The Power of 3

ISSUE 1
November
2015

Driving the future further

Overview

In the latter part of the 20th century, silicon became an elemental game-changer, no more so than when, courtesy of Silicon Valley, it helped revolutionise electronics and computerisation, altering forever the ways in which we work, play and communicate in our interconnected, digital world.

Now, in the 21st century, will lithium, the lightest and least dense metal in the periodic table (atomic number 3), be the revolutionary element *de jour*?

Commentators such as **Vikram Mansharamani** of *PBS News Hour* wonder whether lithium will 'one day eclipse oil as a source of geopolitical and economic power' and if, as a consequence, demand will outstrip supply. Pundit Keith Kohl is in no doubt, touting lithium as 'metal oil', the 'oil of the 21st century', capable of relieving the planet's dependence on fossil fuels and radically reducing carbon emissions in the process.

Lithium was first produced commercially in 1923. Since then, the element and its compounds have become intrinsic to numerous commercial applications, not least the production of lithium-ion (Li-ion) batteries.

Although Li-ion batteries do have certain limitations, not least in terms of safety and stability, three industry groups in particular are driving the research and development of better battery technology:

> **electric vehicles (EVs)**
> **electronics**, and
> the **energy sector.**

In this, the first issue of *The Power of 3*, we discuss EVs (and a beguiling hybrid or two) past, present and future, autonomous or otherwise. As the saying goes, it's the quiet ones you have to watch out for.

EVs – from uniquity to ubiquity?

Even in 2012, the number of modern, mass-produced, highway-capable EVs already on the market was impressive. Now, evidence suggests that, in the years to come, universal uptake of EVs will depend less on their price and size and more on the performance of the batteries that power them.

Some manufacturers are still at the starting line in terms of EV development, while others already have traction.

The Americans

One of the highest-profile proponents of EVs is, of course, arch disruptor and legend-in-the-making Elon Musk, purportedly the inspiration for Robert Downey Jr's character in *Iron Man* and definitely one to watch.

The South African-born, Canadian-American business magnate, engineer, inventor, investor and billionaire – co-founder of PayPal, a backer of SolarCity and CEO of Tesla Motors and SpaceX – has plans to not only develop futuristic 'hyperloop' transport but also transform high-speed internet access via satellites and, one day soon, to colonise Mars.

Right here, right now, Tesla is producing arguably the world's first truly viable (and desirable, albeit expensive) EV.

Whether the Tesla S P90D is currently the world's fastest four-door sedan in 'Ludicrous' acceleration mode is for others to decide, but what really sets the Tesla vehicles apart are the following.

> They're designed around the battery to optimise performance, and that battery is larger than those of its competitors, extending the vehicles' range beyond anything achieved elsewhere.

> Tesla offers long-distance 'destination charging' at free Supercharger stations, of which hundreds have been set up in the US and Europe (with plans for more). These stations can charge a Model S in minutes rather than hours.

Elsewhere in the US, traditional car manufacturers are also gearing up for the EV stampede: General Motors, which has already unveiled its hybrid Volt, will release The Chevrolet Bolt in 2017, Cadillac is busy promoting its 2016 ELR Coupé and Ford is charging ahead with its 2016 Focus Electric.

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The Japanese

In terms of EV ubiquity, Nissan maintains that the LEAF – introduced in the US and Japan in 2010 and evolving ever since – is the most popular electric car on the planet. The company plans a new 30kWh battery pack to extend the LEAF's driving range, and it will soon incorporate an 'intelligent driving system' as well. Nissan aims to produce fully autonomous cars by 2020.

Toyota, meanwhile, has so far focused on hybrid vehicle technology but is 'exploring ways to make EV power cleaner and more practical', while Honda has mooted production of two all-new plug-in cars by 2018.

Mitsubishi, too, has plans for an EV, unveiling its eX concept at the 2015 Tokyo motor show. According to Richard Blackburn of *Cars Guide*, this compact SUV will be 'powered by next-generation batteries and electric motors', with the new technology stretching its range to what only Tesla has so far achieved: 400 kilometres. The company currently mass-produces the i-MiEV, an electric version of the Mitsubishi I.

Mitsubishi eX concept

The Europeans

In luxury European sports mode, Porsche's Mission E concept car was unveiled at the Frankfurt motor show earlier this year. Porsche claims it will be as fast or faster than Musk's Model S and also faster to charge.

Still in luxury sports mode, Audi has filtered the winning technology in its R18 e-tron Quattro™ into the A3 Sportback e-tron, hailing it as a 'revolutionary plug-in hybrid' that strikes a balance between environmental impact and performance.

BMWi3

Speaking of emission levels, Volkswagen (current difficulties aside) has presaged an intensified interest in EV development, while at BMW, new chief executive Harald Krüger is keen to reboot the company's E-Car strategy after record sales of the BMWi3. This model, says *autoblog*, is particularly popular with emergency services, 'in locations as varied as Milan, London and Los Angeles' … even Warsaw in Poland.

Mercedes-Benz, which invented the gasoline-powered motor vehicle in 1886, pioneered its first hybrid electric car in 1906. Its current EV, the much-admired B-class Electric Drive, is based on the standard production car but has an electric drive system sourced from – wait for it! – Tesla. With an eye to the further reaches of the future, Mercedes also revealed two innovative hybrid concepts at international motor shows recently:

- in Frankfurt, a sleek autonomous concept car that, by 'talking' to traffic lights and other vehicles, makes conventional headlights and indicators redundant, and
- in Tokyo, the even sleeker Vision Tokyo, also self-driving and described as a 'chill-out zone amidst megacity traffic mayhem'.

Other major corporations with autonomous EV ambitions include Google, currently refining its expanding fleet of driverless vehicles, and Apple, which, says the *Wall Street Journal*, plans to apply its expertise in battery technology, sensors and hardware-software integration to its own version of a driverless EV sooner rather than later.

Thomas Bartman of the *Harvard Business Review*, however, predicates the role of EVs on humanity's ageing:

> *Disruption from electric vehicles … won't announce itself with high-profile product launches or flashy products. Instead, it'll drive retirees (slowly) to and from bingo, provide cheap transport to thousands of people in emerging markets, and unceremoniously deliver packages to Londoners and New Yorkers.*

Whoever's correct, prescience suggests that, with ongoing improvements in design and energy storage to increase their range, and with opportunities to charge from cleaner grids, EVs are set to become mainstream.

And finally …

As demand grows for more and better Li-ion batteries (for EVs and otherwise), which fledgling Perth company is exploring the use of innovative technology to produce battery-grade lithium carbonate from lithium micas, a 'forgotten' lithium resource?

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ISSUE 2
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The Power of 3

Driving the future further

Overview

Rechargeable consumer **electronics** are so commonplace since the turn of the century that most of us use them daily and take them entirely for granted.

Be they smart phones and watches, tablets, laptops, music players or any of myriad other rechargeable products (including electric vehicles), the success of such devices is due in no small part to the evolution of that which powers them: lithium-ion (Li-ion) batteries. Currently, these are the world's fastest growing and most promising source of transportable power.

Today's Li-ion batteries suffer minimal memory effect (can be charged at any point during the discharge cycle) and store twice as much energy by weight as those first produced commercially by Sony in 1991. And they're ten times cheaper now, but still expensive.

With electronic innovation seemingly never-ending, the race is on to produce 'less with more' – Li-ion batteries that are smaller, stronger and pack more punch than ever before – and battery manufacturers* the world over are scrambling to meet demand.

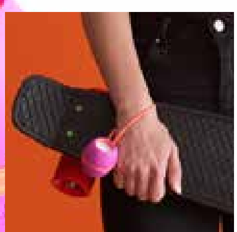
Suggestions for the gadget-inclined

As Christmas approaches, here are some carefully curated and covetable devices – practical, indulgent or simply out there! – for anyone passionate about, or simply intrigued by, current consumer technology.

Sound matters

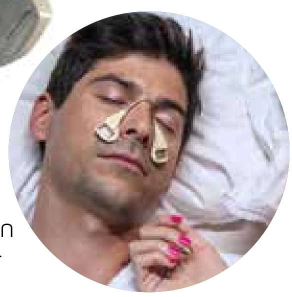
Elipson's Lenny Speaker (above) is *so* Frenchy, *so* chic. Portable and cable-free (it can also be plugged in old-school style), it works with any Bluetooth-enabled Android or iOS smartphone, laptop or tablet, runs seven to eight hours between charges and sounds as good as it looks.

If your style runs more to the miniature, check out Kakkoii's Loop'd Bluetooth Speaker. Bright, tiny and playful, it's the ultimate portable musical accessory: loop it to your bike, your bag, your tent pole, your belt or the nearest tree ... in fact, pretty much anywhere you like.



Still in aural mode, wearable technology doesn't get much smaller or cuter than Skybuds, 'truly wireless premium ear-buds with a battery-boosting smartphone case for charging and storage'. Neat!

Sleep-deprived partners of snorers may take comfort from the Silent Partner anti-snoring device. Said to quell those intensely irritating zzzzzzzz sounds via noise cancellation technology, it's available for pre-order now – if you can bear to wait!



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Wearable art

[Eyecatcher] is a smart, super-charged bracelet that fuses art, fashion and technology to stunning effect. Use it to display custom images, slideshows, app notifications, news and more via an iOS or Android smartphone … the possibilities are endless.

Lights, camera, action

Ligbo (pictured above) is a small, powerful and versatile LED cube designed to light up your life … on bike rides, at parties or just chilling at home. Easily programmed, it's Bluetooth-enabled, so can be fully controlled via an iOS or Android smartphone. It looks great too!

Budding auteurs can capture the action with a Ronin-M 3-axis hand-held gimbal stabiliser. Light, compact and boasting 'astonishing power', it helps 'capture the world' by 'professionally stabilising' hand-held video cameras.

Vroom!

Rev-heads young and old can smoke it up with Anki Overdrive's amazing self-driving toy cars. Described as 'Scalextric for the 21st century', you'll need the track and the cars, and each person racing requires a compatible iOS or Android device.**

Work that body

Fitness aficionados wanting to track their progress and exercise strategically need look no further than Skulpt Aim. This 'Ultimate Fitness Tracker' measures what matters in seconds – 24 different muscle groups, percentage of total body fat, muscle fitness – and sends the results to the wearer's iOS or Android Bluetooth smart device.

For those leading the pack environmentally, what could be better than:

> an E-Station home or office electric vehicle charging station, or

> a smart, two-wheeled, self-balancing electric personal transporter?

Beloved of celebrities the world over, the self-balancing scooters resemble Segways minus the handlebars and, with the right body aboard, are elegant and virtuous in equal measure.

No gadget-lover's arsenal would be complete without a drone (get one now before regulations tighten). Ben Popper of *The Verge* opines that DJI's Phantom 3 is the best that money can buy, plus there's a range of nifty accessories to choose from.

And finally, a timely reminder…

With the festive season almost upon us, and without being alarmist, remember, please, that batteries can be *dangerous*. The lithium button batteries in novelty toys, calculators, key fobs and small remote controls, even musical greeting cards, can be lethal if swallowed by children – and all batteries are toxic*, even deadly, if chewed or ingested by pets. Do those you love (and the planet!) a favour: be vigilant, keep batteries beyond the reach of children and animals, and recycle them responsibly.**

* More in the next issue of *The Power of 3*.

** Brand name for a range of slot car racing sets that first appeared in the late 1950s.

*** US researchers aim to develop an aqueous Li-ion battery with the power, efficiency and longevity of current Li-ion batteries but without the toxic chemicals and fire risk. Watch this space …

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The Power of 3

Driving the future further

Overview

As discussed in *Issue 1*, better battery technology is the Holy Grail of not only the electric vehicle (EV)[1] and consumer electronic[2] industries (both burgeoning) but also the domestic and commercial energy sectors[3].

In light of emission goals set in Paris last year, investing in cleaner technologies has become imperative, not least for energy utilities, which need to manage their useage loads more efficiently and perhaps even decommission plants altogether or delay building new ones, as is occurring in the United Kingdom. And, while Li-ion battery development is 'in its infancy' in terms of grid-scale and particularly home storage[4], the perceived need for more efficient reservoirs of renewable energy is indeed a powerful precursor to innovation[5].

At present, annual Li-ion battery production worldwide is around 35 GWh[6]. Keep that figure in mind as you read on … if all goes to plan, it could increase three or fourfold, or even more, by 2020.

Giga? Mega? Whatever! The behemoths are coming…

Given the potential for massive growth, battery producers worldwide are gearing up on a scale hitherto unforeseen. Manufacturing and R&D are expensive and larger plants can leverage to maximum advantage; hence the plethora of super-sized factories currently commissioned or in the pipeline.

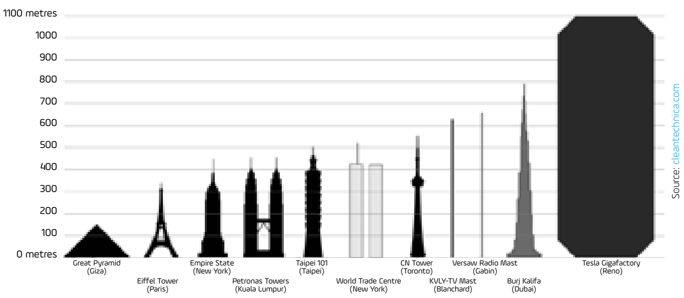
While Tesla's facility has possibly the highest profile, numerous other companies are also investing in large-scale battery production, among them BYD, Foxconn, Boston Power, LG Chem and Samsung. A123 Systems is another to watch, as are Faraday Future, Dyson and Bosch, all of which are girding their loins to join the fray.

Tesla's Gigafactory (35 GWh)

Last year, in its 'New Establishment' series, *Vanity Fair* mused that billionaire disruptor Elon Musk's most ambitious endeavour ever[7] (rocket recycling, space travel and releasing the 'more affordable' Tesla Model 3 aside) could well be relatively mundane: *batteries*.

In symbiosis with his role at SolarCity[8], Musk aims to electrify the planet by way of battery storage systems for homes and businesses[9], as well as – you guessed it! – energy utilities[10].

Tesla, in a joint venture with Japanese battery manufacturer Panasonic[11] and others, will this year begin mass-producing Li-ion batteries for both EVs and energy storage systems at its vast new, US$5 billion Gigafactory (covering up to 10 million square feet) in the US state of Nevada. And, while full operational capacity is some years away, Tesla has also bought 1,200 acres next door, fuelling speculation that future expansion could create the largest building (in terms of footprint) on Earth!



Foxconn (15 GWh)

Taiwanese giant Foxconn Technology Group is China's largest private sector company. Best known for producing Apple iPhones and iPads (but it also supplies Microsoft, IBM, Samsung, Dell, HP and Sony), the company has been newsworthy in recent years for all the wrong reasons[12]. Foxconn is adding 15 GWh of capacity to its Anhui factory.

BYD (20 GWh)

Chinese EV and battery producer BYD ('Build Your Dreams') is shaping up to be a serious contender in the megafactory slug-fest. The company plans to ramp up its current production capacity of 10 GWh to 34 GWh by 2020. However, BYD will not limit its production options to a single factory, as Tesla has, but will also build a facility in Brazil, targeting US and Latin American markets for its electric buses in particular.

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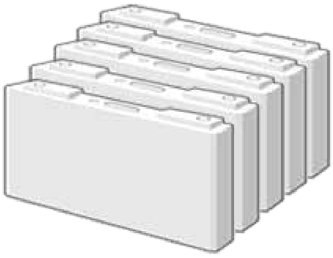
Boston-Power (10 GWh)

Founded in 2005, Boston-Power is a world leader in next-generation EV battery design and production, in particular for Chinese auto-makers. In 2014 it secured US$290 million from Chinese government agencies to upscale its facilities there. Manufacturing capacity at Boston-Power's Liyang factory will increase fivefold by year's end, while capacity at the Tianjin factory is expected to reach 8 GWh by 2018.



Samsung SDI

Sixteen years after entering the Li-ion battery business in 2000, Samsung claims it ranks #1 in terms of global market share. In 2015, Samsung SDI opened a new production facility in China – in Xi'an, Shannxi Province – to mass-produce EV batteries (around 40,000 per annum). The company, which already supplies bus manufacturer Yutong and truck manufacturer Foton, has plans to invest US$600 million (in phases) to achieve a billion sales by 2020. Products will include a lower-profile, higher-energy-density EV battery and a low-voltage system to replace lead-acid batteries in regular vehicles for 'greater eco-friendliness and fuel efficiency'.

Faraday Future

US-based, Chinese-backed EV start-up Faraday Future, which gained notoriety last year for poaching employees from Tesla Motors, Google and Apple, is investing US$1 billion in a 900-acre workshop for 'passionate creators and diligent visionaries' in north Las Vegas, in the same state as Tesla's Gigafactory. Having recently unveiled the FFZero1, a futuristic concept car that looks a lot like the Dark Knight's Batmobile, the company says it will build cars in a wholly original, and much quicker, way.

LG Chem (7 GWh)

Korea's LG Chem, described by Nissan CEO Carlos Ghosn as the best battery-maker in the world, produces mobile phone and automotive batteries, as well as grid energy-storage solutions. With EV battery plants in Ochang in South Korea (slated for further expansion) and Michigan in the US, the company is also investing vast sums in its Li-ion facility in Nanjing, China and plans an EV battery plant in Europe[13]. In China alone, LG Chem aims to generate US$1.3 billion in sales of batteries for all types of EVs over the next five years.

A123 Systems

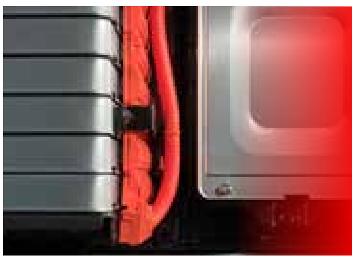
Acquired by Chinese auto-parts maker Wanxiang after going belly-up in 2012, A123 Systems plans to invest US$800 million over the next few years to expand its plants in the US and China and build new ones in Europe. The company produces both high- and low-voltage Li-ion batteries for car manufacturers.

Dyson

Die-hard fans of Dyson products may be intrigued to learn of the company's purchase of battery start-up Sakti3. UK-based Dyson, which wants to improve the battery life of its cordless products using Sakti3's cool, quick-charging solid-state Li-ion technology, is to invest up to US$1 billion in the mass-production of next-generation battery technology, possibly in the States. While some speculate that Dyson will enter the EV market, it's their cleaning robots that many can't wait to see.

Bosch

In August 2015, German auto-parts giant Bosch bought California-based battery start-up Seeo Inc., a developer of next-generation Li-ion batteries that may double the range of EVs.



The challenge ahead?

One very real issue facing all these massive facilities is sourcing enough raw materials – including lithium chemicals – to meet production targets.

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Notes

[1] As reported by Peter Ker in *The Australian Financial Review* of 27 October 2015, Citibank analyst Matthew Schembri expects 1.04 million EVs to be in production by 2020 – a sevenfold growth over the next five years. A subsidy system for new-energy vehicles in China will fuel the trend, as should VW's announcement of its BUDD-e EV concept vehicle, able to travel 600 km on a single charge. Faraday Future may give Tesla a run for its money, with plans to deliver intelligent EVs and mobility solutions, while Navitas Systems LLC's release of heavy-duty Li-ion batteries for forklifts underlines their potential for use in many commercial, industrial and government/military vehicle applications. As always, a key factor is greater energy density.

[2] Improvements in both performance and longevity are the aim and much is happening in this arena. In *engadget*, Jon Fingas reports that researchers have developed new Li-ion batteries that reach a 70% charge in two minutes and should last more than 20 years; this, of course, has immense implications for the consumer electronics and EV markets especially.

[3] The concept of generating 'clean' energy via solar panels, wind turbines and even wave power is becoming ever more accepted, as is awareness of the need for efficient energy storage at both the grid and household levels. That's because renewable energy generation rarely coincides with peak periods of demand. Moreover, says *VSA Capital (7 Jan. 2016)*, developing economies like Africa, with hugely dispersed populations and lack of grid infrastructure, represent a potentially massive market for off-grid power storage.

[4] *Edison Investment Research*.

[5] *CleanTechnica* lists companies to watch.

[6] 'Giga' (derived from the Greek word for 'giant') denotes a factor of 10^9 (1,000,000,000). One GWh is the equivalent of generating (or consuming) one billion watts for one hour.

[7] See Issue 1 of the *Power of 3*.

[8] Chaired by Musk and founded by his cousins Peter and Lyndon Rive, SolarCity – the largest installer of residential solar panels in the US – is ready to mass-produce what they claim is the world's most efficient rooftop solar panel ever.

[9] Tesla's Powerwall offers home-owners freedom from total reliance on the grid, as well as back-up during power outages, while the larger-scale Powerpack – comprising 100 kWh blocks that can be clustered to suit a project of any size – is designed for commercial applications. The Powerwall will be available in Australasia, South Africa, Germany and America this year. Australia, of course, is an ideal destination due to the ubiquity of sunshine and rooftop solar panels, the high price of electricity (the grid component in particular) and its utility tariff structures. Despite this, argues Giles Parkinson in *Renew Economy*, the potential of Tesla's battery storage solutions to disrupt energy business models may lead antipodean networks and retailers to set up as many roadblocks as they can. That said, *The Guardian* reported mid-January that Energex, a Queensland power company, has installed a Tesla system and that of another US manufacturer, in a 12-month trial aimed at rewarding consumers who reduce their reliance on the grid. Meanwhile, in New Zealand, Auckland-based Vector Energy aims to integrate new technology into both its network and the homes it services, and will be among the first to sell these Tesla products.

[10] Tesla, says Musk, has already been approached by a utility seeking a 250 megawatt-per-hour installation. Powerpack customers in the US to date include Wal-Mart, Amazon and Target.

[11] Panasonic (which already produces Li-ion batteries for Tesla, as well as other auto-makers, and is supporting Tesla's advance in China through its operations there) will invest up to US$1.6 billion in the Nevada Gigafactory.

[12] After a large number of employees attempted suicide at its Chinese factory, Foxconn's solution was to install 'safety nets' around its premises.

[13] In close proximity to the giant Cinovec lithium/tin project in the Czech Republic.

The Power of 3
Driving the future further
ISSUE 4 February 2016

Overview

The original, generic meaning of the term 'battery' is 'a group of similar objects functioning together', as in an artillery battery. Benjamin Franklin, polymath and a founding father of the United States, coined the expression in 1749 in relation to articles used in his experiments with electricity [1].

Today, the name is applied to any container in which chemical energy is converted into electricity and used as a source of power.

Put simply, a battery consists of three main components: a pair of terminals, the cathode (+) and the anode (-), each made of a different chemical (usually a metal), and the electrolyte that separates them. The latter, a chemical medium, allows electrically charged atoms to flow between the two terminals, creating an electric current that powers anything connected to that battery.

In battery design, everything depends on the materials used for those components: together, they determine how many ions can be stored and how fast the battery can pump them out.

With primary (disposable) batteries, the electrode materials are irreversibly changed during discharge, meaning these batteries are used once then discarded. An example is the alkaline battery used in flashlights and many other portable devices.

In secondary (rechargeable) batteries, the electrochemical reaction is reversible and the original chemical compounds can be reconstituted, allowing the battery to be discharged and recharged multiple times. Examples include the relatively inexpensive lead-acid batteries used in most motor vehicles, and the much more expensive lithium-ion (Li-ion) batteries that power, for example, portable electronics and electric vehicles.

Oft taken for granted but amazing nevertheless, batteries have become intrinsic to modern living.

Can batteries save the planet?

Battery evolution (a potted history)

Battery evolution has long been an international affair *(see table below)*.

Year	Inventor	Activity
1600	William Gilbert (UK)	Establishment of electrochemistry study
1745	Ewald Georg von Kleist (NL)	Invention of Leyden jar, stores static electricity
1791	Luigi Galvani (Italy)	Discovery of 'animal electricity'
1800	Alessandro Volta (Italy)	Invention of the voltaic cell (zinc, copper disks)
1802	William Cruickshank (UK)	First electric battery capable of mass production
1820	André-Marie Ampère (France)	Electricity through magnetism
1833	Michael Faraday (UK)	Announcement of Faraday's law
1836	John F Daniell (UK)	Invention of the Daniell cell
1839	William Robert Grove (UK)	Invention of the fuel cell (H_2/O_2)
1859	Gaston Planté (France)	Invention of the lead acid battery
1868	Georges Leclanché (France)	Invention of the Leclanché cell (carbon-zinc)
1899	Waldemar Jungner (Sweden)	Invention of the nickel-cadmium battery
1901	Thomas A Edison (USA)	Invention of the nickel-iron battery
1932	Schlecht & Ackermann (Germany)	Invention of the sintered pole plate
1947	Georg Neumann (Germany)	Successfully sealed the nickel-cadmium battery
1949	Lewis Urry, Eveready Battery	Invention of the alkaline-manganese battery
1970s	Group effort	Development of valve-regulated lead acid battery
1990	Group effort	Commercialisation of nickel-metal-hydride battery
1991	Sony (Japan)	Commercialisation of lithium-ion battery
1994	Bellcore (USA)	Commercialisation of lithium-ion polymer
1996	Moli Energy (Canada)	Introduction of Li-ion with manganese cathode
1996	University of Texas (USA)	Identification of Li-phosphate ($LiFePO_4$)
2002	University of Montreal, Quebec Hydro, MIT, others	Improvement of Li-phosphate, nanotechnology, commercialisation

History of modern battery development. Source: BU-102: Battery Developments, *Battery University*

NB: no major new battery system has entered the commercial market since the invention of the Li-phosphate battery in 1996.

Although primitive batteries may have existed in Babylonian times (the evidence is disputed), it wasn't until the 1550s that English scientist William Gilbert made the distinction between magnetism and static electricity (then called the 'amber effect'). Known as the 'Father of Magnetism', Gilbert is credited with establishing the study of electrochemistry.

William Gilbert, the 'Father of Magentism'.
Source: *http://blog.yovisto.com/william-gilbert-the-father-of-electrical-studies/*

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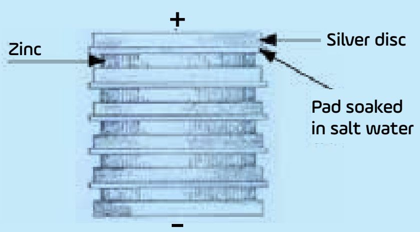
Around a century later, in 1663, German physicist Otto von Guericke invented the world's first electrostatic generator [2], a device subsequently used in many experiments pertaining to electricity.

Then, in the late 18th and early 19th centuries, Italians Luigi Galvani [3] and Alessandro Volta [4] conducted pioneering groundwork in electro-chemical energy storage. (Today, their names live on in the terms 'galvanic cell' and 'volts'.) It was Galvani's experiments with 'animal electricity' in frogs that led Volta to invent arguably the world's first battery, the 'voltaic pile', which produced continuous electric current to a circuit in a process now known as electrolysis [5].



The voltaic pile.
Source: *astarmathsandphysics.com*

In light of the Industrial Revolution, the work of Galvani and Volta excited great interest in galvanic electricity. Two Englishmen to take up the baton were Sir Humphrey Davy [6], who conducted important investigations into electrochemistry, and Dr William Cruickshank [7]. In 1802, Cruickshank designed the 'trough battery' (a variant of the voltaic pile) and, voilà, the first electric storage device capable of mass production was born.

Original Cruikshank's galvanic trough.
Source: *collectionsonline.nmsi.ac.uk*

The nature of electricity, and the challenges of how best to create, store and use it, captured the imaginations of high- and commercially-minded scientists and inventors worldwide, among them such instantly recognisable names as Ampère [8] (France), Faraday [9] (the UK), Jungner [10] (Sweden), Edison (the US) [11] and Tesla [12] (a Croatian who moved to the US).

Assiduous research, not to mention rivalry, contributed to stand-out innovations like telegraphy, power delivery, the telephone, broadcast radio, television, computers and now, in the 21st century, a plethora of products – from electric vehicles and machinery through consumer electronics and power-storage devices to aerospace applications – considered essential (or soon to be) to life as we know it.

Genesis of the Li-ion battery

Steve Levine, writing for *Quartz*, avers that in the past 60 to 70 years the two most powerful inventions in terms of their social and economic import are the transistor and the Li-ion rechargeable battery. The former, created at Bell Labs in 1947, transformed electronics, while the latter, commercialised by Sony in 1991, "took the clunky electronics enabled by the transistor and made them portable. [It] gave the transistor reach."

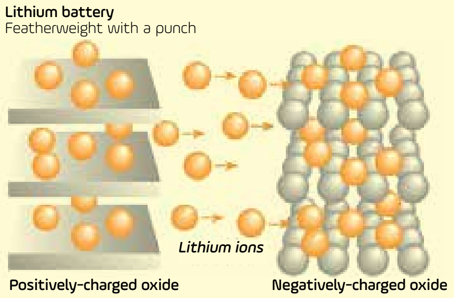
In the 1970s, Stanley Whittingham, a British professor of chemistry and materials science, and colleagues at Stanford University discovered and named the concept of intercalation of electrodes, whereby lithium ions are inserted within layered sheets. The lithium ions can be shuttled from one electrode to the other, resulting in a rechargeable Li-ion battery. Whittingham's rechargeable lithium battery had a titanium disulphide cathode and a lithium-aluminium anode. On the basis of this research, ExxonMobil patented a lithium-titanium disulphide battery in 1976; however it proved unworkable [13].

In 1979, American physicist John Bannister Goodenough [14], then heading the Inorganic Chemistry Lab at Oxford University, improved significantly on that Li-ion battery technology. His brainchild?

... the cobalt-oxide cathode, the single most important component of every lithium-ion battery. From Mogadishu to Pago Pago, from Antarctica to Greenland, and all lands in between, Goodenough's cathode is contained in almost every portable electronic device ever sold. Others have tried to improve on the cobalt-oxide cathode, but all have failed. [15]

Goodenough's discovery opened up new and exciting possibilities for rechargeable battery systems. In 1980, French Moroccan scientist Dr Rachid Yazami developed a graphite anode, which paved the way for Akira Yoshino, a Japanese chemist also researching rechargeable batteries. Yoshino combined Goodenough's cathode with lithium cobalt oxide as the anode, creating a prototype in 1983. This led to development of the lithium-graphite anode used in modern Li-ion batteries.

