PROJECT BLUE

Largo Physical Vanadium

Date: December 2022

1. Vanadium market fundamentals (2013-22)

Project Blue values the vanadium market at over US3.5Bn in 2022. It is a growing market, still driven mainly by steel consumption trends but increasingly exposed to energy transition through vanadium's use in energy storage.

Over the past 20 years, the vanadium market has seen several cycles of deficit followed by oversupply, resulting in dramatic price swings. During this period, the market has also grown considerably, changing from a small market dominated by a handful of producers and consumers to a large market shaped by the interests of not only producers and consumers but also governments and traders.

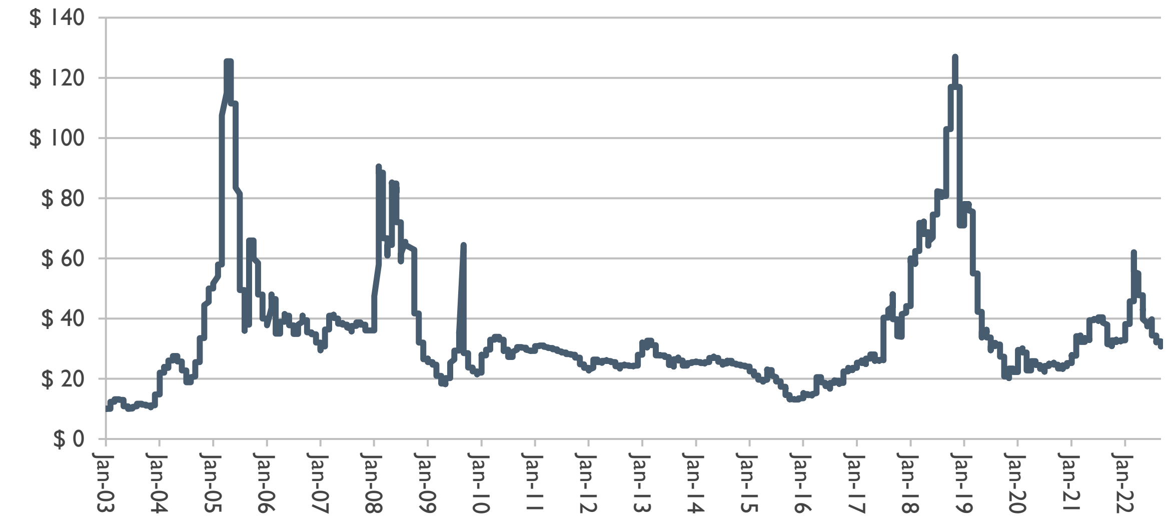
After a sustained period of low prices and oversupply, prices spiked in 2004/05 in response to high demand from steel producers in China, underpinned by the introduction of more stringent construction regulations requiring the use of better (vanadium bearing) steel reinforcing bar (rebar). A supply response led by South African producers led to prices falling back in 2006 despite demand remaining strong. Prices rose sharply again in 2008 owing to production suspensions in South Africa and China but retreated in 2009 as supply came back online and as the global financial crisis impacted steel, and therefore vanadium, demand.

After the world emerged from prolonged recession, vanadium prices remained stable with the market being comfortably supplied between 2010 and 2015. However, in 2016, prices started a gradual yet sustained assent, reaching an eventual peak in November 2018 at over US$125/kg on a ferrovanadium basis.

The price rise was driven by supply- and demand-side factors. Global supply became constrained following the closure of a major producer in 2015 – South Africa's Evraz Highveld, which accounted for around 10-15% of global feedstock output in any given year. The Highveld closure did not immediately push prices higher as global inventories were high, but other shutdowns in China, Russia, and South Africa exacerbated the feedstock availability situation, as did a Chinese ban on the import of vanadium bearing slags from abroad. On the demand side, November 2018 saw the implementation of new construction standards in China mandating the use of higher-quality rebar. Large scale consumer restocking in preparation for these regulatory changes created a very tight market, and prices increased accordingly.

After reaching record highs, prices fell back in 2019. Demand that year was lower than expected as the new regulations in China were inconsistently enforced, steel mills released inventories, and substitution of ferrovanadium for ferroniobium helped to soften vanadium demand. Prices reached a floor by the early stages of COVID-19 but saw upward movement when China emerged early from global lockdowns and went on to post record steel production in 2020. In 2021, prices crept upwards as the post-pandemic recovery saw demand pick up in the ROW and, in March 2022, they shot up on the news that Russia had invaded Ukraine. However, over the rest of 2022 prices retreated as was the case with many commodities, as supply-risk concerns over the war were replaced with demand-side concerns over the health of the global, and particularly Chinese, economy.

Figure 1: Twenty years of ferrovanadium price volatility (US$/kg)



Source: Project Blue

1.1. Introduction to vanadium

Vanadium feedstock is derived from three routes: primary production, secondary production, and co-production. Primary production sees mineral deposits exploited principally for the vanadium within. This takes place mainly in Brazil, China, and South Africa. In China, "coal stone" (a carbonaceous shale) can also be a source of primary vanadium, depending on market prices. Secondary production is from the recycling of spent catalysts that acquired vanadium during crude oil refining, residues from alumina or uranium production, or ash derived from burning vanadium-bearing coal or petroleum. The USA is the world's largest secondary producer with notable volumes also recovered in various Asian countries. It is, however, co-production that accounts for the majority (~70%) of global vanadium supply. This is where a vanadiferous titanomagnetite (VTM) ore (a form of iron ore) is used in the production of steel and vanadium reports to the slag. The valuable vanadium is recovered and subsequently processed into a vanadium product by the steel maker. This takes place mainly in China and Russia.

China is by far the world's main source of vanadium feedstock with Russia, South Africa, Brazil, and the USA completing the "top-five". Primary, secondary, and co-produced vanadium are all converted into vanadates and subsequently into an oxide form. These vanadium oxides (vanadium pentoxide and trioxide) are mainly used as the feedstock to produce the ferroalloys (alloys of iron with a high proportion of one or more other elements) ferrovanadium (FeV) and vanadium nitride (VN). A much smaller proportion of oxides are used to produce high-purity vanadium compounds and chemicals.

Vanadium demand is driven by its use in steel. More than 90% of vanadium consumption is in steel applications where it imparts toughness, strength, wear resistance, anti-corrosion, and anti-oxidation. Vanadium (in ferrovanadium or vanadium nitride form) is used mostly in high-strength, low-alloy (HSLA) steels, although it also finds application in other types of steel and alloys. End-use markets include aerospace, automotive, construction (especially bridges and large buildings), and oil and gas pipelines.

Non-metallurgical applications of vanadium include catalysts, ceramics, dyes, electronics, and batteries. The global drive towards renewable energy has brought about a rapidly growing demand for energy storage for which batteries are ideally suited. Specifically, vanadium is being used in a type of rechargeable battery called a vanadium redox flow battery (VRFB), which has seen increasing commercial deployment over the past decade. VRFBs have large and scalable capacity, can withstand being discharged for long periods, are safe and have a long cycle life making them best suited for utility and grid-scale applications.

1.2. Vanadium feedstock supply

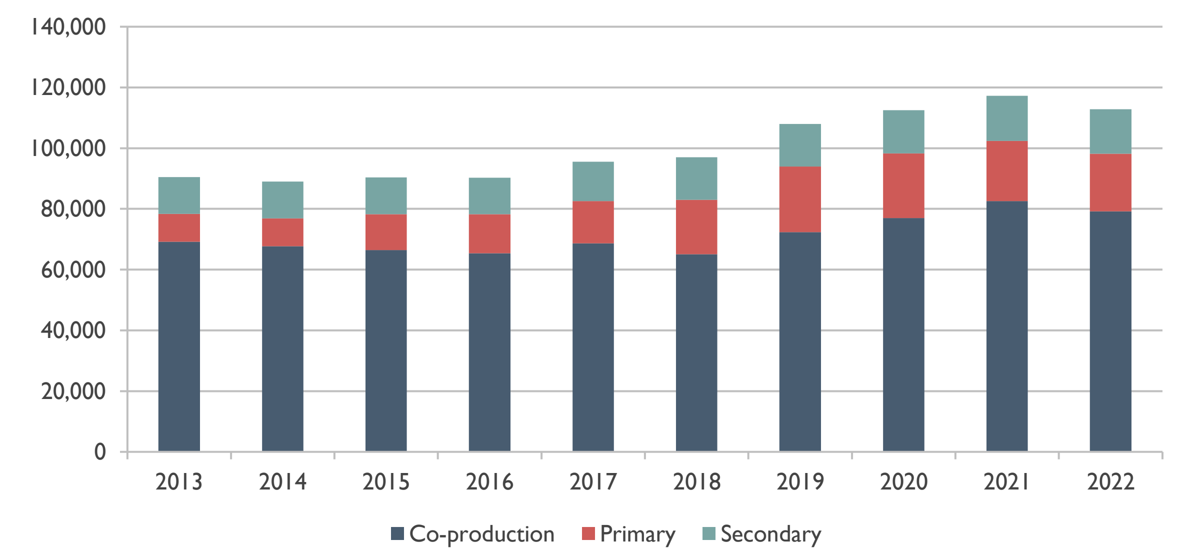
Vanadium feedstock is derived from three routes: primary production, secondary production, and co-production.

