LIGHTS, BATTERIES, ACTION!

High purity alumina (HPA) is critical to LED production. Demand for LEDs has surged since 2010 and this demand now accounts for over half of the world's HPA consumption. But HPA is also being used as coating material for separators in lithium ion batteries.

Dr Richard Flook explores the high purity alumina market and the Australian production projects looking to feed the growing demand.

High purity alumina (HPA) which is usually accepted to be aluminium oxide (Al2O3) of greater than or equal to 99.99% purity (4N or 100ppm impurities) has been forecast to have a high growth future as the raw material which is used to produce synthetic (artificial) sapphire used as the substrate for the manufacture of light emitting diode (LED) lighting.

More recently there have been forecasts for an equally or, even, a more impressive growth market for HPA in the manufacture of lithium-ion batteries (LIBs). This forecast surge in HPA demand has stimulated evaluation of alternative and lower cost production routes for HPA, particularly in Australia where there are now at least six projects in the pipe-line.

HPA Markets: led by LED

It is estimated that HPA consumption in 2018 will be about 38,000 tonnes of which the production of light emitting diodes (LEDs) will account for about 53% of HPA consumption.

Overall LED production is forecast to grow at a compound annual growth rate (CAGR) of 12% from 2018 to 2025. Mini-chip (150-50µm) and micro-chip (50-5µm) LEDs are considered the next growth area for the LED market. The main driving force for LED growth is the reduced energy consumption which the U.S. Department of Energy (DOE) estimated to be at least 75% less than regular incandescent lighting.

In 2018 about 36% of battery separators were coated and nearly 60% of coated separators used HPA. By 2025 they forecast that about 80% of separators will be coated and nearly 75% of coated separators

DOE projections for LED lighting are to rise from less than 1% market share (64 million units) in 2010 and 8% market share (701 million units) in 2015 to 84% market share in 2030. Other countries, notably China, Japan, South Korea and the EU have also had programs actively promoting LED lighting.

About 90% of LEDs currently use a sapphire substrate produced from HPA and this dominance is expected to continue but by 2020, some forecasters predict that approximately 10% of all LEDs will be using silicon substrates and about 18% will be using silicon carbide.

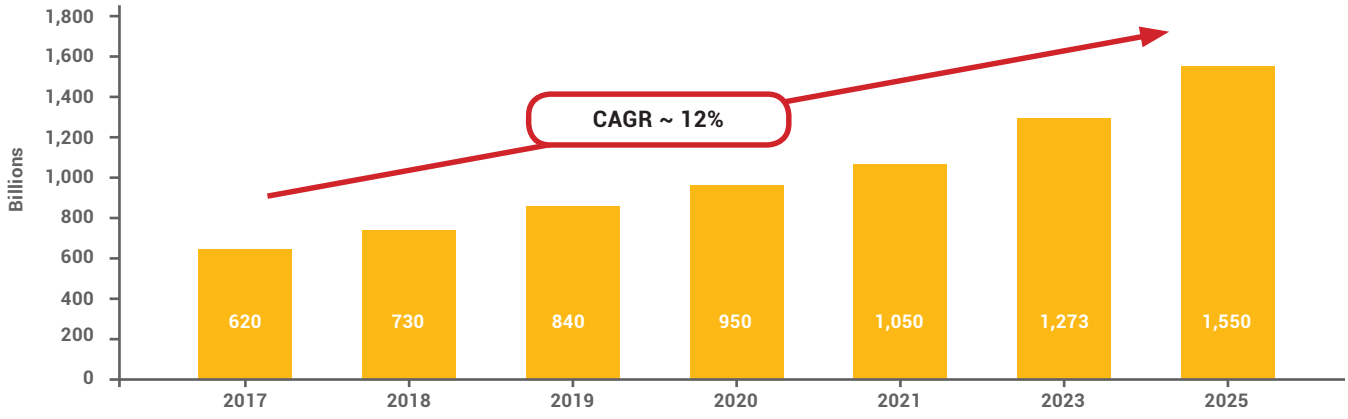
If these predictions are correct, the LED sapphire substrate market share could drop from about 90% to about 70-75% although of a much larger market and at a still impressive 8% CAGR between 2018 and 2025. Under this scenario, the market for HPA in LEDs would be expected to be about 35,000 tonnes by 2025.

HPA in batteries: growth but how much?

A rapidly evolving and potentially significant market for HPA is as a coating on separators in lithium-ion batteries where the insulating properties and safety of the separator, which sits between the battery electrodes, is enhanced by the application of HPA.

