WHITE PAPER

THE GLOBAL HIGH PURITY ALUMINA MARKET

MARCH 2020

Contents

EXECUTIVE SUMMARY

High purity alumina (HPA) is a pure form of aluminium oxide (Al_2O_3), with a minimum purity level of 99.99% or 4N. HPA is a high value and highly demanded product in specialty applications due to its chemical inertness, hardness, and electrical and thermal properties. Currently the global market for HPA is dominated by demand from synthetic sapphire producers, with synthetic sapphire wafers used in downstream production of LEDs, semiconductors, and scratchproof glass for watches and handheld electronic devices. A growing market is also emerging for HPA in the lithium-ion battery sector, where it is being used as coating material on polymer separators used within the battery.

HPA products are typically found as two variants in the market; a powder form used for coating applications in the phosphor lighting and lithium-ion battery sectors, where particle size distribution and surface area specifications are critical; and a pellet or bead product for use in synthetic sapphire boule production where the bulk density becomes a more critical physical parameter. Limits on individual elemental impurity concentrations such as sodium (Na), iron (Fe), and magnesium (Mg) are also typically specified, as these impurities can result in significant quality and safety issues in the end use applications.

The HPA market has been described as a dual market, with current supply dominated by a small number of producers in two groups; established global chemical producers such as Sumitomo, Nippon Light Metal, Baikowski and Sasol; then a range of newer Chinese producers that include Hebei Pengda and Xuancheng Jingrui New Materials. Current producers typically use the alkoxide process for HPA production, which requires refined aluminium metal as feedstock. The cost of HPA production via this method is closely linked the high cost of the expensive feedstock and the electricity consumption required for the process. The cash cost of HPA produced using the alkoxide process is estimated at ~US$15/kg. There are some producers that claim to produce HPA using a modified Bayer process, however residual sodium (Na) concentrations in the HPA produced via this process are expected to be considerably higher and problematic for end-users, as such it is would be unlikely that this product would be of 4N quality. A number of emerging HPA producers, including Altech Chemicals, intend to produce HPA using low cost kaolin as feedstock and a hydrochloric acid leach and crystallisation process, which is expected to result in a high quality 4N HPA at lower overall production costs when compared with existing operations. The Altech stated cash cost of production is estimated to be around US$8.6/kg.

Recent analysis of the HPA market, most notably by Persistence Market Research in 2016 and CRU Consulting in 2019, both concluded that significant growth in the LED and lithium-ion battery sectors will result in a large increase in global HPA consumption over the next decade. Data collected from 2018 estimated global production of 4N HPA to be 21,198 tonnes. Modelling by CRU for the period 2018 – 2028 determined the unconstrained global demand for 4N HPA to reach 272,000 tonnes at a growth rate of 29.9% CAGR. Analysis of the likelihood for expansion of existing production facilities, as well as new producers to commence production has been completed to determine the expected supply volumes over the same period. A constrained demand model which considered the potential areas for product substitution or use of lower quality alumina has also been developed, with constrained consumption in 2028 of 110,288 tonnes. A growing supply deficit has been predicted between 2023 and 2028.

Substitution of HPA with alternative materials has been considered in the major areas of demand. As sapphire substrates dominate in the LED sector, the cost of changing epitaxy processes for new materials is high, and no other materials are viewed as competing on a cost or performance basis. Therefore the risk of substitution of HPA in this application is low. Lithium battery separator producers have already started using lower purity alumina as coating materials, such as boehmite and 3N. However it is believed that these lower purity substitutes only have limited applications, as the impurities they bring pose risks to battery safety, performance and life. Therefore it is expected such separators will be used only in low density, low performance battery applications such as low cost consumer electronics. 4N+ HPA quality material will continue to be the material required for coated separators in high density batteries for the electric vehicle market.

CRU maintain that there is still essentially a dual market of 4N HPA products; material from the established international producers such as Sumitomo, Sasol etc that have a reputation of consistent and high quality products which therefore demand higher prices; and material from emerging Chinese producers that have been alleged to have historically supplied 4N HPA under false or inaccurate specifications. Chinese supply also suffer from quality consistency and poor reputation which is demonstrated in an almost-total lack of Chinese exports of high purity alumina to overseas markets such as Japan and Korea. CRU has reported that overseas market participants simply do not trust Chinese supply.

Analysis on 4N HPA pricing completed by CRU Consulting in 2019 which considered available trade data, online market pricing, and discussions with various producers and end users, concluded that prices ranged from a low of $15/kg to as high as $100/kg (see figure below). The Chinese inferior product claiming to be 4N quality, but actually 3N in quality, tends to have a price below $15/kg.

CRU estimated from analysis of Japanese export data that the average sales price for Sumitomo product was at the higher end of the 4N market at approximately $28/kg, with a higher band at ~$35/kg likely to apply to slightly higher specification product i.e. 4N+ (4N5 or 5N). Rival producer Baikowski's published financial information for 2018 further supports an approximate revenue of $23-29/kg (albeit with some participation in downstream products). CRU reports that Sasol is selling the majority of their 3N-5N purity range in the $15-30/kg range with 8 trades seen at order volumes of over 500kg with an average price of $67.6/kg, reflecting higher quality. Altech has stated publicly that its proposed HPA product is targeted at the premium Sumitomo end of quality and price. Altech has used an average long term price of US$27/kg in its Financial Investment Decision study.

Increasing it is being accepted that rising 4N HPA demand and a predicted supply shortfall, in addition to rising operating costs for existing producers, is likely to result in an increase in 4N HPA price over the 2020-2028 period. CRU forecasts an average 4N+ sale price over this period of US$32.8/kg.

WHAT IS HPA?

High purity alumina (HPA) is one of the purest forms of commercially produced aluminium oxide (Al_2O_3). HPA with a minimum purity level of 99.99% is defined as 4N HPA. HPA is white in appearance and typically granular.

4N HPA is a high value, high margin and highly demanded product as it is a specialised form of alumina with a range of high-tech end uses. It typically attracts significantly higher prices than aluminium oxides of less purity, such as the commonly produced smelter grade alumina (SGA). It is valued for its hardness and mechanical strength, chemically inert properties (corrosion resistance), biocompatibility, and high melting point.

WHAT ARE THE MAJOR APPLICATIONS FOR 4N HPA?

High purity alumina is used in a range of applications and industries due to the advantages of its chemical and physical properties. Typical applications by material properties are shown below.