Primary production (17% of global supply in 2022) sees mineral deposits exploited principally for the vanadium within. This takes place mainly in Brazil, China, and South Africa. Note that in China, primary production refers to the exploitation of 'coalstone' via a process involving roasting, water leaching and the use of large quantities of caustic gases which translate into a low recovery rate (about 45%) and severe environmental problems.

Secondary production (13% of global supply in 2022) is from the recycling of spent catalysts that acquired vanadium during crude oil refining, residues from alumina or uranium production, or ash derived from burning vanadium-bearing coal or petroleum. The USA is the world's largest secondary producer while South Korea is also a key player.

Co-production accounts for the majority (70% of global supply in 2022) of global vanadium supply. This takes place in China and Russia.

Figure 2: Vanadium production by type (t V contained)

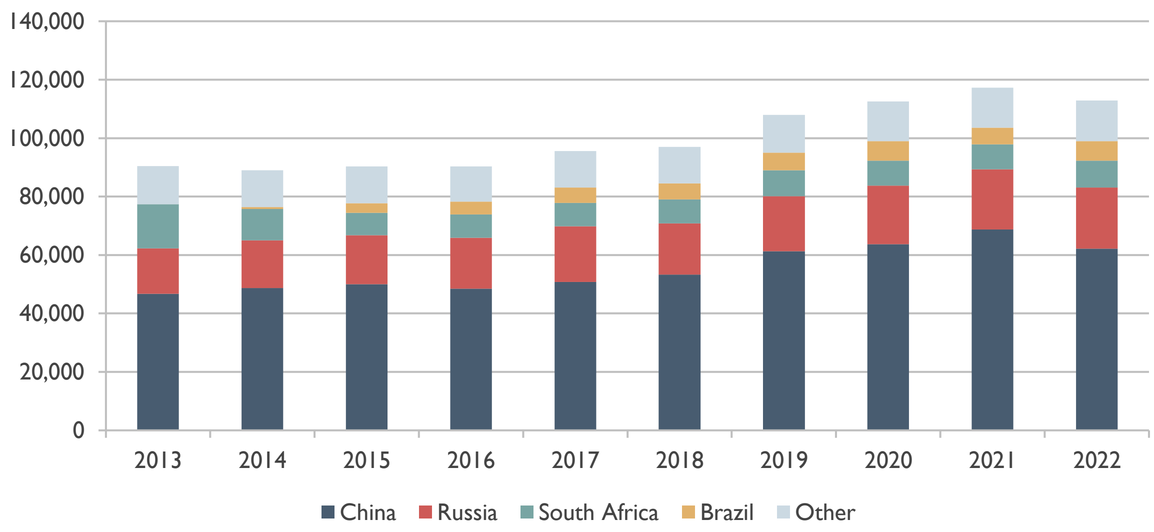


Source: Project Blue

On a regional basis, China is by far the largest producer of vanadium feedstock. It has steadily been growing its market share and accounted for 55% of global output in 2022. Output in China is mainly via the co-production route, where Pangang Group, HBIS Chengsteel, Chengde Jianlong, Sichuan

Tranvic and Sichuan Deshang are the key players. An important primary source of vanadium in China is "coal stone" (a carbonaceous shale), which to some extent serves as the supply chain's swing producer. At times of high vanadium prices, operations (mostly in Shaanxi and Henan) can produce significant tonnages.

Figure 3: Vanadium feedstock production by country (t V contained)



Source: *Project Blue*

Russia is the world's second-largest vanadium feedstock producing country. The majority of its output can be attributed to EVRAZ, a vertically integrated steel, mining, and vanadium business. In Russia, EVRAZ mines vanadium at its KGOK mine which is subsequently processed into a vanadium slag at its NTMK operation. This slag is then refined into vanadium pentoxide and ferrovanadium at Vanady Tula. Some Vanady Tula pentoxide is processed into ferrovanadium at EVRAZ's Nikom plant in Czechia.

South Africa is the world's third-biggest producer of vanadium feedstock. It was previously a much larger source of global supply, but its relative share of production declined and has never recovered since the EVRAZ Highveld operation (which accounted for more than 10% of global feedstock output) shut down in 2015. Today, supply comes from two major players, Glencore, and Bushveld Minerals.

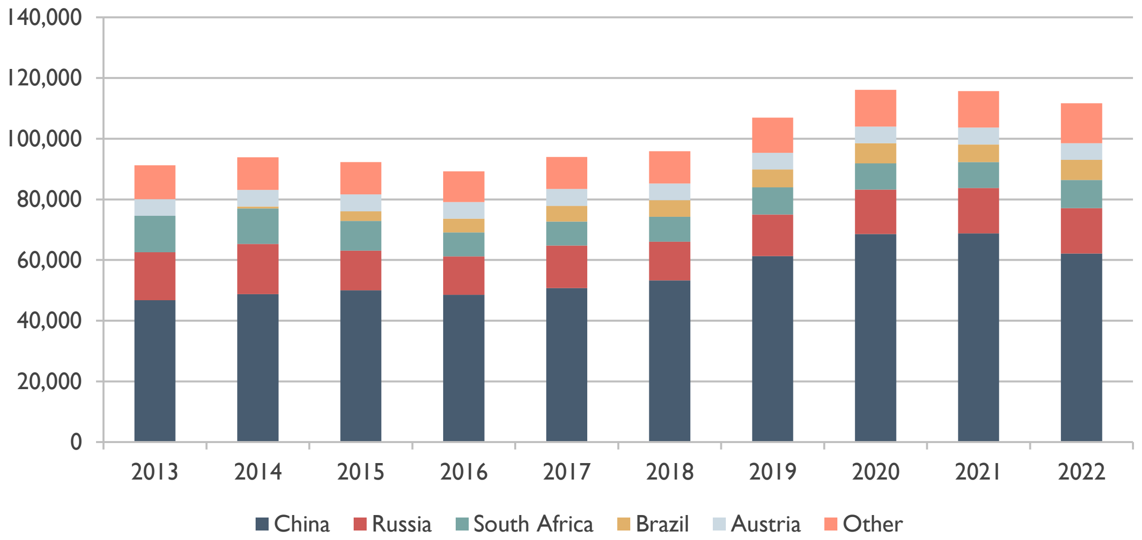
Brazil is the world's fourth-largest producer of vanadium feedstock with output all down to Largo. The company commissioned its Maracás Menchen mine in 2014 and has since ramped up capacity to become one of the world's major producers.

The USA is the world's fifth-largest producer of vanadium feedstock. The most important producers are AMG Vanadium and US Vanadium, which produce vanadium from secondary sources. Depending on prevailing market prices, some vanadium mine production also takes place at uranium mining operations.

1.3. Vanadium product supply

The production landscape for vanadium oxides is strikingly similar to that of vanadium feedstock on a country basis. This is because the leading producers in China, Russia, South Africa, and Brazil all captively process the majority of the feedstock they produce into oxide. One addition to the top five, replacing the USA, is Austria. Through Treibacher, the country is a secondary producer, recycling catalysts and residues that contain vanadium and processing boiler or gasification residues from oil combustion or gasification operations. However, importantly Treibacher also produces large quantities of vanadates from slags imported from abroad (principally Russia and New Zealand).

Figure 4: Vanadium oxide production by country (t V contained)

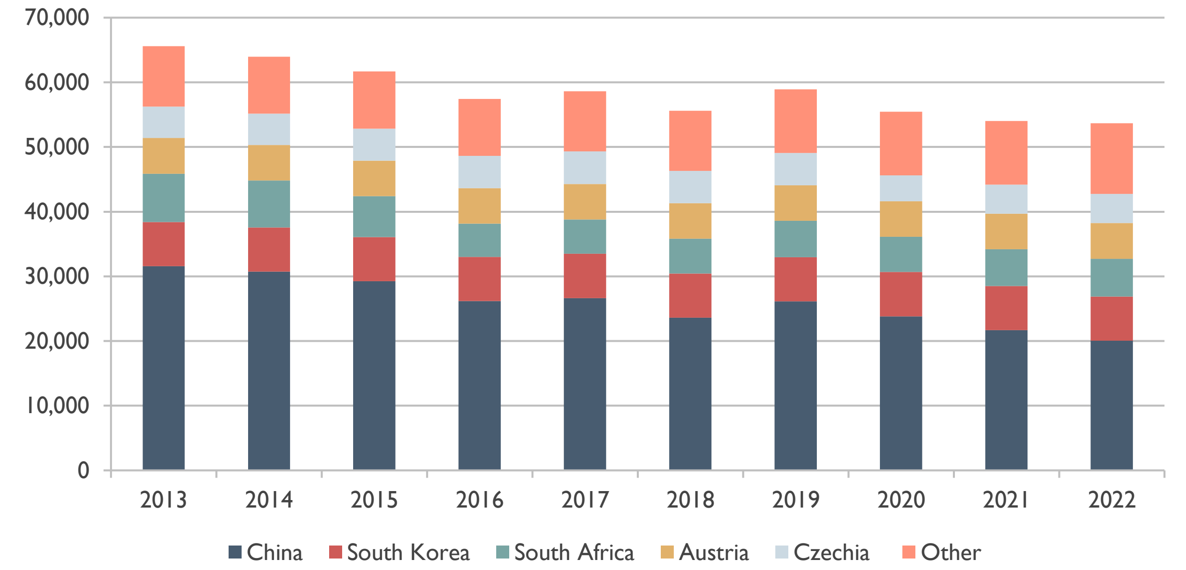


Source: Project Blue

In line with rising steel production and consumption, and higher intensity of vanadium use in steel, consumption of ferrovanadium and vanadium nitride has increased over time with some year-to-year exceptions. Project Blue notes however that (Chinese) ferrovanadium production levels have been slowly declining over time, offset by increasing levels of VN output. This is a consequence of increased microalloying in rebar and a subsequent shift towards more VN consumption compared to ferrovanadium in China.

