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## Batteries & Energy Storage Technology

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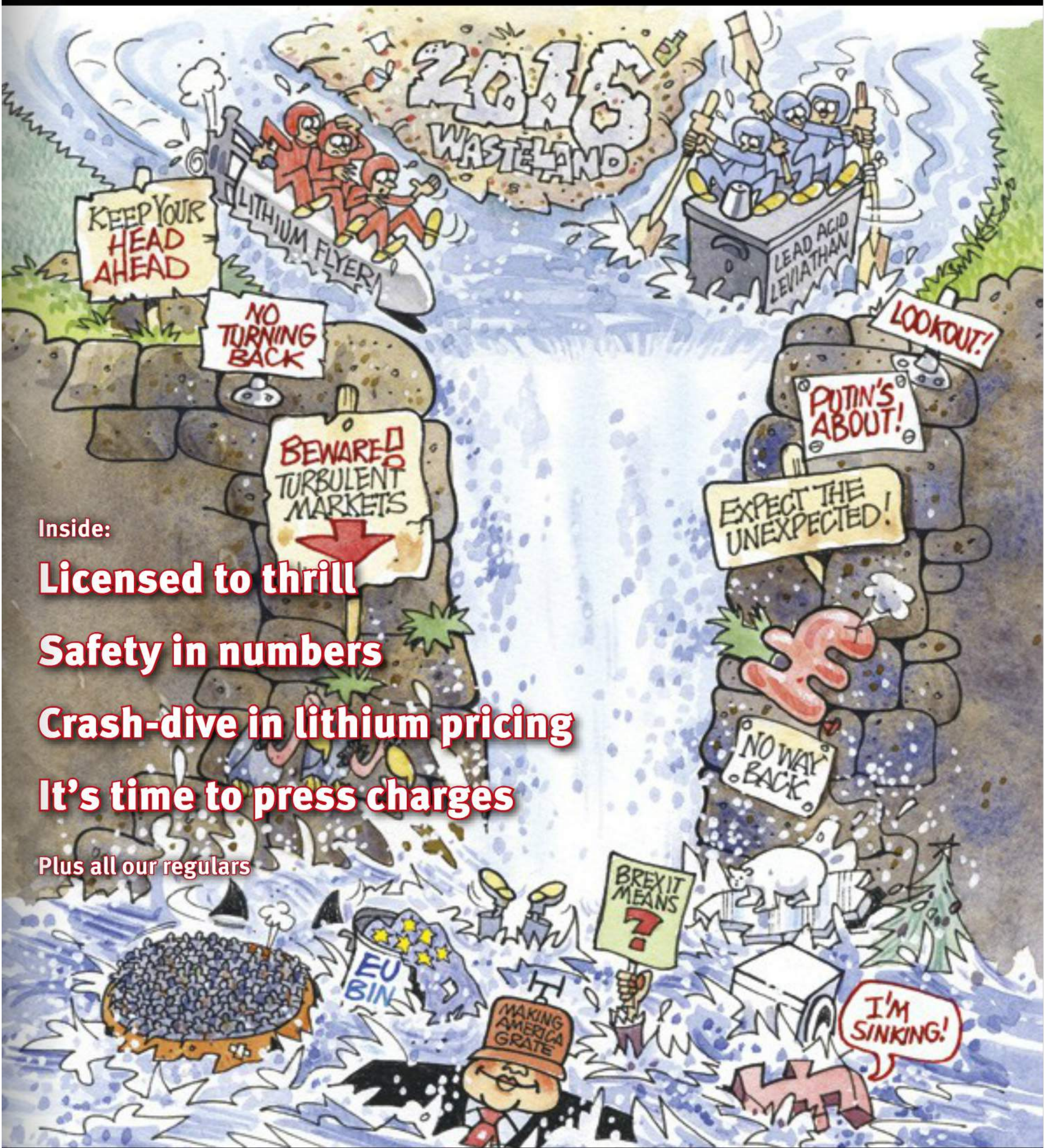


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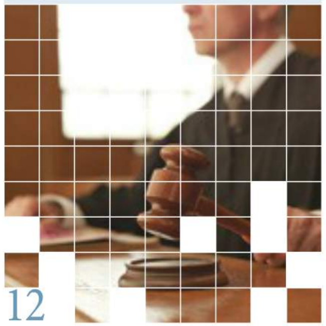

