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HOT ROCKS

Among its various uses, high purity quartz is an integral component in solar's manufacturing chain, used to create the crucibles in which silicon ingots are produced as the basis for solar PV. Its fortunes are tied to a renewable that looks set to help shape the future of energy.

By Simon Rees

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Quartz has been exploited by humans since prehistoric times. The Roman naturalist and philosopher Pliny the Elder contemplated clear quartz and argued it must be a form of petrified ice, created over an immense length of time.

Given the limitations of Ancient science, Pliny's assessment was noteworthy for at least recognising some kind of geological force had been at work.

His audience was curious because the material was prized for making beautiful vessels, jewels and pendants. It commanded high prices that only the noblest houses could afford.

Today, quartz in rock or sand plays a critical role in almost every facet of life, with a plethora of applications stretching from sandpaper to fertilisers, cement to speciality lenses.

But less well known among the general public is the role of high purity quartz.

High purity quartz sand comprises more than 99.995% silicon dioxide (SiO2), with the higher grades used to create crucibles needed by manufacturers in the semiconductor and solar photovoltaic (PV) industries.

It also plays a role in the manufacture of tubing for high-temperature lighting, while slightly lower grades are used in making parts like rods, wafer carriers and windows for semiconductor and solar photovoltaic (PV) manufacturers.

"Most people haven't paid much attention to high purity quartz sand because they don't look beyond silicon metal to the full supply chain necessary for solar PV manufacture," HPQ Materials CEO Stuart Jones told **Benchmark Mineral Intelligence**.

"The high purity quartz sand used to make the crucible is every bit as critical as the need for polysilicon in the manufacture of solar PV and semiconductors. In short, no high purity sand means no solar PV and no semiconductors," he added.

But the market lacks readily-available data or statistics on production, uptake or pricing points. It is opaque to say the least, lacking the quality most sought after in clear quartz by the Romans: transparency.

Shifting sand

Speaking with **Benchmark**, Dorfner Anzaplan managing director Reiner Haus estimated total volumes of high purity quartz sand sold internationally stood between 50,000 and 100,000 tonnes per year (tpy).

Prices are noteworthy, albeit hard to specify because the major producers are privately-held and sell on a contract basis. Purity and demand levels are important price determinates, with the material sold primarily to Asia-based crucible makers, most of whom are located in China.

High purity quartz sand pricing starts at $5,000/tonne, according to Haus, with the majority of material sold between $6,000 and $7,000/tonne. Ultimate-quality high purity quartz sand commands more than $10,000/tonne.

Jones noted that solar-grade is currently being sold at around $6,500-$7,000/tonne and was following an increasing trend.

High purity quartz sand is non-reactive in high temperatures, thermally stable and an ideal source material to make crucibles.

This is done by processing the high purity quartz sand and then creating fused-quartz crucibles by using specialist moulds.

The crucibles are the receptacles in which polysilicon is melted and through which monocrystalline or multicrystalline silicon ingots are produced.

The polysilicon is 99.99999% pure metal, most often produced by using the Siemens method.

It has lower melting point compared with the crucibles that can withstand temperatures of up to 1,750 degrees C. Typical operational temperatures for ingot manufacture are between 1,200 and 1550 degrees C.

Total impurities in solar-grade quartz must not exceed 20-40 parts per million (ppm) and can include iron oxides, alkalis, heavy minerals or other contaminants.

Impurities must be minimal to avoid their transference into the silicon, which could retard a solar's module's eventual efficiency. "The purer the crucible, the less problems arising from impurities introduced into the silicon melt," Haus said.

Manufacturing of multicrystalline silicon for solar PV requires large rectangular crucibles, while monocrystalline silicon utilises rounded crucibles made from purer solar-grade quartz.

