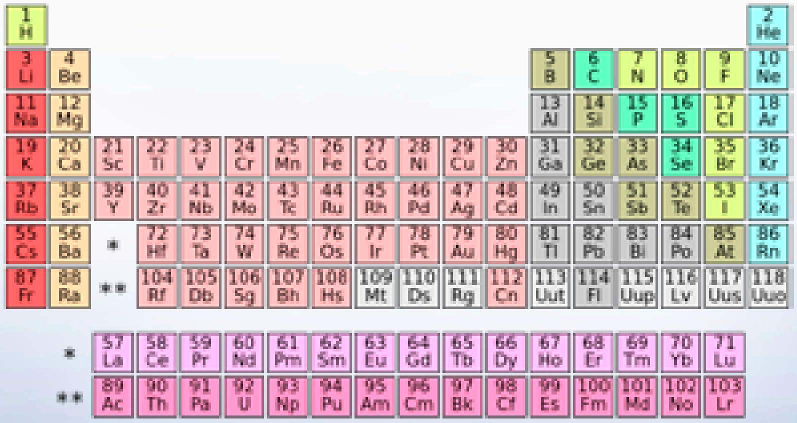
Firstly the Chinese couldn't believe the air is so clean, even though air pollution was considered high in SE England in September.

"That's because we don't have any factories," the Scribe said, "You make it all at home". So what do we make in the UK and London? I gesticulate vaguely on the South bank of the Thames towards the east. "Money", I said, "Banking and finance," as the mighty structures of Canary Wharf Tower and the Gherkin loomed.

Then the Scribe took them on a three-hour tour of the Tower of London, with grisly accounts of all the beheadings that had taken place there – ex-wives, political troublemakers and not forgetting mere Catholics. Of course, the British Establishment had no access to the Internet and social media at the time to upload the beheading videos.

Then there's the naval dockyard at Portsmouth with tales of Nelson, fighting the French the Spanish and so on. The British were always fighting.

"So much history," said the Chinese. "Too much history," I replied, which probably restricts us from looking forward to the future with energy storage and electric vehicles.



"The short form periodic table that adorns the walls of many a high school chemistry lab."

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www.mac-eng.com

Latin America	(Sorfin Yoshimura, Ltd.)	New York, USA:	sorfin@sorfin.com
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Thailand	(Sorfin Yoshimura Thailand,)	Bangkok, Thailand:	sorfin@sorfin-yoshimura.co.th