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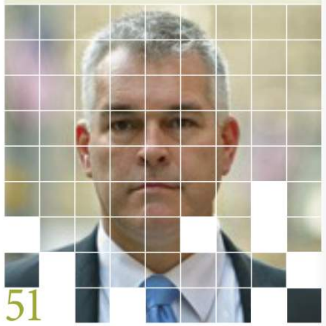

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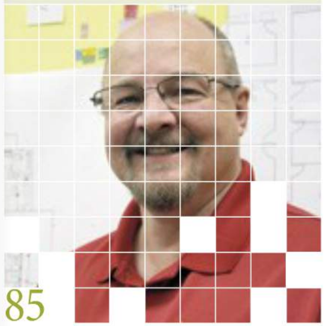

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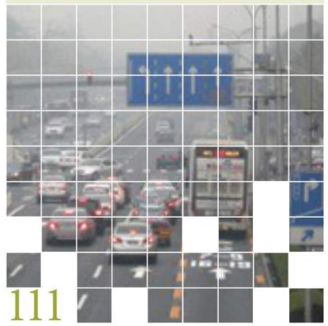

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# EV and ESS lithium-ion demand boosting battery-grade graphite market

Legislation, burgeoning green life-style trends and falling cell prices are making the motive power and energy storage markets an increasingly profitable market for the battery supply chain, as Deputy Editor Paul Crompton found out.

The Energy Storage System (ESS) and electric vehicle (EV) markets have been steadily growing in the past ten years. Now more than ever batteries are at the heart of the world's great 'Green' future storing renewable energy, powering transportation and even the electronic chains that shackle all of us to social-media gadgets.

At the heart of each stationary ESS, EV pack or smart-phone is a battery, and more and more commonly it will feature lithium-ion technology. But lithium is only a small part because each battery requires 20 times more graphite than the battery's core cathodic material.

To those outside the battery industry, graphite is something you draw with or make golf clubs from; within the industry it's the critical input material that comprises the lithium-ion battery's anode.

*Graphitic material from Alabama Graphite Corp's Coosa Graphite Project in Coosa County, Alabama, USA.*

So with even the most rudimentary knowledge of the EV and ESS markets it's easy to see why industry forecasters such as Benchmark Mineral Intelligence (BMI) predict demand for natural and synthetically produced graphite is set to increase from 80,000 tonnes per annum (tpa) in 2015 to at least 250,000 tpa (or as much as 400,000 tpa) by the end of 2020.

That's around 360,000 tonnes of medium flake graphite needed as a feedstock source by 2020. Increasingly that feedstock will come from natural sources; approximately 65% of all battery anode material is sourced from natural graphite, with 30% coming from synthetic graphite material and 5% from other alternatives including lithium titante, silicon and tin.

For example the average output of a Chinese mine is around 11,600 tpa, according to BMI, but forecasters believe by 2019 a 'Gigafactory' will need ten times that amount of graphite to keep up with production. So, if Elon Musk's boast that his Tesla 'Gigafactory' in Nevada, US, will be 150GW it'll need 110,000 tpa of coated spherical graphite. And, let's not forget, that is just one of 12 similar sized plants that are popping up,

*Donald Baxter of Alabama Graphite Corp*

or proposed, in China, Europe and the US.

Currently Asia-Pacific is the largest producer of the world's graphite: China (780,000MT, around 66% of global output) and India (170,000MT) in 2015, according to the US Geological Survey. Those two countries may eclipse the next eight (224,000MT combined), but new mining areas are popping up all the time.

Last year BMI reported that China produces 100% of the world's spherical graphite—predominately sourced from mines in Heilongjiang province in the country's north-east, but that percentage is changing. The firm forecasts 70% of demand for raw materials will come from China as the country's cell manufactures, such as ATL and Lishen, expand operations and a planned seven 'Gigafactories' come online in the country.

**Why graphite is a battery's best friend**

Graphite is an allotrope of carbon, named by Abraham Gottlob Werner in 1789 from the Ancient Greek (graphō), 'to draw/write'. It's used in a number of applications, including pebble-bed nuclear reactors— but an increasing number of graphite mining firms are looking toward the battery industry as a new business stream. And, according to researchers, around 80% of graphite used in batteries was used in lithium-ion batteries in 2012.

But not all things are equal when it comes to battery-grade graphite. It's important to remember the graphite used in the battery industry comes in two forms: natural and synthetic. One is cheaper, the other easier to ensure a consistent quality.