Sony produced the world's first commercially viable Li-ion battery in 1991.



Sony's 1991 Li-ion battery used lithium-cobalt-oxide for the positive electrode and graphite (carbon) for the negative one. As the battery is charged, lithium ions move out of the cobalt-oxide lattice and slip between the sheets of carbon atoms in the graphite electrode – a state of higher potential energy. Discharging the battery causes the ions to move back again, releasing energy in the process. This is known as a 'rocking chair' design.
Source: *Hooked on lithium*, The Economist 2002.

Decades on, improving that technology – to increase the range of electric vehicles, create ever-smarter consumer electronics and efficiently store energy from renewable sources at both domestic and commercial levels – remains the Holy Grail of battery manufacturers the world over.

In light of Earth's woes, including global warming, could batteries – and Li-ion batteries in particular – be the greatest innovation since the Industrial Revolution? Time alone will tell!

The Power of 3 is sponsored by Lithium Australia.
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Notes

[1] Benjamin Franklin (1706-1790) was a leading author, printer, political theorist, politician, freemason, postmaster, scientist, inventor, civic activist, statesman and diplomat. One of his major scientific discoveries was that lightening is an electrical discharge and he subsequently invented the lightening rod.

[2] Otto von Guericke (1602-1686) proved that a vacuum could exist; before that, no one believed it possible. His discovery was essential for further research into electricity. Circa 1660, von Guericke devised a contraption that produced static electricity by friction. It consisted of a glass globe within which a large ball of sulphur was mounted on a pole. When the sulphur ball was rotated by a hand crank, it rubbed against a pad and the resulting friction generated sparks of static electricity. Although von Guericke had no idea what these sparks signified, his device was subsequently used in early experiments with electricity.

[3] Luigi Galvani (1737-98), an Italian physician, physicist, biologist and philosopher, is recognised as the pioneer of bio-electromagnetics. In 1781, Galvani found that he could induce twitching in the muscles of a dead frog when they were touched with different metals or the current from a static electric generator located nearby. He thought, incorrectly, that the fluid in the frog's body was the source of the electricity.

[4] Count Alessandro Volta (1745-1827), an Italian physicist and chemist, made discoveries in electrostatics, meteorology and pneumatics. He is most famous, however, for inventing the first battery. In 1800, Volta proved that the electrical reaction in frogs noted by Galvani was in fact caused by the animal's body fluids being touched by two different types of metal. Subsequently Volta invented his 'voltaic pile', a stack of alternating metal discs of silver and zinc separated by cloth or cardboard soaked in salt water. This wet pile of 'dissimilar' metals created a small electrical current that could be drawn off through wires and used for experiments; several piles assembled side by side and connected with metal strips could create a power source of higher energy. Volta gave his name to the term 'volt', a unit of electrical energy.

[5] The process whereby an electric current is passed through a liquid (electrolyte) that conducts electricity, promoting a chemical reaction between metals (electrodes). To conduct electricity a liquid must contain ions; that is, atoms or molecules with a net electric charge caused by the loss or gain of one or more electrons.

[6] Sir Humphrey Davy (1778-1829) was a leading British chemist and philosopher and inventor of the miner's safety lamp. In 1801 he installed what was then the world's largest, most powerful electric battery in the Royal Institution of London. Davy attached it to charcoal electrodes to produce the first electric light, which, according to witnesses, was "the most brilliant ascending arch of light ever seen." He had begun testing the chemical effects of electricity in 1800 and soon found that, when electrical current passed through certain substances, it caused them to decompose in a process later termed 'electrolysis'. The voltage generated as a result of this process was directly related to the electrolyte reacting with the metal. Davy's assistant, Michael Faraday, went on to establish a reputation even more prestigious than that of his mentor *(see note 9 below)*.

[7] Dr William Cruikshank (died 1810 or 1811) was a Scottish military surgeon, Fellow of the Royal Society and professor of chemistry at the Royal Military Academy in Woolwich. He devised the trough battery, comprising joined zinc and copper plates placed in a wooden box filled with electrolyte (brine or diluted acid) and sealed with cement. Grooves in the box held the metal sheets in place. This 'flooded' design, which did not dry out with use, produced more energy than Volta's stacked disc arrangement.

[8] In 1820, André-Marie Ampère (1775-1836) made a revolutionary discovery: that a wire carrying electrical current can attract or repel another, adjacent wire also carrying electrical current. While the attraction is magnetic, no magnets are required to produce the effect. Ampère went on the formulate Ampere's Law of electromagnetism, producing the best definition of electrical current of his time. He further proposed the existence of a particle now recognised as the electron, discovered the chemical element fluorine, and grouped elements by their properties more than half a century before Dmitri Mendeleev produced his periodic table. The International System of Units (SI) unit of electric current, the ampere (amp for short), is named in his honour.

[9] Michael Faraday (1791-1867), an English scientist, is considered one of the greatest scientific explorers of all time. His contributions to the fields of electromagnetism and electrochemistry, principally in relation to electromagnetic induction, diamagnetism and electrolysis, were remarkable, and his electromagnetic rotary devices formed the basis of electric motor technology. The SI unit of capacitance, the farad, is named in his honour.

[10] In 1899, Swedish engineer Waldemar Jungner (1869-1924) invented the nickel-cadmium electric storage battery, using nickel for the positive electrode and cadmium for the negative.

[11] American Thomas Edison (1847-1931) was a pioneer in applying the principles of mass production and teamwork to inventions to make them commercially viable. He is perhaps best known for devices such as the phonograph, the motion picture camera, a practical, long-lasting electric light bulb and, more controversially, the electric chair, created to illustrate the perils of alternating current (AC) as opposed to direct electrical current (DC), of which he was a firm advocate. In 1901, Edison produced an alternative to Jungner's battery, replacing the cadmium with iron. Cost considerations, however, limited the practical applications of either type of battery.

[12] Nikola Tesla (1856-1943), born in Croatia, moved to the US in 1884. There, he worked briefly with Edison before the two parted ways. Tesla made a significant contribution to the development of AC (as opposed to DC) electrical systems to supply long-distance power, and AC became pre-eminent in the 20th century (it remains the worldwide standard), and also discovered the rotating magnetic field, the basis of most AC machinery.

[13] Steve Levine, author of *The Powerhouse: Inside the Invention of a Battery to Save the World.*

[14] Whittingham's rechargeable lithium battery was based on a titanium disulphide cathode and a lithium-aluminum anode. Titanium disulphide was a poor choice, in that it had to be synthesised under completely sealed conditions, a very costly process. Also, when exposed to air it stank, because the moisture in the air reacted with the titanium disulphide to make hydrogen sulphide. Moreover, because lithium is highly reactive, burning in normal atmospheric conditions due to the presence of water and oxygen, metallic lithium electrodes present significant safety issues.

[15] Among the many prizes he's received, Dr Goodenough was awarded the $450,000 Japan Prize in 2001 in recognition of his work. Still going strong at the age of 93, and currently professor of mechanical engineering and materials science at the University of Texas, Goodenough wants to develop a 'super-battery', a quantum leap in storage capacity that will make electric vehicles, for instance, more competitive and the harnessing of power from renewable sources more economical.

ThePowerof3

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2016

Driving the future further

Overview

Issue 4 of *The Power of 3* posed the question: can batteries – and lithium-ion batteries in particular – save the planet? Perhaps ... but much depends on what happens at the end of their lifecycle, now and well into the future.

Rather than being disposed of in landfill sites, rechargeable lithium-ion batteries (LIBs) should be chemically neutralised and re-used. However, many things can influence this appropriate recycling, not least the fact that almost 90 per cent of LIBs are sold with, or in, the products they power and thus disposed of still within their 'hosts'. Further, a battery's life depends on the frequency with which it is used, and this affects the time gap between it entering the market and being ready for disposal.

Consumer hoarding of superseded or defunct consumer electronics presents another obstacle, as do non-standard battery labelling, issues of transportation, handling and physical sorting, and the chemical processes involved in the end-stages of LIB recycling.

Moreover, the proliferation of plug-in hybrid electric and full electric cars (HEVs and EVs), as well as other forms of electrically powered transport, will compound recycling challenges in the years to come (more on this later and in the next edition).

There is no doubt, however, that the recycling of rechargeable batteries has the potential to not only reduce possible environmental and human health hazards but also provide valuable resources.

Recycling rechargeable batteries: an industry imperative – part 1

Why LIBs die

In time, LIBs lose their capacity to hold a charge. Put very simply, it's a function of extended exposure to high temperatures, repeated charging and discharging cycles that eventually disrupt the progress of the lithium ions travelling between the electrodes, and factors like corrosion and other unwanted chemical reactions.

To make LIBs more efficient, researchers are seeking electrolyte additives that reduce harmful reactions between the electrodes and electrolyte, so they perform better for longer. Experiments with new and more stable components and electrolytes are also ongoing.

In addition, LIB manufacturers and EV producers are working on the battery packs themselves, to devise thermal management systems that keep the lithium-ion cells they contain at a constant, healthy temperature.

LIB types

Six types of high-performance LIB are currently commercially available (cobalt being the main active material in the cathodes of the highest-capacity batteries).

- Lithium cobalt oxide (mobile phones, tablets, laptops, cameras)
- Lithium manganese oxide (power tools, medical devices, electric powertrains [1])
- Lithium nickel manganese cobalt oxide (e-bikes, medical devices, EVs and industrial applications)
- Lithium iron phosphate (portable and stationary devices in which high load currents and endurance are required)
- Lithium nickel cobalt aluminium oxide (medical devices, industrial applications, Tesla electric powertrain)
- Lithium titanate (UPS [2], electric powertrains (e.g. Mitsubishi, Honda), solar-powered street lighting).

Recycling LIBs in EVs

One of the great recycling successes of the past 100 years has been the conversion of the lead-acid and nickel-based batteries used in most conventional vehicles into reusable materials. However, electrically powered transport uses batteries of an entirely different type.

It's predicted that EVs will comprise more than 7 per cent of the global transportation market as early as 2020, with significant time, effort and resources being expended on improving their performance and lowering their cost. To illustrate the point, on April 1 Elon Musk tweeted that orders for Tesla's latest and most 'economical' EV (the Model 3, priced at a cool US$35,000), unveiled a day earlier and due for delivery in 2017, have already exceeded 232,000!

But are such vehicles really as 'green' as they're touted to be? Of particular import in this regard are:

- what powers the grid that charges the vehicle's battery (a coal-fired power station, for example, has the potential for negative environmental impacts), and
- what type of battery propels the vehicle.

In 2013, an intense US study [3] focused on the latter point: not only the 'cradle-to-grave' aspects of the LIBs that drive HEVs and EVs – that is, the materials and processes involved in their manufacture and use through to the end of their life and recycling – but also ways in which the environmental and public health impacts of those batteries might be reduced.

Researchers examined the cathodes of three different types of LIBs – lithium-manganese oxide, lithium-nickel-manganese-cobalt oxide and lithium-iron-phosphate – and at battery anodes containing single-walled carbon nanotubes [4].

Batteries with nickel and cobalt in their cathodes, and electrode processing involving solvents, were found to be the worst in terms of potential environmental impacts (including resource depletion, climate change and ecological toxicity), as well as potential impacts on human health (respiratory, pulmonary and neurological effects).

To mitigate such impacts, the study recommended substitution of the cathode material, solvent-less electrode processing and recycling of the metals contained in the batteries.

At present, even when disposed of correctly, only about 2 per cent of LIBs are recycled. This is due in part to the lack of standardisation of chemical components, and of system complexity, both of which amplify the difficulty of achieving a high recovery rate for the materials they contain.

However, arguments for widespread and effective recycling of new-generation batteries go beyond environmental and health concerns. With respect to the recovery and reuse of lithium and cobalt, for example, the risks associated with the supply, cost and accessibility of these resources are worthy of consideration.

Lithium An alkali metal intrinsic to a number of industries (see *The Power of 3, issue 1*), lithium is also a key component in the production of the LIBs contained in consumer electronics, EVs and stationary energy storage systems. Indeed, growth in the latter three industry groups is boosting demand for lithium like never before.

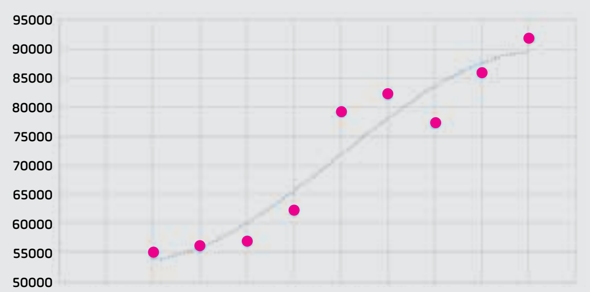
Currently, notes Aswin Kumar, lithium supplies are meeting demand. That said, almost 70 per cent of global deposits are located in South America (Argentina, Bolivia and Chile), regions not known for their political stability. Geo-politics aside, environmental impacts from mining also have the potential to disrupt the availability and cost of this raw material.

Cobalt Cobalt is rarely produced as a primary metal; most often it's a by-product of nickel and copper production. With the nickel and copper markets currently depressed, however, there is little likelihood that global cobalt output will expand any time soon.

Historically, too, cobalt has been a conflict mineral; its sale by the war-torn nations of the African copper belt has financed arms purchases for, and atrocities committed during, numerous revolutions. Restrictions imposed by the US or other governments in order to promote ethical minerals trading in the eastern Congo are likely to further constrain its availability. The US government, for example, wants cradle-to-grave tracking of all battery materials consumed on home soil, to reduce consumption of those sourced from conflict zones.

At present, more than 40 per cent of cobalt ends up in batteries. Thus, if requirements for the LIB market continue to grow at around 11 per cent per annum, cobalt production will reach a tipping point. Clearly demand – driven by continued growth in the battery sector – will outstrip supply, meaning that here too recycling could be part of the solution.

Total refined cobalt availability (annual tonnes)



Source: Cobalt Development Institute

Hence, while LIB recycling is in its infancy, it could in future help mitigate against the risks that result in wildly fluctuating prices.

Which Perth-based company is resolving many of these issues right now?

Seeking the right solutions

Currently, in Europe, the US and Japan, projects are underway to develop comprehensive recycling solutions for LIBs, and EV batteries in particular.

Linda Gaines, in her article *The future of automotive lithium-battery recycling*, is one of many to advocate designing **all** batteries with recycling in mind. Better battery chemistries and models are necessary, as is standardisation of the types that work best.

"Those that could be recycled together would have at least one distinguishing feature in common and, conversely, one to differentiate them from those [having] to be recycled in a different way. Mechanisms [are needed] to return all batteries at the conclusion of their (first or second) useful lives ... to the appropriate recycling facilities in a safe and legal manner ... [with] user-friendly labeling [to facilitate this]. Regulations would assure safe transport and handling, and discourage ... cross-contamination. Sorting/routing could be immediate, via a transfer station or within a unified recycling facility. Separate streams would be processed to produce valuable, high-purity materials [to] be reused in batteries or in another high-value product ... Accomplishing this ... before large numbers of automotive propulsion batteries have reached the end of their useful lives requires research and planning to continue over the next 10 years or so. It is a daunting task, but if there is a broad commitment from industry and government it can be done."

While comprehensive and efficient recycling of LIBs will no doubt be a long and arduous process, it is plainly an industry imperative.

Notes

[1] The system of parts in a vehicle or device that first produces energy, then converts it in order to propel that vehicle or device, be it a car, boat or other machinery.

[2] UPS stands for 'uninterruptible power supply', also 'uninterruptible power source'. UPS, or battery/flywheel backup, is an electrical apparatus that provides emergency power to a load when the input power source, typically mains power, fails.

[3] Carried out by Abt Associates via a partnership with the US Environmental Protection Agency, the US Department of Energy, the LIB industry and academicians.

[4] Although not currently in production, single-walled carbon nanotubes were assessed for their ability to improve the energy density and performance of EV batteries. However, significant resources are expended in the early stages of their production, which may outweigh the benefits of their energy efficiency.

The Power of 3

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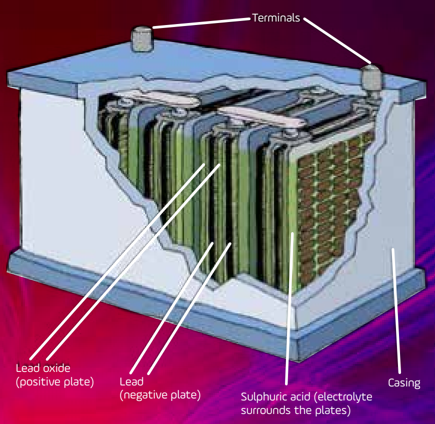
2016

Driving the future further

Overview

The last issue of *The Power of 3* considered some of the many barriers to adequate recycling of lithium-ion (Li-ion) batteries. Not least among these were the plethora of available battery chemistries and components, a lack of standardisation and the fact that so many live and die within the products they power.

One of the most exemplary recycling successes of the past 100 years has been that of lead-acid batteries. Why? Because by law they cannot be discarded, and because all manufacturers use the same basic (and commercially valuable) raw materials and a chemistry not requiring segregation. Thus, lead-acid battery disassembly can be automated, which simplifies the recycling process and helps make it profitable.



The cells of Li-ion batteries, on the other hand, contain many and more various materials, with some of those that are active taking the form of powder coated onto metal foil. All these different materials must be separated from each other during recycling.

Despite the seemingly unstoppable proliferation of Li-ion batteries, it will take market saturation (still many years away), end-of-cycle disposal and cost incentives to ensure viable widespread recycling – and even then, matching the +90% recycling rate for lead-acid batteries may not be achievable.

Recycling rechargeable batteries: an industry imperative – part 2

Cradle-to-grave or re-birthing?

If better technology is the Holy Grail of battery manufacturers, then cradle-to-grave recycling – or even battery re-birthing – may be the Sangraal of those concerned by how many batteries are being produced and the lack of adequate means for their disposal. The environmental impacts of batteries are not limited to the waste stream – they occur during the production, distribution *and* end-of-life phases – but those that end up in landfills and incinerators pose an especially serious health risk to humans and animals.

As *Part 1* revealed, much time, effort and expenditure is being devoted to the cradle-to-grave aspects of the Li-ion batteries that drive electric vehicles (EVs). But what's to say they can't be retired to a less demanding application? Stationary household power storage doesn't need the high recharge rates EVs do, so maybe, rather than buying a Powerwall or similar device, you could park your outmoded Telsa (with the jumper leads permanently attached) to capture the sun's energy, then feed that power, as required, to your refrigerator!

In 2014, in Deptford New Jersey, Jason Hughes did more or less that. Having spent nearly a year 'hacking' the battery of a wrecked Telsa Model S, he reworked it into a stacked array to store energy from his home's solar-power system.

In 2015, Bosch took the idea one step further, announcing a partnership with BMW and Vattenfall known as the 'Second Life Battery Alliance'. Put simply, this involves building a mortuary for car batteries that will double their useful life (to a staggering 20 years!). Gigantic racks will contain hundreds of below-spec EV batteries that can live out their remaining time as municipal power storage.

Recycling whole lithium batteries into less demanding applications is certainly a laudable environmental initiative, but what happens when the market does eventually reach saturation? As millions of batteries head past the point of reincarnation towards their final demise, reprocessing of their components will become an industry imperative. The upside would be the provision of cheaper materials, taking the pressure off the supply of, say, cobalt, which is already problematic.

But, given the many constraints to lithium battery recycling, how *can* the materials they contain be recovered best? Retrieving useful metals from a pile of scrap is not as simple as obtaining the same elements from a pile of rocks. Perhaps the industry needs to reference the technologies that produced the metals in the first place; that is, treating waste batteries as high-grade ore and initiating processes that digest and extract metallic compounds in the battery, just as the original ore was digested.

Battery innovation

As also mooted in *Part 1*, better lithium battery chemistries, then standardisation of those types that work best, would help simplify future recycling.

One innovation under intense scrutiny for more than two decades is the lithium-sulphur (Li-S) battery, which may eventually carry up to five times the density of high-capacity Li-ion batteries of comparable size. Li-S batteries are cheaper to make, less toxic and safer to operate than Li-ion batteries: crucial considerations in encouraging a switch towards renewable energy sources. Moreover, sulphur is virtually free and Li-S devices could help transform what is essentially a waste product into useful technology. The downside of current incarnations of the Li-S battery is leakage of lithium polysulphide from the electrode into the electrolyte, which causes the battery to fail.

Sony, producer of the world's first commercial Li-ion battery last century, is developing a Li-S battery that it hopes to commercialise by 2020, changing the battery recycling landscape forever in the process.

Last year, too, EU-funded researchers in the 'Lithium Sulfur Superbattery Exploiting Nanotechnology' ('LISSEN') project developed a Li-S battery with lithiated silicon as the anode and a nanostructured sulphur-carbon composite as the cathode. Said LISSEN coordinator Riccardo Carelli:

> *"Our efforts … were directed toward the replacement of all present battery components with materials that have higher performance in terms of energy, power, reliability and safety."*

Prototypes are currently being developed and industrial partners are examining fabrication and scaleability issues.

Meanwhile, researchers at Stanford University have engineered a new carbon material said to significantly boost the performance of energy-storage technologies, including Li-S batteries.


Solar Impulse 2 over San Francisco (Credit: Solar Impulse)

And, finally, a picture worth a thousand words …

Speaking of innovation, right now a unique flying adventure is underway, powered by lithium polymer (LiPo) batteries.

Last month residents of San Francisco's Bay Area were treated to a fly-by of the Golden Gate Bridge by the *Solar Impulse 2*, which aims to circumnavigate the globe, breaking world records and promoting clean technologies as it goes.

A zero-fuel aircraft powered by sunshine but able to fly at night, the *Solar Impulse 2* weighs about as much as a large car but has a wingspan greater than that of a Boeing 747. The more than 17,000 solar cells built into its wings charge an extra-efficient LiPo battery pack designed to be ultra-light, energy-dense enough to power the plane's 17.4-horsepower motors, and durable enough to endure continuous discharging and recharging over very extended periods. In fact, the per-cell energy density of the battery system, designed by Korean company Kokam, is more than twice that of a high-capacity Li-ion battery, although the chemistry of both is basically the same.

Conclusion

From a recycling perspective, a major shift towards new technologies such as Li-S batteries could diminish the value of retrievable metals within other types of lithium batteries, rendering their conversion into reusable materials even less attractive commercially.

That said, the simpler chemistry of Li-S batteries would certainly make for easier and more efficient recycling, to the point, perhaps, where it rivalled the success of lead-acid battery recycling.

For the time being, however, Li-ion batteries remain the gold standard for energy storage – and their comprehensive and efficient recycling is essential from an environmental point of view.

Which Perth-based company is resolving many of these issues right now?

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The Power of 3

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Driving the future further

SMARTER POWER = GREATER FREEDOM: AMP UP THE RV!

> "Aboard and light-hearted, I take to the open road, healthy, free, the world before me … heading wherever I choose."
>
> ~ *with apologies to Walt Whitman*

Overview

Travelling somewhere new – and dallying there – is the dream of many, with more and more living that dream. And what better way to do so than in a well-equipped RV?[1]

In Australia right now, over half a million RVs traverse the roads, a number that's expanding at about 25,000 per annum. And it's not just budget-conscious families and baby boomers heading for wide-open spaces; more and more are seniors, or 'grey nomads' – retirees who travel independently, often for extended periods and within their own country, in a caravan, camper van, camper trailer or motor home.

This edition of *The Power of 3* looks at how harnessing solar power, switching from a lead-acid to a lithium battery pack, and sourcing an efficient and reliable battery management system can deliver greater freedom for RV enthusiasts passionate about life on (and off) the road.

Recreational solar

Most modern RVs come with 12- or 24-volt battery systems as standard. Designed to power up while the engine's running, they often incorporate a 240-volt charger that maintains the battery once it's connected to the electricity grid. But accessing 240 volts in more remote locations such as national parks is a rarity, and running a noisy generator or engine is not conducive to relaxation! Indeed, this is now banned in many camping areas and caravan parks.

Today, though, a lot of RVs are rolling off the production line either with a solar system *in situ* or 'solar ready'; that is, the wiring (and perhaps a charge controller) for a solar system have already been installed.

Serenity-seeking owners of more traditionally powered RVs can still opt for rooftop or portable solar panels to lessen distractions for themselves and fellow campers.

Where rooftop solar is being retrofitted to an RV, flexible panels that align with the curvature of the roof are a sensible choice, in that they maximise the useable area.

Portable solar panels are great for smaller vehicles … and an attractive option (along with a lengthy charging cable) for those who prefer to park in the shade. Installation costs (if any) are minimal, no framing is necessary and there are various sizes to choose from, depending on available storage area. Some even fold up and incorporate a carrying handle. On the road again and with panels stowed, the RV battery can be charged via the towing vehicle's alternator.

Whatever the solar option chosen, daily power needs require careful assessment first. That means checking equipment specifications, layout and any other variables likely to influence those needs. An effective power system should also allow for several days' autonomy, for back up on cloudy days or where long periods off-road prevent charging.

Installing an inverter will bolster the home-away-from-home RV experience by converting the low voltage of the solar system to 240V AC. Unlike a generator an inverter only uses full power when the devices connected to it require it. However, all inverters consume electricity (about 10%) when idle, so biggest is not always best. Safety, too, is very much a consideration and, as with most things in life, adequate research and obtaining professional advice are mandatory.

Lithium-ion or lead-acid?

Traditionally, lead-acid batteries stored energy and ran appliances in an RV. Recharging the battery meant visiting powered sites and paying to hook into the grid. Now, though, RV owners can augment the autonomy afforded by solar power with better battery technology, gaining greater independence in the process.

Reliance on the grid aside, lead-acid batteries are old school in that they're heavy, toxic and have a relatively short service life (2-5 years). Moreover, the available energy on offer is limited to about 50% of their rated capacity [1].

For many an RV owner, lightweight, super-efficient, space-saving lithium-ion batteries (LIBs) present a real and practical alternative [2]. Weighing half to three-quarters less than their lead-acid counterparts, LIBs are more energy-dense (safely dischargeable to 100% of rated capacity), less toxic, non-corrosive, longer lasting (3000-5000 cycles compared to 300-500 cycles for most lead-acid batteries), maintenance-free and can hold a full charge for more than a year.

Perhaps the greatest advantage of LIBs for the RV owner, though, is their ability to charge rapidly. Any downsides relate to higher cost and perceived 'safety issues' *(see section below)*.

In terms of cost, replacing the lead-acid battery in an RV with a lithium-based battery pack is expensive but, as is often the case with newer technology, prices will ease with time.

With respect to safety, despite the bad press surrounding recent hover-board fires and aircraft accidents, lithium-ferro-phosphate (LFP) batteries are both durable and very safe (the downside being that their specific energy is lower than that of competing cobalt-based LIBs). That makes them ideal for handling high-load currents, since the risk of thermal runaway (i.e. fire!) is low. They can also tolerate overcharging without damage and suit Australian conditions [3].

As always, however, specific requirements must be carefully considered when weighing the pros and cons of particular battery types for a given application.

Battery management systems

Unlike lead-acid batteries, LIBs are quite complex in terms of how they charge and discharge. So, preserving the longevity of a LIB system in an RV, and also ensuring that it remains within safe operating limits, requires a battery management system (BMS), which electronically manages rechargeable batteries or battery packs.

A 'smart' lithium battery pack designed for an RV includes a BMS with an external communication data bus. The pack is charged by a 'smart' battery charger and doesn't heat up during use or charging like lead-acid batteries [4].

Whether inbuilt or not, the primary function of a BMS is to monitor all the cells in a lithium battery pack continuously for faults. As such, it acts as an insurance policy, protecting against misuse and abuse, including over-charging, over-discharging, excessive continuous current and short-circuiting. A good BMS also monitors the temperature of the battery and disconnects the pack long before it over-heats to the point of catching fire. These functions are intrinsic to a BMS, no matter the type of lithium battery pack used, its size or what it powers, be that an electric vehicle, an RV, a hover-board or Boeing's 787 Dreamliner. In all cases, avoiding a conflagration is essential. [5]

The secondary function of a BMS is to correct imbalances within the battery cells themselves. This is achieved passively (with energy wasted in heat) or actively (with energy transferred rather than wasted) – the former is the most common.

Balancing removes the extra charge from the most-charged cells and/or adds charge to the least-charged cells, thereby maximising deliverable power. If the battery pack has been balanced at the factory that built it, maintaining that balance is far easier – all a BMS need do is compensate for variations in self-discharge leakage in the battery cells themselves.

The consensus is, choosing the right BMS can save a bundle. While they generally restrict the discharge rate of a battery pack, some Australian manufactured BMSs permit discharge of an LFP battery pack at 250 amps: enough to power a fridge, a toaster, a microwave, a clothes dryer and a bar fridge (although not all, perhaps, at the same time). It means that, rather than doubling up on appliances, and depending on available space, much or all of the usual home equipment could be packed into the RV before heading out on the open road.

A word of caution however: in the brave new world of advanced battery technology, the exact role of a BMS, and precisely how much user intervention is required, remain open to interpretation. As always, doing adequate research and seeking knowledgeable advice will help to guard against pitfalls … remembering, again, that big isn't always better!

Which Perth-based company is working to bring the price of lithium down?

Notes

[1] A recreational vehicle, autonomously powered or towed by another vehicle, that often incorporates many of the comforts of home, including a bathroom, cooking facilities and beds.

[2] Smith, S. 'Battery storage for recreational vehicles – why lithium is the next big thing'. *Proceedings of the Lithium Battery Conference*, May 2016.

[3] http://www.enerdrive.com.au/lithium-all-the-rage/

[4] Chan, S. 'Lithium Ferro Phosphate (LFP) Batteries – the "Safe Lithium"'. *Proceedings of the Lithium Battery Conference*, May 2016.

[5] http://www.lithiumion-batteries.com/lithium-rv-deep-cycle.php

[6] MacDonald, G. Lithium Battery Management Systems (BMS) – Electric Vehicles Vs Recreational Vehicles. *Proceedings of the Lithium Battery Conference*, May 2016.