HPA's key attributes

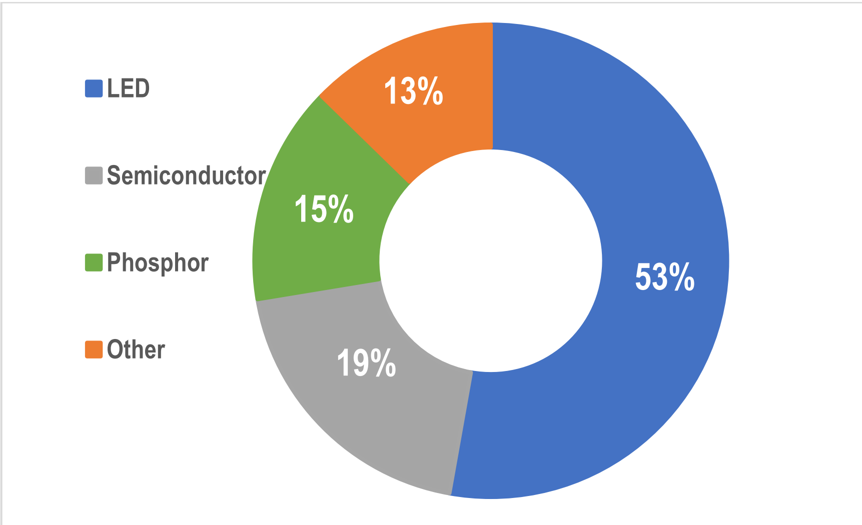
HPA KEY ATTRIBUTES	HPA APPLICATIONS
• **Extreme hardness**	Synthetic sapphire (substrates/micro-chips, LEDs, high speed chips, opto-electronics, watch faces), polishing
• **High Brightness**	LED white lights; advertising displays
• **Inertness** • **(non-conductive; superior electrical insulation)**	Synthetic sapphire (LED/optoelectronics), advanced technical/transparent ceramics (medical, aerospace), automotive sensors
• **Superior corrosion resistance**	Semiconductors, LEDs, tablet/PC screens; advanced ceramics; plasma display panels/TVs (PDPs)
• **High bending strength**	Semiconductor (data processing electronics – memory chips)
• **High heat resistance**	Lithium-ion battery separator coatings, Semiconductors, air-to-fuel sensors (automotive), sapphire single-crystals, LEDs

4N HPA is the critical raw ingredient for the production of synthetic sapphire and cannot be substituted. Synthetic sapphire is used in the manufacture of substrates for LED lights; semiconductor wafers used in the electronics industries; and scratch-resistant glass used for wristwatch faces, optical windows and components for smartphones and other handheld devices. Currently (per 2018 research data compiled by CRU consulting), supply of 4N HPA for the production of synthetic sapphire accounts for the majority of global demand; in the order of 78%. This is largely driven by use of sapphire wafer substrates for LED manufacture.

4N HPA has also seen recent demand growth in the lithium-ion battery sector. 4N HPA is used in this sector to form a protective coating on the surface of the polymer separator material used within a lithium-ion battery. Separator material, as its name suggests, provides a protective separating barrier between the battery anode and cathode material, and is critical to safe operation of the battery. Global consumption of 4N HPA in the production of coated battery separators is currently estimated at 2,030 tonnes p.a., but HPA use in this application is forecast to grow exponentially because of the pending surge in lithium-ion battery production because of the transition to electric vehicles and growing market for renewables energy storage.

Finally, high purity alumina is also used in a number of other high-tech applications, albeit at lower volumes. These include coatings in phosphor lighting products, polishing materials and performance ceramics such as medical implants.

4N HPA (99.99% Al_2O_3) consumption by application (2016)



Source: Persistence Market Research

Synthetic sapphire (LED & Semiconductor Substrates, Scratchproof Glass)

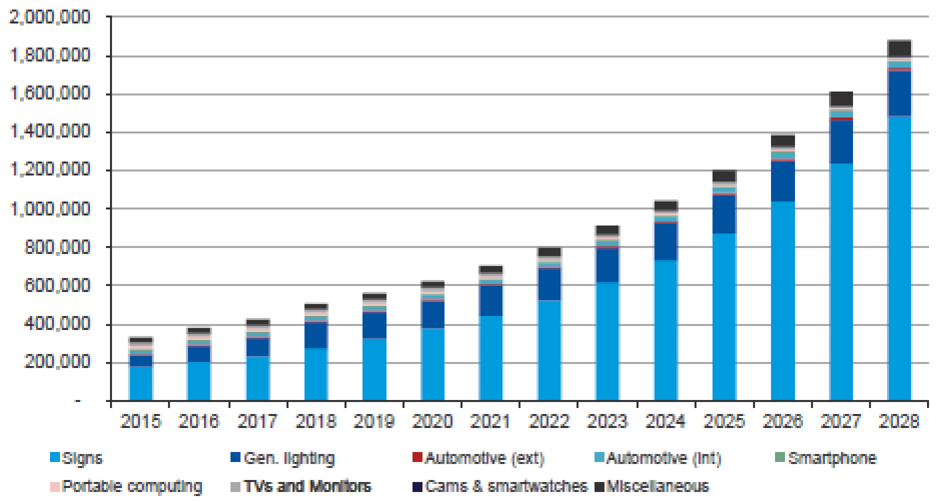
Sapphire is a precious gemstone, a type of mineral called corundum, which is an aluminium oxide (α-Al_2O_3). Sapphire is second only to diamond when it comes to hardness. Synthetic sapphire is identical to natural sapphire, except it can be made (artificially) without the flaws and colour that are found in natural stones.

Synthetic sapphire is used in the manufacture of substrates for LED lights; semiconductor wafers used in electronics industries; and scratch-resistant glass used for wristwatch faces, optical windows and components for smartphones and other handheld devices.

4N HPA demand is underpinned by its status as the non-substitutable raw material for the production of synthetic sapphire, and the use of synthetic sapphire for the manufacture of LED substrates. The worldwide transition from energy-hungry, inefficient incandescent lighting to energy-efficient LED lights is continuing. Synthetic sapphire is used in the production of LEDs as the substrate on which electrical circuitry is mounted. It is the preferred substrate material in approximately 90% of global LED production, as the raw material properties of 4N HPA allow the sapphire substrate to efficient dissipate heat away from LED circuitry, act as an electrical insulator whilst also being a cost effective solution.

LEDs are used in an ever growing range of lighting applications, including home lighting, advertising signage, automotive and television/monitor screens. Depending on the quality and power requirements of the LED application, the substrate material and quality requirements can change. The figure below shows the relative production volumes for LEDs in such lighting applications, and their predicted growth in the next decade.