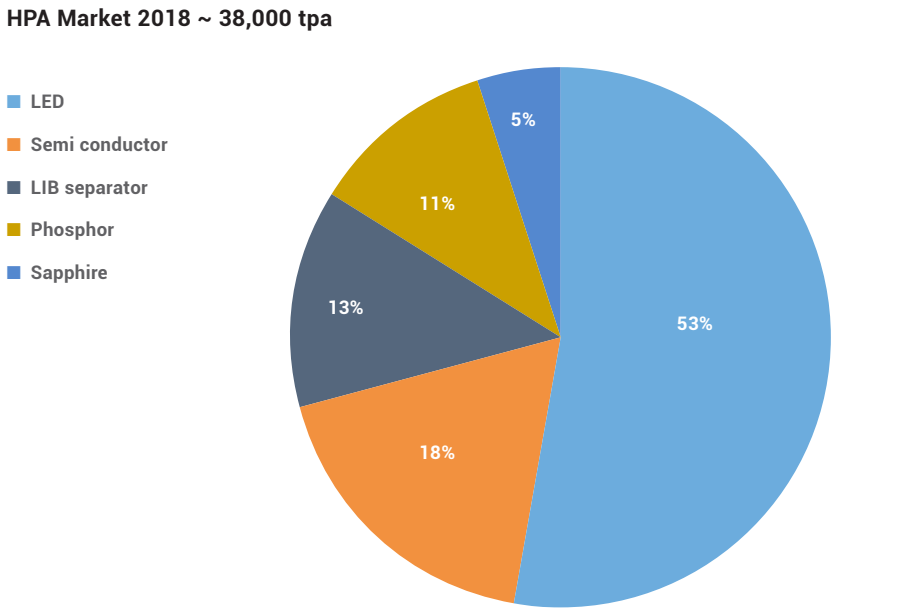
FYI Resources (PFS September 2018) estimated that in 2018 about 36% of battery separators were coated and nearly 60% of coated separators used HPA. By 2025 they forecast that about 80% of separators will be coated and nearly 75% of coated separators

DEMAND FOR PACKED LEDS



Source: SGL Carbon SE Capital Markets Day October 11 2018

ESTIMATED HIGH PURITY ALUMINA MARKET IN 2018



Source: company reports

will utilise HPA. During the same time period the use of HPA in separators is forecast to grow from 5,000 tonnes per annum (tpa) in 2018 to 76,000 tpa by 2025.

However, there have also been significantly lower forecasts for HPA demand in the separator market, with the lowest estimate being 15,000 tonnes pa in 2025 – forecast by Altech Chemicals Limited (June 2016) which has recently (June 2018) provided a revised forecast of about 43,000 tpa in 2025.

Further complicating the difficulty of forecasting is the recent report from Altech (October 2018) that HPA is now being looked at by LIB manufacturers for use as an outer coating directly applied onto anodes and cathodes to improve battery cycling behaviour; reduce dendrite growth (a major cause of battery failure), enhance thermal conductivity and reduce anode/cathode shrinkage and expansion.

Australian HPA Projects

There are currently six Australian companies with HPA production projects at various stages of development. Five of the six companies are looking at using kaolin as the feedstock for the production of HPA and all but one of these companies are planning to utilise hydrochloric acid leaching. The four most advanced projects are compared in Table 1 *(see p42)*.

Altech Chemicals Limited (Altech)

Altech is by far the most advanced of the ASX-listed HPA projects.

Managing Director, Iggy Tan recently summarised progress during the last four years, "the company has completed a definitive feasibility study(DFS) and a final investment decision study (FIDS) for its HPA project; developed and finalised a kaolin to HPA process design; concluded laboratory pilot plant test-work; finalised JORC compliant kaolin resource and reserve estimations; secured and acquired the site for its HPA plant and kaolin mining operation; concluded environmental and development approvals in both Australia and Malaysia; executed a 10 year HPA off-take arrangement; negotiated a US$280m fixed-price lump-sum turn-key EPC contract for a 4,500tpa HPA plant; secured senior project finance of US$190m from German Government owned KfW IPEX-Bank and is in lender due diligence for US$150m of additional project finance initiatives".

Construction is due to commence on Altech's HPA plant in Johor, Malaysia, which will use kaolin from its 100% owned Meckering deposit located approximately 130km east of Perth in Western Australia. The proposed mining schedule at Meckering is based on processing about 43,500 tpa of kaolin ore for the targeted 4,500 tpa HPA production rate.