ThePowerof3

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Driving the future further

Overview

For reasons that include, but are not limited to, the threat of climate change from the production, transport and burning of fossil fuels, the ways in which power is supplied and distributed worldwide are undergoing unprecedented change, with plenty still to come.

Innovative technologies are creating new opportunities that, ultimately, have the potential to disrupt conventional models of power supply – not least the advent of electric vehicles, burgeoning global uptake of which is encouraging broader, and smarter, grid applications.

On a consumer level, disaffection with governments, with 'big business' in general, and with utility companies in particular is prompting tech-savvy customers to investigate going off-grid. Often, the stimulus is not so much a good return on investment or payback time but, rather, the feel-good factor of going green, a desire for autonomy, or perhaps even paranoia associated with being monitored by a 'big-brother' style smart meter (despite the fact that the latter can provide real benefits – for electricity providers and consumers alike – by facilitating innovative demand management initiatives and more economical pricing options, and by informing end-users in more detail about their energy consumption).

Going off-grid: pipedream or promised land?

> *Should I stay or should I go? If I stay I could pay double, but leaving might mean trouble. This indecision's bugging me – should I stay or should I go?*
>
> *[with apologies to The Clash]*

Case study: Australia

In general in Australia, a small number of large, remote generators provide power at high voltage through a transmission system connected to customers via a lower voltage distribution grid. Power flows one way and the distribution networks divide it into small quantities for customers.

However, such centralised power generation, and the traditional poles-and-wires system of delivery, are increasingly problematic in many outlying areas, given the threat of bushfires (and other natural disasters). Whether triggered by network faults, arson or lightning, recent conflagrations nationwide have destroyed hundreds of millions of dollars worth of infrastructure, not to mention people, pets, homes, livestock and livelihoods.

Meanwhile, city households are experiencing ever higher rises in energy prices, despite a decrease in energy use over the past decade. As a result, consumers are becoming more actively 'engaged' in their electricity useage and rooftop solar panels are now ubiquitous. By the end of last year, more than 23 million panels had been installed nationwide, equating to one each for every man, woman and child in the country. Now, the availability of intelligent inverters and smart battery storage systems is accelerating the push for cleaner, cheaper power.

Historically for very remote Australian properties and communities, the tyrannies of distance have put mains electricity out of reach or rendered it prohibitively expensive, with noisy, smelly, expensive-to-run liquefied petroleum gas (LPG) or diesel generators usually relied upon instead.

The winds of change

There is no doubt that the ways in which power is supplied require revamping. Research by Australia's CSIRO [1] reveals huge potential to transform utility business models across the country. By not changing, providers risk losing up to a third of their customers and alienating those who remain and who must bear more of the fixed costs of their grid.

Disruption from renewable generation and demand for side technologies, as well as climate change and other social/political imperatives, look set to severely test current infrastructure [2]. According to the CSIRO, Australian homes and businesses will be powered by more than 20 different energy sources and technologies by 2050, so grids of the future will be operating in a potentially very altered environment.

But moving away from predictable, controllable systems involves a huge amount of effort, capital and capacity building and, unsurprisingly, power networks are dragging their feet. Baulking at reducing costs (which means writing down assets and accepting lower revenue), they are instead trying to retrieve their upfront costs more quickly … hence those higher bills.

Since 2012, the Australian Renewable Energy Agency has been researching clean energy and 'innovative integrated solutions' to support grids, improve network stability and reduce or offset the costs of upgrading the electricity network, with the aim of ensuring a reliable supply for 11 million customers nationwide [3]. Now, given the inevitability of change, preparations are underway for the monumental makeover required.

Battery storage: the key?

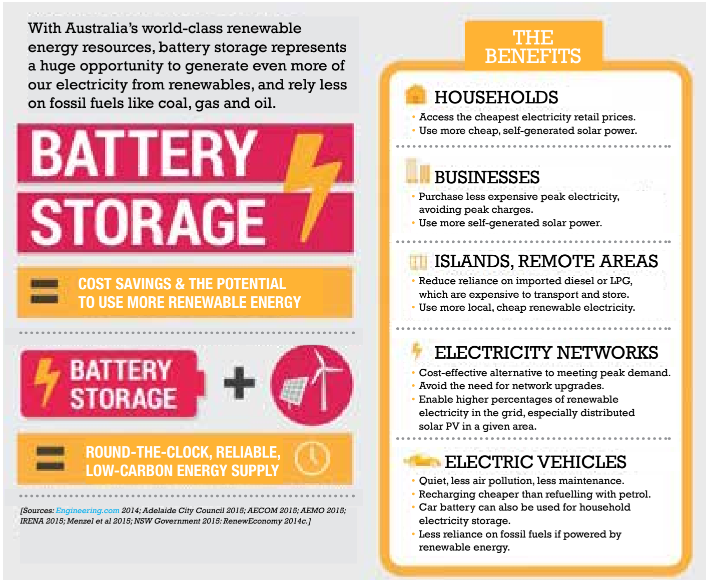
Assuming that both consumers and electricity providers adequately understand and control their power useage (particularly during periods of peak demand), battery innovation has the potential to reduce the two biggest contributors to rising electricity bills – network and wholesale energy costs.

Whether it's consumers actively designing or customising their own solutions to obtaining power, or an entire electricity system in which renewables thrive, battery storage has far-reaching implications for the electricity supply chain.

In *Leaving the grid: an ambition or a real choice?*, Rajab Khalipour and Anthony Vassalo argue that:

> *From an economic perspective, widespread disconnection might not be a realistic projection of the future. Rather, a notable reduction of energy demand per connection point is a more realistic option as [solar]/ battery system prices decline further.*

The prices of photovoltaic systems (PV) have fallen considerably in the last decade, and a similar rapid decline in the prices of battery storage systems [4] would see a flow-on effect of increased demand, at which point economies of scale would kick in. Australia's Climate Council expects the global market for solar panels and battery storage to grow tenfold by 2020, making living off-grid an increasingly viable option … and sounding the death knell for any transmission and distribution industries that fail to adapt.



Off-grid systems

Which system Is right for me?

On-grid systems

[Source: *http://www.offgridnergy.com.au*]

Intimations of the future

Right now in Australia, leaving the grid is unlikely to be cost-competitive for the average urban household; nor can it guarantee a totally reliable power supply. That said, global investment bank UBS predicts that this will change by as early as 2018 [5].

Rob Stobbe, CEO of one of the nation's largest electricity networks, SA Power Networks in South Australia, sees no long-term future for any form of centralised power generation and transmission, believing it's inevitable that all will become redundant over time [6].

Regional operators nationwide are already downsizing their networks in favour of localised generation and micro-grids, with utilities installing stand-alone power systems in a number of rural communities and remote properties. In metro areas meanwhile, facilities such as sub-division-scale battery storage in residential developments are also being trialled by power providers [7].

Happily for many Antipodean households, as for electricity consumers globally, the choice to go completely off-grid – or link to a micro-grid with just a small connection to the main network – is looking less like a pipedream and more like the promised land … all that's required is patience.

Which Perth-based company is working to produce cheaper lithium for battery storage technology?

Notes

[1] Commonwealth Scientific Research Organisation

[2] http://www.futuregrid.org.au

[3] http://arena.gov.au/about-arena/

[5] http://reneweconomy.com.au/2014/ubs-australian-households-go-grid-2018

[6] http://reneweconomy.com.au/2014/sa-network-operator-rural-communities-quit-grid-38514

[7] In Western Australia, for example, a community storage facility will power a new residential development at Alkimos, while in a number of rural towns and properties on the edge of the grid, stand-alone systems with solar panels, battery, inverter and back-up diesel generator are already producing and storing electricity independent of the network and supplying continuous power 24/7, regardless of the weather. Among the benefits are improved reliability of power supply and a reduction in bushfire risk due to the removal of poles in paddocks.

The Power of 3
Driving the future further
ISSUE 9 August 2016

Overview

Although lithium[1] does not occur free in nature, it's found in small amounts in almost every igneous rock[2] and in the waters of salt lakes and mineral springs worldwide. Minerals that contain lithium include lepidolite, petalite, amblygonite and spodumene.

As noted in the *Power of 3, issue 1*, lithium was first produced commercially in 1923. Since then it's become intrinsic to myriad commercial applications – not least as a result of its electrochemical potential, which makes it a vital component of lithium-ion batteries. In the 21st century demand for, and the price of, lithium are being impelled upwards by the electric vehicle[3] and electronics industries, as well as the energy sector.

Until the early 1980s, lithium production was dominated by 'hard-rock' mining, primarily from pegmatites[4]. However, the advent of lithium production from brines, primarily in Latin America, created a paradigm downward shift in operating costs.

By the 1990s, brine producers dominated the market[5] and most hard-rock operations shut down. Of the latter, only those producing high-purity spodumene concentrates for specialist applications maintained viability, since they were not competing in the same market as companies creating low-cost lithium chemicals from brines.

Currently, the global supply of lithium from brine and hard-rock deposits is around 50% for each method[6]. Brine processing results in the direct production of lithium chemicals[7] whereas the output from hard-rock production is mineral concentrate that requires downstream processing to deliver the refined chemicals.

Everyman's guide to lithium production

"In a drop of brine live all the secrets of the ocean, in a lump of rock all the secrets of the land."

~ with apologies to Kahlil Gibran

Lithium from brines

The Salar de Uyuni in Bolivia in the Altiplano of the high Andes, the world's second-largest plateau. The biggest salt flat on Earth, its surface mirrors the sky during the rainy season.

Lithium brine deposits can be classified as continental, geothermal or oilfield.

In general, the operating cost of producing lithium chemicals from brine is less than that for hard-rock deposits. Brine deposits are easier to explore too, but generally require high capital input to develop. Much depends on their proximity to infrastructure and the ease of transporting equipment and personnel to the site – the remoteness of many brine deposits is a major constraining factor, although environmental impacts may be less of an issue.

Continental brine deposits, the most common form of lithium-containing brine, are underground reservoirs containing high concentrations of dissolved salts, including salts of lithium, potassium and sodium. Igneous in origin, most lie within the 'Lithium Triangle' of the Andes, an otherworldly landscape of high-altitude lakes and bright white salt flats that straddles Chile, Argentina and Bolivia. Continental brine deposits are also found in China and the United States.

Generally, continental brine deposits are located below the surface of dried lake beds or 'salars' (Spanish for 'salt lakes'), at high altitudes and in areas of low rainfall where solar evaporation can cost-effectively precipitate the salts.

To extract lithium, the salt-rich waters are first pumped into a series of ponds to evaporate (potassium is often harvested early on).

Once the lithium chloride in the ponds reaches an optimum concentration, the solution is pumped to a recovery plant to produce lithium carbonate. The residual brines are then pumped back into the salar.

Lithium from brines

Although lithium production from continental brines is a now a mature business, few new operations have been commissioned in the past two decades, Orocobre's Olaroz operation in Argentina being an exception. Political factors have proved the main impediment, but so too is the requirement to evaporate huge volumes of water if a project is to be commercially viable – as noted, solar evaporation is the cheapest method. Few locations can match Chile's Atacama Desert, where optimal geology coincides with a climate perfect for the natural concentration of brines.

The Atacama Desert stretches from southern Peru into northern Chile. One of the driest places on Earth, it's occasionally hydrated by flash floods.

Geothermal brine deposits make up about 3 per cent of known global lithium resources. Hot, concentrated saline solutions, they have circulated through crustal rocks in areas of very high heat flow, in the process becoming enriched with elements such as lithium, boron and potassium. The Salton Sea in southern California is the best-known example of a lithium-bearing geothermal brine, but small quantities of the element can also be found in geothermal brines at Wairakei in New Zealand, the Reykanes Field in Iceland and El Tatio in Chile.

Southern California's Salton Sea was created in 1905, when spring flooding broke down the canal gates leading to the Imperial Valley, causing waters from the Colorado River to rush into a depression in the Colorado Desert.

Small geothermal fumarole at El Tatio, Chile.

Oilfield brines, which account for a further 3 per cent of known global lithium resources, are found in some deep oil reservoirs in several areas of the United States.

Lithium from hard-rock mining

With limited new capacity in the production of lithium from brines at present, hard-rock sources are a logical alternative … in the short term at least.

In Australia, Canada, Zimbabwe and Portugal, hard-rock mining and conventional processing techniques are used to produce high-grade lithium from pegmatites containing spodumene and petalite.

Spodumene, the principal ore mineral of lithium, is a lithium-alumino silicate containing 6 to 7% lithium oxide. Once recovered, the spodumene concentrates are sent to refiners, or 'converters' (presently all are located in China), and roasted [8] and leached to generate lithium chemicals. Those chemicals are then on-sold to third-parties.

Citi Research has estimated that some 16 lithium projects – most of them hard-rock deposits – will commence production between 2016 and 2020 [9].

Take Western Australia's Pilgangoora region (purportedly one of the world's largest deposits of shallow, hard-rock spodumene), where a number of miners are targeting near-term concentrate production to sell into the Chinese conversion facilities.

Also in Western Australia, the hard-rock mine at Greenbushes produces various different lithium concentrates to meet specific customer requirements, and is the dominant supplier of high-purity spodumene concentrates for the ceramics industry globally.

Conclusion

Whatever the source, it seems that timing will be key for those hoping to supply lithium raw materials. With moves afoot to develop an 'innovative and sustainable lithium extraction process from medium lithium grade brines' [10], and with Deutsche predicting a 'substantial response [to market conditions] from incumbent major brine producers' over the next decade' [11], hard-rock miners need to get a move on.

Which Perth-based company aims to simplify lithium production from hard-rock sources?

The Power of 3 is sponsored by Lithium Australia.
Enquiries to info@lithium-au.com.

Notes

[1] The term 'lithium' is used loosely here to describe lithium carbonate, lithium hydroxide and other forms of the element.

[2] Igneous rock is formed through the cooling and solidification of volcanic magma or lava.

[3] Tesla, for example, uses 50 kilograms of lithium in its EV batteries.

[4] A pegmatite is an intrusive igneous body of highly variable grain size that often includes coarse crystal growth. Pegmatites occur most commonly in granites and their mineralogy can be simple or exotic: a simple granite pegmatite may contain only quartz, feldspar and mica, while more complex pegmatites can contain minerals like tourmaline, garnet, beryl, fluorite, lepidolite, spodumene, apatite and topaz.

[5] USGS (US Geological Survey) Mineral Commodity Summaries, January 2016.

[6] While lithium can also be extracted from hectorite (a rare clay from volcanic sources) and mines for this type of production are currently in development, the lithium feed grades will be low and the economics of the recovery methods are yet to be vindicated. *[http://lithium-au.com/about-lithium/]*

[7] Lithium carbonate, a stable white powder, is a key intermediary in the lithium market, as it can be converted into specific industrial salts and chemicals or processed into lithium metal.

[8] The energy input for roasting is the main cost component of the process. Production of lithium carbonate, the most commonly traded lithium chemical, from spodumene costs around US$4,000/tonne, whereas lithium carbonate from brines (no roasting required) costs around US$2000/tonne. [Griffin, A. Sources and availability of materials for lithium batteries. *Proceedings of IDC's Lithium Battery Conference, North Sydney, Australia 2016.*]

[9] Citi Research 2015. *Lithium: The Future is Electric.*

[10] https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/content/development-innovative-and-sustainable-lithium-extraction-process-medium-lithium-grade

[11] Ingram, T. Financial Review, 31 May 2016. *Investors get in on the lithium rush.*

The Power of 3

Driving the future further

ISSUE 10 October 2016

"[We] will not stop until every car on the road is electric." ~ *Elon Musk*

Overview

The first edition of *The Power of 3* considered the rapid development and deployment of lithium-ion (Li-ion) battery technology, impelled in large part by the growing interest in, and evolution of, electric vehicle (EV) technology, including plug-in hybrids.

Global energy, metals and mining research and consultancy group Wood Mackenzie says the cost of Li-ion batteries is now approaching the point at which mass adoption of EVs is feasible, despite lingering (and irrational) range anxiety on the part of some.

Nearly a year on, the EV marketplace is going from strength to strength – just ask Volkswagen, Audi, Daimler, BMW, Volvo, Fiat Chrysler, NEVS (formerly Saab), Nissan, Toyota, Hyundai, Mitsubishi, General Motors, Ford, even Jaguar ... and, of course, Elon!

ISSUE 10 October 2016

Clean and green

Early last century, with petrol-powered cars edging out EVs, Clara Ford (wife of Henry) eschewed the Model T, preferring her 1914 Detroit Electric, which she described as simpler, cleaner, safer and nicer to drive.

Echoing those sentiments a hundred years on, the Union of Concerned Scientists asserts that EVs are clean now and will get even cleaner with time, something internal combustion engine vehicles won't ever achieve.

Carrots and sticks

As noted in *Australian Mining Magazine*, **China** has deemed it mandatory that all new residential buildings, and at least 10 per cent of large public buildings and parking lots, be fitted with EV charging stations. China's central government hopes to have five million EVs (preferably made there) on-road by 2020.

Tesla China, which has battled to create a comprehensive charging network in such a vast country (and one with very complicated political mores), is to launch the Tesla Charging Partner Program there, in line with the country's recently developed national EV charging standard.

It's only a matter of time before China introduces an air-pollution levy, so EV uptake there is a no-brainer – sales are up 162 per cent this year alone.

In **Germany**, the government has introduced an incentive program aimed at seeing a million plus EVs on its streets by 2020. Moreover, a resolution has been passed to end sales of internal combustion engines, both petrol and diesel, by 2030, with only zero-emission vehicles allowed on-market after that.

Norway too has acted decisively to encourage EV ownership. Propelled by generous government incentives that include exemptions from VAT, road taxes, parking fees and tolls, EV sales constitute 20 per cent of all new vehicle sales.

Indeed, **all western European countries** offer incentives for EV uptake, among them tax reductions and exemptions, bonus payments and premiums and fiscal incentives for fuel efficiency.

In the **United States**, President Obama, who envisioned a million plus EVs on American roads by the close of the decade – initiated rebate incentives on EV purchases to achieve that end.

Even the US Army is on track, awarding Navitas Systems a $7.2 million contract to develop next-generation Li-ion batteries for military vehicles, which will replace the current lead-acid technology.

Canada too is doing its bit in offering incentives for EV uptake (albeit on a province-by-province basis). **India**, which aims to have seven million EVs on the road by 2020, proffers various subsidies, and **Japan** has had a range of incentives in place since 2009. Sadly, **Australia** remains unutterably unenlightened in this regard.

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Commercial EVs

Electrification of commercial vehicles takes emission control to the next level, not least in the realms of public transport.

Mid-year, Elon Musk proposed expanding Tesla's product range to include, eventually, an electric pickup and heavy-duty truck, as well as new forms of urban transport with a high passenger density. Also, once fully autonomous driving is perfected, Tesla plans to operate its own fleet in cities where demand exceeds the supply of customer-owned cars … all in the interests of "accelerating the advent of sustainable energy …"

Last month, electric bus manufacturer Proterra Inc. unveiled its newest zero-emission vehicle, the Catalyst E2 series. With a nominal range of 194 to 350 miles, it's capable of servicing the full daily mileage needs of just about every US mass transit route on a single charge – so range anxiety be damned!

Britain's Smith Electric Vehicles, headquartered in Kansas City, Missouri and with manufacturing facilities there and in The Future Technology Centre, Sunderland, UK, manufactures and markets zero-emission commercial EVs that it supplies to multiple industries worldwide – including food and beverage, utility, telecommunications, retail, grocery, parcel and postal delivery, school transportation, military and government.

In Europe, EVs are already making inroads into taxi fleets. Visitors to Amsterdam can grab a Tesla taxi at the airport, while the continent's leading e-cab manufacturer, Nissan, has more than 550 electric taxis on European roads (including the LEAF and commercial vans). The top e-taxi countries in Europe at present are the Netherlands and the United Kingdom.

Norway's postal service Posten has ordered 240 Renault Kangoo Maxi Z.E.s to complement the company's current fleet of 900 EVs (cars, bikes, quadricycles and trailers). Posten's electric version of the Kangoo light-duty commercial van will be deployed mostly in high-density urban areas.

With respect to larger commercial vehicles, Li-ion battery technology shifted up a gear recently when German manufacturer Akasol – a pioneer of e-mobility battery storage solutions – unveiled a compact, modular system for commercial vehicles. Completely scalable, Akasol's AKASystem is well suited for use in buses, lorries, construction and other, similar vehicles.

Even the Grand Duchy of Luxembourg is getting in on the EV act. Sales-Lentz, a large public transport operator there, already has 24 Volvo hybrids and 12 Volvo electric hybrids in its fleet. Now the company is amping up its electrification with the purchase of four Volvo 7900 electric buses.

In the Antipodes, the first autonomous, driverless and electric shuttle bus to operate on a public road in Australia has taken to the streets of Perth to begin a three-month trial. Owned by the Royal Automobile Club of WA, the 11-seater French Navya will traverse a short stretch of the Swan River foreshore at speeds of up to 25 kilometres an hour.

At Sydney Airport, meanwhile, Australia's first electric airport bus forms part of a $5 million investment in environmentally friendly ground transport technology there. The Electric Blu is the first of six commercial EVs that will replace the airport's existing diesel buses by the end of 2016.

The future

According to Dr Peter Harrop, chairman of UK market research firm IDTechEx and co-author (with Raghu Das) of two reports on the future of commercial EVs, the next step is vehicles that charge themselves.

Energy-independent vehicles (EIVs) will create their own electricity from ambient energy such as light, wind, waves and tide and, where necessary, store it until needed. Often, they will be navigationally autonomous and 'pure' rather than hybrid EVs, relying on technologies such as energy-harvesting shock absorbers, regenerative active suspension and regenerative braking.

"The logical extension of these one-dimensional movement harvesters is to devices converting movement in all three dimensions into electricity: Caterpillar and Witt Energy have done that experimentally already," the authors say.

Harrop and Das maintain that the commercial EV sector will "grow 4.2 times in the next decade," with transport and logistics already on the right path and scope for earthmoving and lifting vehicles to follow suit. "Excitingly, EV technologies are changing and improving hugely, and innovation often comes [in the commercial sector] before being seen in the more publicised EV sectors, such as cars."

And, finally …

If sporty electrified transport is your thing, what could be better than this?

The German-made Volocoptor, which can take off vertically, has the potential for use away from airports. [Photograph: Volocopter/Nikolay Kazakov.]

Which Perth-based company would love a fleet of Teslas by the decade's end?

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The Power of 3

ISSUE 11 November 2016

Driving the future further

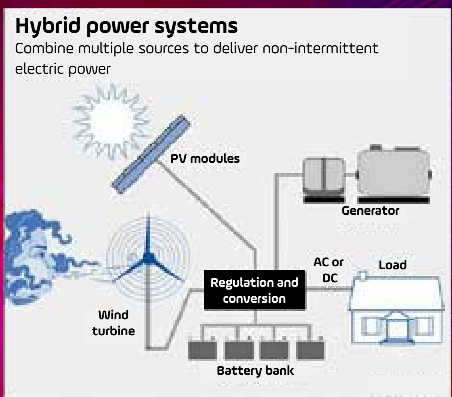
Going off the grid big time!

Overview

As discussed in issue 8 of *The Power of 3* going off-grid right now remains, for the majority, more a tantalising prospect than a reality. And for the power utilities themselves, in developed countries in particular, past investment in conventional long-life plants and distribution infrastructure is affecting the rate of uptake of renewable sources of energy.

In Australia, for example, power utilities are expected to provide reliable, cost-effective and future-proof services to consumers, but their reliance on coal-fired power stations (29% are more than 40 years old!) and pole-and-wire distribution is putting the country at risk ... and not just in terms of energy security.

Recently, though, it's become possible for energy consumers in remote, off-grid and fringe-of-grid locations to cost-effectively install hybrid power systems. These combine multiple power sources such as wind turbines, solar thermal and solar photovoltaic (PV) technology with lithium-ion battery storage to deliver reliable, non-intermittent electric power.



Large industries operating in remote locations also face great challenges, with rugged terrain and the tyrannies of distance leading, historically, to complete reliance on diesel-powered generators, which is expensive and polluting.

Mining needs energy – and needs it clean

Mining is energy intensive, so managing energy use is a business imperative.

The industry – leery not just of increasing fuel costs but also possible measures to put a price on pollution – is keen to explore the use of large-scale renewable energy (solar, wind, geothermal) and battery storage to supply non-intermittent power independent of the grid, thereby reducing both costs and emissions.

Here's where mining is going.

"I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that."

~ Thomas A. Edison

Latin America

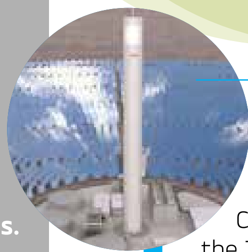
Atacama 1 and Atacama 2 – Chile

Chile has munificent solar resources and a government committed to both cleaner energy and economic development. Many huge mines there, which are inadequately serviced by the weak local grid, have been hit by soaring fossil fuel costs for power generation. Enter Spanish group Abengoa, which supplies innovative and sustainable technology solutions in the energy and environmental sectors.

Abengoa is responsible for Atacama 1, Latin America's first solar-thermal plant, and a subsequent and similar project, Atacama 2. Both are located in one of the most inaccessible and arid regions in the world.

Atacama 1, which will prevent the emission of more than 800,000 tonnes of carbon dioxide annually, combines a 110-megawatt (MW) solar thermal plant and a 100 MW PV park covering 1,000 hectares. It produces enough power 24 hours a day to meet the demands of both households and industry in the region.

Like Atacama 1, Atacama 2 combines a 110 MW solar thermal plant and a 100 MW PV park that, together, can produce clean, stable energy 24 hours a day. The power generated by the PV park will be injected direct into the grid running through the property, while the solar thermal unit has an energy storage system to generate electricity for 15 hours straight.



Atacama 1 solar thermal and solar PV plant.

Also located in the Atacama region are the 100 MW Amanecer Solar CAP, a PV power plant, and the 70 MW Salvador Solar Park, one of the first in the world to supply competitively priced solar energy to the open market without a government subsidy.

Veladero gold mine – Argentina

Barrick Gold's Veladero mine, one of the largest gold mines in Argentina and indeed the world, has no grid connection, so energy comes courtesy of diesel-powered generators alone. However, as in Chile, solar resources there are significant. As a result, Barrick (despite its recent misfortunes in the region) is liaising with world-class solar developers in the hope of offsetting some 30% of the mine's diesel power with solar. If all goes to plan, a solar plant could be installed and fully operational at Veladero by the end of 2018.

DeGrussa solar power project – November 2015.

Australia

DeGrussa copper-gold mine

In an audacious thumbs-up to large-scale renewable power and battery storage, Sandfire Resources has joined forces with an international consortium to finance, develop, operate and own a state-of-the-art 10.6 MW solar plant at the DeGrussa mine, 900 kilometres north of Perth in Western Australia.

The innovative $40 million project – which is integrated with DeGrussa's diesel-fired power station – was successfully commissioned in June of this year.

Spanning 20 hectares and designed to supply around 20% of the mine's power requirements while reducing emissions by approximately 12,000 tonnes of carbon dioxide a year, it's now the largest integrated off-grid solar and battery storage facility in the entire country.

Just this month, the DeGrussa mine was deemed 'Australian Mine of the Year' in recognition of its outstanding contribution to both hard-rock mining and environmental management. As such, the project may well become an international reference site for the use of renewable energy in mining.

Lakeland Solar and Storage Project

BHP Billiton, the world's largest miner, anticipates "strong growth in renewable energy capacity [over] the next few decades" – an important consideration given that around 35% of its gas emissions result from the generation of electricity.

With that in mind, and impelled by forecasts that wind and solar energy could soon achieve price parity with rival sources of power, BHP is keen to explore new technologies that could not only reduce its operating emissions but also, in time, be adopted at its remote and off-grid mine sites.

BHP is betting that an ambitious project in Lakeland, a tiny town in far north Queensland, holds the key to such technologies.

Lakeland (population 227), which has a fringe-of-grid connection to the state's Ergon Energy network, currently boasts a hotel, a café, a roadhouse and a small store. With the advent of the Lakeland Solar and Storage Project, though, that may all be about to change.

BHP has entered into a 'knowledge sharing' partnership with ARENA (the Australian Renewable Energy Agency), Conergy, Origin Energy and Ergon Energy in an Antipodean first: construction of a world leading, large-scale solar plant and battery storage facility connected to a major electricity grid.

Pitched as a first for remote, edge-of-grid technology, and likely to trigger a host of similar projects nationwide, the Lakeland enterprise will comprise a 13 MW solar PV installation and grid-scale battery storage to supply solar power after sundown and during times of peak demand.

Says Ivor Frischknecht, CEO of ARENA, the project is "the first in the world to test a concept known as 'islanding' from the main electricity grid," with the local town powered entirely by solar and batteries for several hours during test periods.

Conergy Australia, part of the German-based Conergy Global group, which bills itself as "one of the world's largest downstream solar companies, specialising in the design, finance, build and operation of high-performance solar systems for utility-scale power and businesses," will construct and run the project.

To infinity and beyond?

As both off-grid power generation and storage capacity blossom, and as the trend extends into fringe-of-grid installations, innovative technology is set to overtake long established grid infrastructure and provide clean, reliable and economical energy for all. Power generation and storage nodes will bloom within existing grid systems, thereby improving efficiency, reducing cost and allowing consumers to become the power generators and traders of the future. The grid as we know it won't disappear; rather, it will undergo a transformation that heralds a remarkable energy revolution.

And finally...

For those blessed with deep pockets, refined aesthetic sensibilities and a burning desire for sustainability, Tesla has come up with the perfect alternative to conventional solar panel roofing: solar shingles.

"The key is to make solar look good," proclaimed Tesla CEO Elon Musk. "We want you to call your neighbours over and say, 'Check out this sweet roof.'"

Which Perth-based company is helping to facilitate the imminent energy revolution?

The Power of 3

ISSUE 12
December
2016

Driving the future further

Overview

In *The Power of 3* issue 1, Thomas Bartman of the *Harvard Business Review* opined on how disruption from electric vehicle (EV) and unmanned aerial vehicle (UAV) uptake will announce itself. And, as noted in issue 10, his prognostications are coming to fruition. EVs – not to mention UAVs – are indeed heading from uniquity to ubiquity. Here, in the final issue of the newsletter for 2016, we take a peek at some of the most exciting on show and/or on the market this year.