The production landscape for ferrovanadium is similar to that of vanadium oxides, with China being the largest producer and Pangang by far the biggest in terms of output. The country is also the largest producer of VN, followed by South Africa. Project Blue believes that, as of 2022, South Korea was the second-largest producer of ferrovanadium, underpinned by output from its three major players, SeAH M&S, Korvan and Woojin. In South Africa all output is from Glencore, and in Austria all production is from Treibacher. Czechia is the world's fifth-largest producer, with all output from EVRAZ Nikom.

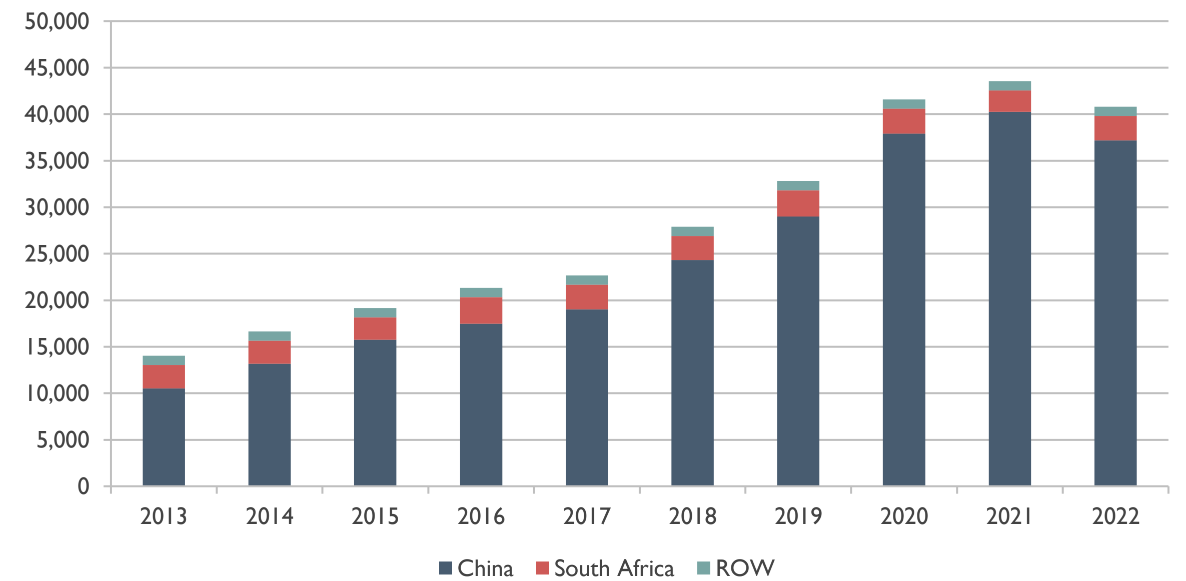
Figure 5: Ferrovanadium production by country (t V contained)



Source: Project Blue

VN production is consolidated in China and South Africa. In China, Pangang is the biggest producer followed by Chengde Jianlong. The market is fairly fragmented in China with as many as 35 producers (although many are subsidiaries of a smaller number of larger entities). In South Africa, Bushveld Mineral's Vametco plant produces VN under the Nitrovan® trademark.

Figure 6: VN production by country (t V contained)

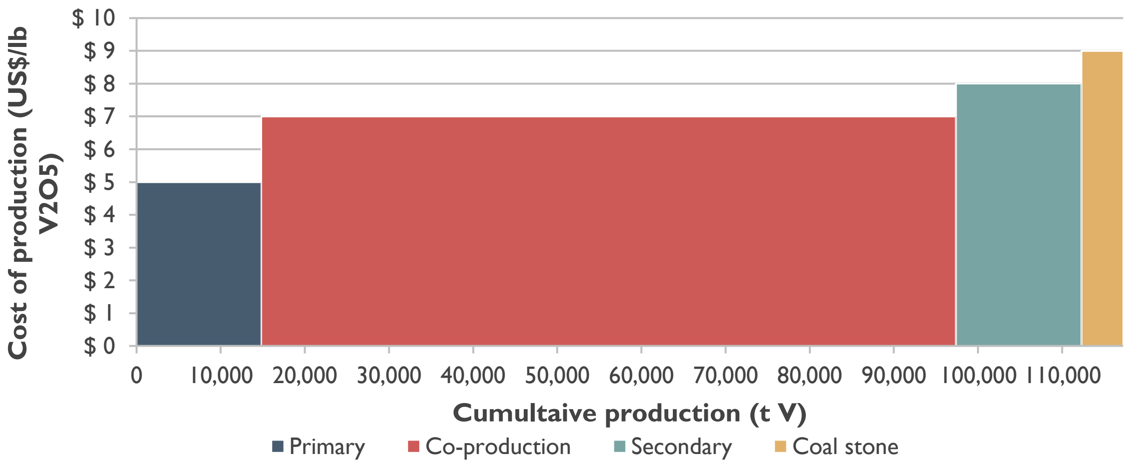


Source: Project Blue

1.4. Vanadium production costs

Vanadium production costs differ widely by production route and geography. The chart below sets out a simplified cost curve for vanadium pentoxide split by processing route. Note that CAPEX is not included and is likely to have increased materially over recent months owing to inflationary pressures and higher interest rates.

Figure 7: Vanadium pentoxide production costs, 2022(US$/lb)



Source: Project Blue

The bottom quartile is dominated by primary producers, which benefit from integrated operations with processing assets (usually) close to mine sites. C1 production costs range between US$4.50-6.00/lb of V_2O_5, with quarterly fluctuations depending on specific operational issues, energy costs or currency movements.

Co-producers are typically in the middle quartiles, e.g., circa US$7/lb V_2O_5 with Pangang and HBIS Chengde thought to be the lowest cost co-production operations. Chinese mills have seen production costs increase in 2022 due mainly to higher energy prices, although the depreciation of the RMB compared to the US$ has reduced total costs in US dollar terms.

There are a wide variety of secondary production routes and feedstocks, and while costs differ between these (and also vary greatly depending on prevalent market prices), in general secondary producers occupy the upper quartiles of the cost curve.

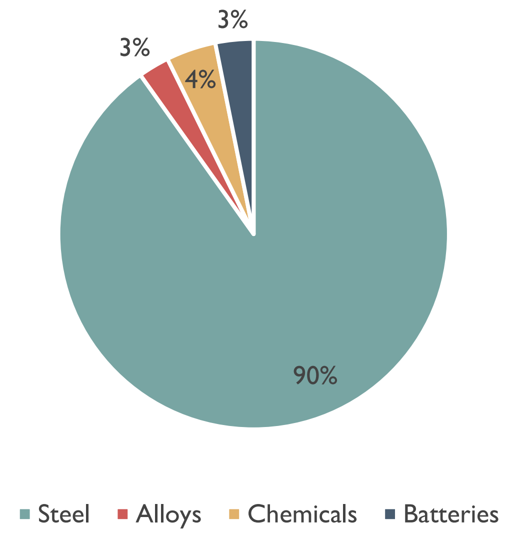
Project Blue estimates put stone coal stone producers in the upper quartile with cost differences depending on whether they are large or small. Most coal stone players are unlikely to have the capital to make the necessary investments for any required new equipment. Therefore, coal stone is expected to remain the marginal cost producer and is at risk of being displaced by lower cost supply coming on stream.

Project Blue notes that there are several primary mine projects which could enter production over the coming decade. While most of these are expected to have production costs at the higher end of the US$4.50-6.00/lb range, some could benefit from low costs owing to by-product credits. Meanwhile recent IMO regulations for low sulphur bunker fuel could trigger new sources of secondary supply from spent catalysts if quantities of available feedstock increase. These trends could translate into a flattening of the vanadium cost curve over the years ahead.

1.5. Vanadium demand and key drivers

Steel dominates vanadium consumption, consistently accounting for >90% of vanadium demand in any given year. Alloys and chemicals markets represent mature, consistent first-use sectors for vanadium consumption, whilst demand from the comparatively new VRFB sector remains lower and, on the whole, more volatile from year to year.