A mining contractor will stockpile kaolin ore from three-yearly mining campaigns. Run of mine (ROM) ore will be loaded into standard sea containers and trucked from Meckering to Fremantle port, before being shipped to Tanjung Pelepas port, Johor, Malaysia. Upon arrival at Tanjung Pelepas the containers will be either stored at the port, or directly trucked about 90km to Altech's HPA plant site in the Tanjung Langsat Industrial Complex.

The HPA plant design incorporates a flexible finished product line capable of producing HPA for both the synthetic sapphire industry (up to 4,500 tpa of high density pellets) and HPA for the lithium-ion

TABLE 1: COMPARISON OF SELECTED AUSTRALIAN HPA PROJECTS

	Altech Chemicals	Pure Alumina (Hill End Gold)	FYI Resources	Alpha HPA (Collerina Cobalt)
Capacity (tpa)	4,500	8,000	8,000	10,200
Capex (USD M)	298	271	179	161
Av.Sale Price (USD/mt)	26,900	25,200	24,000	25,000
Av Production Cost (USD/mt)	9,900	7,668	6,467	6,403 (Note 2)
Project Stage	FIDS October 2017	PFS June 2018	PFS September 2018	PFS November 2018
Anticipated start up	2021-2022	2022-23	2021	2022
Raw Material	Kaolin, Meckering Western Australia	Kaolin, Yendon Victoria	Kaolin, Cadoux Western Australia	"Industrial Chemical"
Process	HCl leach	HCl leach	HCl leach	Solvent extraction
Reserve (M tonnes)	1.22	na	2.8	na
Av. Al2O3 (%)	30	na	24.4	~15.8 (Note 3)
Resource (M tonnes)	12.7	1.6 (Note 1)	9.6	na
Av. Al2O3 (%)	30.5	34.7	23.0	na
Av. Fe2O3 (%)	0.7	1.22	0.8	na
Av. K2O (%)	0.1	0.22	1.2	na

Notes
1. Minus 63 micron concentrate
2. After two fertiliser by-product credits (US$9,634 before credits)
3. Calculated from 65,753 tonnes pa feedstock of unspecified origin

Source: Company reports

battery industry (up to 1,500 tpa of powder at sub-micron particle size). The company has lodged a number of patent applications for its HPA production process in Australia and Malaysia. Altech's product specifications and the estimated operating cost breakdown are shown separately. *(see p43)*.

Processing of kaolin in Malaysia involves removal of coarse silica, calcination at 700C, hydrochloric acid leaching, three stages of aluminium chloride crystallisation, calcination at 700C, roasting at 1200C to produce alpha alumina followed by pelletisation or jet milling.

Altech has executed a 10-year off-take sales arrangement with Mitsubishi Australia Ltd (Mitsubishi) in which Mitsubishi is appointed the exclusive buyer of all the HPA plant's production capacity.

Under the agreement both parties have set specific off-take sales target quantities, with pricing set quarterly at the prevailing market price. Altech intends to supply the higher priced premium end of the HPA market particularly in Japan, South Korea and Taiwan.

Pure Alumina Limited (Pure Alumina)

In May 2017, Hill End Gold Limited signed "A Heads of Agreement" to acquire 100% of a High Purity Alumina (HPA) Project from Pure Alumina Limited, a private company controlled by Syrah Resources founders Tolga Kumova and Tom Eadie. On 1 November 2018, Hill End Gold Limited changed its name to Pure Alumina Limited.

Pure Alumina completed its preliminary feasibility study (PFS) in June 2018 and is aiming to complete a Definitive Feasibility Study (DFS) by the end of 2019. The company is planning to produce 8,000 tonnes pa of HPA from kaolin and as part of the DFS they are assessing building a commercial demonstration-scale plant of up to 1,000 tpa capacity to provide the larger quantities of HPA for customer testing. The plant site is currently nominated as Altona, a suburb of Melbourne, although the DFS will include a site optimisation study including overseas locations.