"The ones crazy enough to think they can change the world are the ones who do"

~ Steve Jobs

Fast and furious

Faraday FFZERO1 Concept

Unveiled at the Consumer Electronics Show in Las Vegas, Faraday Future's concept car is built on an adaptable modular system called Variable Platform Architecture, designed to produce "an industry-leading driving range, acceleration, energy retention, charging time and overall safety." Ultra-modern, powerful and insanely automated, the vehicle, says the company, is a means of exploring and amplifying the design and engineering ideas being developed for its production vehicles. Bruce Wayne, it's time to upgrade!

Cute and curious

Myer Motors' NMG/MPG200e

In 2004, Myer Motors acquired the assets of the Corbin Sparrow, a tiny micro-car that struggled to reach mass production. Today, via crowd funding, Myer Motors hopes to achieve its vision of a second EV revolution: "highways full of light, agile, fun-to-drive, purpose-built, single- or two-occupant commuter EVs for every two-car family."

On the byways

If hoverboards were last year's hit, 2016 has been all about sleek, streamlined and portable electric scooters for urban riders. Buyers are spoilt for choice, but here are a few that caught our eye.

emicro one

Winner of an Australian Good Design Award, this smart, foldable scooter features 'motion control', meaning its powerful motor (installed in the rear wheel; the battery's in the footboard) starts only when a certain speed is reached and the rider's kick is detected. Featuring three different ride modes and 'slope support', it can reach speeds of 25 kilometres per hour.

Xcape

The Xcape portable e-scooter travels at 15 mph, has a range of 25 miles, folds in a second and 'goes anywhere'. A Chinese innovation still at the prototype stage, you can find it on crowd-funding site Indiegogo

URB-E

Billed by its creators as "[t]he world's most innovative folding electric scooter," the URB-E is a joy to behold. With a top speed of 15 miles per hour (mph) and a range of around 20 miles, it charges in four hours and weighs about 35 pounds.

Eon Scooter

Advertised as the "fastest and most affordable" electric scooter ever, the Eon features dual sit or stand modes, up to 30% grade hill-climbing torque, speeds of up to 25 mph and a range of 35 miles. Still at the prototype stage; details from Indiegogo.

No snow? No waves? No problem!

Cycle Board Street Surfer

"Whether you ski, surf, snowboard or skate, multiple riding styles will have you shredding instantly." If that vernacular resonates with you, then this could be your ride of choice in 2017. Neither skateboard nor scooter, it is in fact a three-wheel personal mobility EV that can be personalised, is fully rechargeable, has a 'lean-to-steer' system, offers a choice of riding positions and even has a phone mount. Available to order now, with a two-month lead time.

High, but still up close and personal

PowerUp FPV drone

Pilot this lightweight electronic paper plane and see what it sees. Made of heavy-duty paper, it's equipped with live-streaming camera (FPV = first person view). Control is by way of a smart phone app or by linking to a virtual reality headset, which means you can steer the plane with head movements. You can even fold to your own design if you wish.

And finally...

After numerous widely reported fatalities, the dangers to children (and pets) of ingesting lithium-ion batteries, particularly button batteries, are now well-known. This year, a small origami robot designed to safely remove such batteries was unveiled. Tiny but perfectly formed, the device – which unfolds from an ingestible capsule and is steered by external magnetic fields – crawls across the stomach wall to remove a swallowed battery or patch a wound. While not yet ready for practical application, it's an elegant solution to a very real problem.

Which Perth-based company is advancing its revolutionary lithium recovery process?

The Power of 3

ISSUE 13 February 2017

Driving the future further

Public transport is evolving – fast!

Overview

As discussed in previous issues, emission goals set in Paris in 2015 created opportunities for investment in cleaner technologies and are proving a catalyst for remarkable advances worldwide.

Currently, the production and use of energy accounts for around two-thirds of global emissions. The *Union Internationale des Transports Publics* (UITP), an international network designed to bring together all public transport stakeholders and all sustainable transport modes, predicts that demand for energy will grow by 20 to 35% over the next 15 years alone.

In general, sources of electricity remain beyond the control of transport entities. However, the sector is beginning to realise that, if demand is to be met in a sustainable way, major effort is required *now* – not later.

'Sustainable' transport enhances the social, environmental and economic viability of every region or neighbourhood it serves, not just by promoting mobility but also by limiting the impact of the infrastructure required to accommodate it. To be sustainable, the entire lifecycle of a mode of transport must be measurably effective, efficient and amenable to ongoing optimisation. What's more, the source energy for it should be capable of being supplied indefinitely.

Countries and communities that improve the sustainability of their transport networks create cleaner, more vibrant and liveable towns and cities. What's more, they're contributing to a revolution in renewable energy and methods of storing and harnessing it.

"A developed country is not a place where the poor have cars ... it's where the rich use public transport."

Gustovo Petro, mayor of Bogota, Columbia

No-one owns or taxes the sun ... yet

Based in Paris, the International Energy Agency (IEA) comprises 29 member countries and has four main areas of focus: "energy security, economic development, environmental awareness and engagement worldwide."

The IEA spruiks solar as affordable, inexhaustible and clean, an energy source that can be harnessed globally, not just in sunnier climes. Given that the costs of solar energy and its storage have virtually halved since 2010, solar photovoltaic electricity represents an increasingly viable alternative to new coal-fired power plants.

Solar power, says the agency:

> *... already helps power real-time passenger information at bus stops in London and ticket machines in New York [and] is used extensively on rail networks: Phoenix Valley Metro recently unveiled a solar plant that is helping to power its depot and, in Japan, JR East has launched its first large-scale solar power generation facility to help power trains, reducing CO_2 emissions by around 500 tonnes a year.*

In Australia, with its coal-dominated electricity grids, the federal government is dragging its feet with regard to renewables, but not so the states.

Earlier this year, for example, the Victorian government announced plans for a new, 75-megawatt solar farm, much of the energy from which will power the state's entire tram network (the world's biggest) by the end of 2018. The project forms part of Victoria's commitment to achieving zero net emissions there by 2050 (which is, perhaps, optimistic, given the increase in emissions statewide in recent years).

Digital impression of a tram that runs on solar energy. [Photo courtesy of Australian Solar Group.]

Riding the winds of change

Wind power too makes real economic sense, with onshore wind the cheapest form of new energy generation in Europe today. According to Wind Europe, energy from the wind is reducing costs so rapidly that it will play a central role in that continent's power mix going forward.

Right now, in a European country that's harnessed wind energy since the Middle Ages, about 600,000 train passengers a day travel courtesy of new-generation windmills located offshore and country-wide.

Nederlandse Spoorwegen (NS), The Netherlands' national railway company, runs all its electric trains on wind power, making it the first company of its type in the world to do so using renewable energy alone.

The 1.2 billion kilowatt hours of wind energy required is supplied by energy company Eneco, drawing from wind farms in The Netherlands, Belgium and Scandinavia. Eneco even built projects exclusively for the trains, ensuring low prices for Dutch commuters.

At present, a Dutch a wind turbine takes an hour to generate the power needed to run a train for 120 miles (~193 kilometres), but NS hopes to reduce energy consumption by 35% before 2020, so the trains will go further on less.

But how do trains like this work? In an article for Forbes.com, Laurie Winkless explains. Rather than using conventional engines, electric trains:

> *... act like a component in an electric circuit. Rail networks source electricity from the grid [or, in this case, elsewhere], transmitted via high-voltage lines. Once it's in the network, [the] three main options for getting the electricity to the trains themselves [are] on-board energy storage systems such as batteries, an overhead wire that the train connects to, or an extra 'live' rail that has direct current flowing through it at all times ... How ever the electricity is delivered to the train, once there it's used to power lights and air-conditioning, as well as the traction motors [that] turn the train's wheels. Electric trains also use regenerative braking, similar to what's found in hybrid and electric cars. [It's used] on underground trains in Los Angeles, Auckland and Buenos Aires, among others.*

Regenerative braking is a method by which energy is extracted from the parts being braked (in this case, the train's wheels) to be stored and re-used, or used elsewhere.

Trains in the US city of Philadelphia, for example, utilise regenerative braking, and any excess power produced is directed to a centralised bank of lithium-ion batteries and then on-sold to the main electricity grid. So simple; so clever!

Back in Oz, as part of its push to lower emissions, the Victorian state government also recently green-lighted more wind farms – a step in the right direction for a country whose investment in large-scale renewables fell sharply last year.

And finally ...

SpaceX hypes the Hyperloop

In 2013, Elon Musk, founder of Tesla and SpaceX, envisaged a fast (1,200 kilometres an hour), efficient and cost-effective way of transporting commuters and cargo between moderately distant locations (San Francisco and Los Angeles, say, or Melbourne and Sydney) with minimal environmental impact.

This alternative mass-transit option, the Hyperloop, is a futuristic sub-sonic train comprising two massive, low-pressure tubes mounted on pylons, along which pods are propelled by magnetic accelerators. Musk described it as "a cross between a Concorde, a railgun and an air-hockey table," which would, by virtue of solar panels on the roof, be environmentally clean *and* self-powering.

SpaceX sponsors Hyperloop competitions to encourage the development of prototypes. Meanwhile, various companies and governments are exploring the concept of what, effectively, could be seen as "broadband for transportation."*

Artist's impression of VicHyper's Hyperloop, an Australian finalist in the SpaceX Hyperloop Pod completion held in January 2017.

Opines *Digital Trend's* Will Nicol:

> *It remains unclear whether commercial Hyperloop systems will ever be widely adopted. As the global population swells and the environment declines, however, better mass transit systems will become essential. Leonard Bernstein once claimed that great endeavors require two things: 'a plan, and not quite enough time'. The plan for the Hyperloop is there, but how much time do we have?*

Timing aside, one thing is sure: sustainable public transport will not be pedestrian.

* *https://hyperloop-one.com*

Which Perth-based company is on board with the notion of sustainability?

The Power of 3 is sponsored by Lithium Australia.
Enquiries to info@lithium-au.com.

ThePowerof3

Driving the future further

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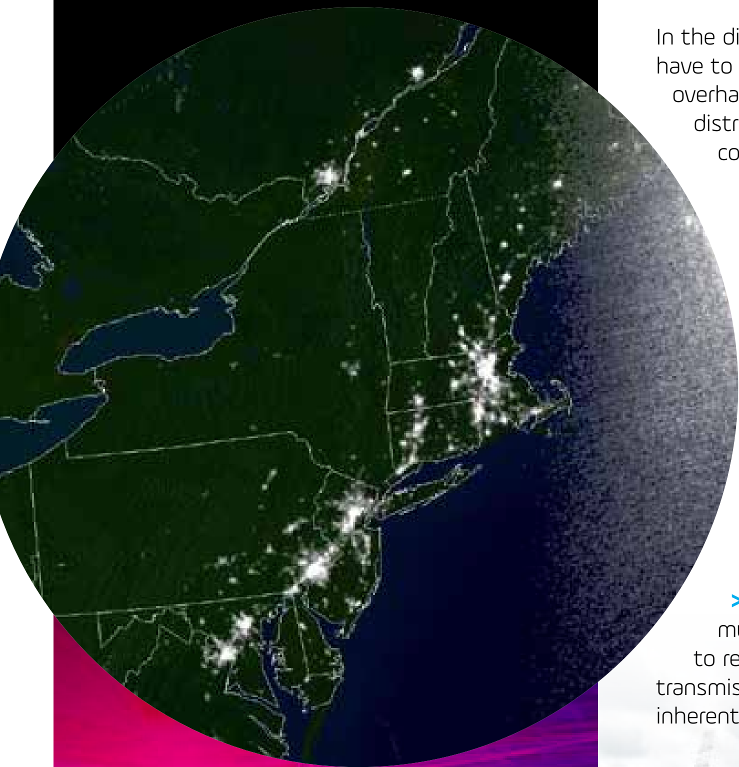
THE ENERGY INTERNET – AN INTERNET OF THINGS

"If you want to go fast, go alone. If you want to go far, go together."

~ *oft-quoted African proverb*

Overview

In August 2003, massive electricity grid failures blacked out huge areas of the US and Canada and, a month later, the entire length and breadth of Italy. In 2006 it was the turn of Germany, France, Italy and Spain, in 2008 Chenzhou in China, in 2009 Brazil and Paraguay and in 2012 India. The latter was the world's largest power outage ever, and the country ground to a standstill. (To this day, acute and recurring power outages occur there).



Blackout in northeastern USA, taken August 14, 2003 [NOAA, US Department of Commerce].

Because power grids are such vast interconnected networks a blackout, once triggered, is hard to contain – the 'domino effect' comes into play, a failure in one section creating a cascading effect down the line.

Imperatives for change

Whether from natural causes or human error, major power outages are harbingers of the need for faster, more intelligent solutions to managing unforeseen and catastrophic disruptions.

Certainly, they highlight the shortcomings of power grids based on mid-20th century technology born of the Industrial Age – technology that's now old-fashioned, lacking in effective communication and storage capacity, expensive, harmful to the environment, vulnerable in terms of energy security and almost willfully wasteful. In 2012 in the United States, for example, more than 61% of all energy input into the economy was wasted … that's enough to power the United Kingdom for seven years!

In the digital age, power utilities have to embrace change and overhaul how energy is generated, distributed, stored and consumed. They need the ability to:

> obtain and assess real-time information on the state of the grid and, using that data, control the flow of power fast enough to avoid blackouts;

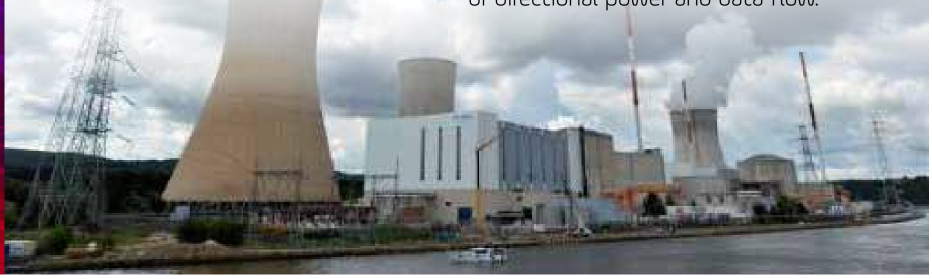
> upgrade their networks so more energy can be pumped through the grid safely, and

> produce and store power much closer to customers, to reduce the need for ageing transmission lines and the losses inherent in the use of those lines.

Technologies capable of achieving these ends have been around for a while, but what's missing are economic incentives to hasten their uptake. One only has to consider the current controversies raging in Australia with respect to power outages, renewables and a perceived unwillingness on the part of the government to eschew fossil fuels to realise the extent of the problem.

But, with the spectres of terrorism (including cyber attacks) and natural disasters (fires, storms, solar flares, tsunamis) looming large, the writing is on the wall: incumbent large-scale, centralised power production, controlled by a few main suppliers, is rapidly reaching its use-by date.

Energy generation needs to be cheap, effective and much more efficient in terms of *not* wasting what's produced. A transition from fossil fuels to renewables will be key, as will modularity and bi-directional power and data flow.



Hooking up

The 'energy internet' is predicated on the notion of distributing electricity in a manner that mimics the workings of the Internet (and, in so doing, matching the latter's lasting impact on communications). The aim is to achieve a comprehensive power supply via multiple coordinated micro-grids rather than a conventional one-way grid.

> *[It's] really the Internet brought to energy and it's a perfect fit. The great economic revolutions … occur when new energy regimes emerge and new communication revolutions emerge to organize them.*

So says Jeremy Rifkin, economic and social theorist and a leading expert on the innovations that will shape the future and solve many of the challenges the world faces.

In his 2014 interview with the *Big Think*, Rifkin explained that:

> *[t]he digital age will allow such a system to be decentralised, efficient and reliable. That's the theory, anyway.*

Again, how energy is produced, transmitted, stored and consumed will be key to the advent of this emerging system, in which no part acts alone; rather, they form a coordinated whole.

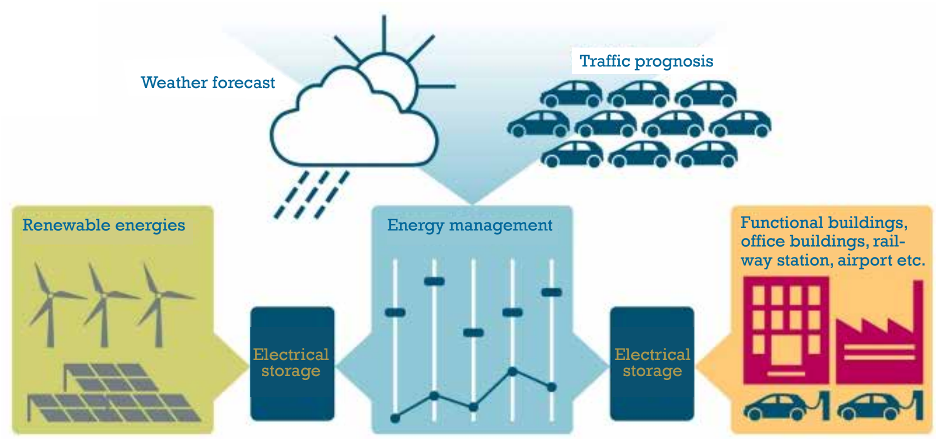
The energy internet is about *things* – buildings, electric vehicles, appliances, electronic devices and power plants, woven into an over-arching whole with renewable energy, traditional power plants and transmission lines, smart sensors and meters, storage batteries and wireless communication. Each *thing* 'talks' to those around it in real time … about, for instance, electrical loads, wind speeds, hours of sunshine and the price of energy, all while sharing power.

Demand for energy fluctuates according to the amount of power available and its price, and availability and price depend in turn on how much power is produced, as well as demand itself and how much electricity has been stored.

At the core of the system are renewable energies; increasingly economically viable, these ensure an energy marketplace ripe for technological innovation. That's why, right now, Europe is leading the energy internet movement.

"We're taking … the whole transmission grid [of Europe] and transforming it to an energy internet using the same technology we used with the communication Internet," explained Rifkin.

Internet of energy for electric mobility



[Source: siemens.com]

With the energy internet, a main power grid is partnered with decentralised generators, ranging from fossil fuel to wind turbines and solar power, to apportion energy to multiple micro-grids within a designated network. Then, depending on load, each micro-grid injects spare power into, or absorbs power it lacks from, either other micro-grids or the main grid.

So, three scales of grid – national, regional and local – are required.

[Source: get-d.net]

- Nationally, large renewable plants act in concert with coal and nuclear, each backing the other up.
- Regionally, many smaller, local renewables can plug in.
- Locally, every customer can become a player in the energy game – generating and storing power and potentially selling it on.

Sophisticated self-learning software (including artificial intelligence) that can minimise human error while utilising and managing data from renewable energy systems, smart thermostats and battery storage systems and other site-specific and grid-connected devices (all communicating in real time and at scale) will be critical for a smooth transition to the energy internet. Some of it's here already, with a lot to follow.

So, as noted in issue 11 of *The Power of 3*, off-grid power generation and storage capacity are merely the forerunners of a revolution that will see the grids of today transform into the energy internet of the future … a future in which machines and devices will be smarter than ever before, where outages are a thing of the past and where consumers of all kinds can produce, store and trade in power to their heart's content.

And finally …

How's this for 'seamless urban mobility' in the coming decade?

At this year's Geneva Motor Show, Italdesign and Airbus unveiled the truly futuristic Pop.Up, a concept 'passenger capsule' that morphs from a self-driving taxi into a vertical takeoff and landing (VTOL) drone and even a passenger module on a Hyperloop-type train. They're saying 10 years from concept to completion. We're saying wait and see.

Which Perth-based company aims to be part of the energy internet equation?

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Driving the future further

THE HIDDEN LIVES OF LITHIUM

"Lithium is like a beautiful lady, very much sought and pursued..."

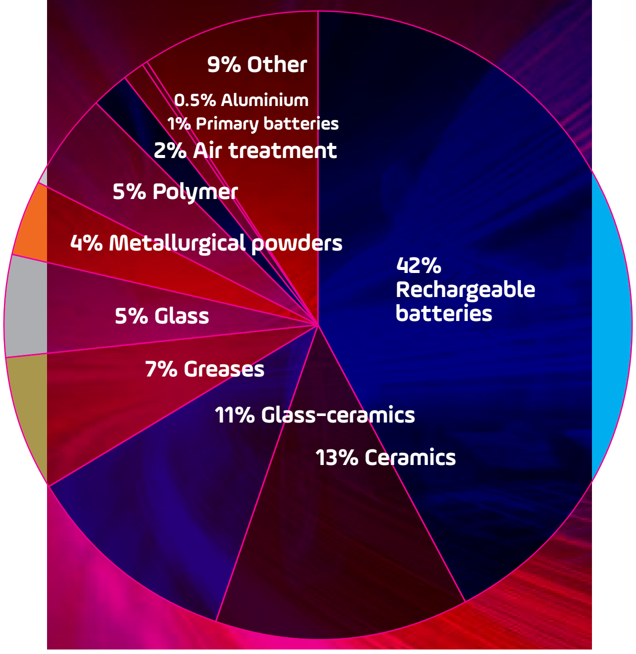
~ Evo Morales, President of Bolivia

Overview

The hype surrounding lithium batteries right now is enormous ... so much so that many assume the battery industry has always been the primary consumer of lithium and its various compounds. However, while there's no doubt this market represents the fastest growing sector in terms of demand for Earth's lightest solid element, lithium, historically, has had many other uses.

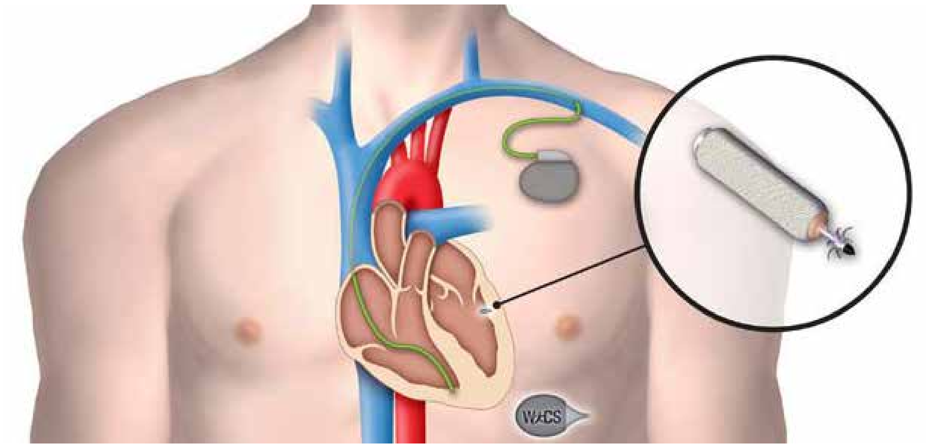
In the past, most lithium was produced for the glass and ceramics industries but, more recently, its applications have become multifarious. It's now utilised in everything from aeroplanes to golf balls, toilet bowls to stove tops, prescription medications to lubricants, space craft to welding fluxes, air-drying and air-purification systems to road-marking paints, and much, much more.

In fact, the use of lithium has become so widespread that it could be described as the world's most versatile element.



Living with lithium

Most rechargeable batteries available today incorporate lithium metal or alloys. That makes lithium vital to 21st century living – it boosts the juice that drives mobile phones and tablets, laptops, digital cameras, hand tools and all manner of electric vehicles, and allows for stationery storage of electricity from renewables (arguably, though, not utility-scale storage, despite Elon Musk's assertions to the contrary).



Lithium is often a component of primary (non-rechargeable) batteries too, the kind that power things like pacemakers, kids' toys and clocks.

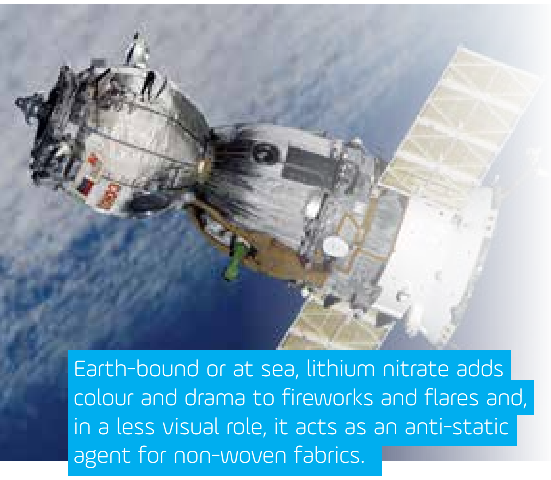
Lithium metal and heat transfer go hand in hand, and it's a valuable reducing and alkylating agent in many chemical reactions. Walter M. Fenton *et al* outline its value "in the production of synthetic vitamin A and other pharmaceutical products, as an ionic catalyst in new polymer technology, as a direct reducing agent in certain organic reactions, as a flux in new brazing techniques, as a starting point in the production of metal hydrides and borohydrides and as a potential heat-transfer agent in new engineering developments."

Many metals are combined with lithium to form alloys, among them lead, copper (to reduce free oxygen and porosity), silver, silicon, aluminium and magnesium. Adding lithium to the latter two elements makes them stiffer, stronger and lighter. Magnesium-lithium alloys, for instance, are used for armour plating, while aluminium-lithium alloys are used in components for aircraft (including space vehicles), bicycle frames and high-speed trains.

Various lithium compounds play important roles as industrial chemicals, being widely used in the processing of metal oxides, for making adhesives and, when mixed with oils, creating high-temperature lubricants.

Living with lithium

Other-worldly uses for lithium compounds include numerous aero-space applications ... right down to scrubbing carbon dioxide from the atmosphere of manned space flights.



Earth-bound or at sea, lithium nitrate adds colour and drama to fireworks and flares and, in a less visual role, it acts as an anti-static agent for non-woven fabrics.

Lithium acetate improves the viscosity of dyes and helps stabilise PVC, lithium aluminate is used in micro-electronics and nuclear technology, lithium bromide is a medical desiccant and fungicide, lithium borate is added to soap, greases and fluxes, lithium hypochlorite kills algae and sanitises swimming pools, and lithium sulphate is used in electrical conducting glass and as a concrete accelerant.

Lithium carbonate, too, has numerous applications, not least in glazes and quickset cement. When added to molten glass, it makes it lighter and stronger.

Somewhat surprisingly, lithium carbonate also contributes to human health. In the mid-1800s it was considered efficacious for bladder stones, gout, rheumatism, mania, depression and headache. Then, in 1949, John Cade, an Australian physician, found an exciting new use for it: as a mood stabiliser in patients with 'manic depression'. Despite its action on the brain not being fully understood, and in spite of the risks and side-effects associated with its use, lithium carbonate remains to this day an important tool in dealing with the extremes of bi-polar disorder.

Some holistic practitioners aver that lithium orotate achieves results similar to those for lithium carbonate but with less risk of harmful side-effects, and recommend it as a means of protecting brain cells from toxicity, facilitating brain-cell regeneration and improving blood sugar metabolism.

The black dog aside, conspiracy theorists (perhaps in need of lithium too?) might consider how the use of salts such as lithium fluoride in thorium nuclear reactors produces breakdown products far more acceptable to the health of humans and the planet, and wonder why uranium- or plutonium-fuelled reactors are built instead? Well might they ask, since thorium reactors are touted as offering – potentially – so many advantages over conventional solid uranium-fuelled light water reactors. BUT ... a by-product of uranium fission is, of course, plutonium, so useful in the construction of nuclear warheads.

A Huffington Post article, 'Cold fusion heats up', cites claims by Italian-American engineer/entrepreneur Andrea Rossi that he's developed a working table-top reactor, fuelled by a powder of 50% nickel, 20% lithium and 30% lithium aluminium hydride. Although details are shrouded in secrecy, other research teams are also working on abundant heat production from a reactor device using similar materials as fuel. For now, scepticism remains in order; however, the potential impacts for low-energy nuclear reactions could be far-reaching on a global scale, not just politically, economically and environmentally but also in terms of the ramifications for transportation, water purification, small businesses and homes.

Getting back to compounds, lithium oxide is used in the production of specialty glasses and glass ceramics, while lithium chloride and bromide, perhaps the most hygroscopic (absorbing moisture from the air) materials known to man, are used as desiccants in air-conditioners and industrial drying systems.

Lithium stearate is useful as an all-purpose, high-temperature lubricant and lithium carbide (a chemical compound of lithium and carbon) is useful in radiocarbon dating procedures.

Lithium hydride is used to store hydrogen for use as a fuel, while, according to a paper by T. Ichikawa *et al* in the *Journal of Alloys and Compounds* (Vol. 365), lithium nitride:

> *... reversibly absorbs hydrogen and can be used to store the gas as a solid medium for transport or as a fuel source. Potentially [it provides] a portable energy solution to rival the lithium-ion battery – the hydrogen fuel cell.*

Tom Fleischman, writing for the *Cornell Chronicle*, notes that a stabilising molecule to counter performance inefficiencies could pave the way for lithium-air fuel cells that boast energy-density levels comparable to fossil fuels, making them a promising candidate for future transport-related energy needs.

Speaking of transport, lithium is also an additive in hybrid traffic marking and safety paints that are fast-drying, long-lasting and abrasion-, moisture- and solvent-resistant, and in permanent, durable stains for concrete, masonry and the like.

And finally ...

A Rice University research team has used carbon nanotubes to develop a paint that can transform any surface into a lithium-ion battery. The researchers believe their paint has the potential to create a functional, rechargeable solar battery on just about any surface. Bring it on!

In the Rice University experiment, ceramic tiles were coated with battery paint, then heat-sealed powered LEDs were used to spell out the word 'RICE' for six hours.

Which Perth-based company aims to revolutionise the production of lithium compounds for a range of applications?

The Power of 3 is sponsored by Lithium Australia.
Enquiries to info@lithium-au.com.

The Power of 3
Driving the future further
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BATTERIES ARE POWERING EMPOWERMENT

"Turn obstacles into opportunities and problems into possibilities"

~ Roy T. Bennett

Overview

Previous issues of *The Power of 3* have considered the rapid development and deployment of lithium-ion battery technology and the relationship of that technology to the evolution of electronic devices and electric vehicles, all of which are extending possibilities in every direction.