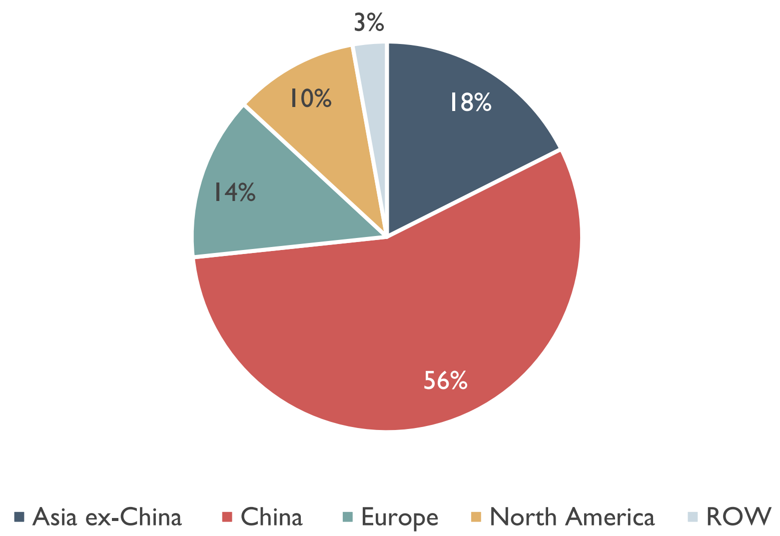
Figure 8: Vanadium demand by key application, 2022



Source: Project Blue

On a regional basis, China accounts for more than half of global vanadium consumption. This is reflective of several factors including its thirst for construction, its enormous steel sector, and recent trends towards production of higher quality microalloyed steels.

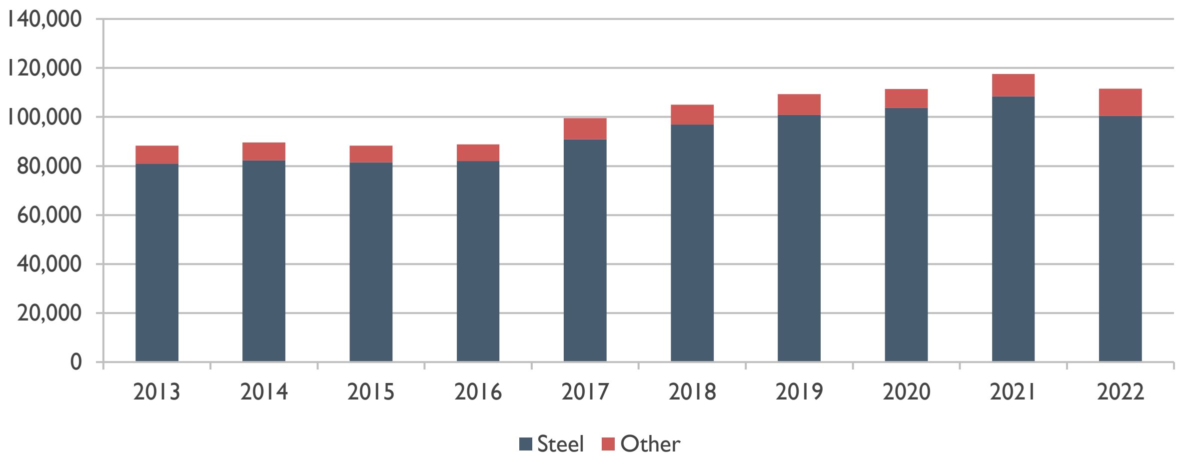
Figure 9: Vanadium consumption by region, 2022



Source: Project Blue, Vanitec

Vanadium demand trends are mostly driven by its use in steel, especially high-strength low-alloy (HSLA) steel. Vanadium finds application in structural long steel products, notably reinforcing bars (rebar). It is also used in a variety of other steels, including tool steels and stainless steels. Vanadium consumption in steel has risen considerably in recent years, although fell back in 2022 owing to lower-than-expected construction in China.

Figure 10: Historical vanadium consumption steel vs other end uses (kt V)



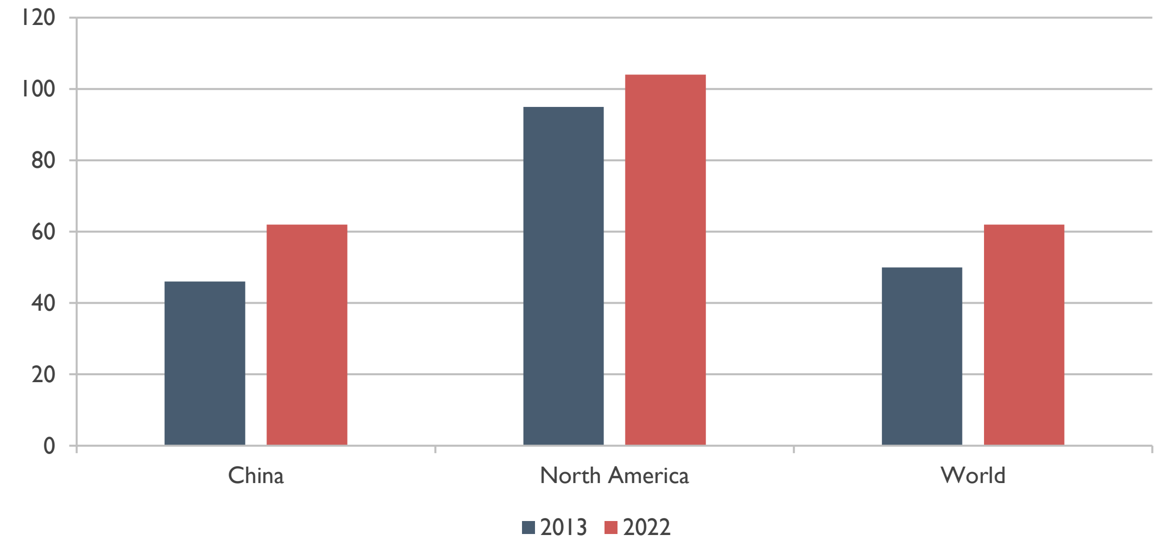
Source: Project Blue

Increased vanadium demand in steel applications isn't just a factor of higher steel output (although crude steel production has increased substantially over the past decade, especially in China). It is also because the *intensity* of vanadium usage in steel has increased over time. Put simply, more grammes of vanadium are being consumed per tonne of crude steel produced.

This intensity trend has mainly been supported by new construction standards in China mandating the use of microalloyed steel in rebar. Rebar is the main area of vanadium consumption in China; about 80% of the vanadium consumed in steel in China is in rebar. November 2018 saw the implementation of new Chinese rebar standards designed to promote the application of high-quality construction materials. The standard required Chinese steel mills to eliminate HRB335 grade rebar and start producing HRB600 grade rebar, which has better earthquake resistance. The standard was long overdue, with new construction codes in China having been called for since the devastating 2008 Sichuan earthquake. However, for a long time in China, lower quality 'quench and temper' rebar has been used in construction.

Initially, enforcement of the standard was inconsistent. Larger mills, for the most part, conformed to the new standards (in some cases before the rules came into force) while many smaller mills did not. Nevertheless, the new standards have made an impact, aided to some extent by national inspections on rebar quality in 2019, and general improvements and consolidation in the sector which have been ongoing over the past decade. While rebar produced using quench and temper methods is still produced in China, the proportion is diminishing year-on-year. This will continue to increase Chinese vanadium intensity of use towards levels seen in North America as shown in the chart below.

Figure 11: Intensity of vanadium usage over time (g V/t crude steel)

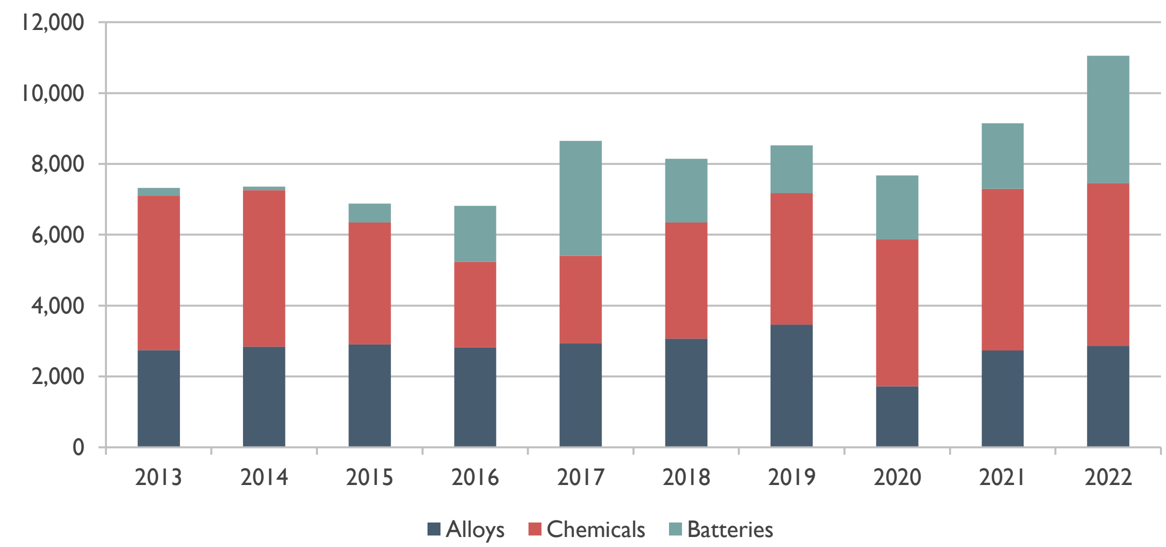


Source: Vanitec

Of the non-steel applications for vanadium, chemicals represent the most significant first-use in tonnage terms. The most significant first-use for vanadium compounds is in catalysts including catalysts for sulphuric acid production, chemical and environmental catalysts, polyethylene production catalysts, and desulphurisation and denitrification catalysts. Vanadium compounds are also used in gas processing, colouring compounds, batteries, dye fixants and vitamins.