"The highest purity is required by

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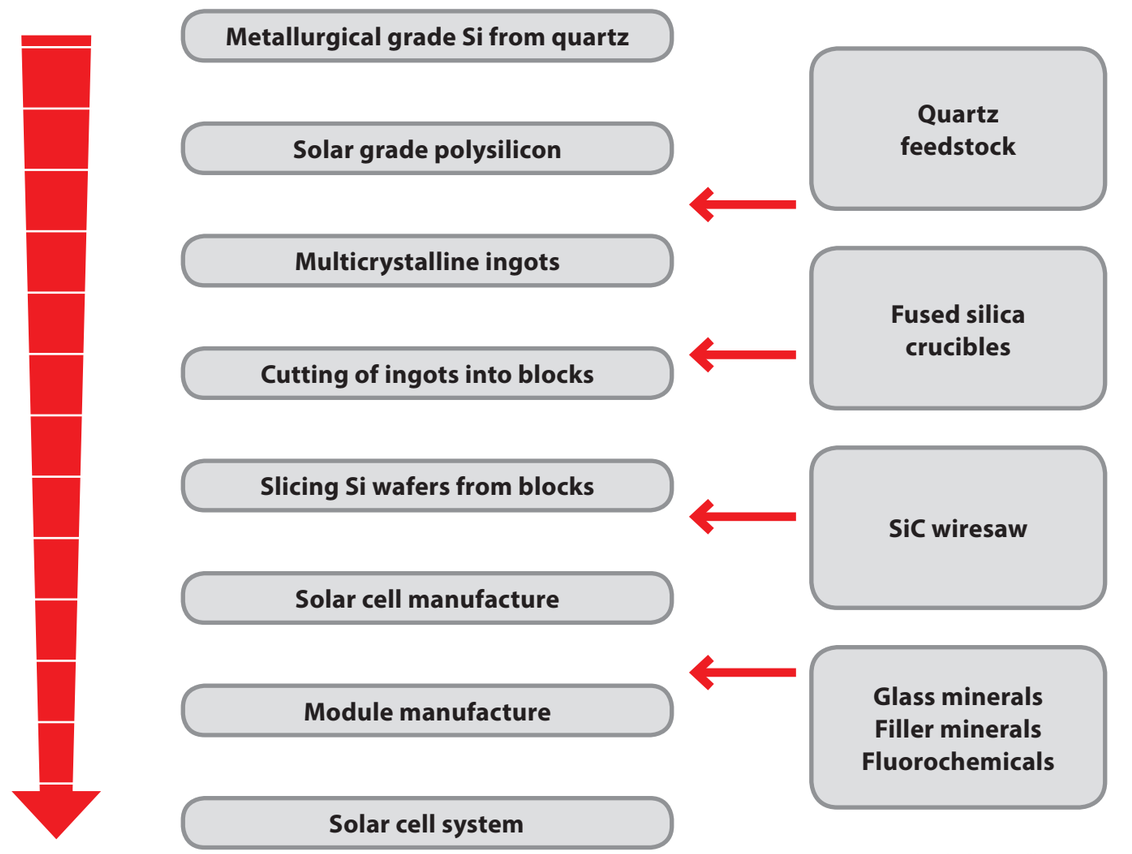
THE SOLAR SUPPLY CHAIN AND RAW MATERIAL INPUTS



Source: Benchmark Mineral Intelligence, HP Quartz

Czochralski process [for monocrystalline production], while slightly less pure quartz is acceptable for crucibles used to make multicrystalline," Haus said.

The Czochralski process uses polysilicon with dopants added. A rod-mounted seed crystal is then grown within this molten mix and slowly withdrawn under rotation to form a long monocrystalline ingot, often called a boule.

This phase is called "crystal pulling" and the largest producers run numerous banks of furnaces at once.

Boules are sliced at the top and sides before being cut into blocks. Multicrystalline ingots are sliced into bricks after being removed from their crucibles.