For those with a disability – around a billion worldwide, according to the World Health Organisation (WHO) – improvements in battery technology have, directly or indirectly, facilitated accessibility where often there was little or none ... and that equates to a quantum leap in empowerment.

Go, baby, go! Five years ago Cole Galloway, a professor of physical therapy at the University of Delaware in the United States, saw a gap in the marketplace for mobility devices suitable for very young children, for whom powered wheelchairs are not an option.

Being independently mobile rather than pushed in a pram or carried about gives kids active control over the way they experience the world through movement, and that enhances the development of cognitive, social, motor, language and other skills.

By modifying off-the-shelf, battery-powered ride-on toy cars, Galloway realised he could enhance independence for children with mobility issues in the critical early years of their development – and do it relatively cheaply. 'Go Baby Go', a national, community-based design and outreach programme, was born.

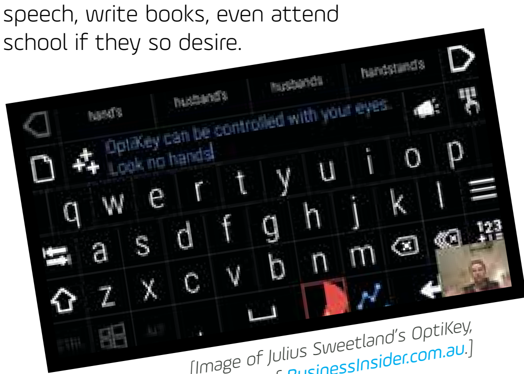
The Sit-to-Stand car improves mobility for kids who will probably walk unaided with time.

Today, reports New Atlas, the programme has expanded to Oregon State University with two new additions: the Sit to Stand car, which "encourages late bloomers to rise up and take charge" and the Throw Baby Throw car, which allows " kids with limited upper limb movement to join in during throwing games and activities."

Eye-controlled assistive technologies

Ailments like Parkinson's, ALS, motor neuron disease, multiple sclerosis, muscular dystrophy and severe spinal-cord injury can leave sufferers with 'locked-in' syndrome, trapped in their bodies and speechless, with little other than eye movement possible – and that's where eye-tracking technologies can prove so useful.

The study of eye tracking dates back to the 19th century, and harnessing it to control computers began as early as the 1980s. Since then, the implementation of eye-controlled assistive technologies and eye-tracking systems allows just about anyone unable to use a computer keyboard, mouse or touch screen to generate speech, write books, even attend school if they so desire.



[Image of Julius Sweetland's OptiKey, courtesy of BusinessInsider.com.au.]

Ultimately, of course, brain-machine interfaces are destined not just for the disabled but also many innovative applications for the able-bodied.

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Remote assistive technologies

Worldwide, says the WHO, 39 million people are blind, 246 million have low vision and 285 million have some form of visual impairment. Right now, for them, things are looking up.

Consider 'Be My Eyes', brainchild of a Danish not-for-profit tech start-up. A free app, it connects those with little or no vision to sighted volunteers via their smartphones. Steve O'Hear of TechCrunch explains.

> *If you're a sighted person you register with the service and wait for the app to send you a notification that a visually-impaired person who has also signed up requires help. Once a match is found, the two of you are connected via an audio/video call, essentially enabling you to 'lend' your eyes to the visually-impaired person, who points their phone's rear-facing camera at whatever it is they want to see. The two of you then collaborate over the call to solve the problem.*

US-based Aira, meanwhile, is a subscription-only 'visual interpreter' service that "empowers the blind to experience their world and surroundings like never before" with instant access to information.

[Photo of smart glasses courtesy of Engadget.com.]

Aira's platform works on wearable devices (smart glasses) that can be paired with smart-phones. The tiny camera on the smart glasses allows trained company agents to 'see' what the blind or vision-impaired person 'sees' in real time; simultaneously, the agents can locate that client via Google Maps and also access their personal profile, so they're able to talk the person through whatever it is they need.

Mobility-enhancing exoskeletons

Until recently, the term 'exoskeleton' was used to describe the natural, protective outer structure of creatures like beetles, crabs and lobsters. Now, though, a number of commercial and experimental powered exoskeleton suits for humans (metal frameworks with motorised 'muscles') are in operation globally, albeit without the capabilities of Tony Stark's in *Iron Man*. Even so, they're a godsend for the disabled and infirm.

Take, for example, Tony Sanchez, a paraplegic since 2004 and now test-pilot-in-chief for suitX. Here he's pictured in the Phoenix, an 'investigational device' said to be:

> *... the world's lightest and most advanced exoskeleton, designed to help people with mobility disorders be upright and mobile.*

[Photo courtesy of suitX.]

As well as making for greater independence and quality of life, it allow users "to break out of the wheelchair bubble," as Sanchez describes the interactions that disabled individuals have with others. "Just being able to walk up to people really changes how they react to you."

But it's not just adults who can benefit from a 'power suit'. Currently undergoing clinical trials is an exoskeleton for children, designed by engineers at the Spanish National Research Council. According to New Atlas, the 12-kilogram battery-charged suit is for use by kids aged 3 to 14 who suffer from spinal muscular atrophy. By helping these children walk upright, the device keeps their muscles active and trained, potentially saving them from the onset of osteoporosis and other, sometimes fatal, complications.

[Photo courtesy of the Spanish National Research Council, via New Atlas.]

And, while lower-body exoskeletons for rehabilitation and/or to improve quality of life are available right now (albeit they're expensive and constrained at this stage by a limited power supply), workplace systems for the able-bodied that augment on-the-job performance and enhance safety are sure to follow.

Soft exosuits

In today's world, the aged population is increasing at a rate greater than that of the rest of society, so empowering the elderly is imperative.

On the drawing board right now at Superflex Powered Clothing™ are stylish, sensor-activated garments equipped with 'electric muscles' to provide core support and strength to senior citizens with incipient or actual mobility issues. The company aims to release its first consumer products by mid-2018.

[The Aura soft exosuit for people with mobility issues. Photo courtesy of nbcnews.com.]

And finally ...

Imagine a toothbrush that cleans teeth in as little as 10 seconds. Successfully crowd-funded, the GlareSmile smart toothbrush is purported to be 7.5 times more effective than a manual one and, like a fitness tracker, it reports back via a companion app on the user's phone. Ergo, it may well suit children, disabled users and the elderly (who often have less mobility in their hands) – even those so chronically time-poor they would relish cutting several minutes a day from such a routine chore.

Which Perth-based company wants to empower the battery industry worldwide?

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The Power of 3

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August 2017

Driving the future further

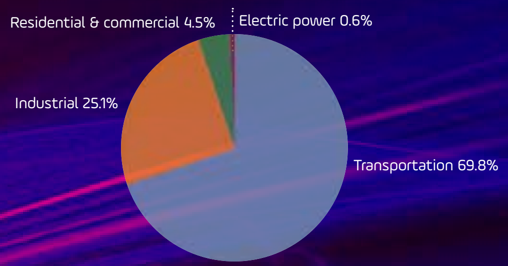
Overview

For the past 150 years, oil has fuelled phenomenal economic and population growth right across the globe. In fact, as Michael Schirber noted in Live Science almost a decade ago, apart from water, humans have relied on "no other liquid ... more than petroleum to fuel their vehicles, heat their homes, pave their roads and manufacture countless consumer products."

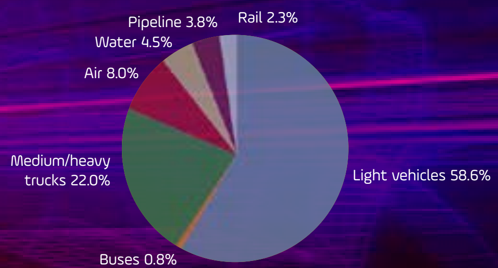
In the 1970s though, the world began to realise that oil doesn't grow on trees (the trees themselves being a whole other story), and the prospect of peak oil[1] has been a disquieting possibility ever since.

Nevertheless, transport remained the most rapidly expanding consumer of crude oil for many years and still dominates consumption ... but along with that consumption comes pollution.

Crude oil consumption



Crude oil consumption by type of transport



[Source: https://www.c2es.org/energy/source/oil]

Enter the new millennium and advances in electronics and computerisation gained traction fast ... as did the perceived potential of lithium-ion batteries (LIBs) to not only power devices of all sorts but completely transform our way of life, including in the realms of transportation. The Energy Revolution had arrived.

Will EVs be 'The cars that ate OPEC'?

"The industrial age of energy and transportation will be over by 2030. Maybe before."
~ Tony Seba

Electrons, not oil, will drive the future

Today, it seems, the world can't get enough of the world's lightest metal, but what's driving that demand? It is in large part powered vehicles, the very innovation that made oil so profitable in the first place ... but now minus those gas-guzzling internals. Legacy engines are fast giving way to electric motors fuelled not by hydrocarbons but by the flow of electrons from LIBs.

Tony Seba, in his book *Clean Disruption of Energy and Transportation*, agrees.

> *Exponentially improving technologies such as solar,* [EVs] *and autonomous ... cars will disrupt and sweep away the energy and transportation industries as we know* [them]. *The same Silicon Valley ecosystem that created bit-based technologies ... is now creating bit- and electron-based technologies that will disrupt atom-based energy industries.*

Seba maintains, though, that transitioning to the new energy economy (which is already under way) will have less to do with climate change, government regulations or politics and more to do with various technological trends – renewable energy, energy storage, EVs and autonomous vehicles among them; they're converging and reinforcing one another, which will lead, ultimately, to disruption of the existing oil and electric utility industries:

> *We'll make the transition to clean energy for the same reasons we went from sail to steam, from horses to internal combustion – because the new technology is better and, eventually,* [will be] *very much cheaper.*

Although eclectic (electric) vehicles are far from new (see *The Power of 3* # 10), today, thanks to LIBs, EVs for private as well as commercial use offer increasingly viable alternatives to internal combustion vehicles, in terms not just of practicality, performance and cost but also the health of humankind and the planet as a whole.

And, while it's true that EVs still require more energy to manufacture than their petrol- or diesel-fuelled counterparts, this is typically offset by their much lower emissions during their useful life.

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The world is coming on board

Traffic in central London [image courtesy of flipboard.com.]

Governments and consumers alike are dreaming of cleaner, greener cities.

Earlier this year Britain and France joined Germany, Norway, The Netherlands and India in opting to ban the sale of fossil-fuelled cars within the (very) foreseeable future, while China is stipulating that zero-emission vehicles comprise 8 per cent of sales there next year, rising to 12 per cent by 2020.

And, on the manufacturing front, automakers are rising to the challenge. Tesla, which led the charge with the release of its Roadster in 2010 (followed by several models since), has pledged to build a million vehicles by 2020. Volvo's fleet will be all-electric or hybrid by 2019, and Audi and Mercedes-Benz are rolling out hybrid cars right across Europe. At Mercedes too, an electric version of its popular Sprinter van is on the drawing board.

Meanwhile, VW announced earlier this year that its target, like Tesla's, is a million EV sales, albeit by 2025.

Even Ford, synonymous with the internal combustion engine, will be packing LIBs into the power units of 40 per cent of its fleet within three years (could that be the ghost of Clara whispering, "I told you so, Henry!"?)

With a swathe of new electric models scheduled for release in 2018, including from Tesla, Nissan, BMW, Renault and Hyundai, it seems the barriers to broader ownership of EVs – that is, availability and cost – are being broken down.

But (and it's a big but) where will the lithium for the batteries that drive these new cars come from? VW, with some 50 years of EV research under its belt, says the world will require the likes of 40 Tesla gigafactories (enough to fill Sydney Harbour five times over) to meet global demand by 2025.

Joe Lowry, aka the 'king of lithium', agrees.

> *There's no longer any doubt that EVs and energy storage systems for renewables are growth markets [unless, perhaps, you're Tony Abbott]. And, while debate continues regarding EV penetration, the bottom line is that even a mere 3 per cent EV annual sales penetration, coupled with conservative growth assumptions for other markets, will drive demand for lithium well over 500,000 million tonnes eight years from now.*

But, Lowry continues…

> *Elon Musk seems to think if he builds cars the lithium will come. His current chaotic battery supply chain should convince him that perhaps he [ought to] dedicate a bit [more] of his creative thinking time to mundane matters like where the massive quantities of lithium he needs are going to come from.*

Recently, in *The Weekend Australian*, Greg Ip opined that for EVs to entirely displace internal combustion engines (and, by extension, for lithium to oust oil), some combination of higher oil prices and cheaper battery storage is necessary. Only time will tell.

Renault Kangoo ZE testing the wireless charging road for electric cars.

Note

1 A hypothetical point in time when the global production of oil reaches its maximum rate, after which production will gradually decline.

And finally … Imagine a world in which wired-up roads charge EVs while they're being driven. Well, that scenario is already being tested – by Renault, no less. As Harry Hoster, director of Energy Lancaster and Professor of Physical Chemistry at Lancaster University in the UK, posits: *"Standardised electrified roads could become what the railways were to the 19th century: not only a leap in transport efficiency but also the core of a [whole] new industry."* These are exciting times…

Which Perth-based company is facilitating the supply of lithium carbonate for LIBs in the EV era?

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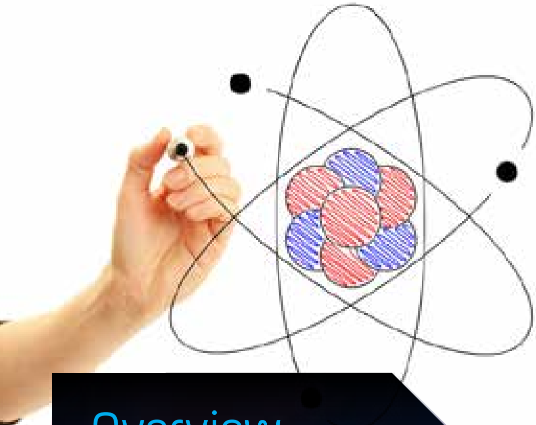
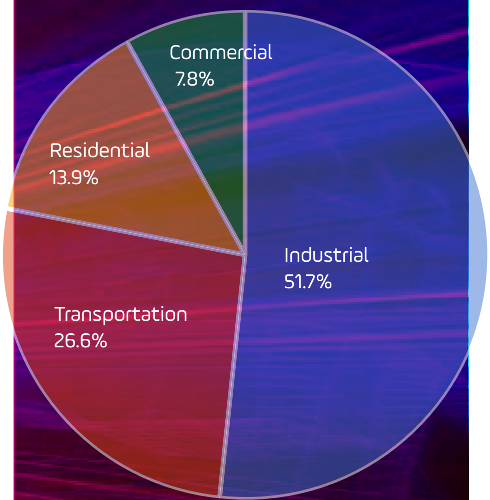
ThePowerof3
Driving the future further
ISSUE 18 October 2017

Is the 'nickel/graphite' battery good enough?



Overview

With all the world's major automotive producers committing to the production of electric vehicles (EVs) now or in the near future, and with those who govern roughly half the world's population putting the legislative nail in the coffin of the internal combustion engine (see *The Power of 3*, issue 17), which energy storage device can best power transportation (currently around 27% of all energy consumed) globally?

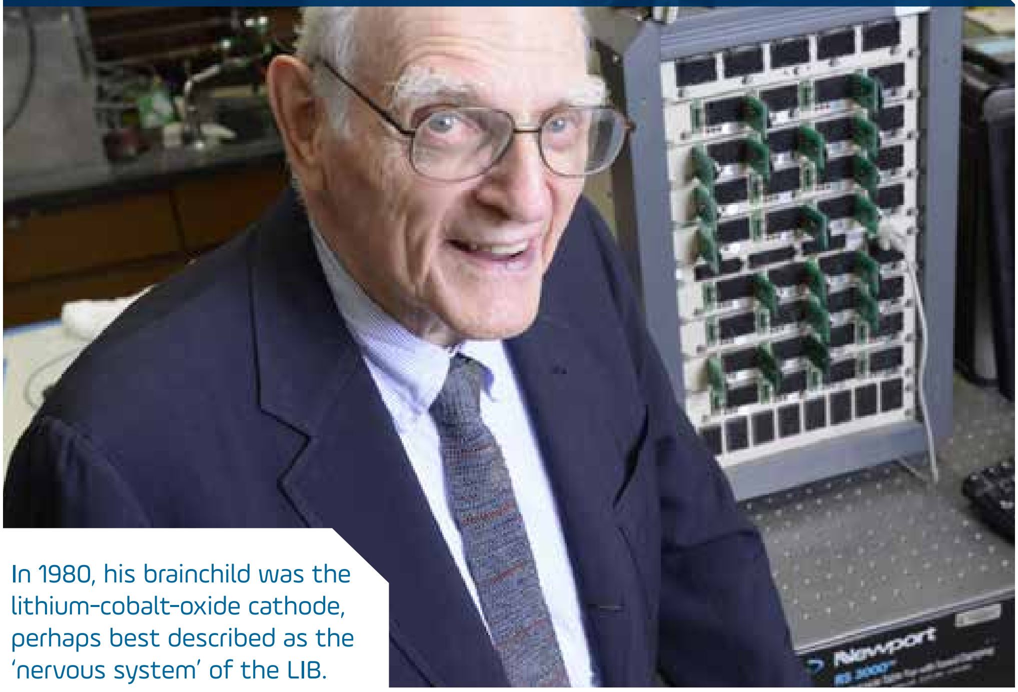


World energy consumption by sector, 2012

[Source: EIA Data]

What says John Goodenough?

At 95 years of age, Professor John Bannister Goodenough can justifiably be described as the father of the modern lithium-ion battery (LIB).



In 1980, his brainchild was the lithium-cobalt-oxide cathode, perhaps best described as the 'nervous system' of the LIB.

By 1991, Sony had combined Goodenough's cathode and a carbon anode to create the world's first commercial rechargeable LIB (see *The Power of 3*, issue 4).

Goodenough's cathode – or a variation of it – can be found in almost every portable device ever sold, and to this day no competitor has managed to improve on it. Seemingly not content with that, however, Goodenough has now teamed with physicist Maria Helena Braga in a bid to jump-start the EV revolution with more disruptive battery technology, lodging new patents (and clearly seeking royalty revenues) as he prepares to embrace a second century spent on planet Earth.

And that technology is ... ?

Braga and Goodenough have managed to dumbfound electrochemists worldwide by inventing a solid-state battery (one in which both the electrolyte and electrodes are solid) with an electrolyte of glass and both the anode and cathode composed of graphite.

Although solid-state batteries are considered safer than most LIBs, and may have the potential for higher energy density, to date issues of cost and lifecycle have proved problematic with this type of technology.

Goodenough says of his latest findings, though, that:

Cost, safety, energy density, rates of charge and discharge and cycle life ... all [are] critical for battery-driven cars to be more widely adopted. We believe our discovery solves many of the problems inherent in today's batteries.

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Like father like son?

If Goodenough is the father of the LIB, then Elon Musk must surely be its son, given that he's taken the product invented by the former and hugely popularised its application in EVs in particular. In fact, at this moment in time Musk's company Tesla is the world's biggest consumer of LIBs, no mean feat given the time frame in which he's achieved it.

LIBs also feature in Musk's Powerwall energy storage systems, which might just be used in the first colony on Mars, which Musk plans to establish by catapulting humans across the solar system in his own SpaceX rocket ships.

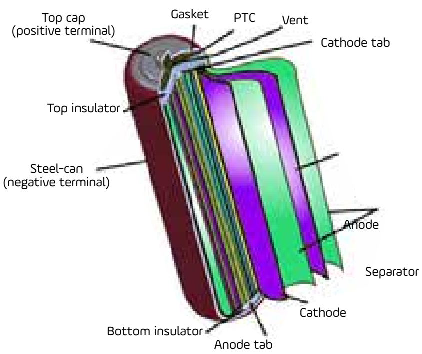
It's Musk, too, who is credited with the statement that the device he's popularised to such an extent, the LIB, is actually a 'nickel/graphite battery' – not a LIB at all!

Other entrepreneurs have made similar statements, but emphasising other components (such as cobalt and copper) to benefit their promotional thrusts.

But why can the now-ubiquitous LIB be described in so many ways? Two answers spring to mind.

1. LIBs incorporate a range of chemistries, each combination having specific properties and hence specific applications.
2. By weight, the lithium content of a LIB is generally quite small, with other metals (in varying concentrations) making up most of the mass.

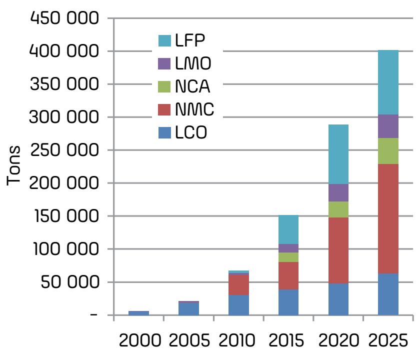
Examining the anatomy of a LIB makes it easier to understand.



Cylindrical LIB

Most of the metal in a LIB is consumed in the manufacture of the cathode, which generally takes the form of mixed metal oxides, including lithium, or mixed metal phosphates. The anode is generally graphite, manufactured to a stringent particle size, shape and porosity standards. In the most common LIB type – the cylindrical 18650 (18 mm in diameter and 65 mm long) – the anode and cathode are manufactured as thin films, rolled together then inserted into a metal canister to protect the fragile components. In other words, it's the cathode that, to a large extent, determines the unique properties of the various types of LIB ... and it's those properties that will determine market demand going forward.

Avicenne Energy has estimated demand for the various battery chemistries as follows.



Cathode active materials 2000–2025

The cathode chemistries (the *anodes* are graphite) can be characterised as follows.

LFP	Lithium-iron-phosphate
LMO	Lithium-manganese oxide
NCA	Lithium-nickel-cobalt-aluminium oxide
NMC	Lithium-nickel-manganese-cobalt oxide
LCO	Lithium-cobalt oxide

In general, cathodes containing cobalt store more energy per unit of mass, meaning that NCA/NMC chemistries are more suitable for EVs. LFP batteries, on the other hand, have a much greater service life than their cobalt counterparts, being capable of very high current delivery, but store less energy per unit of mass. Moreover, LFP batteries are not at risk of thermal runaway (meaning they can power a hover board without it catching alight) and are generally considered the 'safe' LIB. LFP batteries have found their niche in hybrid EVs, as storage mechanisms for renewable power and in other applications where longevity is more important and size and mass less critical.

But back to Musk's statement about the 'nickel/graphite battery' and why he made it. Tesla has adopted NCA technology in its EVs, to provide maximum power storage with minimal weight – and in that way mimimise 'range anxiety'. Published estimates of the metal imports required to produce them may provide the key to Musk's assertion.

The figures look something like this.

NCA batteries	Graphite	Cobalt	Nickel	Lithium	Total
Tesla '000 tpa	42.00	5.00	12.92	4.60	64.52
% by mass	65.10	7.75	20.02	7.13	100
Molecular %	78.27	1.90	4.92	14.91	100

If viewed in terms of mass, the batteries that propel Musk's EVs are indeed dominated by nickel and graphite. However, if they're viewed in terms of molecular proportions, then lithium is the dominant metal – with a molecular weight of only 6.9, that small mass packs a lot of atoms, and it's the charge carried by the lithium ions that drives the battery.

As the planet relinquishes its dependence on fossil fuels and renewable sources of power become the norm, the requirement for reliable energy storage will increase ... and that's the domain of the LFP, the *safe* LIB.

Goodenough's innovations notwithstanding, demand for lithium, graphite, nickel and cobalt is set to skyrocket, with lithium remaining a vital ingredient of EV battery technology.

And finally ...

Fancy a device you can see through? As New Atlas reports, Stanford University researchers say they've developed a see-through, flexible LIB for powering fully translucent mobile gadgets like cell phones, tablets and e-readers.

Although their prototype see-through battery is only about half as powerful as a standard LIB of the same size (it's comparable to the nickel-cadmium battery used in some less-energy-intensive devices), the researchers hope that "by aligning multiple electrodes together, the amount of energy stored can be increased without sacrificing the transparency." Wait and see ...

Which Perth-based company has a vested interest in LFP, the 'safe' LIB and emphatically NOT a 'nickel/graphite' battery?

ThePowerof3

ISSUE 19 November 2017

Driving the future further

Watch out, Tesla: there's a dragon on your tail!

'Luck is what happens when preparation meets opportunity'

~ Seneca the Younger

Overview

According to the *Nikkei Asian Review*, Chinese manufacturers "continue to electrify global markets for lithium-ion [Li-ion] batteries" for use in consumer electronics, with China leading the world in battery-cell manufacturing.

Already in China, more than 40 established companies mass-produce low-cost battery components for the electronics market: high-purity electrolytes (a core component); separators (which isolate cathode and anode) and materials for the cathodes and anodes themselves. Companies from other sectors are also moving into this space.

Now that all major automotive producers are committed to electric vehicle (EV) production and governments worldwide aiming to phase out the internal combustion engine, and with power utilities simultaneously beginning to install huge storage systems to smooth the ebb and flow of renewable sources of energy, the canny Chinese see serious opportunities in the emerging EV market – what *Forbes* describes as a US$240 billion industry in the making, for which reliable, high-performance batteries are essential (the same being true for stationary energy storage).

Like a raft of others, *Bloomberg* predicts that, in China, EVs and the batteries that power them will become very big business in the next five years:

As Elon Musk races to finish building the world's biggest battery factory in the Nevada desert, China is poised to leave him in the dust.

What's the rush?

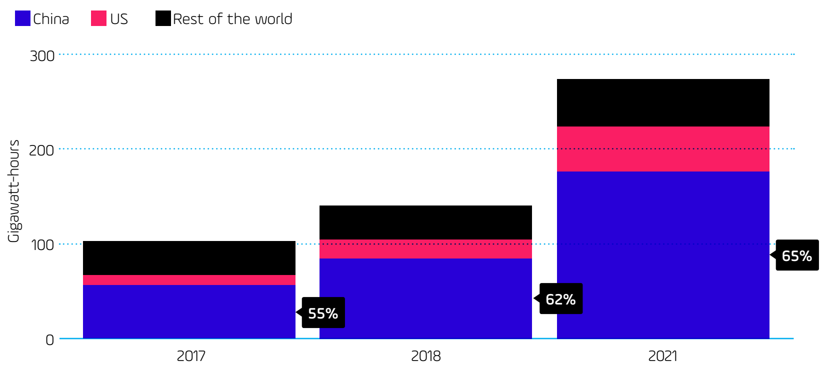
Like many other governments, Chinese central planners want to phase out diesel and gasoline cars in favour of EVs sooner rather than later. Their motivations, says *Green Car Reports*, are that China:

- desires technological leadership globally;
- imports more oil than it produces or has in reserve;
- suffers from severe urban air pollution, and
- lacks intellectual property in plug-in hybrid vehicle technology (touted by some auto-makers as a practical transitional technology while the world weans itself off oil and internal combustion engines).

For the past decade China has ranked as the largest vehicle market in the world. Chinese auto-assemblers generally choose home-grown products; therefore, more than 90% of locally made EVs are powered by locally produced batteries. Ergo, pretenders to the throne of global leadership in EV battery manufacture face fierce competition from The People's Republic.

Power surge

China's share of Li-ion battery production is forecast to hit 65 per cent by 2021.



[Source: Bloomberg New Energy Finance.]

The biggest producers you probably never heard of …

At present in China, so many companies are churning out batteries for EVs that the country's leaders have set minimum capacities, as *PushEvs.com* notes:

> *With electric cars the battery technology is the most important part; it's what differentiates the best from the rest. Knowing this, in 2016 the Chinese government passed legislation that requires EV cells to achieve an energy density of at least 200 Wh/kg*[1] *…*

> *Chinese companies [with] vast resources to invest in acquiring or developing battery technologies are more likely to dominate the global battery cell market in the coming years.*

The Chinese are also considering minimum production standards to further strengthen their position among leaders in the field.

Some industry sources maintain that to become a champion in the battery-making stakes, a Chinese company must first shed any foreign investment, making it eligible for subsidies and other policy support. While China has certainly subsidised its EV makers heavily since 2012, this year Beijing called for Chinese companies to double their EV battery capacity by 2020 and encouraged them to invest in factories overseas.

Build Your Dreams (BYD)

Right now (although opinions differ), Panasonic – which teamed with Elon Musk to open Tesla's vast Gigafactory) – leads the world in EV battery manufacture … but only just.

Warren Buffet-backed, Hong Kong-listed **Build Your Dreams** (BYD) is China's – and the world's – leading manufacturer of EVs (cars and buses), as well as a major supplier of batteries globally, with a market capitalisation of US$18.7 billion.

At the APTA Expo in the US recently, the company unveiled "the world's first 45-foot battery-electric commuter coach bus" and showcased a number of other commercial EVs. Today, more than 27,000 of its electric buses are in service around the world.

The *Financial Review* maintains that this year BYD overtook Tesla in the battery and EV business, and that the company's battery factory near Shenzhen is more than *eight times larger* than Musk's behemoth in Nevada (see *The Power of 3*, issue 3).

Contemporary Amperex Technology Ltd (CATL)

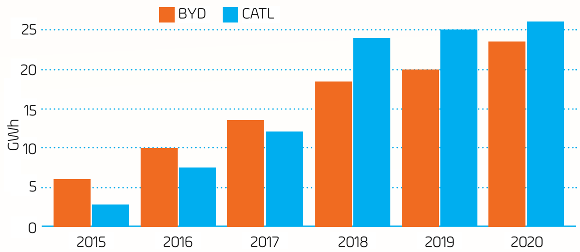
The focus of large – and inexorably expanding – Chinese company CATL is narrower: it's dedicated to Li-ion battery research, development and production for EVs and energy storage systems, and the evolution of battery management systems.

Robin Zeng, founder of leading Li-ion battery-maker Amperex Technology Ltd (ATL), established CATL in 2011 and the latter is now valued at US11.5 billion. Initially, ATL held a 15% stake in CATL … until, that is, EV sales took off. However, the two companies are said to maintain a close relationship.