Edward Goodrich Acheson invented synthetic graphite in the mid-1890s when he discovered that overheating carborundum produced almost pure graphite.

Currently around 46% of synthetic graphite comes from China. Companies such as Panasonic, which manufactures much of Tesla's lithium-ion batteries, use synthetic graphite, primarily because of security of supply. But at around $20,000 per tonne, compared to natural coated spherical graphite at $8-12,000 tonne, its costly. But not only does synthetic miss the mark when it comes to the bottom line, it's also an incredibly energy intensive process to produce and not at all aligned with the spirit of 'green energy'. To make synthetic graphite powder, manufacturers mix a special kind of needle petroleum coke with pitch (typically obtained from the bottoms of oil refinery tanks). The lumps are pulverised, coated with pitch and then pass through several heating stages before graphitisation.

"Mesoarbon microbeads (MCMB) graphite was the first kind used in lithium-ion batteries," said Donald Baxter, president, chief executive officer and executive director of US-based graphite development company, Alabama Graphite Corp. (AGC).

"It is made by carbonising and graphitising pitch particles. It has lower capacity (around 20%) than natural graphite and is up to three times the price.

"Natural battery-ready graphite is better because once purified to around 99.5%, by cleaning out the layers, it ensures the pathways are clear of silica or other impurities that would knock off the capacity of the battery.

"Synthetic graphite is porous, with lots of nooks and crannies for impurities to get into and build up, which will eventually affect the capacity of the battery."

**Natural is best**

In the natural sphere, flake graphite is used in most rechargeable lithium-ion batteries; less than 10% of other materials are used, with the alternatives having lower capacity and higher costs.

There is no feasible anode material replacement for graphite on the horizon, says Baxter. "All have significant commercialisation problems – cost and, more importantly, safety concerns.

"Natural flake graphite is the dominant material of choice for the anode in a lithium-ion battery because it copes well with the expansion that comes with lithium intercalation. Graphite anodes have a very low expansion and it is important to note that all other potential substitution anode materials (e.g. silicon, tin, etcetera) expand considerably, by many 100s of percent."

Flake graphite is subdivided into large, medium and fine sizes and is the most common form of natural graphite (other forms of natural graphite are amorphous and vein/lump). Formed in metamorphic rocks or calcareous sedimentary rocks, the grade of flake graphite ranges from 2-20% Cg, and the purity varies from 85-95% carbon after refining.

Unlike most things in the natural world, size matters when it comes to flake graphite. That's because you cannot use graphite thicker than the anode paste, which is around 100 microns, because if it sticks out of the paste, it can create paths that reduce a battery's capacity. The principle grade used is d50 20 +/- microns. But sizes as low as 10 microns are used.

"The smaller the flake the shorter the path for the lithium-ion to fill the graphite gallery," says Baxter. "But it is difficult to spheronise very small graphite flakes; the surface area is higher, so less graphite can be incorporated without exceeding viscosity limits of the machinery."

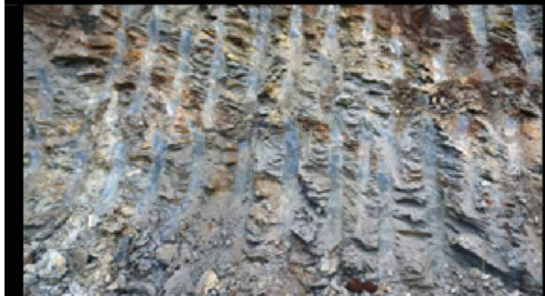
> "Unlike most things in the natural world, size matters when it comes to flake graphite."

The production of natural graphite is kinder to the environment as well. AGC's method for producing its battery-grade material is based on a modified purification process, originally patented in the 1950s, and begins by excavating the mineral ore before taking it to a primary processing plant, where it is processed via flotation. At this stage the graphite concentrate will be around 96% Cg and is now ready for the secondary-processing plant.

During the secondary processing, the graphite concentrate is then dried and heated in the presence of chlorine that converts the impurities into volatile chlorides, referred to as a low-temperature carbo-chlorination purification process. The impurities are undesirable and harmful to the performance of the lithium-ion battery cell, therefore, impurities must be removed to less than 0.05%. The ≥99.95% purified graphite is then micronised and spheronised (or rounded, made into a potato-like shapes).