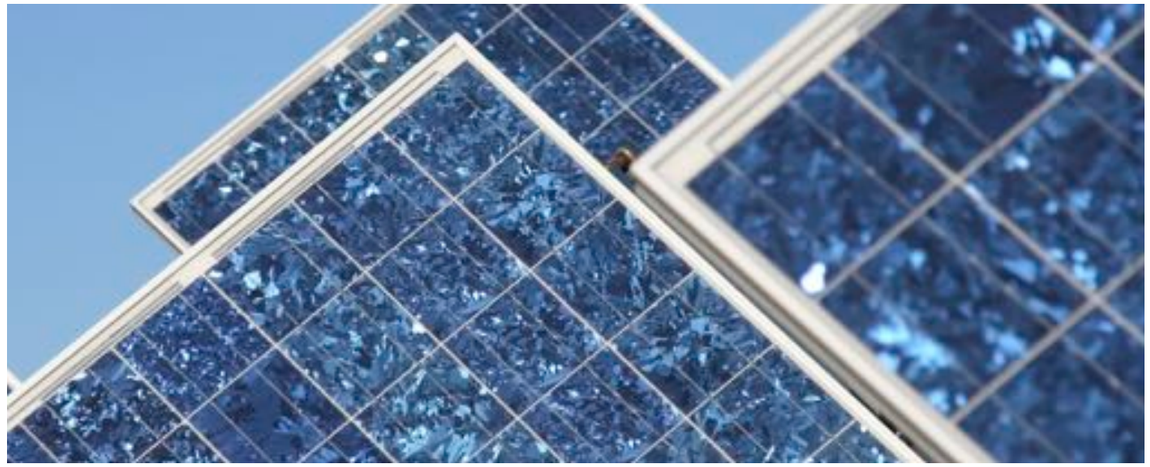
Both blocks and bricks are then wire-cut to produce wafers that are further processed to make solar cells. The crucibles cannot be re-used because of impurities risk and are discarded.

The manufacturing process can also have some variance as ingot producers use specialist in-house proprietary technology.

Diamonds in the rough

Quartz in rock and sand is the second most-abundant mineral on the planet. But finding the right material for high purity quartz sand status requires a specific type of deposit with levels that can deliver the minimum 99.995% SiO2.

Such deposits are rare but found globally. However, deposits that are also substantial in size and economically viable are rarer still.



There are hydrothermal deposits in Australia, Madagascar and Russia; feldspar deposits in the USA; quartzite deposits in China, India and Norway; and crystals in Brazil and the USA.

The ease with which impurities can be removed is also essential. For example, a company might find a deposit with a small level of impurities that prove to be locked-in at the molecular level.

Such deposits are uneconomic because the impurities removal would be both expensive and time-consuming, preventing market entry.

"A great deposit is one where you can liberate impurities from the quartz and do so with existing technologies, allowing for purification to the ultimate quality," Haus said. "However, deposits that fulfil the necessary requirements are quite rare, which is why people are searching for them all over the world."

The largest producer of high purity quartz sand is Unimin Corp, a wholly-owned US subsidiary of Belgium-based privately-held Sibelco. Its material is processed and sold to crucible manufacturers under the Iota brand name.

The company does not report its output or sales figures publically.

Unimin's high purity quartz sand deposits are located in Spruce Pine, North Carolina. "Interestingly, they're not quartz deposits but feldspar. The quartz is a residual sold as a by-product," Haus noted. "The rest is feldspar and mica."

The material undergoes detailed analysis to manage product consistency and uniformity after extraction, with impurities removal carefully fine-tuned from the batches supplied.

"The assessment of samples requires preparation, analytical procedures and processing development," Haus said. "The work is tailor-made to certain deposits."

Delineation of grade is undertaken during processing, while any specific customer demands are also met at this stage.

The highest purification level is the 99.999% SiO2 required by the semiconductor manufacturing market

The market's other key participant is the Quartz Corp, a joint-venture between France-based Imerys and Norway-based Norsk Mineral. It also mines in the Spruce Pine area.

Its high purity quartz sand is extracted and semi-processed before being shipped to its dedicated production unit at Drag, northern Norway, for full beneficiation.

The company told **Benchmark** that it was permitted to produce 30,000 tpy from its Norwegian unit.

Other producers have smaller footprints than Unimin or the Quartz Corp, such as Kyshtym Mining, based in the southern Urals and also known as Russian Quartz.