Describing itself on its website as 'the rising Chinese lithium power' and the 'third-largest lithium battery manufacturer in the world'[2], CATL's ethos is that of contributing to a sustainable energy future, one that involves innovative EV batteries with longer range and shorter charging speeds.

With respect to China's minimum standards, CATL's second-generation NMC battery cells (see *The Power of 3*, issue 18) have already significantly exceeded the nominated capacity.

Today, CATL collaborates not just with Chinese auto-makers but also international enterprises like BMW, Hyundai, Daimler and NEVS (formerly SAAB), and in so doing is rapidly extending its reach. Further, CATL is currently in the running for a huge contract with Volkswagen and rumoured to be working with Apple on a confidential EV-related project.



[Source: company data, BofA Merrill Lynch Global Research.]
Note: 2015 output figures compiled by BofA.

According to the Bank of America (BoA), CATL could surpass BYD in battery production by 2018[3].

Fortune, too, predicts that by 2020 the company could be a dominant force globally:

> *CATL is China's answer to Japan's Panasonic and South Korea's LG Chem, [having] tripled its production capacity for lithium-ion car batteries in the past year to keep up with the surge in China's sales of EVs.*

And finally …

Fancy aerial ride-sharing? That's Uber's grand plan for the not-too-distant future. Indeed, the company's first partner cities for its Elevate project – Dallas-Fort Worth in Texas and Dubai in the United Arab Emirates – are already aboard.

Potential problems include noise, how to regulate testing and the implementation of technology, and how flying cars could conform to existing certification processes and air-space management systems.

Such issues aside, Uber, as *The Guardian* reports, has progressed its plans by signing a contract with NASA to develop management software for its all-electric flying taxi service. The company has already partnered with five manufacturers to develop vertical-takeoff-and-landing (VTOL) aircraft and initiated plans to build 'skyports' for its VTOLs in Los Angeles. Uber says it will begin testing the service in LA in 2020. The adage 'An eye in the sky' may take on a whole new meaning …

NOTES

1 Watt-hours per kilogram (Wh/kg) = a unit of specific energy used to measure the density of energy in batteries and capacitors: 1 kilo of battery material can produce electricity at a level of 400 watts for an hour.

2 CATL is probably now the second-largest Li-ion battery manufacturer in the world.

3 CATL maintains that, as of mid-2017, it's already overtaken rival BYD in terms of sales.

Which Perth-based company aims for lithium sustainability in the EV era?

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The Power of 3

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January
2018

Driving the future further

Life is too short to drive a boring car …

"Are you ready for the new age? They're setting the stage for the renegades … Let's get electrified."
~ Africa Shox, Leftfield

Overview

To welcome in 2018, précised in this edition are just a few of the covetable – albeit not always practical – all-electric vehicles (EVs) good to go in the next couple of years. With demand stimulated not only by consumers but also 'green' legislation around the world, who says EVs have no future?

Fancy but 'affordable'

The four-door **Tesla Model 3** luxury sedan is, says the company, "a smaller, simpler and more affordable electric car [than its previous models], designed and built as the world's first mass-market EV" and, as such, it's a critical step in the company's mission to "accelerate the world's transition to sustainable energy."

Mass-produced the Model 3 may be, but as Pedro Lima of *PushEVs* avers, its combination of looks, performance and efficiency (range 350-500 kilometres or 220-310 miles) – plus production numbers that put it in a league of its own compared to other electric cars – make it the first EV to really put the wind up legacy automakers, the Germans in particular.

[Photo: Jaguar Land Rover Classic.]

Fast, faster, fastest?

Jaguar Land Rover Classic is electrifying the past with its **Jaguar E-type electric** sports car; it's based on the 1968 Series 1.5 E-type Roadster, described by Enzo Ferrari as "the most beautiful car in the world." Says company director Tim Hannig:

> *In order to seamlessly combine the new electric powertrain of E-type Zero with the dynamic set-up of the original E-type specification, we have limited the vehicle's power output [to provide] the optimum driving experience.*

That's not to say performance has been compromised: the E-type Zero is quicker than the original, accelerating from 0-100 kilometres per hour (62 mph) in only 5.5 seconds, about a second quicker than a Series 1 E-type.

Faraday Future's all-electric **FF91** is the first production vehicle and flagship model for this US-based, Chinese-backed company (see also *The Power of 3*, issue 3). Its engineers, says the company, are pushing the limits of electric performance and range with the FF91, not least with its 'Variable Platform Architecture', which securely houses the battery, powertrain and patented FF Echelon Inverter. Three electric motors and 1050 horsepower take the car from 0-97 kilometres per hour (60 mph) in 2.3 seconds, 'dynamic vehicle control' integrates the torque vectoring, four-wheel steering and semi-active damping systems to keep it firmly on the tarmac, and energy-dense lithium-ion battery cells offer 480+ kilometres (300+ miles) per charge.

Those with the need for even more speed could invest in the all-new, four-seater, all-wheel drive, next-generation **Tesla Roadster**. With three electric motors (two in the back and one up front), it's touted as "the quickest car in the world, with record-setting acceleration, range and performance": that's 0-100 kilometres an hour (62 mph) in 2.1 seconds, a top speed of +400 kilometres per hour (250 mph), and a range of an outstanding 1,000 kilometres (620 miles). With numbers like that, the Roadster looks set to give combustion-engine supercars a real run for their money.

Jaguar, meanwhile, has revealed its **I-PACE** five-seater production model. Available from the second half of this year, it's the company's first-ever battery-powered vehicle, able to accelerate from 0-100 kilometres an hour (62 mph) in around 4 seconds and drive 350+ kilometres (220 miles) on a single charge.

Yummy mummies will swoon

When it comes to building an electric car, many automakers are opting to go with a sports utility vehicle (SUV), a strategy *Business Insider* describes as smart at a time when "demand for smaller sedans is waning and electric cars still only make up roughly 1 per cent of auto sales."

Once again Tesla is at the forefront with its all-wheel drive **Model X**. Billed as "the safest, quickest and most capable [SUV] in history," it's not just fast but has ample seating for seven adults (or children) and their gear, and a range of 565 kilometres (350+ miles). Moreover, it can be customised to suit the specific needs of a particular family.

When size matters

At last year's Frankfurt Motor Show, the BMW Group showcased its first purely electric **Mini**, to go into large-scale production in 2019. A variant of the brand's core three-door model and a pillar of its line-up, it will be on the roads precisely 60 years after the classic Mini was first launched.

The fourth-generation battery-powered **SmartForTwo electric drive** micro car is, at ~2.6 metres (102 inches) in length, a little longer than the original but still remarkably tiny. With a range of 160 kilometres (~100 miles), the focus here is on city driving, while the output of its lithium-ion battery pack is guaranteed for eight years and 100,000 kilometres (62,000+ miles). And, while it may not suit hilly San Francisco, in a metropolis of less extreme topography it offers, in the words of *Motoring* magazine, "terrific tight-street practicality."

Car&Driver describes the **Audi E-tron Quattro** – and the racier **e-tron Sportback** – as true rivals for Telsa's Model X and "the first from the Volkswagen Group built on a new set of battery-electric vehicle components developed for both global sale and volume production" ... which means lots of attention has been paid to the durability of the power and drive systems. Both versions will be offered in battery sizes that correspond to the driving range required.

[Photo: Benjamin Zhang/Business Insider.]

And, finally, for the road less paved ...

If a no-nonsense, sexy-but-brutal, back-to-basics beast is more your style, you can't go past the Bollinger B1. Touted as the "world's first all-electric, all-wheel-drive, off/on road sport utility truck," it comes in both half- and full-cab versions. The rugged, heavy-duty design features a classic, three-box look not dissimilar to that of Land Rover's gritty, timeless Defender series. This one, though, has been developed, designed and engineered in upstate New York. Built for – and in – the great outdoors, it boasts 360 horsepower and a range of up to 320 kilometres (200 miles).

The MD of which Perth-based company plans to ditch his Defender in favour of a Bollinger B1?

ThePowerof3

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Driving the future further

"Where have all the batteries gone?
Time keeps passing ...
Where have all the batteries gone?
Gone to landfill, nearly every one!
When will we ever learn?
When will we ever learn?"

~ with apologies to Peter, Paul & Mary

What's the solution for our wasteful society?

Is recycling the answer?

Every year, more than 40 million tonnes of 'e-waste' is generated globally but at present only 15 per cent or so finds its way back into the system for recycling.

Overview

The science fiction of the previous century has become reality in the 21st. Remember Maxwell Smart's 'shoe phone', Dick Tracy's wearable-tech, Inspector Gadget's getaway vehicles or, indeed, the Star Trek communicator? Of course, recall depends on one's age, but no-one can deny that today all of these former fantasies, and more, are available in some form or other.

But concomitant with the surge in the supply of – and burgeoning demand for – everything from smart and smarter phones and thin and thinner laptops/tablets to the nimblest of drones, vertical-take-off-and-landing aircraft and fast and faster electric vehicles (not to mention renewable energy storage and the like) is the fact that the supply of the primary raw materials essential to powering these innovations simply cannot keep up with demand.

The dynamics for lithium-ion batteries (LIBs) are similar, with global recycling rates of less than 10 per cent – and of the metals that *are* recovered, lithium lags far behind the rest.

With the current acute shortage of cobalt, and international embargos on any such material produced in the Congo, demand for this energy metal for battery production alone is destined to outstrip supply in the foreseeable future. And there are growing concerns that lithium production too may not keep up with demand in years to come.

So, why are LIB recycling rates in particular so low? A major reason, of course, is that we've become a society of consumers, living in the moment with little thought or concern for how our behaviour affects the planet now or in the future. This disposable lifestyle is fuelled by ever-decreasing prices for portable electronic items deemed desirable, not to mention their built-in obsolescence. Neither creates much incentive to recycle what's no longer considered useful ... guilty consciences aside (and also in short supply). For the vast majority, it's easier to dump devices past their use-by-date into the rubbish that goes to landfill, including the LIBs that power them (see *The Power of 3*, issues 5 & 6).

Recycling International discusses a new analysis by Creation Inn, a London-based business development consultancy with expertise in energy storage and circular economy:

> *The total volume of recycled lithium could reach 5,800 tonnes – or 30,000 tonnes lithium carbonate equivalent (LCE) – in 2025...*

That's just 9 per cent of the world's total supply of LIBs. While the outlook for cobalt is somewhat better – it's anticipated that 22,500 tonnes from recycled batteries will reach global markets in 2025 – the recycling volumes for both lithium and cobalt will still be relatively low.

> *Long service lives [of the batteries], positive prospects for second use and poor collection of portable batteries are said to be the main reasons behind this...*

Another is the recycling technology itself. At present, only a handful of countries, among them South Korea and China in particular, are researching and developing the ability to recycle many of the materials found in e-waste (including LIBs). Even here, though, lithium, one of the elements most critical to powering electronic devices and electric vehicles, is recovered at very low rates. The issue lies in smelting the complex metal mixes emanating from e-waste and batteries before their recovery and refining. Because lithium is volatile, it ends up in flux or discharges as unrecoverable vapour. But that may be about to change.

Again, China leads the world

Creation Inn suggests that, of the 9 per cent of lithium expected to be recycled globally mid the next decade, more then 66 per cent (191,000 tonnes) of that will be in China, which is seeking to fuel its rapidly expanding battery-material industry (see *The Power of 3,* issue 19)**.**

In China too, recycling of batteries containing cobalt is expected to result in a 76 per cent recovery rate for that element by 2025.

But, while the Chinese labour to ensure sustainability nationally, the country's recent ban on importing many categories of solid waste has exacerbated the recycling dilemma for Europe and America, two of the fastest growing markets for LIBs outside of Asia. This makes it imperative that the rest of the globe recognises the value in used batteries and a new industry is established in the western world.

China has long been a dumping ground for the world's waste [photo courtesy of PhysOrg*].*

Closing the loop on the energy-metal cycle

Creating a new industry to recycle energy metals requires more than merely regenerating metals from e-waste and LIBs. What's needed is a comprehensive sustainability plan that includes re-birthing the products from which those energy metals were recovered.

In the case of LIBs, the ultimate circular economy could be realised via the use of hydrometallurgical techniques that generate complex metal solutions – from which battery cathode materials can be directly precipitated. Unlike commonly used pyrometallurgical processes (in which high temperatures are used to extract and purify metals), hydrometallurgical processes (involving the use of aqueous chemistry instead) can recover lithium as well as other strategic metals from recycled and residual materials.

Saving LIBs, and hence lithium and cobalt, from landfill will vastly improve the sustainability of these two elements in the supply chain, and in so doing quash the greatest threat to continued production of smart phones, tablets, EVs *et al.* It will also promote despatch of these new and desirable devices via drones, Uber-copters and various autonomous delivery vehicles.

And finally … Speaking of autonomous delivery vehicles, check out this cutie. Built of ultra-light materials, about half the width of a normal car, designed to travel on roads like other vehicles, and destined for neighbourhood use only, Nuro (the vehicle) is the brainchild of Dave Ferguson and Jiajun Zhu, formerly principal engineers with Google's self-driving car project. Other team members hail from the likes of Apple, Uber, Tesla and GM, so Nuro (the company) boasts sound credentials.

Which Perth-based company plans to combine LIB recycling with the re-birthing of battery cathodes?

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The Power of 3

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Driving the future further

"We're finally in the future/There's a new bird in the sky/Watching from above/ with an electronic eye/I finally have the feeling/that there's nothing we can't do …"

~ with apologies to DJ Earworm

Overview

Drones (unmanned flying robots) – some as large as airliners, some as small as pigeons – have been both lauded and maligned as agents of subterfuge and destruction, deployed by the military to spy on and strike at 'enemy' targets.

Today, of course, compact drones are ubiquitous. Not only are they getting smaller but also cheaper and easier to operate and, as is the case for many devices with wide appeal, the potential for misadventure and misuse (collisions with aircraft, infrastructure and individuals, the performance of malicious acts) is escalating as regulations on their use are finalised. (Sadly, in Russia the test flight of a mail delivery drone ended prematurely when it crashed into a building.) That said, the positives of adapting such innovative technology to myriad private, public and commercial ends are readily apparent.

As global insurance giant agcs.allianz.com reports, drones are becoming mainstream across the globe and within many industries. They can be used to perform menial or dangerous tasks, help problem-solve and overcome challenges and enhance the safety of thousands of workers every year while significantly reducing costs. Drones are ideal for industrial inspections, aerial photography (including cinematic shots), crop surveys, goods delivery in far-flung regions and situations involving emergency personnel, right down to dispensing fast food in the outback.

And, yes, drones-for-hire is a 'thing' now too.

Up, up and away – drones are shaping the future

Generally, civilian aviation authorities regulate the operation of drones over a certain weight, particularly for commercial applications … unlike in the Ukraine, where unmanned aerial vehicles abound but no meaningful attempt at control has been made.

Despite the advances of the Digital Age, it seems though that more future proofing is required before unmanned aerial vehicles are as common as the delivery vans and trucks on our roads.

Project Wing trials fast-food delivery in the outback.

Delivery by drone

Companies large and small are investing in drone delivery, not least Amazon, UPS, Walmart and Domino's, while a plethora of start-ups have the same thing in mind.

New kids on the block …

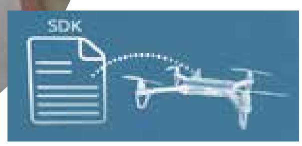
In 2016 Australian start-up Flirty, based in Nevada, executed the first instant drone delivery in the US under the watchful eye of the Federal Aviation Authority. In so doing, it pre-empted the big guns throwing money at the same technology.

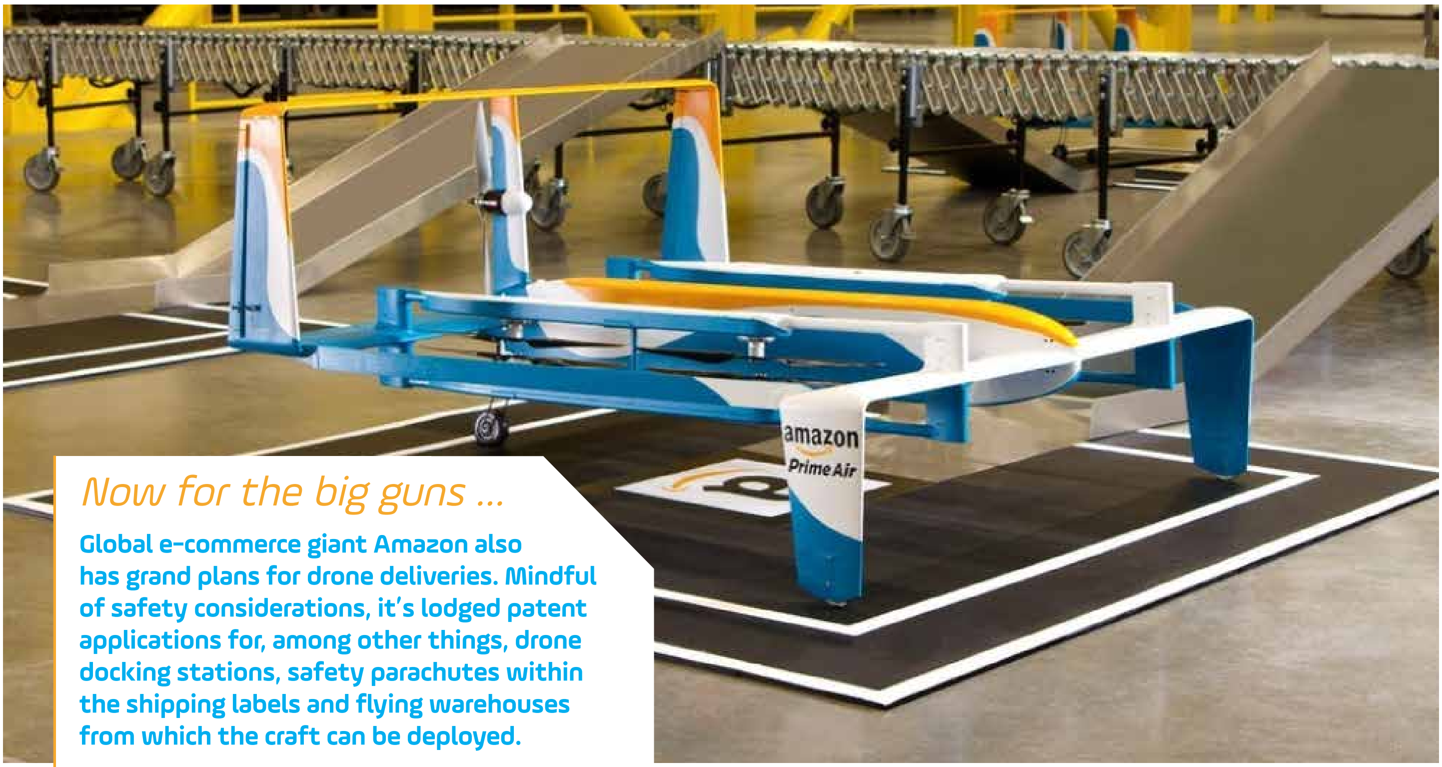
Flirty set its sights on markets for humanitarian relief, online retail and food delivery, practising in Australia and New Zealand, where it teamed with Domino's to deliver the world's first 'pizza by drone'. Before anyone gets too excited though, Domino's admits the concept has a way to go, especially in the Antipodes.

Other small-ish companies touting drone deliveries include Californian-based Matternet, whose vehicles share the same airspace as emergency helicopters and constantly broadcast their location as they move blood and other medical resources between hospitals in urban parts of Switzerland. Recently, Matternet and e-commerce start-up siroop teamed with Daimler's Mercedes Benz to test the latter's van-based drone delivery concept in Zurich. Matternet plans to expand into the rest of Europe, the US and Japan.

Further afield in Rwanda and Tanzania, Zipline (also California-based) drone-delivers vital medical supplies to health workers in remote locations. Orders are sent by text, prepared by the company and dropped by parachute in a matter of minutes, with workers kept in the loop throughout. This week, Zipline unveiled "the fastest commercial delivery drone on Earth," capable of flying at up to 128 kilometres per hour (80 mph), and it has plans for a pilot programme in the US.

Flyver.co is a drone software company producing aerial solutions for industry. It maintains that, with a combination of autonomous drones and cloud software, any business can deliver straight to their clients' doorsteps. Apparently, the challenge is all in the code.





Now for the big guns ...

Global e-commerce giant Amazon also has grand plans for drone deliveries. Mindful of safety considerations, it's lodged patent applications for, among other things, drone docking stations, safety parachutes within the shipping labels and flying warehouses from which the craft can be deployed.

Its latest patent application is for drones that disintegrate if there's a problem, spreading the load of metal and plastic showering down on unfortunate passers-by. While trials are currently underway, legal considerations mean the concept may not take flight for some time yet. Amazon was, however, recently granted a patent for delivery drones that incorporate not just a flight controller but also a 'fragmentation controller' that dictates when certain parts can be broken off and released in the event of an operational emergency.

Meanwhile Alphabet, Google's parent company – also with drone delivery as one of its core goals – has been testing its Project Wing autonomous hybrid drone delivery initiative in the Australian Capital Territory. There, according to project co-leader James Ryan Burgess, the size of estates and housing lots allows flying and delivery in areas not overly populated and where residents interested in new technology and innovation are willing to provide vital feedback.

Unlike traditional quadcopters, says *The Guardian*, Alphabet's Project Wing drones incorporate the best aspects of fixed-wing aircraft and classic rotary-wing drones, in that they're able to travel long distances at high speeds with comparatively little power and can take off and land without a runway, as well as hover in place.

Last month another US retail colossus, Walmart, published a patent, filed in 2017, to create a system of drones that can assist its customers with price verification and locate products for them within its stores. According to the patent, Walmart drones will be fitted with sensors to avoid collisions with other drones, objects within the store and, of course, customers.

Walmart also wants a patent for drone technology that not only pollinates and monitors crops but sprays insecticides as well. In light of bee colony collapse disorder and crashes in bird and insect populations globally in recent times, not to mention the much-opposed Bayer-Monsanto merger, this could be seen as ominously prescient.

Catch it while you can

Among Japanese company Prodrone's 'revolutionary drones for professionals' is the weatherproof PD6B-AW-ARM. Incorporating two remote-controlled robotic arms, it can attach or join things, cut cables, turn dials, flick switches, drop life-saving equipment, move cargo to out-of-the-way areas and so on. Able to grasp, carry and release a payload of up to 10 kilograms, it can even perch on railings.

And finally ...

Ever left your keys at work (or somewhere far more inconvenient) and had to drive or take public transport to retrieve them? That's where UK-based Bizzby SKY's "mobile-first, on-demand drone delivery" can help. An app-summoned service that went live in London three years ago, it uses 'drone highways' to deliver objects like keys or products such as medication almost instantly within the city. Bring it on in Oz!

Which Perth-based company is supply-chain planning for the Digital Age?

ThePowerof3
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Driving the future further

Size matters – the intriguing world of nanotechnology PART ONE

'The mysteries of the universe involve size, not time'
(to paraphrase Stephen King)

Overview

US engineer Eric Drexler first coined the term 'nanotechnology' in the 1980s. His vision of 'molecular manufacturing' – a sea of self-replicating nanobots moving molecules so quickly and positioning them so precisely that they could produce almost any substance from ordinary ingredients in a matter of hours – inspired a generation of chemists, computer scientists and engineers to start thinking small. (Drexler also hypothesised the doomsday scenario of 'grey goo', whereby those self-replicating bots consume Earth's entire biomass while building more of themselves.)

Fantasies aside though, what *is* nanotechnology?

The *American Heritage® Science Dictionary* describes it as "the science and technology of precisely manipulating the structure of matter at the molecular level. The term … embraces many different fields and specialities … but all are concerned with bringing existing technologies down to a very small scale, measured in nanometres. A nanometre [nm] – a billionth of a metre – is about the size of six carbon atoms in a row … "

From *The Foresight Institute*: "Nanotechnology is the study of phenomena and fine-tuning of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale."

Most importantly, Thomas Theis of the IBM Watson Research Centre describes it as "an upcoming economic, business and social phenomenon [that some say] will revolutionise the way we live, work and communicate."

"Despite unprecedented government funding and public interest," avers *IopScience* however, "few can accurately define [its] scope, range or potential applications."

Nanotechnology now

While getting a handle on nanotechnology may not be easy, for decades scientists have been working at the nanoscale courtesy of electron microscopy, scanning probe microscopies and similar technologies that can now 'see' with a resolution down to the scale of a single atom.

Cells crawling across ceramic crystals [credit: Karin Hing, courtesy of the Wellcome Collection].

To give an idea of scale, consider the following:

- a strand of human DNA is 2.5 nm in diameter;
- there are 25,400,000 nm in an inch (2.54 centimetres);
- a human hair is around 80,000-100,000 nm wide;
- one gold atom is about a third of one nm in diameter, and
- a human fingernail grows around one nm a second.

Even the best compound microscopes cannot resolve parts of a specimen that are closer together than about 200 nm, so nanoscience involves considerable ingenuity. Tools and instruments – the hardware, software and supplies – used to measure and manipulate structures on the nanoscale include microscopes, probes, lithography systems, manipulation and fabrication systems, software and other accessories. In essence, though, nanotechnology is nothing more than the most fundamental understanding of how nature works at the atomic scale.

Science fiction, of course, has led the world to expect a great deal more: miniature body-probing robots and miniscule submarines; tiny cogs and gears created from atoms; carbon-nanotube space elevators; weather machines – even interplanetary exploration and habitation. Only time will tell …

Meanwhile, in the real world nanoscience has generated a plethora of new industries and delivered innovations in a range of others, including:

- quantum dots
- medicine and healthcare;
- computing;
- telecommunicxations;
- sensor technology;
- petroleum refining;
- automobiles;
- lightweighting of vehicles;
- tires;
- coatings;
- personal-care products (including sunscreens);
- smart and antibacterial fabrics;
- household products;
- packaging;
- construction and mining;
- environmental remediation;
- desalination;
- solar cells,

and more.

Gold nanoparticles coated with a cancer antibody that binds to tumour cells to aid in diagnosis and treatment [credit: Annie Cavanagh, courtesy of the Wellcome Collection].

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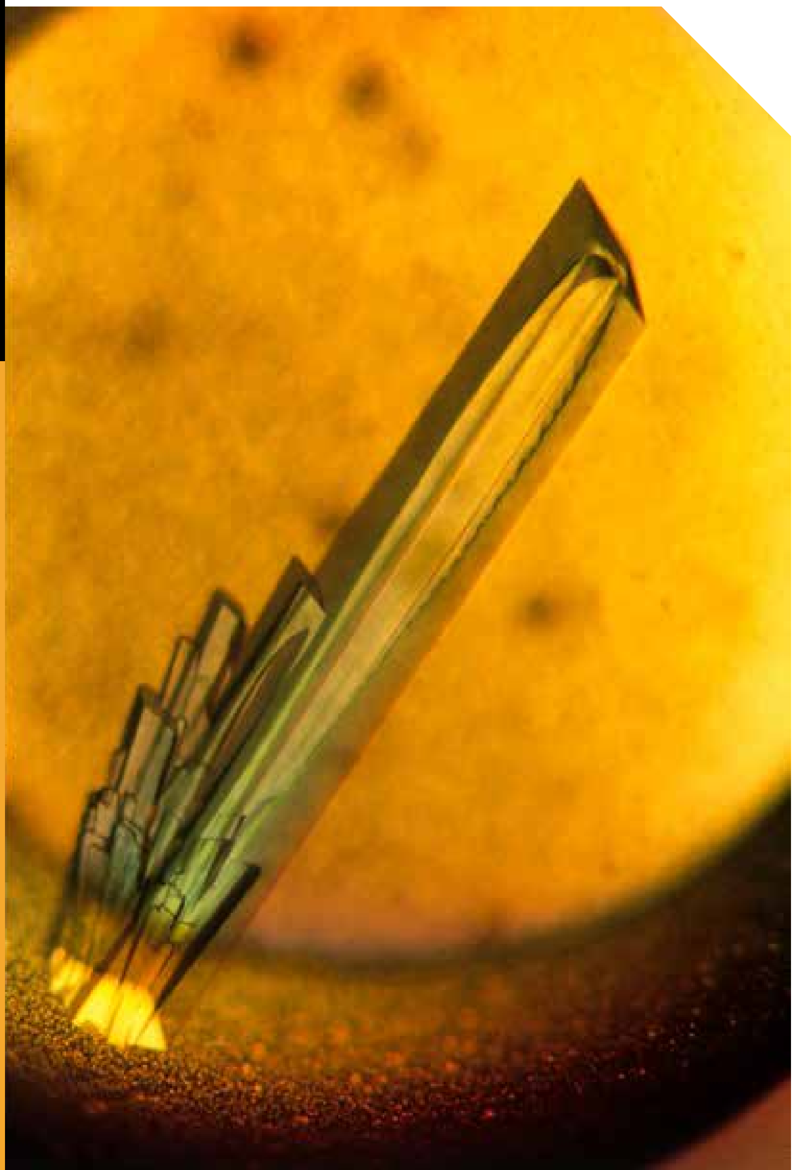
Can nanotechnology green the planet?

Today, many concede that one of the most pressing problems facing Earth is global warming. It's impelling many countries to relinquish their dependence on fossil fuels and embrace cleaner forms of transport, as well as renewable sources of power and storage mechanisms for the energy they produce – which, as outlined in previous issues of *The Power of 3*, has led to burgeoning demand for and manufacture of rechargeable lithium-ion batteries. The result? Even more pressure on the planet's already depleted resources, plus the potential to create massive environmental headaches in terms of end-of-use disposal.