Alloys are also a sizable market for vanadium. Vanadium-aluminium master alloys are used to improve the physical properties of titanium alloys for use in jet engines, airframes, and other critical-quality applications. Vanadium is also used in select superalloys, although most don't contain vanadium. The impact of COVID-19 on aerospace had a knock-on effect on raw material demand for aeroplane manufacture and maintenance. Vanadium demand was particularly affected in 2020 and 2021 but recovered well in 2022.

Figure 12: Non-steel consumption of vanadium (t V contained)

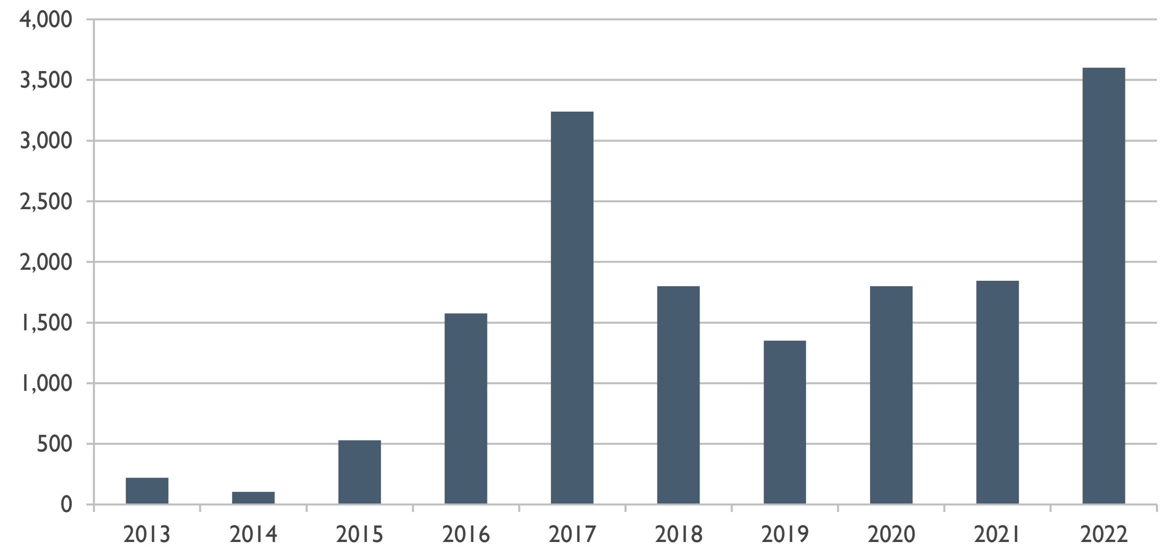


Source: Project Blue

There is potential for the battery market to become a sizable consumer of vanadium units in the future. Vanadium is used in vanadium redox flow batteries (VRFBs) in which a vanadium electrolyte is used to store energy and enable wider use of renewable power generation such as wind and solar.

VRFBs were first successfully tested in the 1980s but have only seen commercial deployment since 2010. Since then, there have been a number of installations globally, of varying sizes, resulting in irregular bouts of vanadium consumption. VRFBs have large and scalable capacity, can withstand being discharged for long periods, are safe and have a long cycle life. However, capital costs and most centrally the high cost of vanadium as an electrolyte have prevented significant market penetration.

Figure 13: Vanadium consumption in VRFBs (t V contained)



Source: Project Blue

The chart above highlights the variance in demand for vanadium in VRFBs over time. Large spikes in vanadium consumption are mostly driven by the commissioning of large systems. Major VRFB installations now operational include the Dalian-UET/Rongke Power VRFB system, a 200MW energy storage project in Liaoning, China. The rated storage capacity of the project is 800MWh and the battery was connected to the Dalian grid in May 2022. Another sizable installation is Sumitomo Electric's 15MW/60MWh system in Japan commissioned in 2015.

Major installations planned or under development include a 100MW/500MWh project by VRB Energy in Hubei, China, a 50MW/200MWh project by KORID Energy Company Limited in New York, USA, a 50MW/200MWh project by CellCube in Port Augusta, Australia and a 100MW/40MWh project by Shanghai Electric in Jiangsu, China.

1.6. Prevailing market conditions (2020-2022)

Like all markets, the vanadium market felt, and continues to feel, the impacts of the COVID-19 pandemic. While supply saw some short-term disruptions owing to lockdowns, the effects were seen mainly on the demand side. While demand showed slight overall growth between 2019 and 2020, there were divergent trends at the regional level.

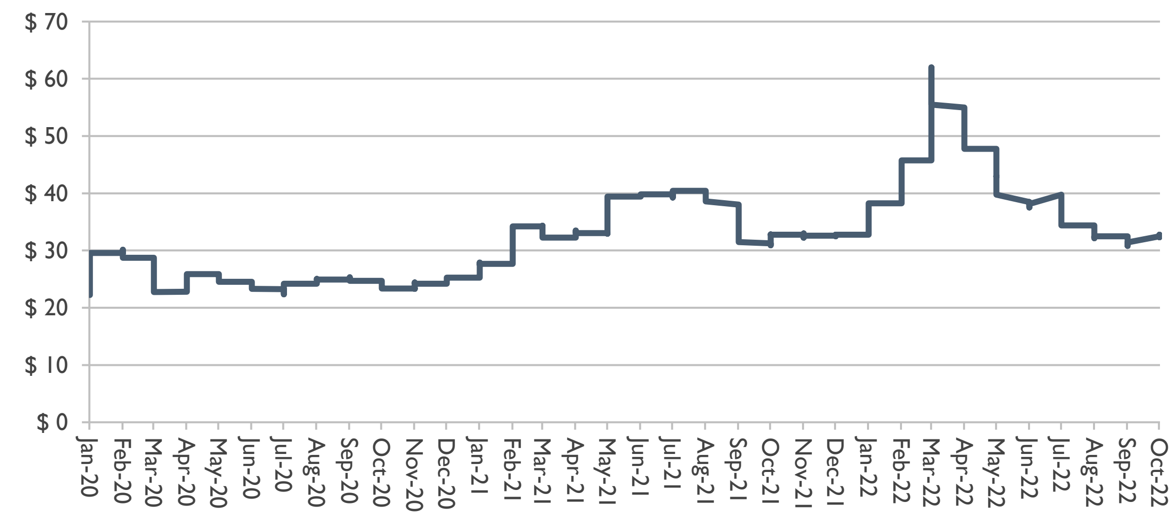
China was hit by COVID-19 early and strict lockdowns were imposed in Q1 2020. However, these were subsequently eased in Q2, and the country went on to deliver record crude steel production that year. As a result, Chinese vanadium demand remained strong in 2020. In comparison, protracted lockdowns lasting long into H2 resulted in ROW steel production falling sharply and vanadium demand was weak as a response. However, Chinese consumption was strong enough to outweigh declines in the ROW.

In 2021, demand was strong in both China and the ROW in H1, but as steel output was clipped in China in response to government-led environmental shutdowns, vanadium demand fell back. Meanwhile, in the ROW demand remained steady as the post-COVID recovery endured.

In 2022, the vanadium market has performed similarly to many others commodity markets. Prices rose in Q1 owing to continued post-COVID recovery and tightness in the European market in particular. Prices then spiked in March in response to the Russian invasion of Ukraine. While most commodity prices followed similar trends, the vanadium market's principal consideration was the impact of the war (or sanctions related to the war) on exports from Evraz in Russia.

Prices started to fall back in Q2 and continued a broadly downward trend in Q3 before recovering a little in Q4. The rebound was due to the restarting of steel mill operations after some weeks of maintenance. The declines reflect soft demand in China in particular, related to the impact of its 'zero-COVID' policy, its faltering property sector, and its depressed construction sector. These factors, together with environmental cuts to production, limited steel demand and supply in China in 2022 and, therefore, meant that vanadium demand in the country fell back given vanadium's exposure to the rebar segment.

Figure 14: Ferrovanadium price trends, 2020-2022 (US$/kg)



Source: Project Blue

On the supply side, surging inflation in most countries, except China, has had an impact on vanadium production costs. In South Africa, data suggests that inflationary pressures and higher raw material costs have pushed prices up by more than 10% in 2022 compared to 2021. In Brazil, costs have also been elevated owing to higher prices for critical consumables, including heavy fuel oil and ammonium sulphate. Thus far however, rising costs have not been reflected in prices, because of weak prevailing demand.