LED Units by Application 2015-2028



Source: CRU Consulting High-purity alumina market outlook

Another key use of synthetic sapphire is in semiconductors, particularly in the production of a range of high-performance electronics. 4N HPA's superior plasma corrosion resistance and high strength make it a preferred material for use in semiconductor wafer processing and other related components. 4N HPA is used in the manufacture of epoxy moulding compounds (EMC's) that are used in the semiconductor industry to improve heat dissipation.

Demand for synthetic sapphire also comes from applications where clear, scratch resistant glass is required. Historically this has been for production of watch-face crystals, however demand by handheld electronic device manufacturers is expected to grow, as smartphone and tablet producers increasingly demand synthetic sapphire for various components of their products such as the camera lens, home button, as well as the smartphone display screen.

The manufacture of synthetic sapphire glass requires the production of large single crystal boules made from melting 4N HPA (pure aluminium oxide Al_2O_3); synthetic sapphire wafers are then cut and shaped into various sizes and diameters, depending on their target end-use.

Lithium-ion battery separator coatings

The use of 4N HPA in the production of lithium-ion battery separators is a rapidly growing sector, driven by the development of more energy dense batteries to serve the surging electric vehicle (EV) and renewable energy storage markets. The lithium-ion battery separator material must be permeable (to allow for lithium-ion transit), stable at battery operating temperatures, chemically inert and offer mechanical strength and flexibility – 4N HPA delivers all of these attributes.

Historically, consumer electronics accounted for a near 70% share in overall global lithium-ion battery demand (2016), whereas automotive applications accounted for a share of around 27% in the same year. Recently however, lithium-ion battery manufacturers have channelled their efforts towards expanding production capacities to meet expected demand from the EV and renewable energy storage markets. This trend is expected to continue and lithium-ion battery production is expected to witness significant double-digit growth during the next decade. According to a lithium-ion battery market research report published by Deutsche Bank (2016), lithium-ion battery usage is forecast to rise more than 7-fold, from 70GWh per year in 2015 to 535GWh per year by 2025.

Battery separator sheets have typically been made from polymer materials, with polypropylene and polyethylene being the most common examples. 4N HPA is now being used in the production of separator sheets by deposition of a microlayer of alumina in the order of 3 to 5µm onto the outer surface of the polymer sheet. The 4N HPA coating provides additional thermal stability to the separator sheet, allowing for construction of batteries with higher energy density and operating temperatures, such as those with NMC 622 and NMC 811 cathode materials. Lithium-ion battery producers are reporting battery usage of between 40 - 120g of 4N HPA per kilowatt-hour (kWh).

4N HPA is also used to increase a lithium-ion battery's discharge rates; lower self-discharge; lengthen life-cycles, and reduce flammability during thermal runaways. Uncoated separator sheets are likely to continue to be used in low cost consumer electronic batteries where energy density and battery life considerations are not as critical. However, all indications are that 4N HPA coated separators will dominate in batteries where battery performance and safety are key design requirements, such as batteries used for electric vehicles, domestic and industrial energy storage and high quality electronics.

Electric vehicle manufacturers are increasingly demanding lithium-ion batteries with cathode and anode electrode separator sheets coated with 4N HPA. The particle size of HPA used as the coating for this application is ultra-fine, and typically less than 1 µm (micron).

Future - Solid state lithium batteries

There has been increasing discussion about the next generation of lithium-ion batteries called solid state batteries. These are batteries where the organic combustible liquid electrolyte in the battery is replaced by non-liquid "solid state" electrolyte which appreciably improves battery safety and allows for significantly higher battery operating temperatures. Will 4N HPA will be used in future solid state lithium-ion batteries where there are no ceramic coated separators? Based on extensive research of prevailing technologies, Altech believes that 4N HPA will continue to be a key ingredient of future commercialised solid state lithium-ion batteries. Similarly, the amount of 4N HPA used is also likely to be higher than the amount used in the production of current ceramic coated separators.

Phosphor Coatings

High purity alumina has been used in small amounts as a coating for fluorescent lighting products, including compact fluorescent lights (CFLs). In this application, HPA is used to form a protective layer on the internal surface of the tube, preventing discolouration and extending product life. Demand for fluorescent lighting has been rapidly replaced by LEDs in the lighting market, and therefore consumption of HPA for this application is expected to decline over the next decade.

Polishing Applications

HPA powder is used in the production of polishing slurries which are then used for polishing of metals, semiconductor wafers and a range of microelectronics. HPA is valued in this application for its hardness and chemical inertness, as well as overall purity as it most commonly used where a high specification finish is required with control of surface contamination being critical. CRU estimates global demand for HPA in 2018 to have been 1,371 tonnes.

HPA SPECIFICATIONS

Within the HPA market, there exists a broad range of product specifications depending on the chemical and physical property requirements of the end user and the material application.

HPA is typically defined firstly by the overall purity specification, and can broadly be divided into the following purity grades;

- 4N (**99.99%** Al_2O_3 equivalent to 100ppm total impurities)
- 5N (**99.999%** Al_2O_3 equivalent to 10ppm total impurities)
- 6N (**99.9999%** Al_2O_3 equivalent to 1ppm total impurities)

The term “4N+ HPA” is also used in HPA market analysis, which captures all HPA with a purity at 99.99% or higher. The term is also used to differentiate from 3N HPA, which may be misrepresented and sold as higher purity 4N material.

4N quality HPA accounts for the majority of market volume of the three (3) HPA grades, with Persistence Market Research (Persistence) reporting a 74.2% market share in its 2016 research.

The price and performance of HPA varies widely depending on its degree of purity (as above), and other critical specifications. In addition to an overall 4N HPA purity specification, some end use applications call for upper limits on the concentration of specific elemental impurities in the 4N HPA. For example, sodium (Na), iron (Fe) and magnesium (Mg) are often specified as <10ppm in 4N HPA products, as such impurities can lead to defects like discolouration, cracks and inclusions during synthetic sapphire production, resulting in higher material wastage or classification for use in only low quality applications. Similarly, 4N HPA products for the lithium-ion battery sector are concerned with Na and Fe content, as these impurities inhibit the flow of lithium-ions within the cell, and can contribute to the formation of dendrites on the graphite anode material which ultimately effect battery life and also pose a risk of separator puncture and electrical shorting in the battery cell.

Alumina can be produced with a number of different crystal structures, which are largely dependent on the calcination temperature in processing. α (alpha) is the preferred crystal structure for HPA applications, and is produced at calcination temperatures of approximately 1200 °C.