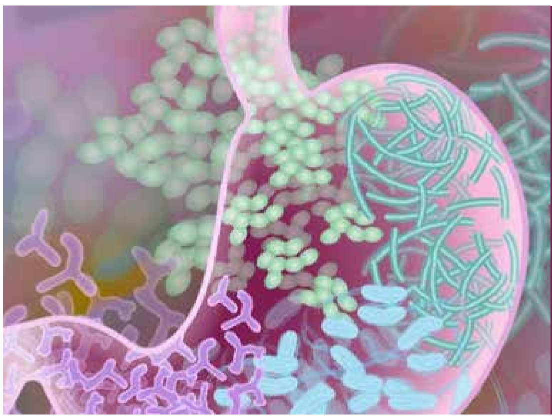
Part of the answer lies in more efficient reservoirs of energy – new generations of battery materials that fulfil the needs of end-users – and the most promising of those will involve nanotechnology, which has the potential to:

- improve safety through the creation of less flammable battery materials;
- enhance a battery's available power and lessen charging time by coating the surface of the electrode with nanoparticles;
- increase the surface area of a battery's electrode and in so doing facilitate the flow of current between the electrode and the chemicals within that battery;
- improve energy density (charge per unit volume) by packing more material into battery electrodes;
- enhance the electrochemical properties of electrodes by doping them with trace metals on a molecular scale, and
- improve battery shelf life by using nanomaterials to separate the liquids and solids within, thereby eliminating the low-level discharge common to conventional batteries.

In summary, and despite the doomsayers, nanoscience and nanotechnology involve exciting interchanges across a range of disciplines working at the tiniest of scales. Together, they represent a new and expanding frontier with great promise for improvements in quality of life, including new treatments for disease, greater efficacy in computer data storage and processing, and ever more efficient energy storage and use.



Crystals of a DNA repair protein bound to DNA [credit: Bernard O'Hara & Renos Savva, courtesy of the Wellcome Collection].



Beneficial gut bacteria [credit: Darryl Leja, National Human Genome Research Institute, National Institutes of Health].

And finally …

Microbiomes are communities of microorganisms that exist almost everywhere on Earth and influence how plants and animals (including humans) interact with their environments. One new and exciting area of health research involves investigating the holistic effect of the gut microbiome on the human body. As so often happens, scientific insights follow on technological development – in this case, advances in nanoscience focused on DNA research. Scientists now know that the human gut microbiome plays a role in a whole range of moods, behaviours and illnesses, among them anger, depression, PTSD, obesity, high blood pressure, colon cancer, multiple sclerosis, Alzheimer's disease … the list goes on. While studies are ongoing, it's becoming increasingly evident that a wholesome diet, lack of disruption to circadian rhythms and adequate exercise all play a role in keeping people well. The adage 'You are what you eat' (and how you sleep and play) has never rung so true.

Which Perth-based company will use nanotechnology to help close the 'energy-metal' loop?

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ThePowerof3

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Driving the future further


ThePowerof3
Driving the future further
Size matters – the intriguing world of nanotechnology
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Nanotechnology now

Overview

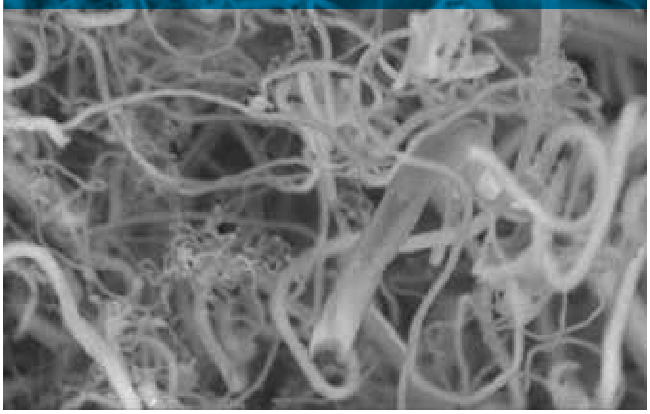
As noted in *The Power of 3* issue 23, nanotechnology has delivered (or promises to) on some of the wilder concepts in 20th century science fiction. Consider, for instance, the following.

- Buckypaper, made from millions of carbon nanotubes, is ten times lighter and can be 500 times stronger than steel.
- Energy from heartbeats can now be harnessed and built into fabrics, meaning clothes could soon be recharging portable devices.
- Nanofibres injected into mice with paralysed limbs have facilitated the regeneration of lost or damaged cells, allowing the limbs to be used again.
- Bullet- and knife-proof business suits made of carbon nanotubes (shaped with a saw) retail for US$20,000.
- At extreme temperatures, nanotube sheets cause light to bend away from objects so they 'disappear', creating potential for a 'cloak of invisibility'.

With nanotechnology the possibilities, it seems, are endless …

Climate change

According to *New Atlas*, US scientists can convert atmospheric carbon dioxide (CO_2) into high-yield carbon nanofibres (at low energy) for use in anything from bulletproof vests and artificial muscles to wind-turbine blades and commercial airliners. Scaling up their operation to cover an area of less than 10% of the Sahara Desert would, the researchers claim, cut the concentration of CO_2 in the atmosphere to pre-industrial levels within a decade – supplying materials for manufacturing in the process.


High-yield nanofibres produced from atmospheric CO_2.

Size matters – the intriguing world of nanotechnology

PART TWO

The Energy Revolution

In the pursuit of higher energy densities, lower costs, and longer life, nanotechnology is regularly employed to create new materials and processes … A wonderful example is the commercialisation of the lithium iron phosphate cathode, which functions as a high power material only in a nanophase form, clearly demonstrating the benefit of nanotechnology.[1]

Some surmise that oil companies could pipe or pump (or deliver in tankers) electricity as a nanofluid using existing infrastructure, just as petrol is distributed today.[2]

While interest in proposals like this continues to grow, the ubiquitous lithium-ion battery (LIB) is also undergoing many transitions, with nanotechnology supporting ever-improving performance.

The electric vehicle (EV) industry offers a great example of how rapidly things can change. In just a few short decades, EVs have progressed from employing macro-technologies (like towing a trailer load of lead-acid batteries to achieve the required range) to being powered by LIBs, thanks to the development of nanopowders that enable those batteries to outperform their lead-acid predecessors by an order of magnitude – making today's self-contained EVs a reality.

Meanwhile, the use of graphene nanotubes in LIB anodes is hailed as a means of improving their performance. Although the addition of silicon and lithium metal in the anode may also yield much higher energy densities, such advances are never simple. Silicon, for example, coordinates with far more lithium atoms than carbon and should therefore be ideal as a cathode material. However, the large quantity of lithium that silicon can consume creates a problem, in that the silicon in the anode expands and contracts by up to 400% on charge and discharge cycles. This puts immense strain on the cathode and results, ultimately, in degradation. The solution? Nanotechnology! Incorporating the silicon as nanowires or encapsulated particles – like the yolk within an egg – allows its electrochemical advantages to be exploited while negating many of its disadvantages.

Also on the drawing board is a cheap, non-toxic LIB with sand rather than graphite in the anode. Purifying the sand, powdering it, grinding it with salt and magnesium and then heating it to remove oxygen produces porous 'pure' silicon, which unlike normal nano-silicon not only degrades slowly but is also easier to produce in large quantities. While still in the R&D stage, the Sand Battery is said to perform three times better than current types of LIB.

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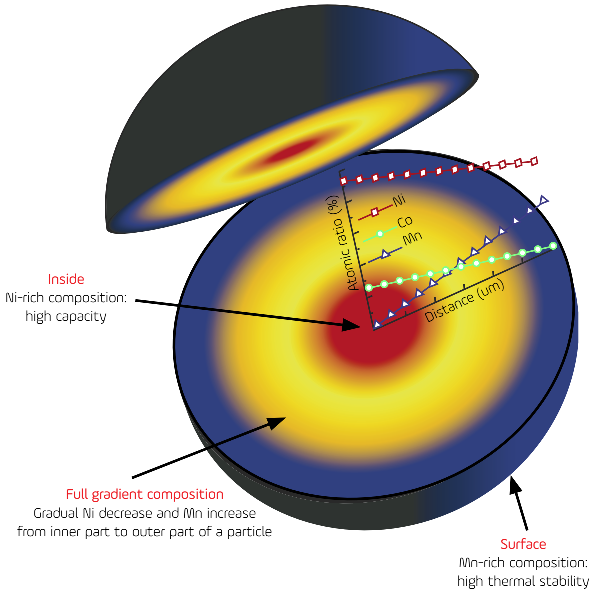

The Energy Revolution *(cont.)*

Another issue with some LIBs (NCM compositions in particular) is the propensity of the cathode to react with the electrolyte. This dramatically shortens battery life. Again, though, the problem can be overcome with nanotechnology: today, particles with a graduated composition can be produced, the nanoparticles in the cathode powder having a nickel-rich core and a manganese-rich rim. (Ni = nickel; Mn = manganese in the diagram above). The nickel improves battery capacity but cannot react dangerously with the electrolyte, while the manganese improves the safety of the material by forming the front line of defence. Further, atomic layer deposition[3] can be used to develop a protective coating that permits the passage of lithium ions but prevents the electrolyte penetrating and degrading the cathode particles.

And finally …

New Atlas reports that Nawa Technologies, a French startup, is working on a new type of battery using carbon nanotube ultra-capacitors to produce "crazy-fast charging [while saving] a ton of weight" and adding significant power output. Unlocking its full potential in the EV space, however, means combining it with a lithium battery for maximum range and energy storage.

NOTES

1. Bruce Dunne *et al* 2013 Nanotechnology 24 420201.
2. John Katsoudas, *Nano-liquid batteries*: https://www.youtube.com/watch?v=YZuYnX3IQSQ
3. Atomic layer deposition (ALD) is a technique capable of depositing a variety of thin film materials from the vapour phase. ALD has shown great promise in emerging semiconductor and energy conversion technologies.
4. In a flow-cell battery, energy is produced by two chemical components dissolved in liquid and separated by a membrane.

Another innovation, the StoreDot charger, comes courtesy of the nanotechnology department at Tel Aviv University. It uses biological semiconductors made from peptides (the building blocks of proteins) to recharge a smart phone in 60 seconds. An EV battery that charges in five minutes and offers a range of 300 miles (480+ kilometres) is also in the works.

With the blue battery concept, meanwhile, molecular sieves decompose water into both hydrogen ions and hydroxyl ions for charging, with those ions then recombining to form water as the battery discharges. The technology required to control the molecular movements is not dissimilar to the reverse-osmosis equipment commonly used to remove salts from domestic water supplies. The concept is compelling in that it utilises active materials from the ocean to produce rechargeable batteries and can store energy for use when the wind doesn't blow and the sun doesn't shine. A pilot project has been underway since November in The Netherlands; however, the system still has some way to go before commercialisation.

Also getting the nano-treatment are flow-cell batteries[4], which are usually pretty large! Bi-ION is the liquid energy carrier for the nanoFlowcell®, an extremely compact version of the technology with output scaleable for various applications. Said to be cost-effective, eco-friendly, sustainable and safe, its manufacturers aver that this innovation will produce "the electricity of tomorrow," surpassing all currently available battery technologies for static and mobile applications.

Conclusion

Presented above are just a few leading-edge transformations in energy storage achieved thanks to nanotechnology. Major innovations aside, much can also be gained by manipulating the particle sizes within the cathodes of existing LIBs. The Goldilocks formula applies here: the particles should be neither too big nor too small, porous enough for the lithium ions to move through freely but with a surface area small enough to prevent unwanted reactions between the cathode and the electrolyte. While the parameters vary for each type of battery chemistry – and there is no 'one size fits all' – nanotechnology is hard at work here too.

Which Perth-based company is generating advanced cathode powders directly from solution?

ThePowerof3

Driving the future further

ISSUE 25
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2018

Lithium Valley – opportunity knocks

"The key to success is being in the right place at the right time, recognising you're there, and taking action!" Ray Kroc

Overview

As previously noted in this publication, in the latter part of the 20th century silicon was an elemental game-changer. In the US, its use in transistors revolutionised electronics and computerisation, altering forever the ways in which humans work, rest and play in today's interconnected digital world.

Now, as the Energy Revolution of the 21st century ramps up, lithium has become the *element de jour*. So, where on Earth is the ideal base for the world's burgeoning lithium-ion battery (LIB) economy?

An electronics super-economy

Silicon Valley, on the west coast of the US, was – and is – the culmination of decades of synergy and evolution. But how did a provincial backwater in California become the world capital of technology? Over a century or so, it was the combination of infrastructure, logistics and synergistic businesses, fierce space-age competition, a 1960s-induced cultural renaissance and an open-minded, risk-taking approach that resulted in a powerhouse of intellectual property and manufacturing encompassing some of the world's largest companies, among them Google, Apple and Tesla, to name but a few.

Tellingly, it was the advent of the silicon (rather than germanium) transistor in 1956 that began the reinvigoration of California's electronics industry – to the extent that, in 1971, US journalist Don Hoefler coined the term 'Silicon Valley' for the entire region … and it stuck.

The rest, of course, is history. Silicon Valley is now an industrial business network valued at around US$3 trillion dollars[1].

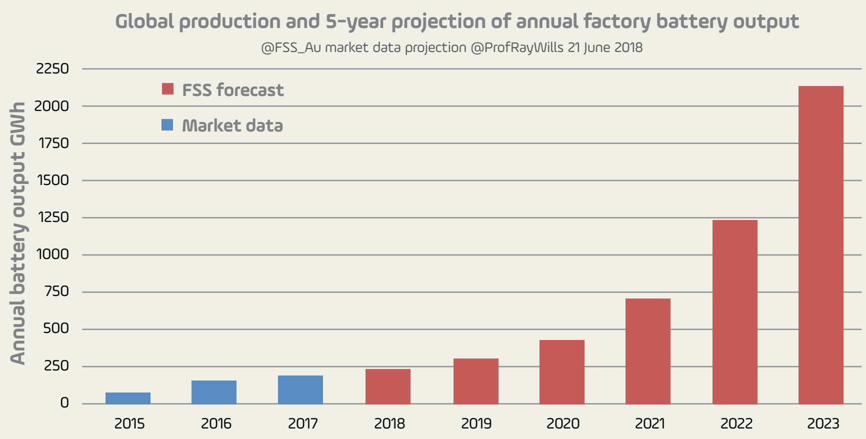
Knowledge doubling

This is how *Industry: Tap into news* describes Buckminster Fuller's creation of the 'Knowledge Doubling Curve':

> *[He] noticed that until 1900 human knowledge doubled approximately every century. By the end of World War II knowledge was doubling every 25 years. Today things are not as simple, as different types of knowledge have different rates of growth. For example, nanotechnology knowledge is doubling every two years and clinical knowledge every 18 months. But on average, human knowledge is doubling every 13 months. According to IBM, the build-out of the 'internet of things' will lead to the doubling of knowledge every 12 hours.*

Surge in demand

Silicon Valley took a century to develop but the pace of the Energy Revolution is far more frenetic. In the age of the LIB, knowledge and markets are the great enablers. With a global desire for cleaner air (via cleaner energy) increasing exponentially – propelled by government policies, consumer demand and OEMs[2] committed to phasing out internal combustion engines in favour of electrically propelled vehicles – an Energy Revolution powered by LIBs is hardly a 'bubble'. Demand, now and well into the future, is locked in.



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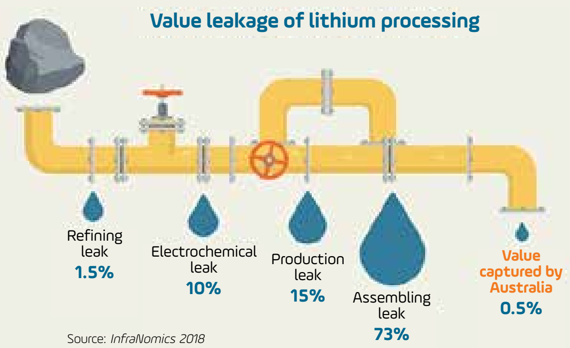
Lithium Valley – the concept

Western Australia (WA), long home to the world's largest lithium mine (at Greenbushes), wants to make its mark on the Energy Revolution. To do so, it is evolving from its previous 'quarry' mentality, with plans to process lithium concentrates and produce lithium chemicals rather than just mining and exporting the raw ore.

Currently, WA dominates the raw material input of lithium globally, supplying more than 50% of what's required for total LIB production worldwide. Much of that originates from the Greenbushes mine of Talison Lithium. In recent years, another six mines have been commissioned in WA – three in the Pilbara , two close to Kalgoorlie and one near the south coast at Ravensthorpe. Meanwhile, Kidman Resources/ SQM are close to turning the first sod at Earl Grey. Right now, the producing mines export mineral concentrates without any downstream processing, meaning that WA captures only 0.5% of the lithium value stream.



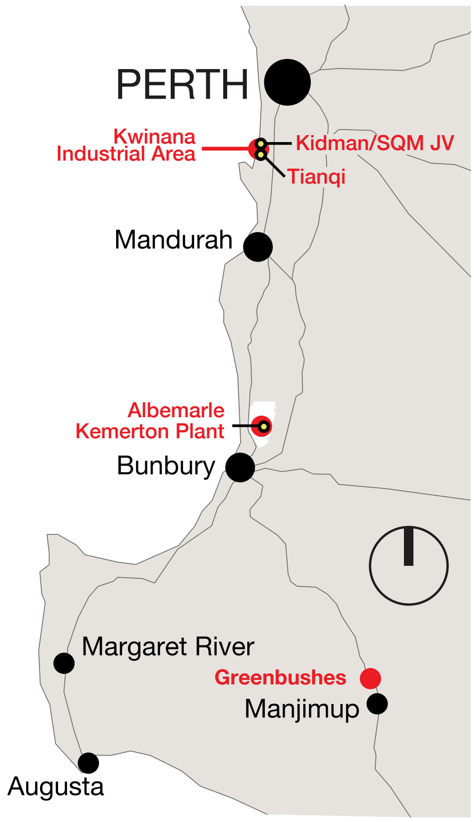
That may all be about to change though, with the creation of an Antipodean 'Lithium Valley'. The plan is for much of the lithium WA produces to migrate to its coastal refineries, where some of the nation's best industrial infrastructure, as well as synergistic businesses, are already *in situ*. One lithium refinery is close to completion, another has been committed to and a third is in the final stages of assessment. It's all happening on the west coast, with the focus on Kwinana, located near the state's capital city, Perth.

The Kwinana Industrial Area, which evolved in the early 1950s, remains one of the most advanced industrial parks in the world – home to petroleum, alumina, nickel and cobalt refining, as well as the production of fertilisers, industrial chemicals, gases and cement; in fact, most of the ingredients necessary to support that Antipodean Lithium Valley.

As with Silicon Valley in the last century, WA is an emerging entrepreneurial hub in its own right. With appropriate infrastructure, logistics and synergistic enterprises already in place, there's a strong parallel with the pre-transistor days of California. Meanwhile, critical mass is building in the form of a thriving local lithium concentrate business, while construction of the world's largest lithium-hydroxide refinery is also underway. What's all-important now is an ecosystem of risk-taking and innovation facilitated by affirmative government policies that encourage investment across the board.

Locally, Regional Development Australia has developed a blueprint for establishing Lithium Valley in WA, with the state government setting up a taskforce to facilitate the opportunity. The newly formed Lithium and Energy Materials Industry Consortium, an industry-based group, aims to work with the state in augmenting this once-in-a-generation opportunity.

Unfortunately, the nation's federal government, despite its 'commitment to innovation', is taking the shine off this vision for the future by heralding reductions in R&D benefits for companies developing and advancing technologies in the lithium sphere.



If Lithium Valley can indeed be successfully implemented, WA's stronghold on the primary inputs will provide significant leverage over the rest of the supply chain. In so doing, an environment ripe for the creation of a flourishing downstream processing hub will eventuate, capturing that supply chain, projected to be worth trillions of dollars in the not-too-distant future.

Right now, Australia has the opportunity to net a large proportion of the revenue stream that could flow from a Lithium Valley in the west, a stream that could dwarf the nation's current GDP. What's required is affirmative political will – particularly on the part of the country's federal government – to turn that vision into reality.

And finally ... As pointed out previously in this publication, lithium batteries are toxic when chewed or ingested. Given their size and shape, button batteries are a particular risk to small children and animals. Now, researchers have found that administering honey quickly and at regular intervals can prevent major damage before the battery can be removed. However, this is not recommended where sepsis is present, if the aesophagus has already been perforated or when an infant is less than a year old. Of course, prevention beats cure, so keep button batteries safely out of reach of those at risk.

(Photo courtesy of New Atlas; credit – pxhidalgo/Depositphotos.)

Which Perth-based company can help make Lithium Valley a global success?

NOTES

[1] *https://www.businessinsider.com.au/silicon-valley-history-technology-industry-animated-timeline-video-2017-5?r=US&IR=T*

[2] An OEM (original equipment manufacturer) is traditionally defined as a company the goods of which are used as components in the products of another company, which then sells the finished item to users. The second firm is referred to as a VAR (value-added reseller), which, by augmenting or incorporating features or services, adds value to the original item. A VAR works closely with the OEM, which often customises designs based on the VAR's needs and specifications.

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ThePowerof3
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Driving the future further

Overview

As noted in the first edition of this newsletter, even in 2012 the number of modern, mass-produced, highway-capable electric vehicles (EVs) on the market was impressive. Five years on, more than three million EVs are on-road globally, a million of them since 2017.

Nevertheless, in years to come universal uptake of EVs will depend less on their looks, price and size and more on the efficiency and performance of what powers them, be that hydrogen or lithium-ion (Li-ion) batteries.

While both methods of propulsion can be produced using low- or zero-carbon sources, and both are cleaner and more efficient by far than internal-combustion engines running on fossil fuels, there's plenty of debate about which, ultimately, is better.

Toyota, for one, is banking on the success of its hydrogen-fuel-cell vehicle (FCV) technology, whereby hydrogen and oxygen react with each other to yield the electricity that powers the vehicle. Having first introduced its FCVs in 2014, it plans to mass-produce the Mirai FCV, as well as pick-ups, SUVs and trucks, in the near future. The company also plans to build 80 hydrogen-fuelling stations by 2022. Other automakers, including Nissan, Hyundai and Honda, are following suit.

Elon Musk, still the face of Tesla (but no longer its chairman), has on the other hand called the use of hydrogen 'incredibly dumb', the issue being, ultimately, efficiency.

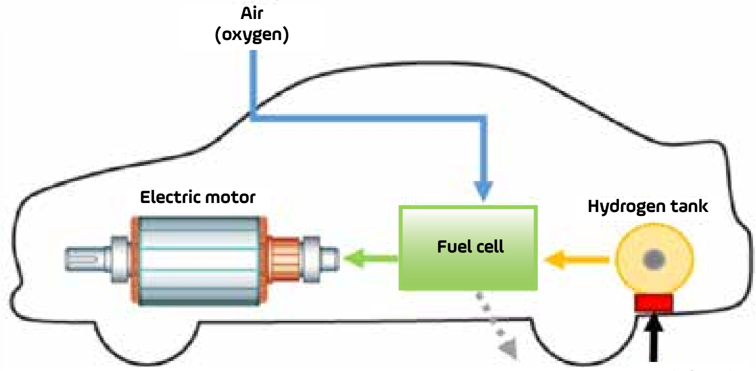
Hydrogen is an energy storage mechanism ... not a source of energy. So you have to get that hydrogen from somewhere. If you get [it] from water, you're splitting H_2O, electrolysis is extremely inefficient as an energy process... if you [take] a solar panel and use the energy from that to just charge a battery pack directly, compared to trying to split water – take the hydrogen, dump the oxygen, compress the hydrogen to an extremely high pressure (or liquefy it) and then put it in a car and run a fuel-cell, it is about half the efficiency, it's terrible. Why would you do that? It makes no sense.

Hydrogen or lithium?

The quest for pollution-free consumer transport

FCV or EV?

An EV runs off an electric motor and a Li-ion battery pack. In an FCV, though, it's hydrogen – stored under pressure – that flows to the fuel-cell stack. There it chemically reacts with oxygen, ultimately generating the current that powers the electric drive motor. Hot water, a by-product of the reaction, is manually discharged at the rear of the vehicle.



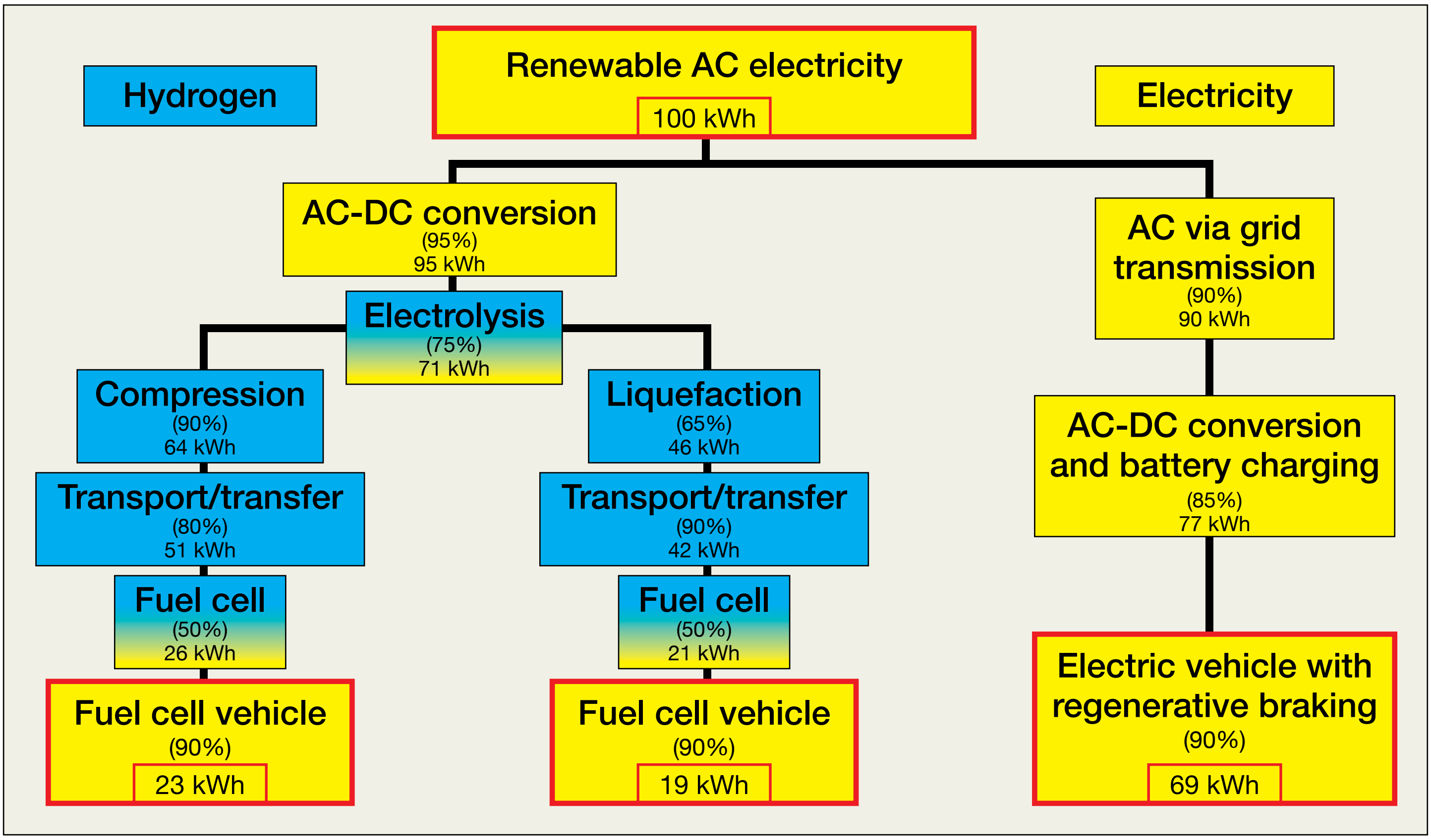
[Image courtesy of Firehouse.com.]

Since both FCVs and EVs draw their enegy from renewables and are close to emission-free (ignoring the costs in energy required to build wind and solar farms, etc., as well as the energy sources involved in manufacturing the vehicles themselves), then technically FCVs *are* EVs.

A quick comparison of FCVs and EVS reveals the following.

- Build costs are similar.
- Operating costs for EVs are about a third of those for FCVs.
- Unlike FCVs, EVs are grid-compatible.
- Currently, infrastucture for hydrogen refuelling is limited.
- EVs have a relatively long charge time, whereas FCVs can be refuelled in three minutes.
- Unlike FCVs, EVs are already well-established, with a rapidly growing market, as is the charging infrastructure for them.

FCV or EV?



Energy efficiency of FCVs versus EVs

(source: http://phys.org/news85074285.html).

Confusingly, too, not all FCVs are created equal, in that they can use either compressed or liquefied hydrogen fuel cells to power the car.

Then there's the matter of range. The weight penalty incurred in increasing the range of an FCV is modest, making it a more pragmatic solution to range anxiety than the alternative – increasing range in an EV means more batteries, more weight and more superstructure to carry that weight. From a practical viewpoint, then, EVs must incorporate next-generation Li-ion batteries to circumvent those range and weight issues.

So, from an environmental point of view, comparisons appear to favour hydrogen as a fuel source. However, the production, compression, distribution and storage of hydrogen involve numerous challenges, consuming enormous amounts of energy and thus being inherently inefficient.

These considerations, though, are not deterring Japan, which aims to be the first hydrogen economy in the world. Why? Because the country is small in terms of area, with high population densities, and the hydrogen infrastructure can be concentrated in small areas to service the large population.

Elsewhere, however, product advances are more likely to favour established technologies. Given that it's taken 30 years to perfect Li-ion batteries to the point at which they are truly effective in EVs, much momentum would be required to shift to an alternative at this stage.

From that perspective, what would it take for Li-ion battery technology, and therefore EVs, to reign supreme well into the future? Certainly, the following will play a large part.

- Cost reductions as production volumes increase.
- Greater energy-storage capacity resulting from changes in cathode chemistry (for example, lithium sulphur).
- Battery anodes with higher capacity (such as lithium metal, graphite/silicon).

With Li-ion battery-powered EVs, then, there is significant potential for cost reductions and removal of range anxiety and, given the leading position of such vehicles today, they are likely to rule the roost for some time to come.

And finally ... As *The Guardian* reports, this month Germany launched 'Combino' – the world's first autonomous tram – in Potsdam, west of Berlin. Articulated and powered by renewables, it's been developed by a team of 50 computer scientists, engineers, mathematicians and physicists at German engineering company Siemens. Although its makers acknowledge that Combino is still some way from being commercially viable, they consider it an important milestone on the way to autonomous driving. As one observer noted, " ... it's a bit like what it must have been to witness the transition from horse-drawn to steam trams, or gas to electric."