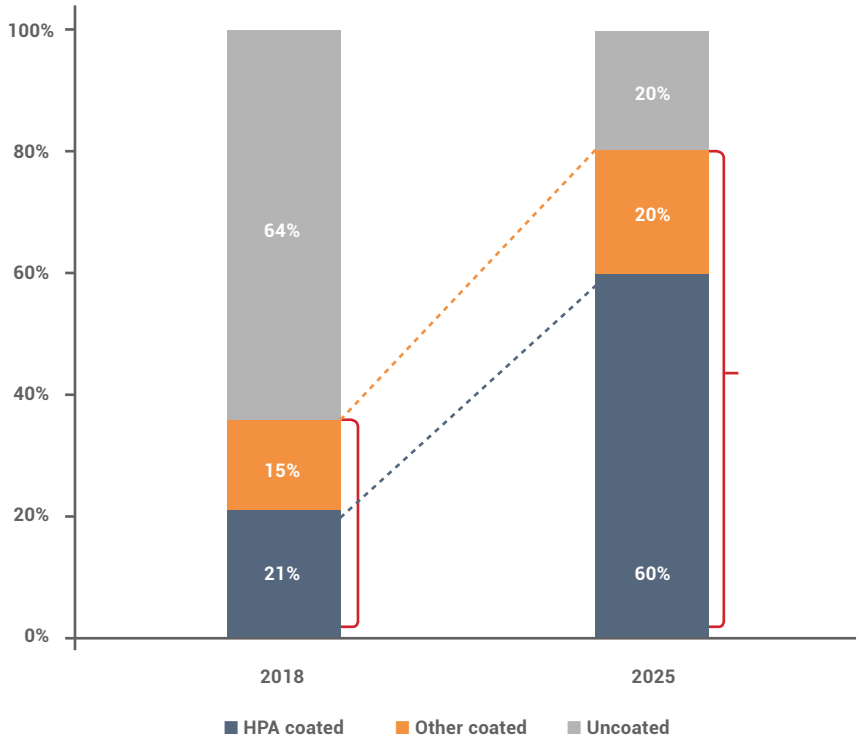
The process described in the PFS consists of physical separation of the fine kaolin from

ALTECH HPA PRODUCT SPECIFICATIONS

LED & LIB grade HPA	Specification
Alumina (Al2O3)	<99.99%
Silicon (Si)	<20ppm
Sodium (Na)	<10ppm
Magnesium (Mg)	<10ppm
Calcium (Ca)	<10ppm
Iron (Fe)	<10ppm
Copper (Cu)	<10ppm
Crystal structure	alpha
Dry Bulk density (LED pellets)	2.2 t/m3
D50 particle size (LIB powder)	<1.0 micron

Source: Altech Chemicals FIDS October 2017

ESTIMATED LITHIUM ION BATTERY SEPARATOR MARKET SHARE



Source: FYI Resources PFS September 2018

coarser material, calcination of the kaolin, dissolution in concentrated hydrochloric acid and crystallisation of aluminium chloride hexahydrate (ACH). The ACH would then go through cycles of dissolution-crystallisation until the purity was sufficiently high to proceed to calcination of the ACH to HPA.

The project's kaolin assets are located at Yendon near Ballarat, Victoria only 80 kilometres from Melbourne and in areas where kaolin mining and processing has continued for decades.

Metallurgical test work is said to have "defined a robust chemical process to convert Yendon kaolin to HPA. This process is based on the industry-standard process derived from the US Bureau of Mines published and public data customised by Hill End specifically for the Yendon orebody."

FYI Resources Limited (FYI)

FYI Resources (FYI) has recently completed a preliminary feasibility study (PFS) for the production of HPA from its Cadoux kaolin deposit in Western Australia. The company has now committed to, and commenced, a bankable feasibility studies (BFS) for an 8,000 tonnes pa capacity HPA plant based at Kwinana near Perth in Western Australia. The BFS which will include a pilot plant scoping study, is scheduled for completion in the first half of 2019.

Mining and initial beneficiation will take place at the Cadoux kaolin deposit which is located 220 kilometres northeast of Perth and is estimated to contain a total resource of 9.6 million tonnes of kaolin at an average 23% alumina content. Leach extractions of up to 97.2% alumina from the kaolin have been reported in metallurgical tests.

FYI's HPA flowsheet development is said to be specifically engineered towards Cadoux's unique geology, mineralogy and physical characteristics and substantially different to a "standard" HCl leach and precipitation process.

In November 2017, FYI had announced that it had entered into a memorandum of understanding (MOU) with Aco Korea for the exclusive marketing in South Korea and China of high purity alumina produced by FYI. Market investigations in the key markets of East Asia and Europe are said to be ongoing.