CRU noted in 2019 market research report that the LED sector has a strong preference for high quality and consistency 4N+ HPA feedstock for its sapphire production, rather than the lower cost, marginal 4N quality material. This preference is primarily driven by a shift to larger diameter sapphire wafers (6" and 8") which are more heavily impacted by imperfections in the sapphire boule and the available quantity of unadulterated sapphire within boule to produce larger diameter wafers. Imperfections can affect the crystal structure of the synthetic sapphire, which ultimately impact electrical insulation and heat dissipation properties of the substrate.

The physical properties of the 4N HPA product are also often specified to align with end use requirements. Particle size distribution, bulk density and surface area are all common measurements specified by 4N HPA producers to the market.

In general, there are two main categories of 4N HPA products currently available: powder products, where the mean particle size and distribution are critical along with surface area; and pellet or bead products, where bulk density is favoured as the defining physical parameter. Powder products are the preferred form for lithium battery separator coating, where the shape and size of particle is critical for creating an even coating layer thickness, and to maintain permeability through the separator for consistent power output. Beads or pellets are the preferred option for sapphire production, as higher bulk density means that a larger quantity of HPA can be filled into the sapphire boule furnace, improving the efficiency of boule production.

Below is a comparison of the two general categories of 4N HPA products which highlights the similarity in chemical purity specifications, and the difference in physical characteristics.

Typical 4N HPA Product Specifications

	Units	Powder	Beads
Crystal structure		α	α
Purity	%	≥99.99%	≥99.99%
Particle size	µm	D50<0.5, D90<1, D100<3	-
Loose bulk density	g/cm3	0.3-0.5	2.0-2.2
Tapped bulk density	g/cm3	0.6-0.9	-
BET surface area	m2/g	3-6	0.1-0.6
Si	ppm	<20	<20
Fe	ppm	<10	<10
Na	ppm	<10	<10
Mg	ppm	<10	<10
Cu	ppm	<10	<10
Ca	ppm	<10	<10
Others	ppm	<30	<30
Packing – PE bag		20kg	20kg
Application		Coatings	Single crystal

Specifications supplied by Altech

CURRENT 4N HPA PRODUCERS

The global 4N HPA market is currently supplied by a small number of diverse chemical producers, with the eight (8) largest HPA producers estimated to supply around 73% of the global 4N HPA market from data reported by CRU in 2019. These producers can roughly be divided into two groups; established multinational chemical companies, based in Japan, South Korea, Europe and USA; and a growing group of Chinese producers focussed only on production of HPA, and supply to a growing domestic market. Below is a list of the largest producers by their projected 2020 production capacities.

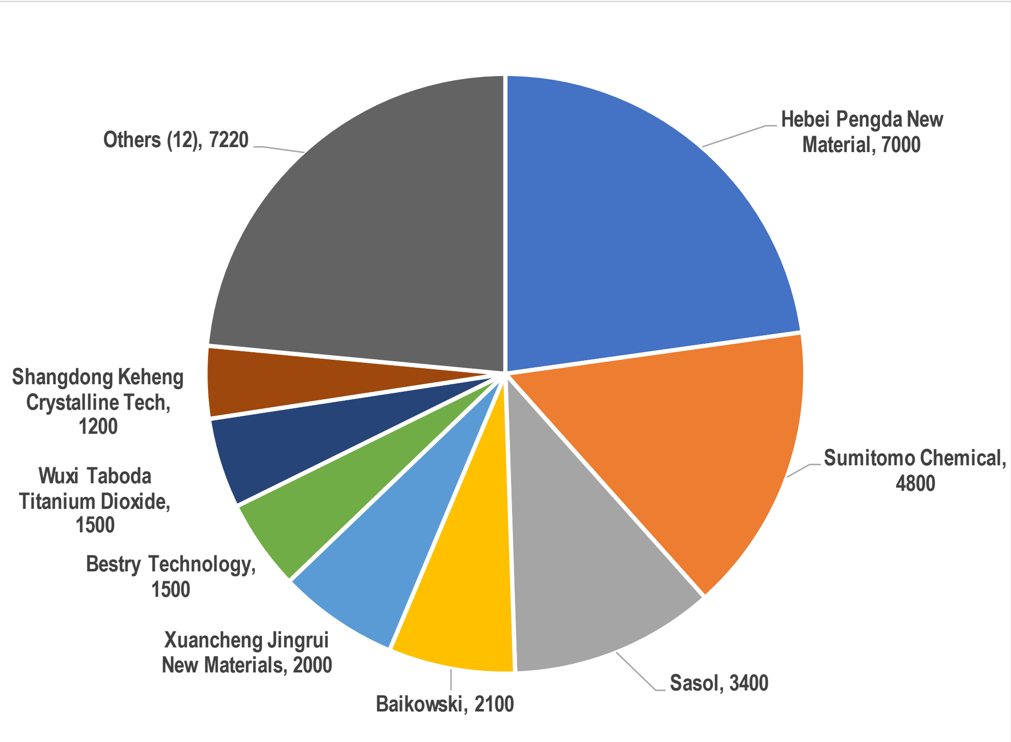
Global Producers

- Sumitomo Chemicals : 4,800 tpa capacity at facilities in Japan and South Korea
- Sasol: 3,400 tpa estimated capacity at facilities in Germany and USA
- Baikowski: 2,100 tpa estimated capacity at facilities in France and USA
- Nippon Light Metal: 1,000 tpa estimated capacity at facility in Japan

Chinese Producers

- Hebei Pengda: 7,000 tpa estimated capacity at facility in China
- Xuancheng Jingrui New Materials: 2,000 tpa estimated capacity at facility in China
- Bestry Technology: 1,500 tpa estimated capacity at facility in China
- Wuxi Taboda Titanium Dioxide: 1,500 tpa estimated capacity at facility in China

Global HPA Producers – 2020 Projected Production in tonnes



Sumitomo Chemical is the largest ex-Chinese producer and the second largest globally, with 4,800 tonnes per annum (tpa) capacity; it has production facilities in both Japan (at Niihama, 3200 tpa) and South Korea (under its subsidiary 'Dongwoo Fine-chem', 1600 tpa). Sumitomo's 4N+ HPA product is widely noted to be exceptional, both in terms of purity and consistency, which has allowed Sumitomo to garner the reputation of the market's "best producer". In particular, the AKP-3000 series is an ultra-high-purity HPA product, that the company specifically markets to the lithium battery separator industry. Sumitomo employs the aluminium alkoxide hydrolysis process.

Sasol, the major global chemicals company, is likely to be the second largest ex-China producer; CRU has estimated global production in 2019 at 3,000 tpa. At present, it operates two HPA production facilities, one in Brunsbuettel, Germany, and the other in Lake Charles, USA. Baikowski is the only major ex-China producer to be focused primarily on HPA. Nippon Light Metals (NLM) makes up the last of the sizeable ex-China producers, with approximately 1000 tpa of production capacity. Hebei Pengda is believed to be the largest market participant, having recently announced an expansion to 7000 tpa capacity, of which 5000 tonnes is reported to be 4N and 2000 tonnes is ~5N.