Which Perth-based company is currently engineering next-gen Li-ion battery precursors?

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The Power of 3
Driving the future further
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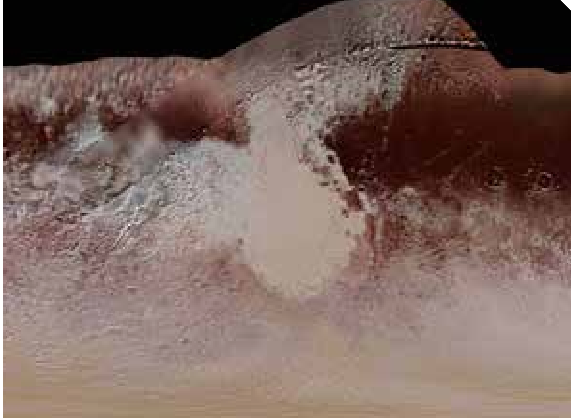
Back to the future

"The best way to predict the future is to create it"
~ Alan Kay

Overview



Global colour map of Pluto [collated images from NASA/New Horizons spacecraft].

The original *Blade Runner* movie, released in 1982, is set in a post-apocalyptic Los Angeles in 2019. There, humans and robot servants navigate the dystopian urban environment in flying cars, giant animated billboards hawk brand-name products and advertising drones blare announcements about the off-world colonies to which large numbers of Earth's population have decamped. While that bleak depiction of the future lacked much of the tech taken for granted today, it feels prescient nonetheless.

Nowadays, Sophia the Robot appears on TV, drones are ubiquitous, the first hyperloop capsule has been unveiled, Elon Musk's tilt at Mars and NASA's Mars and Pluto missions are harbingers of interstellar travel, vertical take-off and landing craft are being trialled as aerial taxis, and Elon (him again!) has foreshadowed a Neuralink product designed to seamlessly connect human brains to computers.

[Image credit: Pixabay.com/Geralt.]

Artist's impression of the skyport at Paramount Miami WorldCenter, under construction now.

Chinese scientists plan to send three artificial moons into space [ABC News – Jarrod Fankhauser].

Less beguiling, perhaps, than flying cars or the new 'moons' China is planning to put into orbit, the technologies outlined next – while not new – will gather momentum through 2019 and beyond. And, like species extinction and global warming, their effects will be far-reaching.

‘Harnessing the chaos of continual change’

Every year, global research and advisory firm Gartner Inc. lists what it considers the most important trends for businesses and organisations worldwide. At a symposium in Cape Town recently, Brian Burke, Gartner’s vice-president and head of research, described the future as an intelligent digital mesh of people, devices, content and service. It will, he opined, rely on a proliferation of artificial intelligence, cloud and edge computing and internet of things (IoT) platforms, with blockchain the digital guardian of privacy and security.

Artificial intelligence (AI)

AI, says the online dictionary, is “the theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making and translation between languages.” Knowledge engineering, machine learning and machine perception are all key components, and robotics a major field to which AI relates. And, when an artwork created using AI sells for around half a million dollars, perhaps no section of society is beyond its reach.

Gartner foresees a massive shift towards AI-enhanced virtual health care and facial recognition in particular and, more generally, says Burke:

... from stand-alone intelligent things to a swarm of collaborative intelligent things, with multiple devices working together, either independently of people or with human input. For example, if a drone examined a large field and found it was ready for harvesting, it could dispatch an autonomous harvester.

Cloud computing

Cloud computing relies on shared computing resources rather than a local server or personal device to store, manage and process data. A service provider like Apple’s iCloud, for instance, allows people to share resources, software and information and use applications from any device that can access the Internet, without the need to invest in hardware or infrastructure. Gartner predicts that the number of cloud-managed service providers will triple by 2020.

Edge computing

An edge device is any piece of hardware that controls data flow at the boundary between two networks. In so doing, it reduces the communications bandwidth required between sensors and a central data collection centre by performing analytics and knowledge generation at or near the source of the data. Edge computing focuses on devices and technologies attached to the ‘things’ in the IoT (see *The Power of 3*, issue 14), where speed and fast data are key: think asset management, process optimisation, supply chain management – in a hyper-connected world the list will go on and on. This has elevated the role of edge devices, ushering in the need for more intelligence, computing power and advanced services at the network edge.

IoT platforms

These are the digital ‘plumbing’ or middleware that connects edge devices with data-driven applications for end users, allowing information from sensors, devices, networks and software to come together and unlock valuable data that can then be acted upon.

As the flow of data from the IoT becomes a deluge (think sensor-intensive and thus data-intensive smart homes, smart buildings and smart cars, for a start), cloud storage, edge networking and IoT platforms will form the basis of next-generation services.

Blockchain

Originally devised for energy-draining cryptocurrency Bitcoin, blockchain technology allows digital information – not just financial transactions but virtually anything of value – to be distributed *but not copied*, creating the backbone of a new type of internet. Writing for Forbes.com, Gideon Kimbrell cites it as the new big thing in verifying identity and protecting privacy at a time when online data privacy legislation is being enacted worldwide. Says he: “People won’t be demanding blockchain, so businesses will have to lead the charge in transitioning to this system.” Despite considering blockchain technology ‘immature’, Gartner predicts its effect on businesses will be enormous, creating a massive US$3.1 trillion in value by 2030.

An autonomous vehicle for the farm: Yanmar’s YT5113A robotic tractor [source New Atlas].

And finally ... Fancy an ‘electric’ feed? *The Guardian* reports that Finnish researchers are close to commercialising a nutrient-rich protein with no input from animals or plants. Rather, the ingredients are hydrogen-oxidising bacteria, electricity from solar panels, water, carbon dioxide from the air, nitrogen, and trace quantities of minerals like calcium, sodium, potassium and zinc. The resulting compound is 50-60% protein, the rest being carbohydrate and fat. Solar Foods has teamed with a European Space Agency programme that helps start-ups with space-related business ideas – like how to make food on Mars. So, if Earth’s rivers dry up, bees are wiped out, crops fail and the only creatures left alive on the planet are human, there’s some hope after all ... provided Elon can get us there!

Which Perth-based company seeks to power and recycle future tech?

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The Power of 3
Driving the future further
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Smart gifts for Christmas and beyond

'I always like the gifts I get, but how I love the gifts I give!'
~ Carolyn Wells

Overview

The ongoing evolution of lithium-ion batteries (LIBs) has facilitated the development of a plethora of rechargeable consumer products (including electric vehicles) for just about every walk of life.

As year's end approaches, LIBs still take centre stage as the world's fastest growing and most promising source of portable power. Globally, vast amounts of time, money and effort are being invested in creating 'less with more' and today LIBs for portable devices are smaller, lighter and pack more punch than ever before.

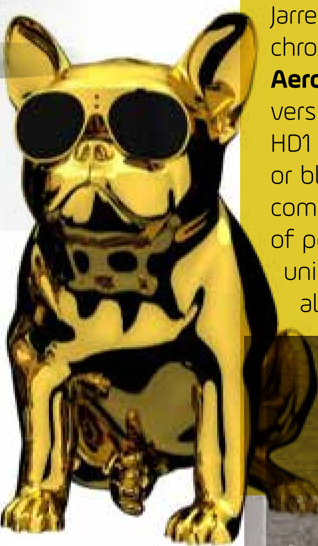
Meanwhile (as detailed in previous issues), in an increasingly interconnected world, mining companies, technology researchers/ developers and battery manufacturers everywhere are scrambling to meet demand for, and lower the cost of, these amazing storehouses of energy.

As the giving season approaches, check out some nifty devices designed with both fun and functionality in mind.

Pump up the volume

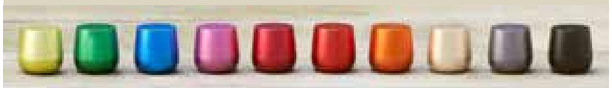
Music makes everything better, and what better way to play it than wirelessly?

Like Apple's AirPods (but pricier), **Sennheiser Momentum True Wireless earbuds** ditch pesky wires and anything around the neck. With Bluetooth support, access to Siri or Google Assistant and optional 'Transparent Hearing', which blends ambient sounds with the music being played (allowing for conversation or awareness of approaching vehicles), they promise to "redefine the audio benchmark for true wireless earbuds."



French bulldogs with bling? In this the Chinese Year of the Dog, Jarre Technologies (founded by French composer Jean-Michel Jarre) released 99 limited edition chrome-gold versions of its **Aerobull HD1** speaker. Cheaper versions of the fashion-forward HD1 puppy come in red, white or black. Smartphone/tablet compatible, they pack 200 watts of power, 2.1 amplification and unique 'Digital Sound Processing' algorithms. Woof!

Not wearable but eminently portable, the **Lexon Mino BT** speaker is small in stature but packs a punch in terms of sound quality. With Bluetooth and a USB charger, it's affordable and beautiful and comes in a range of stunning colours.



Cinema on the go

Resembling a VR device but not, **MovieMask Premium** provides a true cinema experience – anywhere, any time. Content is chosen on a smartphone, the phone is placed inside the device (adjustable for maximum comfort) and the wearer then watches their movie with full resolution (100% 1-1 pixel conversion) ... the mask works with glasses too. Magic!

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Tech for tots and teens

The **Dino-Lite digital microscope** comes with the power of surprise – it's amazing what can be seen! This hand-held device plugs into a computer, laptop, tablet or smartphone, shows from 10x up to 220x magnification and boasts four LEDs to illuminate whatever's examined.

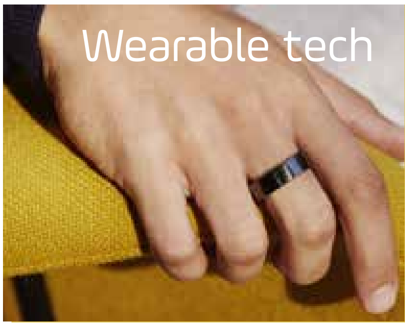
Sphero BOLT is an educational toy with staying power, designed to get budding programmers off to a great start. With a striking LED matrix and advanced sensors, this app-enabled robot provides endless opportunities to be creative and have fun while learning.

This tech IS a 'pet'

Now trending on Indiegogo, Nybble is an advanced robotic kitten that can be brought to life with a small computer, customisable software, a basic components kit and whatever upgrades/ mods its owner chooses, including choice of language. Patience and precision will unlock curiosity and joy.

Another fun, educational software-coding toy robot, the **Anki Cosmo** comes pre-assembled and fully tested, and can perform a variety of tasks when paired with the free smartphone app.

Wearable tech



For those who prefer wearing a watch to a wrist-type fitness tracker, the second-gen **Oura Ring** could be an alternative. Sleek and discreet, it monitors sleep, heart rate, body temperature, respiratory rate, steps taken, calories burned and more.

Tech for pets

Stimulate bored, home-alone pets with the crowd-funded **Mia** pet robot, founded on the idea that a curious pet will follow it around, deriving mental and physical stimulation in the process. Guilty pet parents can program it to dispense treats and it shuts off automatically if tipped over. Optional extras include the Wi-Fi equipped WoofBox, which notifies owners when their dog barks and can distract the animal when it does so, and the MiaCam, for those wishing to spy on their pet/s remotely.

And finally ...

Wary of overindulging at Christmas? **Lumen** may be the answer. Another crowd-funded device nearing release, it's designed to track and monitor metabolism through the breath, advising users on what to eat (and when) to reach their weight loss and fitness goals. Too good to be true? Wait and see ...

Which Perth-based company recently manufactured LIBs from processed mine waste?

ThePowerof3

ISSUE 29 March 2019

Driving the future further

Electric planes are taking flight

Overview

In October 2018 the UN warned that the rate of climate change is more rapid than expected and that urgent, unprecedented changes are necessary to reduce the risks of extreme heat, drought, floods and poverty globally – including cutting carbon pollution 45% by 2030.

While consensus on the issue is lacking, there's no doubt that aviation is a significant and growing contributor to climate change. Indeed, in 2018 air transport accounted for 2 per cent of man-generated carbon emissions. And, with the number of air passengers expected to almost double by 2036 to 7.8 billion per year, its impact can only increase substantially.

However, says Pacific Standard Magazine, replacing fuel-guzzling planes with electric ones could put a real dent in global emissions:

> *Electric aviation, long stymied by the limitations of battery technology, is finally taking off: battery-powered air taxis, passenger drones, autonomous aircraft, and even passenger planes are all under development by aerospace and aviation companies around the globe."*

But, says wired.com, achieving this aim means designing electric motors with the right power-to-weight ratio to take off and defy gravity once airborne. And, as with electric vehicles before them, both range and power demands are hindering the development of all-electric planes.

"The similarities between commercial airplanes and automobiles are striking. It's all about safe and efficient transportation using the latest technology and the best fuel efficiency."

~ Alan Mulally (former CEO, Boeing & Ford Motor Company)

VTOLs

Electric vertical take-off and landing craft (eVTOLs) that accommodate two to five passengers (or the equivalent weight in cargo) are already in development, with 300+ entities – including NASA, Boeing and Airbus – investing in this sector. Germany's Volocoptor (*issue 10*), for example, has an agreement with Dubai's Roads and Transportation Authority to regularly test autonomous air taxis there.

Meanwhile, work on Uber's 'flying taxi' service (*issue 19*) continues apace. Dallas and Los Angeles will be the first two launch cities, with Japan, France, Brazil, Australia and India being considered for third spot. Although Uber's plan to cram city skies with electric taxis is barely more than nascent, the company has already convened two summits and signed up numerous partners to assist it.

Image courtesy of Uber.

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Airbus E-Fan X hybrid electric flight demonstrator

Short-term

Icy conditions, heavy winds and rugged, mountainous terrain notwithstanding, Norway boasts some of the busiest flight routes in Europe. And, despite being western Europe's largest exporter of oil and gas, its stated aim is that of being 'Powered by nature'. Ergo, Norway plans to lead the way in the market for electric planes, initially with small aircraft on relatively short hops. That said, the country's largest carrier, Norwegian Air, like other major airlines, won't go there until the technology matures and the commercial machines of today are replaced by fully proven electric airliners.

Elsewhere (and part-funded by the UK government), Rolls Royce – the aerospace, power and defence company, not Rolls Royce Motors – is entering the fray as part of the 'Accelerating the Electrification of Flight' (ACCEL) project, a joint venture between it, electric motor manufacturer YASA and aviation company Electroflight. They plan to develop the world's fastest electric aircraft by next year, using the experience to go on and build an electric passenger jet.

Meanwhile, British-based budget airline EasyJet, in partnership with US start-up Wright Electric, has promised a fleet of electric planes to cover short-haul routes as soon as 2030.

Longer-term

Having announced it will cease production of the A380, its 'super-jumbo flying palace' (the second most iconic aircraft to be retired after the Concorde), Airbus has embarked on another ambitious project.

In partnership with Siemens and Rolls Royce (and with financial support from the UK government), Airbus is developing the pioneering Airbus E-Fan X hybrid-electric flight demonstrator, the next step in an electrification journey that began with the all-electric, battery-powered, two-seater E-Fan. Since then Airbus has produced the hybrid E-Fan 1.2, which combined a 60 kW motor with a combustion engine. While these were major achievements in their own right, the steps between each were incremental, whereas the E-Fan X is by comparison a huge leap forward.

Key to that leap are rapid advances in battery and fuel-cell technology. Each of the industry partners will focus on developing certain parts for the E-Fan X, with manufacturing to begin this year. Airbus will be responsible for overall integration of the electric motor into the test aircraft, with ground testing to follow.

Boeing too is developing hybrid-electric aircraft technology for journeys of 500 miles or less and capacity for up to nine passengers, while its venture capital arm, HorizonX, has invested in aerospace and manufacturing start-ups that include Zunum Aero, the latter promising delivery of its first electric aircraft in the early 2020s.

Mid-century

As with the revolutionary Concorde of the 20th century, conceptualised way before the technology caught up, the commercial electric planes plying the skies in years to come are already on the drawing board, many awaiting better battery technology to make them a reality.

And those battery improvements are emerging almost as fast as the aircraft designs themselves. With so many plane and engine manufacturers investing in electric aviation, the goal is to replace conventional systems by 2050, reducing emissions, noise and travel costs in the process.

And finally …

UK-based Astigan Ltd's A3 High Altitude Pseudo Satellite (HAPS) is bringing map-making into the 21st century. An unmanned solar-powered aircraft, it will fly at an altitude of 67,000 feet (~20,500 metres) – nearly twice the cruising height of a commercial airliner – for up to 90 days, bridging the gap between aerial and satellite surveys for more accurate, higher-resolution map-making and other applications. Using HAPS, existing maps can be updated and geospatial databases created for areas where conventional surveys are unviable. It could even monitor transient events like shifts in the ice caps or oil spills in real time, and benefit areas such as smart cities and autonomous vehicles, which rely on accurate 3D mapping.

Which Perth-based company is developing next-gen battery technology?

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Driving the future further

Overview

Often, industry analysts seize on the current statistics for lithium supply and demand as indicative of long-term trends in the market for this valuable commodity.

For many, it seems, the rapid increase in hard-rock production, combined with a slower-than-anticipated uptake of electric vehicles (EVs), is a sure sign that with respect to the lithium price, the sky is about to fall in – they forecast a glut in supply that will send the value of lithium, and the chemicals produced from it, tumbling fast.

Look closely, though, and nothing could be further from the truth ... at least not on the supply and demand sides of the equation.

Part 1

Infinite Lithium

The effect of competition

As with all commodities, the lithium price is driven by supply and demand. That said, competition is also a great enabler. As more lithium players enter the market and supply increases, inevitably there will be downward pressure on price. But, if lithium prices do soften, the bonus is that lithium-ion batteries (LIBs) will be cheaper. Why? Because the chemicals they contain represent a large proportion of the cost of those batteries (which remain relatively expensive). So, if the price of the main commodity (lithium) required to produce the battery chemicals falls in line with current projections, so also will the price of LIBs, which are very much in demand.

The *Australian Financial Review* noted recently that, in February, the Canadian Dutch metals tracker Adamas Intelligence cited 76% more lithium carbonate equivalent (LCE) being deployed worldwide in the batteries of new electric, plug-in hybrid and hybrid electric passenger vehicles compared to the same month in 2018. The research company, which monitors EV registrations and battery chemistries in more than 80 countries, averred that among all metals and materials found in EV battery cathodes, lithium use saw the greatest gains.

And, according to *Bloomberg*, the Global X Lithium & Battery Tech ETF (exchange-traded fund) – valued at less than $US50 million in early 2016 – had by June 2018 received more than $US900 million of net inflows.

Moreover, a recent *Renub Research* study tipped the global automotive LIB market to surpass $US65 billion by the end of 2024, it being underpinned by growing government support for clean energy and environmentally friendly modes of transport.

Reaching economies of scale in LIB production will be a significant step in decreasing the overall cost of EVs, which are expected to surpass traditional vehicles in market share by 2038.

So, lithium 'glut' or not, significant pricing pressure on lithium chemicals will lead to competition among battery manufacturers in the first instance, with EV producers to follow, and have a major influence on cost outcomes right across the board.

Capacity

In terms of lithium supply, production of spodumene (hard-rock production) is expanding the most rapidly worldwide, it being the mineral feed source for most lithium-concentrate refining operations (generally referred to as 'converters'). It is the capacity constraints of these converters that limit the delivery of lithium chemicals to battery producers … and in so doing inhibit the ability of the EV industry to meet global demand for such vehicles.

In other words, the fact that EV uptake is not meeting projected trends is due neither to a lack of demand for EVs nor a problem with the supply of the lithium itself to feed that demand – the issue is that of insufficient downstream processing capacity.

Nor are increasing stock levels of spodumene concentrates symptomatic of lack of demand for lithium; rather, they too are are indicative of insufficient conversion capacity.

Easing constipated supply

New refineries committed to or currently under construction will help alleviate constraints in the lithium chemical supply chain, allowing for a better match between lithium mine capacity and demand not just in the EV space but also for energy storage.

It appears, though, that as new refining capacity is brought on line the supply pressure point may result in the unfortunately-longer-than-planned commissioning of battery megafactories. Tesla's, for instance, are yet to achieve full design capacity and it seems other plants are experiencing similar issues. This means that, potentially, the 2030 targets outlawing new internal combustion vehicles (ICVs) may be almost impossible to attain in that time frame. But will that affect the price of spodumene? Probably not.

Demand seems infinite

Today's most common LIB chemistries consume approximately 700 grams of lithium per kilowatt/hour (KWh) of storage capacity. Since around 1.5 terrawatt hours (TWh) per annum of LIB production capacity will be installed by 2028, it's easy to see how supply constraints could arise.

Such capacity will require about 700,000 tonnes of lithium annually (equating to ~3.6 million tonnes of LCE). Given that current levels of LCE production are barely above 200,000 tonnes per annum, an increase in the production of lithium chemicals in the order of **15-fold** will be required over the next decade to meet future EV demand alone. (In fact, that volume equates to the roughly 50 million new EVs required annually to replace the ICVs due to be outlawed in many jurisdictions – including much of Europe, as well as China and India – by 2030.)

So, despite what's happening in Australia – where production of lithium concentrate is escalating rapidly – it's unlikely that either primary supply or new LCE production can meet demand globally in the longer term.

Satisfying demand for lithium requires not only greater resource utilisation (improved recoveries) but also exploitation of less conventional sources of this element.

Drivers of demand

As mentioned, commentary on demand for lithium (and LIBs), and the reasons why, is ongoing and ubiquitous. Suffice to say here (as in previous issues) that the commitment of many nations to the **Paris Agreement** and the subsequent **One Planet Summit**, as well as campaigns like **EV30@30**, is indicative of policy goals globally (with Australia and the US notable exceptions).

Also as detailed in past issues, original equipment manufacturers in the vehicle industry have hit the ground running, with the majors announcing the introduction of EVs across most of their range.

In fact, the figure of around 50 million new EVs by 2030 that was mentioned earlier could well be eclipsed by factoring in consumer demand.

Moreover, off-grid, supplementary and renewable power applications – which all necessitate energy storage – will be big contributors to lithium demand, despite the lack of weight afforded analyses of this sector.

Australia currently represents the largest market for domestic energy storage, with the South Australian government announcing subsidies for 40,000 household units. In Western Australia, meanwhile (where 30% of power distribution costs service only 2% of the population), there is a huge imperative to go off-grid. Indeed, electricity utility Western Power has plans to establish 25,000 remote-area power units, complete with battery backup, to rationalise its per-capita distribution costs – a potential benefit for all consumers in that state.

With respect to demand for energy storage overall in Australia, utilities are at the fore – South Australia already hosts the world's biggest battery (courtesy of Elon Musk), and batteries are being used by diesel power stations to achieve superior load sharing and reduce the **spinning reserve** that would otherwise be required.

And finally … Speaking of EVs, electric now has a Mercedes:

"Here we are again. Back where we were 130 years ago, when we invented the car. At the start of something really great. That's what the first drive in the EQC feels like. Without a single drop of petrol, with no local emissions, and with no trouble whatsoever – it changes everything. Join us as we embark on the next 130 years."

After a long period of intimations, the Mercedes EQC is finally rolling off production lines in Germany. With an 80 kWh LIB pack linked to two electric motors (one on each axle), it's all-wheel drive with around 450 kilometres of range … and it can tow up to 1,800 kilograms. Just the thing for a spot of glam weekend camping, boating or fishing. Expect it later this year …

Which Perth-based company is closing the loop on energy metals?

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Driving the future further

Infinite Lithium

Part 2

Overview

As noted in *issue 30*, many industry analysts have seized on recent statistics for lithium supply and demand as indicative of long-term market trends. Some forecast a glut in supply that would send the value of lithium – and the chemicals produced from it – tumbling. Closer examination reveals this is far from the truth, but – and it's a big 'but' – how can 'infinite lithium' supply be achieved?

Alternative sources

Current mining expansion won't meet lithium demand longer term, and as the mines mature production will dwindle. New mines sourcing lower grades can come on-stream to fill the gaps, but alternative sources of lithium may prove more attractive as genuine supply shortages put pressure on conventional production. So, what are some of those sources?

As Earth's 'throwaway society' matures and (hopefully) develops a culture of custodianship for the planet, recycling will replace new materials as the preferred source of supply. When the market matures to the point of product saturation, with continual expansion no longer required, demand for, and the recycling of, lithium will synchronise. If that does happen, newly mined material will only be necessary to top up that regained through recycling.

Such a scenario seems a long way off though, and if global population continues to increase by around 1.07% a year (82 million people), it may never be realised. In the meantime, meeting the exponentially increasing demand for lithium has many in the industry scratching their heads at how to achieve this.

Potential sources of lithium to meet future demand include:

- seawater;
- geothermal and oilfield brines;
- recycling of spent lithium-ion batteries;
- lithium clays;
- waste from conventional spodumene processing, and
- lithium micas found in pegmatites and greisen.

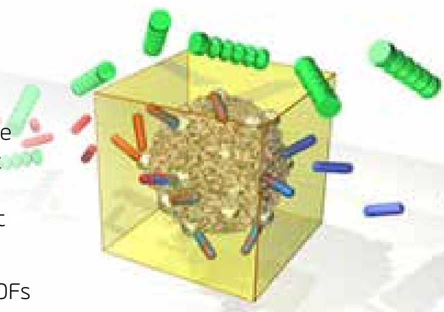
Seawater

Seawater contains lithium in very low concentrations (around 0.17 parts per million) but has attracted interest as a potentially commercial source. Approaches that involve evaporation ponds won't work, due to the large volumes of water required. Also, seawater contains many other dissolved minerals, so traditional separation technologies like membrane filtration, ion exchange (a reversible chemical reaction to remove dissolved ions from solution and replace them with other, similarly charged ions) and reverse osmosis would involve not only huge energy consumption but also fouling of the filtration media and/or regenerants.

The amount of lithium in solution can certainly be boosted through evaporation, adsorption (where atoms, ions or molecules adhere to a surface to create a film) and electrodialysis (where ions are driven through a selective membrane, then separated and concentrated under the influence of an electric field), followed by purification and, finally, the precipitation of lithium carbonate. Viable lithium recovery is certainly achievable where the medium contains higher initial lithium concentrations.

Metal-organic frameworks (MOFs) could be another approach. MOFs are crystalline powders full of molecular-sized holes. Made of metals joined by organic linkers, they can store, separate, release or protect just about anything.

In addition to seawater, MOFs have the potential to recover lithium from both produced water and wastewater streams, though they have not yet been implemented on a large scale.



Here, the large green molecules are excluded from the MOF and don't interact with it. The smaller red molecules do, and are changed into blue molecules by it. [Source: CSIRO.]

Geothermal and oilfield brines

The recovery of lithium from geothermal and oilfield brines has been much studied. Usually, the solution phase is targeted, although sludge and scale precipitated as a result of changes in pressure and temperature have also been evaluated. Recovery techniques investigated include ion exchange, adsorption, membrane filtration, and precipitation.

Again, the low concentrations of lithium in such sources are challenging in terms of processing and, in the case of oilfield brines, the expense of pumping from great depths.

Although lithium has been recovered from geothermal brines in Japan and New Zealand, bids to recover it and other metals from the Salton Sea geothermal field in the United States (where lithium could be considered a by-product of geothermal power) have not succeeded.

In the Cornish tin belt in the United Kingdom, tin and copper – as well as other volatile and incompatible elements, including lithium – are found in hot springs in many mine workings. This has led to assessments of mine water as a potentially commercial source of lithium and prompted regional exploration for other lithium brine occurrences.

Recycling

Worldwide, enthusiastic adoption of lithium-ion batteries is causing great environmental concern since, once depleted, most end up in landfill. Presently, only around 9% are recycled (in Australia, it's less than 3%!) to recover the valuable metals they contain. In fact, the huge quantities of batteries discarded globally could prove asignificant lithium resource.

Belgium, South Korea, China and Canada recycle the most spent batteries, usually by smelting. However, the extreme volatility of this form of processing is disadvantageous in terms of recovering lithium, which is usually lost in flux or off-gas. Flux is generally used as aggregates and fillers rather than reprocessed, precluding reuse of the lithium, but research into recovering lithium via condensation of smelter off-gas is now being undertaken.

Meanwhile, the shortfalls inherent in battery recycling are spurring research and development into alternative, more efficient processes.

Lithium clays

Lithium clays, albeit low-grade in comparison with more conventional hard-rock lithium deposits, have also garnered attention in recent times. Deposits in Mexico have already been metallurgically assessed and future production from the region is anticipated. Other lithium clay deposits – including in Nevada – contain both lithium and boron. All such clay deposits are challenging in that lithium recovery can be very energy-intensive.

Spodumene processing

Spodumene (hard-rock) mining and concentrate production are other areas in which alternative methodologies could facilitate resource utilisation and production of considerably more lithium from each tonne of ore extracted. With conventional processing, only relatively coarse spodumene is converted into lithium chemicals, while finer particles are discharged as waste. Now, new processing technologies that improve recovery and utilise material unsuitable for conventional lithium conversion are in development. They present the industry with a great opportunity, since their implementation could supply battery manufacturers with far more lithium chemicals without any increase in mine production.

Lithium micas

Lithium micas are the world's most abundant lithium minerals. Lepidolite in particular is commonly associated with tin, tantalum and tungsten mineralisation. Mining operations for those elements often discharge vast quantities of lithium micas as waste ... and that waste seems an obvious target for lithium production, since the costs of extraction and some processing are already covered by exploitation of the primary minerals. That said, innovative processing technologies are required to turn lithium micas into a practical source of critical metals. Indeed, they could even see the lithium element of such mining operations become the initial target, with the tin (or other metals) a by- or co-product.

"To infinity and beyond"

If demand for lithium-ion batteries grows beyond the pundits' wildest expectations, which it seems it may, then conventional sources of lithium supply simply won't cope with demand. Unconventional sources will have to fill the gap. How, and when, those will be exploited is the fundamental question.

And finally ...

Bentley's EXP 100 GT – a "car that connects with its passengers" – is still at the concept stage, but the jury's out on this one!

Which Perth-based company is exploring several unconventional sources of lithium supply?

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