Alpha HPA Limited (Alpha HPA)

Alpha HPA (formerly Collerina Cobalt Limited) is developing the only Australian HPA project that is not based on hydrochloric acid leaching of kaolin. The Alpha HPA

process uses established hydro-metallurgical processes, and operates at atmospheric pressures and temperatures with the exception of the final calcination step which is common to all HPA flow sheets.

The company released their PFS in November 2018 for a solvent extraction process to produce 10,200 tonnes pa of HPA from about 66,000 tonnes pa of an unnamed source described as "bulk industrial chemicals" or "industrial chemical feedstock". The process also produces about 116,000 tpa of two unspecified fertiliser by-products.

The plant location is also unspecified but the company is investigating sites within the industrial port area at Newcastle in New South Wales.

The company has now committed to the establishment of a pilot plant in Brisbane as part of a DFS in 2019 which should enable the company to proceed to a FID study and then potentially to a full scale plant in 2022.

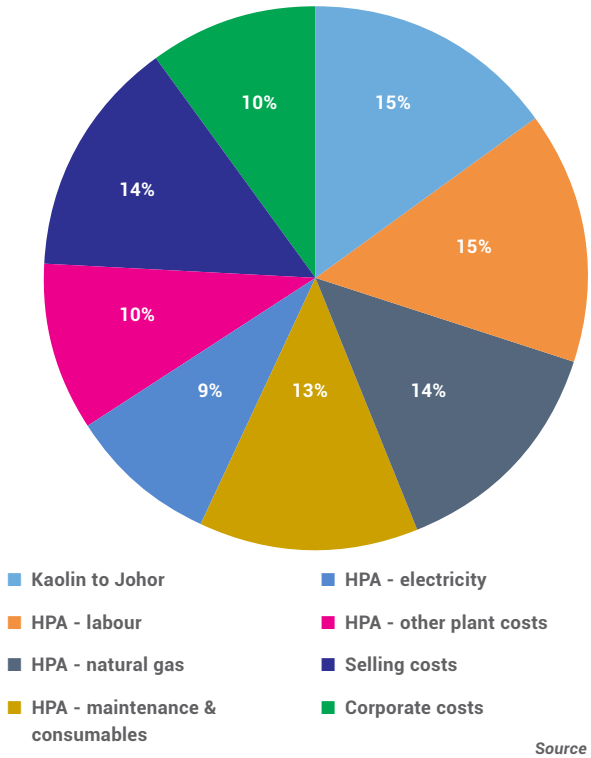
Other Australian HPA Projects

Andromeda Metals Limited is planning to develop a halloysite/kaolin resource at Poochera in South Australia. As well as planning halloysite exports mainly to China's ceramic industry, the company has reported positive test work for the production of 4N HPA. The company is now targeting test work to produce 5N HPA.

Halycon Resources Pty Ltd is a private company with a kaolin resource at Tambellup, 320 km south-east of Perth in Western Australia. The company is promoting a process which utilises digestion of kaolin by ammonium sulphate and sulfuric acid to produce 4N HPA and equal tonnages of minus 10 micron amorphous silica.

Alchemy Resources Limited and Platina Resources Limited have both announced that they are testing their nickel-cobalt resources for HPA production.

ALTECH HPA OPERATING COST US$9.90/KG



Source Altech FIDS October 2017

LIB Separator Market- major capacity expansions

Separators are a critical component of lithium-ion batteries since they isolate the electrodes to prevent electrical short-circuits whilst allowing lithium ions to pass freely through them.