HPA PRODUCTION METHODS

Established suppliers produce HPA using highly processed feedstock such as aluminium metal or aluminium sulphate. The most common production route utilised involves the alkoxide hydrolysis process, which involves the dissolution of refined aluminium metal in alcohol, hydrolysis to produce a hydrated alumina, and then a calcination stage to achieve the required crystal structure and purity level for HPA products. The advantage that the alkoxide process offers is that the use of a refined feedstock ensures that a high level of purity can be achieved in the end product, assuming reagent purity and material handling and packaging equipment is engineered to minimise contamination. However, the use of refined aluminium metal as the process feedstock, and electricity consumption of the hydrolysis process, mean that the cost of production are driven by external factors and are higher than other production methods. The cost of goods sold (not including depreciation) for 4N HPA produced using the alkoxide process is in the region of US$15/kg.

One alternative production route used by a number of producers is via thermal decomposition of alum, or ammonium aluminium sulphate. This process involves drying and calcination of an alum feedstock to produce the desired alumina product. Producers have highlighted advantages of particle size control using this method, however production of sulphur oxides as part of the decomposition process require significant treatment and control which result in higher costs of production than the alkoxide process.

Finally, some producers use a "Modified" Bayer process to refine hydrated alumina (aluminium hydroxide) feedstock produced from bauxite. The process involves additional steps of clarification, precipitation, filtration and calcination to produce the required level of alumina purity, not typically achieved with the standard Bayer process. This method has the advantage of a readily available and cost effective feedstock, however the process typically retains elevated levels of sodium (Na) in the alumina crystal structure; an impurity which is detrimental in sapphire production and coated separator performance. It is likely that HPA produced using this method fall into the lower quality/lower cost category, and are unsuitable for some of the high-tech applications.

Although not currently used in commercial production of HPA, a number of companies are developing projects which use kaolin clay as their process feedstock. Kaolin is an aluminosilicate clay with low levels of impurities; its aluminium content is leached in hydrochloric acid, followed by crystallisation and calcination steps to produce high purity alumina. The advantage of kaolin processing is the low cost ore feedstock when compared to existing production methods, and the low level impurities are readily removed through the leaching and crystallisation steps, unlike sodium in the Bayer process. The Altech stated cash cost of production is estimated to be around US$8.6/kg.

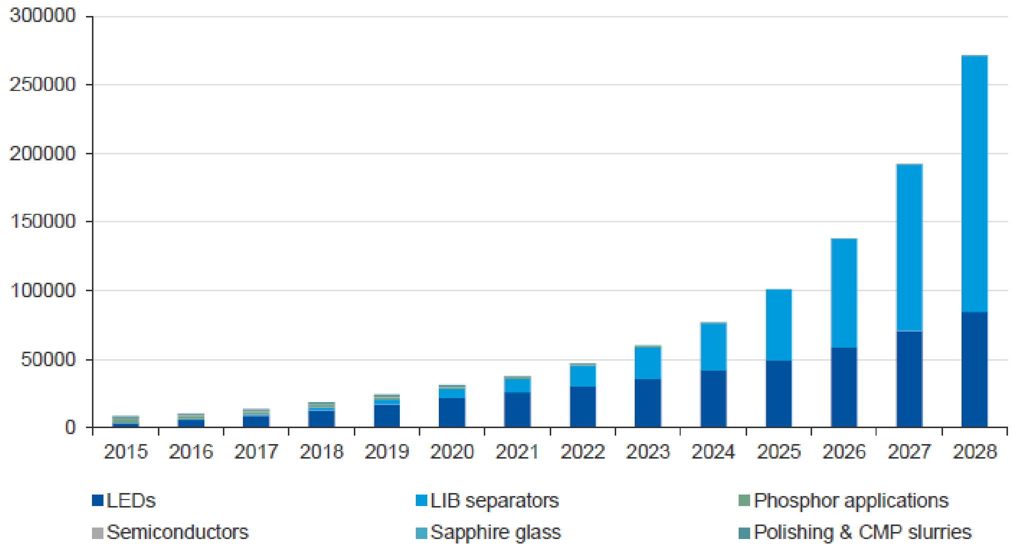
HPA GLOBAL MARKET & DEMAND

The current global market for 4N HPA is estimated to be in the range of 20,000 to 25,000 tpa. CRU reported global demand of 4N+ HPA to be 21,198 tonnes in 2018, with a projected compound annual growth rate (CAGR) of 29.9%. This is an increase on previous estimates of growth by Persistence of 16.7% in 2016 for the period 2016-2024, largely as a result of more ambitious estimates of growth in electric vehicles, and the resulting demand for 4N HPA in lithium battery coated separators.

Predictions on market size and growth can be somewhat dependent on the purity specification being considered; as an example, CRU Consulting did not consider volumes of some purported 4N HPA production using the modified Bayer method in its 2019 analysis, as it is widely suspected to be of lower quality and priced in line with 3N alumina products.

Increasing demand from the LED and electronics industries for sapphire substrates, coupled with the emergence of HPA coated separators in lithium-ion batteries, are driving the increase in demand for 4N HPA. The demand modelling completed by CRU in 2018 predicted the global market for 4N+ HPA products to reach 272,000 tpa by 2028, as shown in the figure below. This modelling was in line with previous estimates published by Persistence in 2016 which predicted 4N HPA demand to increase to 86,831 tpa by 2024.