Japan-based Sumitomo Corp took a 28.69% stake in Russia Quartz in Q3 2013 for $50 million and, at that time, noted the operation had a high purity quartz production facility with a 3,000tpa capacity.

There are some other producers as well, although it is difficult to determine production or quality levels. "Output is either a small amount or at an unknown quality as of yet," Haus said.

Several noteworthy projects comprising high purity quartz sand are in varying stages of development around the world.

Australia-based HPQ Materials is developing a mine and processing facility in Queensland and Victoria. It estimates a 40-year life of mine.

Its high-purity output, including solar-grade under its HP7 brand, will be exported into Asia, primarily to crucible manufacturers in China and South Korea. India is another potential market.

HPQ Materials is also working to stimulate Australia's solar sector, potentially establishing manufacturing chains that comprise crucible production and into which HP7 could be sold.

The company's operation would target 20,000 tonnes solar-grade and 4,000 tonnes semiconductor-grade over a five-year ramp-up programme. The lower-grade output would be sold into alternative markets, such as speciality quartzware.

"HPQ Materials does not target being more than 10-12% of the solar and semiconductor sand market when fully ramped up in five years," Jones said.

It estimates a development spend of A$30m ($21.6 million) is required to bring the project on stream

Multi and mono

Assessments of high purity quartz sand often treat the material as extracted and sold in a vacuum. But sector developments and an assessment of the solar PV market should be considered to better understand its prospects.

An important change has been the growth in monocrystalline capacity, although multicrystalline accounts for a larger market share. Installed multicrystalline produced 26.2 GWp for 2014, which compared with monocrystalline's 16.9 GWp, according to Fraunhofer ISE.

Multicrystalline requires more cells and larger land areas compared with monocrystalline. It also has solar-to-power conversion efficiencies that rank between 13% and 15% for commercial products.

By comparison, monocrystalline delivers more power from a greater density and has efficiencies between 15% and 23%. It has traditionally been more expensive than multicrystalline.

But per-watt module costs keep declining for both multicrystalline and monocrystalline, while the price differential between the two has also narrowed, reaching parity at times in China.

This dovetails with Swanson's Law that notes solar PV modules cost 20% less with the doubling of cumulative shipped volume.

Solar cost $76.76 per watt on a cell basis in 1977, according to the Economist. Effective June 8, it stood at $0.30 per watt for Chinese multicrystalline cell and $0.37 per watt for monocrystalline cell, according to EnergyTrend.

As the market grows, the product becomes cheaper. However, the cost efficiency focus is expected to remain at the downstream manufacture and installation level for some time, according to Jones.

Several major solar manufacturers have installed more monocrystalline capacity as the product's inherent strengths becoming increasingly attractive.

In addition, the efforts to improve solar's performance are more notable. For example, Passivated Emitter Rear Cell achieves an average efficiency of 21-22% with monocrystalline.

Indeed, there is an argument monocrystalline fortunes could be undergoing a slow sea change, whereby it makes much greater inroads at multicrystalline's expense.

And that could further enhance the prospects of the high purity quartz sand produced and processed specific to monocrystalline requirements.

It comes as no surprise that high purity quartz sand producers keep a sharp eye on market trends such as these.

The Quartz Corp believes its capacity is well-tuned to current conditions, even stating that demand for high purity quartz sand has slid somewhat.

"While the installation of solar panels continues to grow, there are very strong learning curves being followed (i.e. the Swanson effect) that mean, in reality, the demand for high purity quartz sand is actually declining somewhat," the company told **Benchmark**.

The company did not foresee potential

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bottlenecks for crucible manufacture, arguing there was sufficient capacity to accommodate a doubling of demand or more before further capacity increases were necessary.

The Quartz Corp also said it had invested in capacity to meet higher demand. "It would therefore be unwise and unlikely for new operations to come on stream for the foreseeable future," it said.

The company noted it was open to expanding capabilities to meet market demand if it showed sustainable and attractive growth. "However, with current available capacity and capabilities, we do not see this [as] likely in the coming years," it added.