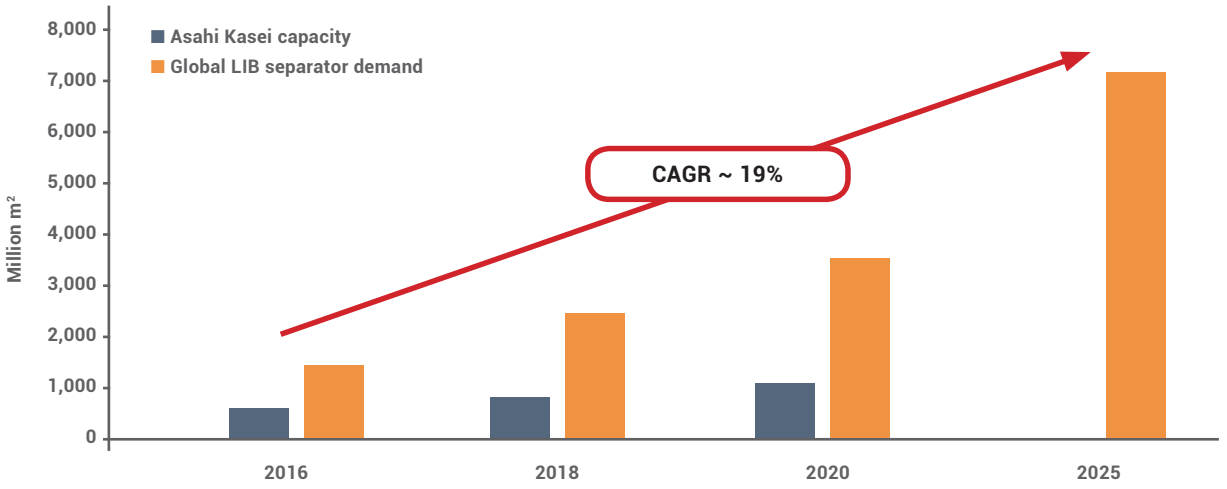
Plastic (usually polyolefin) separators are widely used and are generally made by one of two processes, a wet or dry process. In the dry process the plastic is annealed then rapidly stretched to produce elongated pores and about 35-45% porosity. In the wet process a plasticizer/polymer mixture is extruded, stretched and the plasticizer is extracted to produce more spherical pores and higher porosity (40-50%). Pore size is less than one micron.

Monolayer and multilayer as well as non-polyolefin plastics and non-plastic separators are some of the options.

Inorganic particles such as HPA can be added to one or both of the separator surfaces utilising hydrophilic polymer binders to produce ceramic coated separators (CCS).

Asahi Kasei is a major producer of battery separators with dry-process manufacturing plants located in the USA (North Carolina) while wet-process manufacturing plants are located in Japan (Moriyama, Shiga, and Hyuga, Miyazaki) and Korea (Chungbuk). The company's LIB separator capacity is planned to almost double between 2016 (600 million (M) m2) and 2020 (1,100 M m2) to match an anticipated market CAGR of about 19% .

ASAHI KASEI SEPARATOR CAPACITY & GLOBAL LIB SEPARATOR DEMAND



Source Asahi Kasei & Sumitomo Chemical

Toray Industries is planning to grow even larger than its rival Asahi Kasei by tripling its 2017 separator production capacity to 1.95 billion (B) m2 by 2020 and is investigating plants in Europe and the USA.

SEMCORP (Shanghai Energy New Materials Technology Co Ltd) is planning to install an additional 1B m2 in China.

Smaller producers are also expanding. Ube Maxwell doubled separator sales between 2015 and 2018 entirely from increased sales of coated separators which increased from 16% of total sales to 64% of total sales in the same period. The company is anticipating doubling its separator capacity to 400 million m2 by 2021.

SK Innovations (SKI) with 360 M m2 separator capacity in South Korea in 2018 is expanding in both South Korea and China to raise it capacity to 850 M m2 by 2020.

Sumitomo Chemical are forecasting a global separator market over 7 B m2 by 2025. Other forecasters are predicting that this market demand will be reached by 2020 which is feasible given that China alone produced 1.08 B m2 in 2016 and is predicted to produce 3.5 B m2 in 2020.

The difficulty of forecasting separator market growth, more specifically CCS market growth or even more specifically HPA-CCS market growth in a rapidly growing and technologically developing market is not surprising. Nor is it surprising that the majority of separator producers have low profitability in a highly competitive market which also requires consistent new investment capital.

In the longer term it would be expected that the specifications for consumables such as HPA will become more stringent and there would also be pressure to reduce HPA prices particularly if or when the threat of solid state batteries becomes a reality.

ABOUT THE AUTHOR

Dr Richard Flook has worked for both suppliers and consumers of minerals with global companies including, Steetley plc, Anglo American, Commercial Minerals (now Sibelco), Normandy Mining Ltd, Omya AG and Shinagawa Refractories.

Richard has been CEO, Managing Director & Director of Asian and Australasian companies. He has specialized in new business opportunities including strategic planning, trading, market development and acquisitions in the industrial minerals industry and has been involved in managing and developing mineral operations and businesses in Asia and Australasia.

Richard is a Fellow of the Australasian Institute of Mining & Metallurgy (FAusIMM (CP)) and the Australian Institute of Company Directors (FAICD). Richard is a graduate of Sydney University (BSc First Class Honours, PhD) and the University of NSW (Master of Commerce).

Since 2014, Richard has been the Managing Director of Mosman Resources, a private consulting business, specialising in the production and marketing of industrial minerals and chemicals.