Total 4N+ HPA Demand 2015-2028

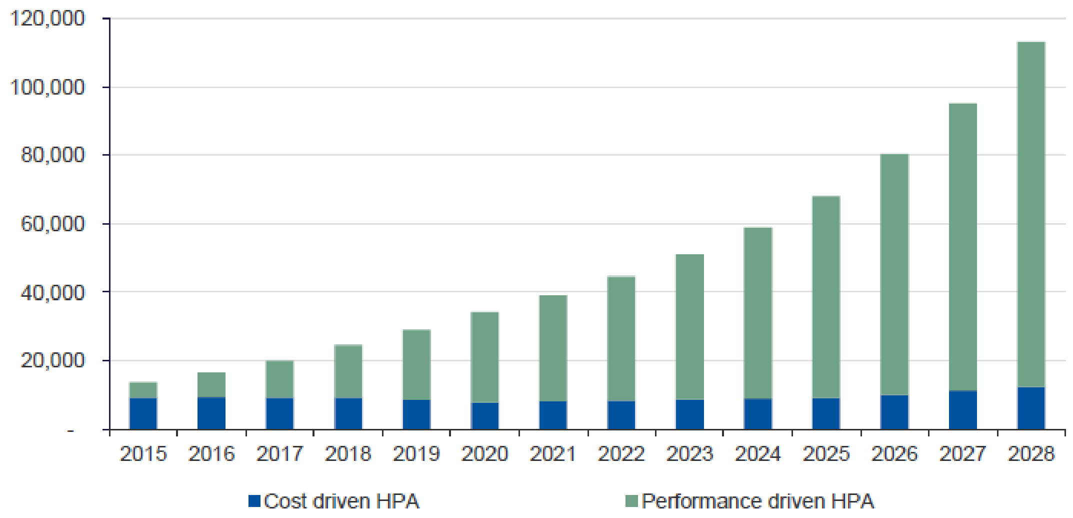


Source: CRU Consulting High-purity alumina market outlook

Demand for LEDs has been predicted to grow at 14% CAGR over the period 2018 to 2028. Total demand for 4N+ HPA in 2018 for LED sapphire substrates was estimated to be 15,344 tonnes by CRU in its analysis. Demand for 4N+ HPA in LED applications is driven by a need for lower impurity, higher quality feedstock required for the transition to larger sapphire wafers (>6”). However demand is also potentially moderated by substitution of sapphire by silicon carbide (SiC) substrates in higher power LED applications and growth of OLED market share in electronics displays.

Nevertheless, CRU's modelling predicts that the unconstrained global market for 4N+ HPA in this sector will grow to 85,000 tpa by 2028 at 20.7% CAGR. This is reflected in the figure below.

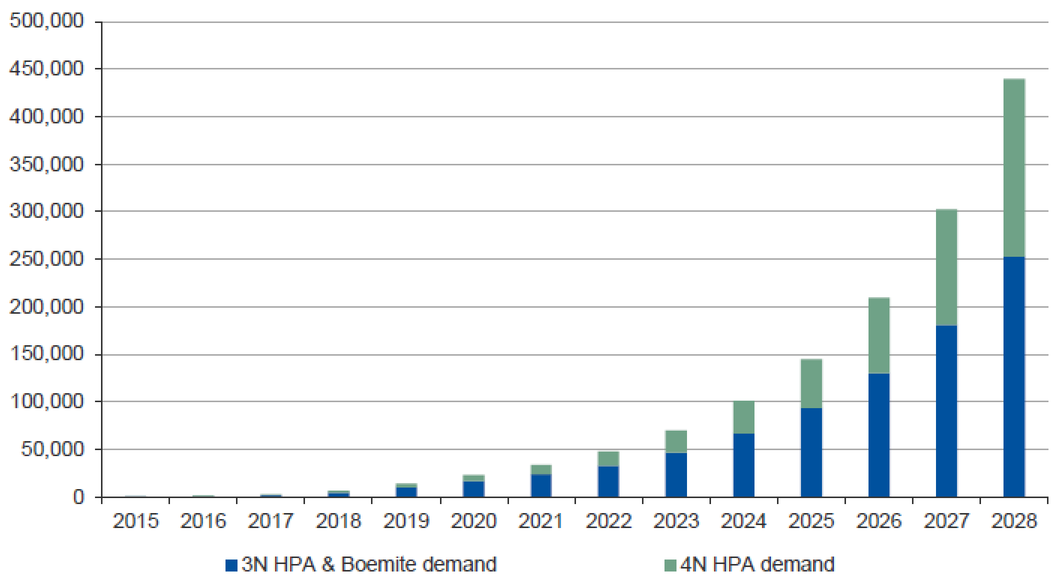
4N HPA Demand in LED Sector 2015-2028



Source: CRU Consulting High-purity alumina market outlook

The 2018 global market for 4N+ HPA in lithium-ion battery separator coatings was estimated to be 2,030 tonnes. However, CRU Consulting identified this sector as having the largest growth potential due to predictions on the electrical vehicle and battery market (~25% annual growth), in addition to a significant shift in separator manufacturers using HPA coatings as demand for higher energy density, NMC and NCA cathode battery types increases by vehicle manufacturers. 4N+ HPA demand has been predicted to rise to approximately 187,000 tpa at 57.2% CAGR by 2028.

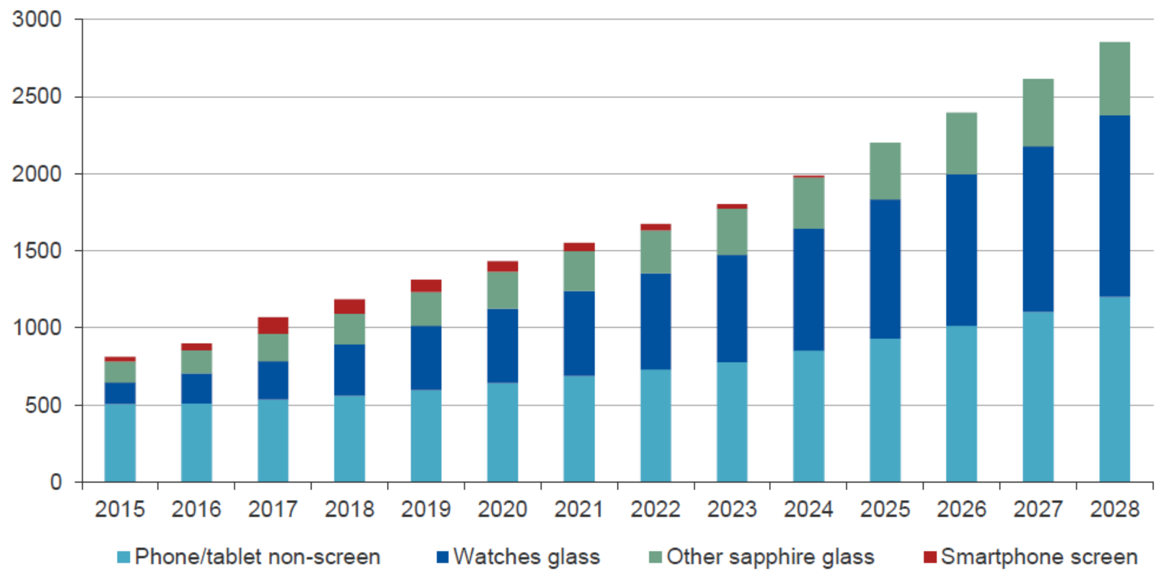
3N & 4N+ HPA Demand in Lithium Battery Sector 2015-2028



Source: CRU Consulting High-purity alumina market outlook

Global consumption of 4N+ HPA in the scratch resistant sapphire glass sector was estimated to be 1,200 tonnes, and growing to approximately 2,800 tpa by 2028. Growth in these applications is not anticipated to compete with that of the LED and lithium-ion battery applications.