But the producing deposits are not limitless and have been exploited for five decades, Jones argued.

That potentially allows high purity quartz sand producers, the ones with qualifying quartz deposits and low production costs, to enter the market.

This is not a simple task, as several would-be contenders slated to arrive since 2012 have discovered.

They have largely been unable to achieve their goals because of difficulties in obtaining the high purities needed on an economic basis, Jones noted. Meanwhile, the potential for polysilicon shortages – a proxy for increased solar manufacturing – are still affecting the industry, he said. Prices were stimulated by and responded positively to the United Nations Climate Change Conference (COP21) held in Paris towards the end of 2015.

He also saw important similarities between the lithium and high purity quartz sand markets, and a linkage between battery storage development and solar PV.

Global initiatives to bolster renewables and developments in battery storage, most notably those tied to solar grids or domestic solar arrays, will be a significant driver of demand growth in the solar PV market.

The effects of this will be felt on upstream supply chains and feeds, including high purity sand.

Judgement of Paris

If high purity quartz sand demand is currently being met, and its rate of growth does not exactly correlate with that of solar, its fortunes certainly track end-use uptake.

On that point it is worth noting that solar's future looks bright.

SOLAR SPOTLIGHT

60%

CAGR OF SOLAR INSTALLATIONS FROM 2015 TO 2015

7,500 MW

OF US SOLAR CAPACITY INSTALLED IN 2015, COMPARED WITH 900MW IN 2010

209,000

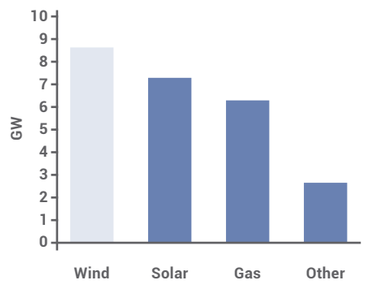
US WORKERS IN THE SOLAR INDUSTRY IN 2015, DOUBLE THE NUMBER IN 2010

420,000

US WORKERS IN THE SOLAR INDUSTRY FORECASTED BY 2020

Source: GTM Research

INCREMENTAL CAPACITY ADDITIONS IN THE US BY POWER SOURCE, 2015



Source: Goldman Sachs

"In oil equivalent terms, solar and wind are now on a par with the US shale oil boom

Goldman Sachs, June 2016

In 2015, the research and consultancy group Wood MacKenzie pondered whether the sector had the potential to become the "next shale" in terms of its transformative capacity. It also noted the fall in module costs and how increased efficiency was now the "next frontier".

Market information firm IHS forecast installed solar PV capacity would reach 69GW in 2016, compared with 59GW for 2015. The USA, India and China are expected to be the key markets, with their capacity predicted to grow by 5.6GW, 2.7GW and 0.9GW respectively.

Increasing solar levels in China stems from a need to reduce the country's notorious emissions levels. The 'Top Runner' programme is just one facet of this, with the government seeking to embed minimum efficiency rates for the manufacture of commercial monocrystalline and multicrystalline.

In the USA, it is worth noting the number of jobs associated with solar reflects the overall growth. The sector is expected to employ just over 238,000 people in 2016, according to the National Solar Jobs Census.

By contrast, the oil and gas industry employed around 180,000 people at the start of 2016, according to the US Bureau of Labor Statistics.

All of this was good news for the high purity quartz sand and the solar PV supply chain in general, Jones said, arguing that existing high purity quartz sand producers would be approaching capacity when viewed through this prism.

"High purity quartz sand pricing will rise in the interim absent new supply," he said, adding the market would welcome another globally-relevant producer with low production costs.

It would also add to security of supply.

However, there could be some macroeconomic caveats of note, including the potential for recessionary forces or a stalling in the global economic recovery.

Macroeconomic factors could also have implications, such as the potential for recessionary forces or a stalling in the global economic recovery.

THEnergy founder Thomas Hililg stressed the importance of interest rates on solar installation, with long-term financing instruments usually required.

"Investment decisions today are based on certain assumptions on specific contracts with regards to financing," he noted. "And all of these financing conditions are different depending on the location and country."