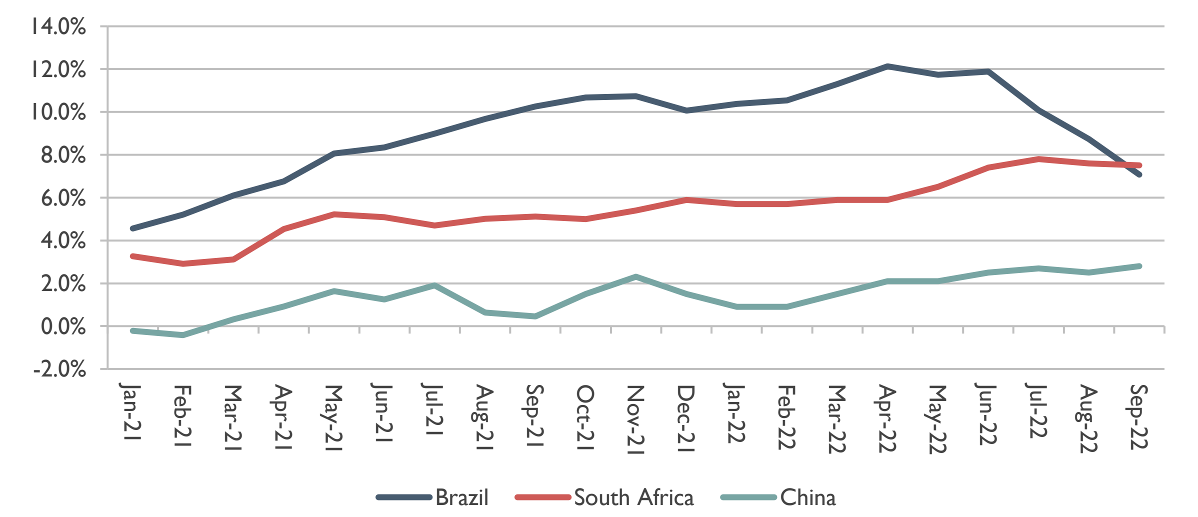
With current inflation rates running at 8-10% in North America and Europe, Central Banks in developed countries have embarked on aggressive monetary policies, aiming at bringing back inflation to pre-pandemic levels. Monetary policies take time before their effects are felt on the economy and interest rates are forecast to keep increasing in the USA (and to a lesser extent in Europe) over the months ahead. Market expectations are for inflation to peak in 2023 but the extent to which interest rates remain high for an extended period will depend on the 'stickiness' of the inflation and the magnitude of any economic downturn.

'Demand-pull' inflation, which occurs when there is an increase in aggregate demand, could drop reasonably fast, as economic contraction acts as a demand break. 'Cost-push' inflation (the decrease in aggregate supply of goods and services stemming from increased costs) might be stickier – and it is questionable as to whether annual inflation will return to the low levels seen over the past decade (around 2% in the USA). A significant component comes from energy costs but other major developing trends, such as de-globalisation or 'greenflation' could translate into a higher structural inflation.

The world's three major *primary* vanadium producing countries are China, Brazil, and South Africa. Brazil and South Africa have seen high inflation rates over the past few months, driven by food and energy prices. However, in both countries, it looks like inflation has reached its peak, and is likely to gradually recede.

China, meanwhile, has seen muted inflation, mainly because of weak domestic demand, due to the country's 'zero-COVID' policy and depressed property market. The outlook for Chinese economy is subdued, with no indication from Beijing that COVID-19 policies will be relaxed, or that additional large-scale infrastructure stimulus is ahead. Therefore, inflationary pressures are unlikely to emerge in China as long as the economy remains frail.

Figure 15: Inflation rates (y-on-y)



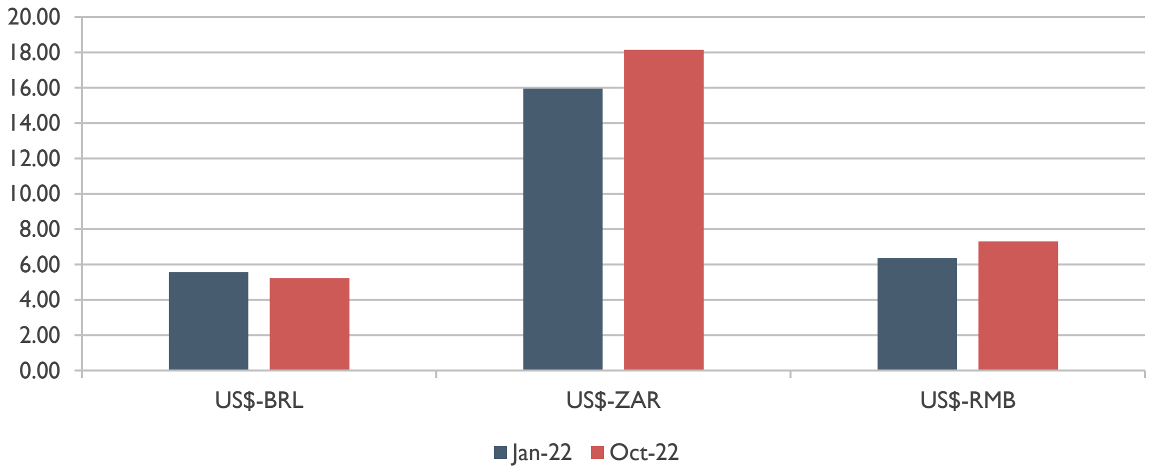
Source: Various

Another key factor affecting vanadium costs is the strength of the US dollar, which has outperformed most currencies in 2022. The dollar's strength has been driven by market perception that the Fed has more room to increase rates than other Central Banks due to a more resilient economy, lower risk of energy crisis in the USA, and its safe-haven status compared to other asset classes. A strong dollar allows the US to 'export' inflation to countries with a weaker currency, while cushioning it domestically through cheaper imports in dollar terms.

Although some vanadium production costs are in US dollars, such as energy, a weak South African Rand and Chinese RMB offers a mitigating factor in dollar terms for production costs in local currencies. During the January-October 2022 period, the Rand has depreciated by 13.7% vs the US dollar and the RMB by 15%. RMB depreciation has more than offset any inflation-related costs, reducing total production costs for Chinese steel mills. Meanwhile, the Brazilian Real appreciated by about 6% during the same period, increasing costs in dollars terms.

A likely scenario is that declining levels of inflation will also mark a peak in interest rates and, implicitly, of the US dollar. A weaker US currency would be positive for vanadium prices, as it would be for all commodities which trade in dollars.

Figure 16: US dollar vs. other key vanadium currencies (2022)



Source: Various

While vanadium production costs rose because of inflation, vanadium prices did not increase as demand was subdued globally. The key question over the short-to-medium term is whether higher costs will be sustained and if so, whether they will be reflected in prices once demand recovers.

One scenario is that a demand recovery will align with a taming of inflation although, as noted above, some inflationary pressure could be 'sticky'. Taking the USA as a benchmark, a medium-term inflation rate of 3-3.5% is plausible. However, the price of energy is traditionally volatile and will remain influenced by climate change measures such as carbon taxes, geopolitical factors, and technology. In such a scenario, vanadium prices could reflect the structural and durable elements of inflation.

Price rises may also depend on Chinese steel mills' profitability. Although vanadium costs represent a fraction of costs for Chinese steelmakers, very low margins could prompt mills to use quenching and tempering methods (assuming limited regulatory enforcement) or to substitute with ferroniobium.

Another scenario sees a period of sustained high inflation (above 5%) with a rebounding global economy. In this case, rising costs could and would be reflected in prices, assuming that demand is strong enough. Such a scenario would imply that Central Banks have shifted their priority from inflation to growth.

A third scenario under which inflation remains very high in a high interest rate environment does not appear likely. Sustained high rates would trigger a global recession, depressing demand and implicitly lowering prices.

2. Market outlook (to 2032)

2.1. Market drivers: steel

Project Blue believes that steel production in China reached its peak in 2020 at a level of 1,065Mt. Over the past two decades, steel production in China rose at a 11% CAGR, driven by industrialisation and urbanisation. With its 14th five-year plan, China has entered a new chapter of its development with a focus on information technology, biotechnology, artificial intelligence, aeronautics, and astronautics. For the most part, infrastructure projects will be more specific, targeting the development and implementation of green energies, urban equipment optimisation, such as water treatment facilities, and high-speed railway. Steel consumption per unit of GDP is set to decline.

The Chinese government also appears firmly committed to its 2030 peak carbon emissions target and has fixed 2060 for being carbon neutral. Steel industry de-carbonisation, a theme that will dominate the sector this decade and next, also implies a restructuring and a downsizing of the Chinese steel industry. However, Project Blue does not anticipate a sharp decline in steel production as the economic structural transition will take time to implement. Instead, we expect a plateauing of steel production over the next few years before a gradual decline later in the decade.

Short term fluctuations remain possible. Steel production in 2022 was impacted by the country's 'zero-COVID' policy and by a depressed property market, a situation which could potentially continue throughout 2023. Alternatively, 2023 could potentially see an uptick in Chinese steel if recent infrastructure stimulus and a strong recovery take effect. But overall, and regardless of short-term fluctuations, steel production in China is forecast to plateau over the coming years before dropping below the 1Bnt level around the end of the decade.