4N+ HPA Demand (t) for Scratch Resistant Glass Applications 2015-2028

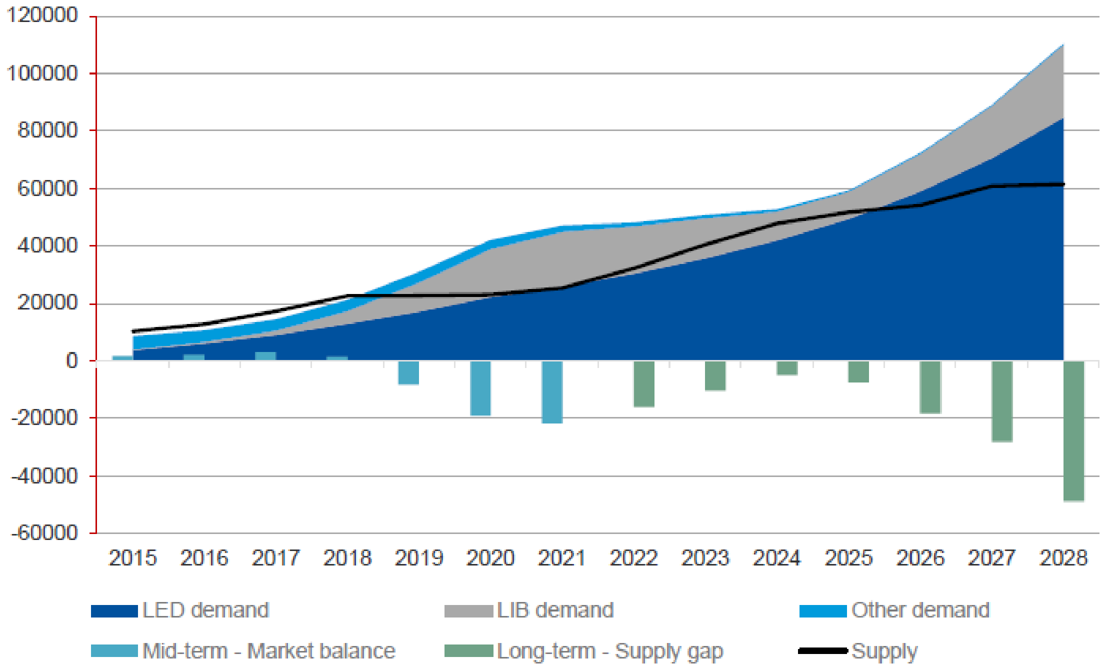


Source: CRU Consulting High-purity alumina market outlook

4N HPA demand is generally highly concentrated within the Asia Pacific region, driven by China, Japan and South Korea (collectively >42% of total LED market in 2015). The Asia Pacific region was the largest market for 4N HPA, accounting for nearly 72.4% of global 4N HPA consumption in 2016.

Predictions for the unconstrained global demand for 4N+ HPA from 2018-2028 have also been assessed against potential production volumes of existing and developing producers. It is clear from this analysis that a growing shortage of HPA will exist on the global market, and therefore substitution of lower quality HPA or alternative materials will be likely over this period. Analysts suggest the lithium-ion battery coated separator application, whilst growing most rapidly, is the most likely to adapt to a modified 3N specification with focus on deleterious elements most critical to the battery sector rather than the high specification required in sapphire substrate applications. A constrained demand model was also developed by CRU consulting in 2019 considering this scenario, with global demand still projected to reach 110,288 tpa by 2028. Nevertheless, the market is still expected to experience 4N HPA supply shortages in the mid and long term, as shown in the figure below.

Constrained 4N+ HPA Demand & Supply Gap 2015-2028



Source: CRU Consulting High-purity alumina market outlook

SUBSTITUTION RISKS

CRU reports that more than 90% of the global LED substrates market has been supplied by synthetic sapphire substrates, which are made from HPA, as these currently offer the best compromise between cost, durability and thermal efficiency. Although these account for the vast majority, not all LEDs produced use sapphire wafers as their substrate for epitaxy: alternatives include gallium nitride (GaN), silicon carbide and silicon. However, CRU reports that none of these alternative substrate materials are noted to be cost or quality-competitive with sapphire yet, in part because of the economies of scale that sapphire epitaxy enjoys. The risk of substitution is low.

In the lithium battery separator coatings area, other types of materials such as silica, boehmite and lower quality alumina have been used as substitution for the 4N HPA. CRU has reported that silica have been known to react with lithium in the battery causing performance and safety issues. Boehmite (~5,000 ppm impurities) and lower quality alumina (~1,000 ppm impurities) add 10-100 times more impurities to the battery cell. These impurities, depending on their composition, can ultimately damage the cell in a number of ways. Elevated levels of sodium, for example, react with the Li-ion channels and can reduce power output. Metallics can steadily assist in the formation of dendrites, which pose a puncture risk and therefore short-circuit. All impurities are believed to contribute to power fade, and so the useful cycle life of the cell.

These materials may be used in low density lithium ion batteries. However, for high density, chemical stable, safety critical, long life batteries for the electric vehicle industry, there appears to be little substitution for 4N HPA. The material is considered a performance-driven raw material in these high density batteries.