Cuts to solar subsidies also weigh on country-specific uptake, while basic issues such as geographical location and irradiation levels affect demand as well.

"You have to think about location and the differences between equatorial zones or somewhere like Scandinavia or northern Canada, where solar PV is twice as expensive," Hilig said. "That's because you get half the yield in these places compared with locations closer to the equator."

The US presidential election could prove important as well, with Donald Trump voicing strong support for conventional energy formats and feeds.

"We're going to cancel the Paris climate agreement," he said at the end of May, referring to US environmental and emissions commitments made at COP21.

By contrast, Hilary Clinton claims her administration would rapidly expand the USA's solar capacity to 140 GW by 2020. Red tape associated with installation would also be cut.

With or without the USA, the commitments made by nations attending Paris are significant. "Paris reflects widespread social concerns that something must be done about climate change," Jones said, adding that most countries have ratified their commitments.

Demand in the renewables space could be propelled forwards on this, particularly for solar PV, with another boost felt across its upstream feeds, including high purity quartz sand.

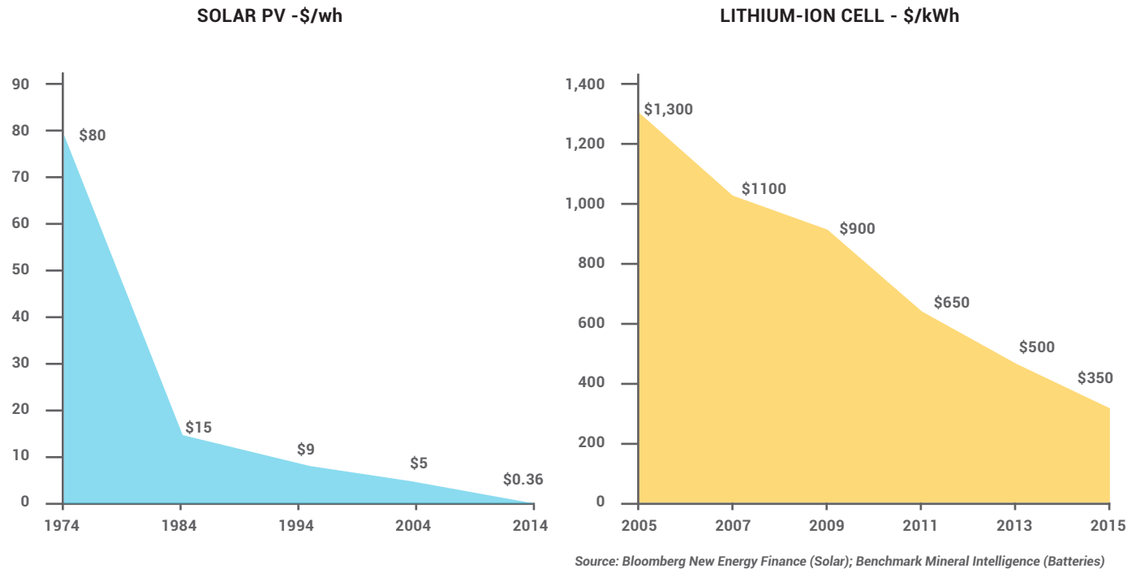
Hilig also stressed the conference's importance, noting it reflected the desire of many governments to make renewable energy a critical component of national energy mixes.

It is not implausible to argue that solar will be a part of everyday life for billions of people within the next 20 years, linking the sector to the seismic shifts now underway as economies attempt to decarbonise and enter the fourth industrial revolution.

The opportunities and the implications for solar's feeds, including high purity quartz sand, could be monumental when compared with the parameters of today's market.

But for the producers and those seeking to enter the market some fundamental things will remain unchanged: great deposits are required; a hawkish eye for detail is needed; and consistent quality must be achieved.

UTILITY STORAGE: THE FALLING COST OF PRODUCTION



Source: Bloomberg New Energy Finance (Solar); Benchmark Mineral Intelligence (Batteries)