Steel production in the world ex-China (ROW) will show diverging trends. Increasingly stringent environmental restrictions and steadily declining demand will, in theory, translate into a downsizing of the EU steel industry. However, the de-carbonisation process and the 'green steel' concept pushed by the EU Commission could translate into more protectionism through the implementation of a carbon border adjustment mechanism (CBAM), an import tax designed to protect the European steel industry and corral other countries into tackling climate change. Steel production in the USA is likely to show a flat trend with imports continuing to fill the supply-demand gap, while steel production in Japan is set to decline, in line with lower demand.

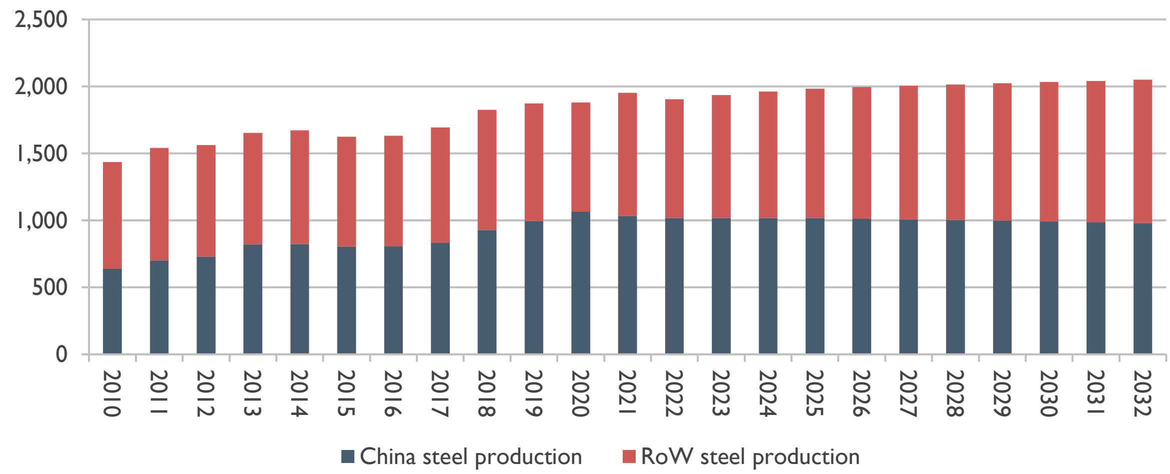
Meanwhile, steel production in large emerging countries is forecast to increase, underpinned by economies still in their industrialisation phase and largely exposed to construction and infrastructure. This growth in steel production will only come from a handful of countries, primarily India, but also Iran, Indonesia, and Vietnam and to a lesser extent Turkey and Brazil. With steel production of 125Mt, India is already the world's second-largest steel producer, and its output is forecast to reach about 200Mt in 2032. Southeast Asian countries (primarily Vietnam and Indonesia) are also building their steelmaking capacities which will gradually replace Chinese imports. The six countries mentioned above account for more than 65% of steel production growth between 2022 and 2032 in our forecasts.

Over the past two decades the steel industry has been shaped by the expansion of the Chinese steel industry. This decade (and most likely the next one) will be shaped by steel industry de-carbonisation implying a switch, when possible, from BOFs to EAFs.

As steel produced through EAFs cannot meet all quality requirements depending on end-usage, scrap must be complemented with other metallics, primarily directly reduced iron (DRI) or hot briquette iron (HBI). Another step will be the deduction of DRI with hydrogen instead of natural gas.

Vanadium in China is mostly co-production from steel plants using vanadiferous titanomagnetite ore (VTM). Steel output using VTM is estimated at about 35-40Mtpy, or 3.5% of China's current steel production. Project Blue does not believe that production coming from VTM will be too impacted by the forecast decline in steel production as its economics are more driven by vanadium than by steel, although the risks are to the downside.

Figure 17: Outlook for crude steel production (Mt)



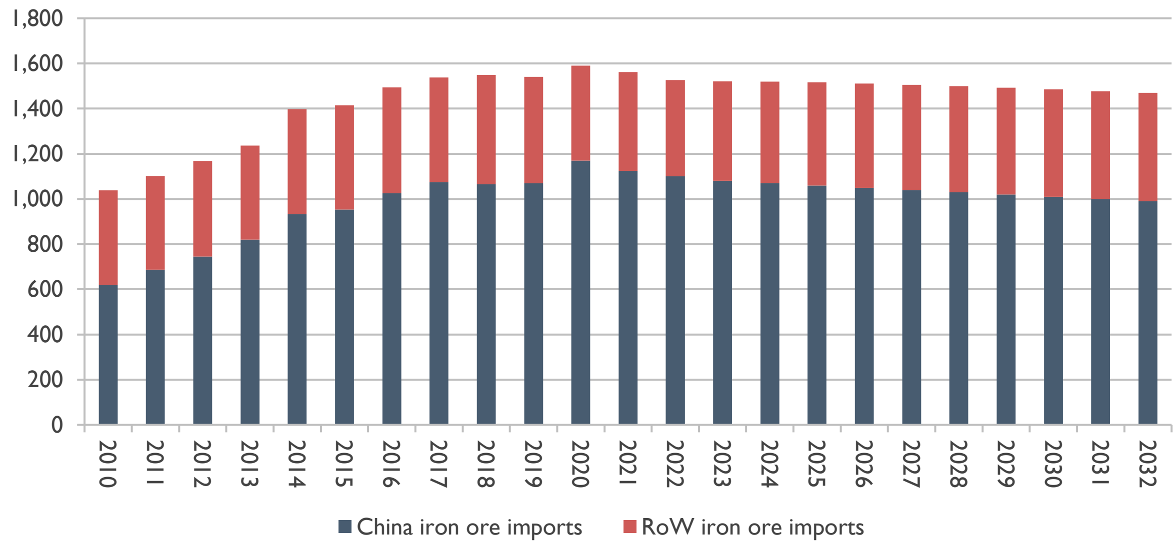
Source: *Project Blue*

2.2. Market drivers: iron ore

Over the past two decades, the iron ore market has been driven by the Chinese steel industry. China's iron ore consumption increased from about 200Mt in 2000 to 1.4Bt in 2021, as China developed its steelmaking capacity through blast furnaces. China's iron ore resources bear low iron grade, necessitating beneficiation and implying higher production costs. As a result of China's increasing demand for higher quality ore (higher Fe content and lower gangue), seaborne imports gradually displaced domestic material. The iron ore market has been increasingly concentrated in the hands of the large mining companies in Australia and Brazil, which control about 85% of China's iron ore imports.

As China's steel production starts plateauing, its iron ore consumption will peak. Moreover, China is committed to increase the share of its steel production from EAFs, for environmental reasons but also because the country will generate more scrap. Therefore, a gradual decoupling between steel and pig iron production will take place, amplifying the decline in iron ore consumption. Although China aims at increasing its domestic production and its stakes in overseas projects, Project Blue believes that China will continue to rely on imports from large mining companies for the foreseeable future.

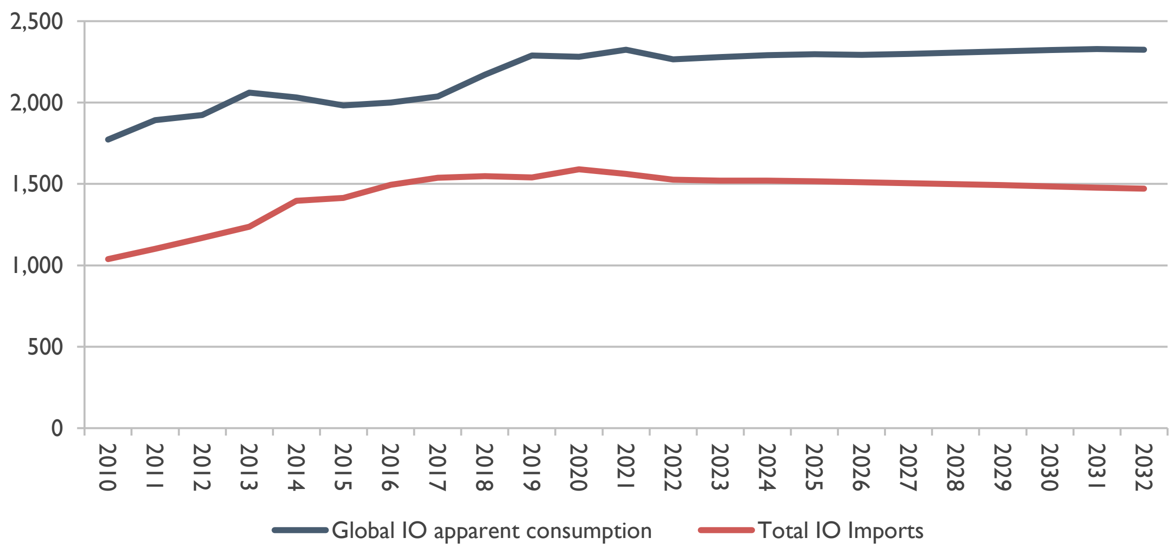
Figure 18: Outlook for China and ROW iron ore imports (Mt)



Source: Project Blue

As mentioned in the previous section, steel production in the world ex-China will continue to increase, with growth mainly coming from large, emerging countries. It happens that several of these countries (India, Iran, and Brazil) are self-sufficient and even iron ore exporters. As a result, although global iron ore consumption may increase, the total iron ore import market will decline, mostly driven by lower volumes to China. Other large iron ore import markets, such as the EU and Japan are also on a declining trend due to a gradual downsizing of their steel industry but also because they will replace BOFs with EAFs, owing to stricter emissions regulations.