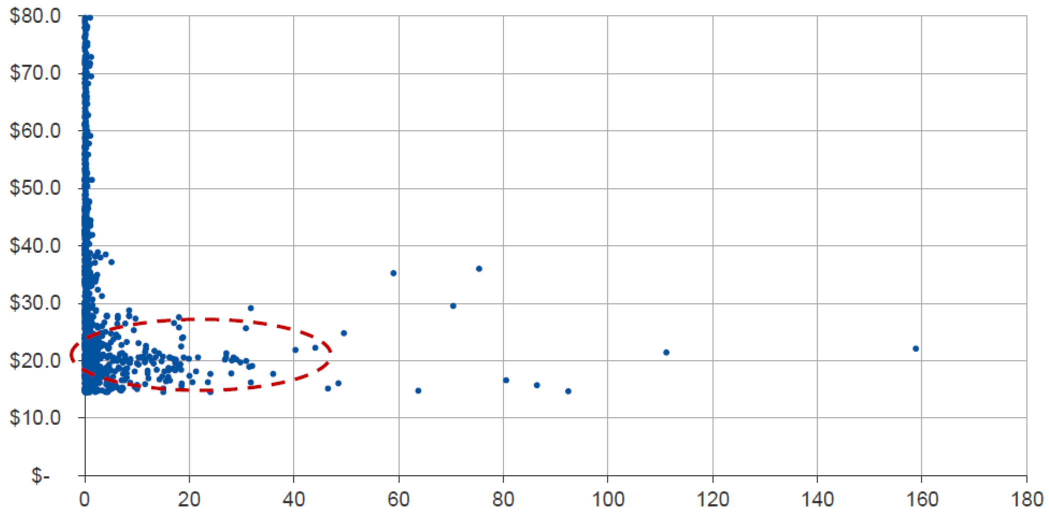
HPA PRICING

The market for High Purity Alumina is largely opaque and pricing is typically negotiated between producer and customer. HPA prices remains secretive and benchmark pricing is largely unavailable. HPA is a speciality material and the product is bespoke and often tailored to a customer's requirements. The price of 4N HPA can vary widely depending on the degree of purity, specific end user specifications such as product density and particle size, long term supply agreements, country of origin, producer reputation, and order quantity.

CRU maintain that there is still essentially a dual market of 4N HPA products; material from the established international producers such as Sumitomo, Sasol etc that have a reputation of consistent and high quality products which therefore demand higher prices; and material from emerging Chinese producers that have been alleged to have historically supplied 4N HPA under false or inaccurate specifications. As 4N HPA is relatively difficult to analyse for purity (given the low detection tolerances required) and varying test methods are used in the industry, it has taken a number of years for end users to consistently identify inferior products and suppliers in the market. Chinese supply also suffer from quality consistency and poor reputation which is demonstrated in an almost-total lack of Chinese exports of high purity alumina to overseas markets such as Japan and Korea. The difficulty of accurately assaying this material has meant that many consumers purchased, and continue to purchase, sub-standard product on an unwitting basis. CRU has reported that overseas market participants simply do not trust Chinese supply.

Analysis on 4N HPA pricing completed by CRU Consulting in 2019 which considered available trade data, online market pricing, and discussions with various producers and end users, concluded that prices ranged from a low of $15/kg to as high as $100/kg (see figure below). The Chinese inferior product claiming to be 4N quality, but actually 3N in quality, tends to have a price below $15/kg.

Global Alumina Exports - $/kg vs shipment tonnes (minimum $15/kg).



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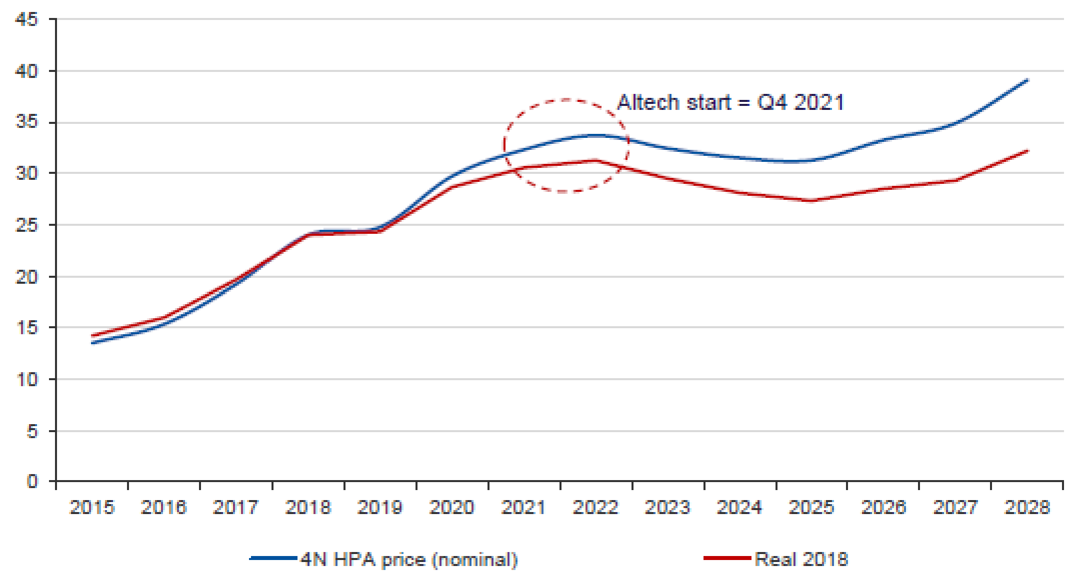
CRU estimated from analysis of Japanese export data that the average sales price for Sumitomo product was at the higher end of the 4N market at approximately $28/kg, with a higher band at ~$35/kg likely to apply to slightly higher specification product i.e. 4N+ (4N5 or 5N). Rival producer Baikowski's published financial information for 2018 further supports an approximate revenue of $23-29/kg (albeit with some participation in downstream products). CRU reports that Sasol is selling the majority of their 3N-5N purity range in the $15-30/kg range with 8 trades seen at order volumes of over 500kg with an average price of $67.6/kg, reflecting higher quality. Altech has stated publicly that its proposed HPA product is targeted at the premium Sumitomo end of quality and price. Altech has used an average long term price of US$27/kg in its Financial Investment Decision study.

CRU reported that the average market price of 4N+ HPA in 2018 was around $24/kg or US$24,000/t (see figure above).

Previous analysis of 4N HPA market pricing by Persistence in 2016 estimated that 4N HPA by leading producers for sapphire applications was approximately US$28,000/t. A review of developing HPA producers also finds that all use 4N HPA pricing is in the range of US$ 23,000 to US$ 27,000/t in their financial modelling.

Increasing it is being accepted that rising 4N HPA demand and a predicted supply shortfall, in addition to rising operating costs for existing producers, is likely to result in an increase in 4N HPA price over the 2020-2028 period, as illustrated in the figure below. CRU forecasts an average 4N+ sale price over this period of US$ 32,800/t.

Price Forecast 4N Grade HPA



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CONCLUSION

High purity alumina is a premium priced, specialty chemical product with significant demand growth projected over the next decade. HPA's use in synthetic sapphire production, largely for downstream LED substrate manufacture, is predicted to grow at a rate of 20.7% CAGR through to 2028. In addition, HPA's use as a separator coating in the manufacture lithium-ion batteries, is expected to grow at a rate of 57.2% CAGR. As a result of the increased up of 4N HPA in both of these applications, a global supply deficit is forecast between 2023 and 2028.

Projects currently under development, such as Altech Chemicals HPA project, are well positioned to take advantage of the projected growth in global consumption of 4N HPA, due to demand from both the LED and Lithium-ion battery sectors.