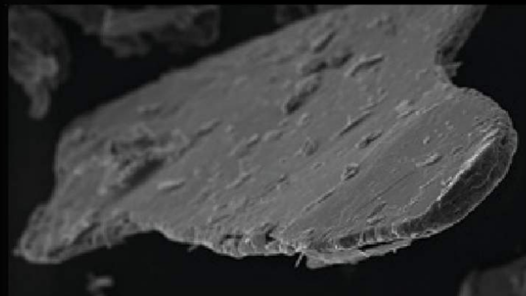
AS Tyler Dinwindle, executive vice president at AGC said: "One cannot have a 'green' car with a 'dirty' battery. Unlike with the production of synthetic graphite or natural graphite produced in China via hydrofluoric acid purification, AGC has demonstrated its sustainable, environmentally responsible purification and production process and, further, tested its battery-ready graphite performance in lithium batteries."

Finally, the spheronised graphite is coated with carbon to control the anode's reaction with the electrolyte. This is the product AGC intends to sell—trademarked as 'ULTRACSPG™'.



*Graphite smear from the Coosa Graphite Project.*

*Alabama Graphite's.7% Cg graphite concentrate produced from the Company's Pilot Plant.*



*An SEM image of Alabama Graphite's 99.99% Cg purified graphite – the feedstock material to produce the Company's sourced and made in America ULTRACSPG™ coated spherical battery-ready graphite.*

*An SEM image of Alabama Graphite's 99.95% Cg ULTRACSPG™ battery-ready graphite.*

The company is also the only firm building a business model based on exclusively supplying the battery industry, and not selling primary graphite. "The bottom line is the battery industry is going to be tremendous for us. Not merely a graphite mining company, AGC plans to become a green-energy supply-chain producer. We are providing a sourced-and-manufactured-in-America solution and sourcing claims are tremendously important to certain potential US end users, namely the US Department of Defense lithium-ion battery manufacturers," says Baxter.

The last stage of the mine-to-cell process comes with the battery maker, who will mix the spheronised material with a polymer binder solution and apply it to a thin copper foil substrate (conductor). This is then heated to remove solvent and calendered to the correct thickness. The anode is then ready to be combined with the separator, cathode and electrolyte to make the final cell.

Other materials such as silicon should be better for use in lithium-ion anodes, in laboratories at least. However, silicon expands by about 400% of its volume— this causes fragmentation, loss of electrical contact and results in a very short cycle life— not ideal criteria for the health and safety brigade.

So, for now, natural battery-ready graphite remains the safest, most cost-effective anode active material in commercial lithium-ion batteries.

## The Emperor's new material

A third element of the graphite industry is graphene. Either the best thing since sliced bread, or a promotional tool used by junior mining firms to raise funding. Apparently if your graphite supplier is talking graphene, then it probably isn't worth continuing the conversation.

However, its reputation (depending on your viewpoint) has been growing in the battery industry since the 2010 Nobel prize in physics went to Andre Geim and Konstantin Novoselov, who isolated and characterised it in 2004.

Graphene is the one-atom-thick layer of carbon atoms arranged in a two dimensional hexagonal lattice. It is the building-block of graphite (imagine the graphene as sheets of paper and the graphite a stack of those papers).

> **"On paper that's "manna from heaven" for the battery industry, as manufacturers try to produce better, lighter and more powerful cells as the EV and ESS industries expand."**

It reputation is built on its two dimensional properties, which effects the material in ways scientists are only just learning to understand.

Because graphene is perfectly crystalline and the atoms packed together in an regular array, battery makers can make very small devices out of them. Because they are small the electricity passes across them quickly and because electricity goes so quickly any way the hope is that super-fast transistors can be made out of graphite.

On paper that's 'manna from heaven' for the battery industry, as manufacturers try to produce better, lighter and more powerful cells as the EV and ESS industries expand.

However, graphene is more a materials process, says Baxter. "If you talk about graphene— an advanced nanomaterial that multi-billion-dollar multi-nationals are trying to figure out and without much success I might add. Graphene, especially as it pertains to a graphite development company, is promotional. We stay away from talking about graphene, which is only about a $12 million unestablished industry, compared to the well-established multi-billion-dollar battery-ready graphite industry."

So with graphite's reputation hardened amid a billion-dollar industry, it will come as little surprise to know mining firms are trying to muscle into the sector— either adjusting its business model or making claims on their 'superior' product.

To this end Australian firm Kibaran Resources Limited (KRL) aims to target anode manufactures outside China (despite 43% of passenger car plug-in EVs being sold there in 2016).

Currently lithium-ion also dominates the ESS market, where 300MW/500MWh of utility-side meter energy storage projects came online in the first six-months of 2016, and 1.8GW of behind-the-meter installations is expected in 2016 due to a surge of use in the US, Australia, UK and Germany.

## Faster, cheaper, better

With this in mind, mining affiliated firms are attempting to make better and cheaper battery-grade graphite for the rapidly growing EV and ESS markets.

And with no industrial scale lithium-ion battery recycling process in place at the moment— although there is a discussion paper on the subject going around the Australian government and a plant in Europe— guys like Musk, who has a foot in both the EV and ESS camps, will have to source spheronised graphite (natural or synthetic) from somewhere, and lots of it, as we saw earlier.

Kibaran is only one of a plethora of firms announcing it has produced 'superior quality, battery-grade' graphite from its mines.

The company, like many others, is aiming to establish a vertically integrated business model—from its Epanko Project mine in Tanzania to graphite production; and all to supply the lithium-ion battery market.

Samples of KRL's graphite, produced under commercial production conditions, have been sent to anode manufacturers in Japan for testing via graphite trader Sojitz Corporation. The firm claims tests show its graphite has a high carbon content, high tap density (allowing more active material to be packed into the battery to increase capacity) and low impurities.

Kibaran's managing director Andrew Spinks said: "Kibaran is capitalising on the strong forecast growth in demand for battery-grade graphite from the booming lithium-ion battery industry."

## Purity key to better product

Another firm angling for a portion of the anode market is Canadian minerals company Elcora Advanced Materials. Its method claims to reduce or eliminate the need for spheronisation, purification and coatings, and is designed to reduce the carbon and energy footprint of the anodes. Of course, this has the beneficial side-effect of reducing costs.

The company aims to source graphite from different mines to minimise supply risks and ensure sufficient volume. Tests are currently underway with industry experts to prove the technology and to design a production facility.

Troy Grant, president and CEO of Elcora, said: "With the significant increases in the electric car market over the next ten years this is an exciting focus on downstream technologies to maximise value."


*Talga Sweden project map*

Earlier this year Australian firm's Talga Resources' threw its hat in the ring when its Swedish ore was shown to require less milling, purification, shaping or coating to meet commercial level performance in capacity over 100 cycles in cell tests.

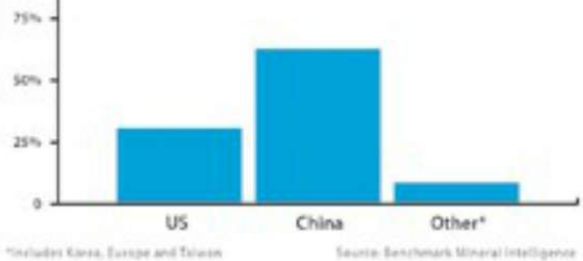
Independent test-work was carried out at the Max Planck Institute of Polymer Research and Dresden Technical University in Germany using samples of Talga's Vittangi feedstock. Tests showed the graphite ore had a first charge capacity of 375mAh/g, a first discharge capacity of 481mAh/g and average charge capacity over 100 cycles of 357mAh/g.

Vittangi predominantly consists of flake graphite that is naturally less than 15 microns. Its managing director, Mark Thompson, said the results were significant because charge capacity results matched, and for a period, surpassed those from batteries reliant on industry standard spherical graphite anodes.

"The difference being that Talga's sample came in a relatively raw natural state and did not require energy hungry milling and toxic refining steps," he said.

"Aside from operational cost reductions without micronising and spheronising, any opportunity to avoid significant capital outlay on complicated spherical graphite plant and equipment is a huge bonus."

EXPECTED NEW LITHIUM ION BATTERY CAPACITY IN 2020




## Strength to strength

In an industry where battery makers and researchers are trying to squeeze every last drop of energy density from its technology, graphite holds an exciting place in the future.

The industry is also moving from synthetic graphite, with its inherent uniformity, to the cheaper and increasingly better quality natural flake graphite. This is especially true as firms like Alabama Graphite seek to harness the financial benefits of supplying directly to the battery industry. As a result firms are aiming to make their product better, or at least making claims to its superiority. Just look at the reports about that latest contender, graphene.

So while lithium-ion technology continues to be used in a greater number of EV and ESS applications, the graphite industry, in all its guises, will go from strength to strength.