Figure 19: Outlook for apparent IO consumption vs imports (Mt)



Source: Project Blue

With the development of its steel industry, China has been looking for higher quality ore, which improves furnace efficiency, especially when steel margins are high. When margins are low, mills give the preference to lower grade ores and lower costs. With environmental measures becoming more stringent, mills have been forced to increase their consumption of higher grade, low gangue ore to reduce carbon emissions. Although economics will continue to play a role, the higher-grade ore premium is likely to fluctuate at above historical levels.

An increasing demand for DRI/HBI implies an increased consumption of iron ore DR pellets feedstock. Also, magnetite projects which could deliver high grade beneficiated ore of ~67% could become more economically attractive.

The price of iron ore has been primarily driven by China over the past decade, with the pricing mechanism changing in 2011 from a contract-base to a daily index. Project Blue believes that the short-term price of iron ore will continue to be led by China macroeconomics.

As per the comment in the previous section, VTM economics are based on their vanadium content and not on their iron content, where Fe is averaging 20% or below.

On the supply side, large miners have been changing their strategies over the past few years from developing greenfield mines to brownfield projects, aiming at maximising their assets' efficiency rather than investing large capex in new mines. As a result of depletion, supply growth has increased only moderately, also impacted in 2019 by Vale's Brumadinho accident. Over the coming years, Project Blue forecasts that supply from large miners will grow at a slow rate, while, as above mentioned, demand will plateau and decline. As a result, the long-term price of iron ore is forecast to decline with the marginal cost producer in Australia or Brazil setting the price.

2.3. Market drivers: rebar

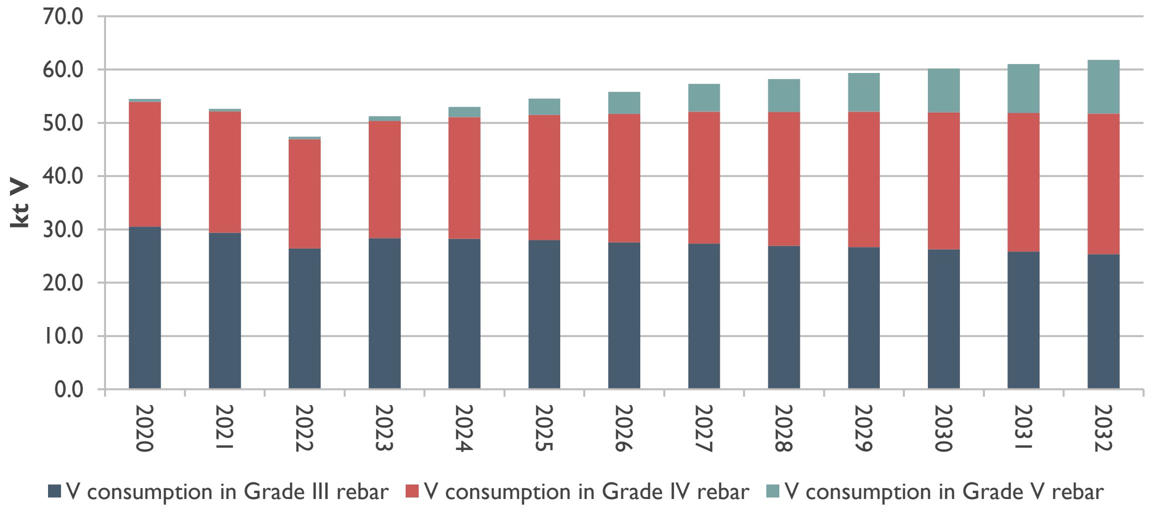
The rebar sector is important for vanadium consumption and particularly Chinese rebar; not only because China accounts for about 75% of the world rebar production but also because the sector accounts for about 85% of the vanadium consumed by the Chinese steel industry.

Rebar production in China reached 266Mt in 2020, driven by China's infrastructure spending in response to COVID-19. This number probably also marks a peak, with rebar production set to decline in line with steel output. On a relative basis, rebar production may drop faster than other steels as China will keep focusing on more value-added products. By 2032, Project Blue forecasts that China's rebar production will be ~217Mt.

Not all rebars are high strength and Project Blue believes that ~90% are. Although higher construction standards may drive this percentage higher, there will always be a demand for commodity rebar. In 2021, Project Blue believes that the Grade III rebar (HRB 400) accounted for about 79% of total high strength rebar, the balance being Grade IV rebar (HRB 500). Production of Grade V rebar (HRB 600) remains marginal. Vanadium content ranges from 0.03% in Grade III, 0.06% in Grade IV and 0.1% in Grade V.

However, not all Grade III rebar use vanadium. The quenching and tempering market share is estimated at 25% while Project Blue believes that 20% of Grade III rebar use niobium (Nb), mainly for smaller size rebar. In 2021, Project Blue estimates that 75% of Grade III and 80% of Grade IV rebars use microalloying (V or Nb), a number forecast to increase in coming years.

Figure 20: Outlook for Chinese rebar and V consumption in rebar



Source: Project Blue

Although total rebar production is forecast to decline, vanadium intensity is set to grow mainly because Grade IV rebar (and to a lesser extent Grade V) will replace Grade III. This gradual substitution will benefit vanadium consumption because Grade IV and V rebar use more vanadium. Some mitigation could come from a vanadium-niobium mix which is believed to provide steel with a higher strength with less alloy. Also, Project Blue believes that niobium will continue to gain market share in rebar, reaching 25% at the end of the decade.

Overall, Project Blue forecasts that vanadium consumption in Chinese rebar will increase to 62kt V in 2032. Note that vanadium consumption in rebar is forecast at 47.4kt in 2022 vs 52.6kt V in 2021 due to the deterioration of the Chinese economy and its depressed property market.

2.4. Market drivers: energy storage

Energy storage is fundamental to decarbonizing the global energy system and reducing greenhouse gas emissions. Furthermore, energy storage systems are an increasingly important part of resilient electricity networks.

There are a wide number of differing energy storage systems and technologies, which can be broadly grouped as either electro-mechanical (compressed/liquid air, flywheel, and pumped hydro), electro-chemical (batteries), and other (thermal, chemical, or electromagnetic). Electromechanical (mainly pumped hydro) is still the most deployed storage technology today, but batteries are catching up.

Battery Energy Storage Systems (BESS) are essential for replacing fossil fuels with renewable energy. BESS are devices that store energy from intermittent renewable sources such as wind and solar and allow that energy to be released when required. Currently, lithium-ion batteries are the BESS technology of choice in terms of deployed capacity, due to their widespread availability, cost-effectiveness, and high efficiency. However, there are other BESS with enormous growth potential.

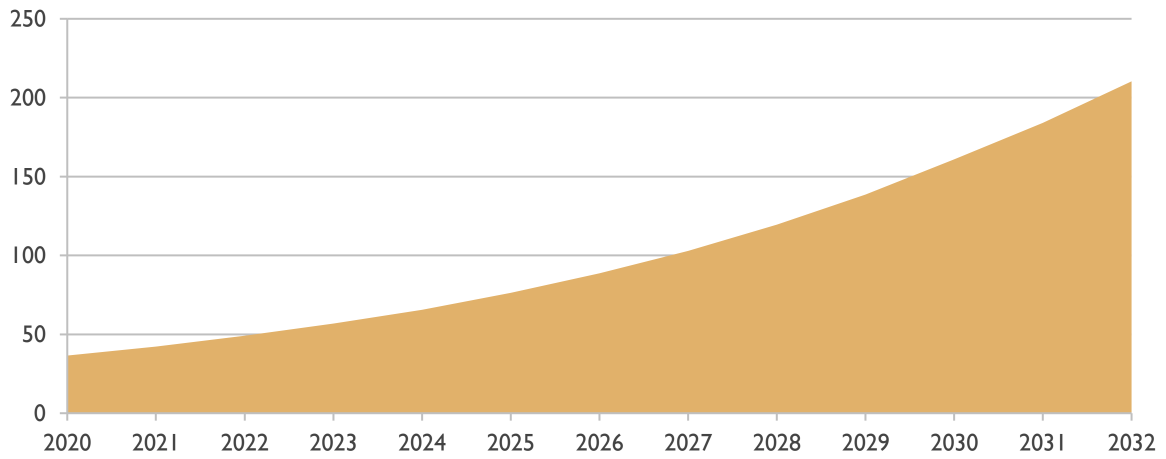
One such technology is the flow battery, batteries which transform the electron flow from activated electrolyte into electric current. Flow batteries have many positives – they are safe, scalable, durable, recyclable, have a long lifespan, and can be completely discharged for long periods of time with no ill effects.

The Vanadium Redox Flow Battery (VRFB) uses vanadium electrolyte to store energy. The technology was first developed in the 1980s, although the technology has only seen significant commercial deployment over the last decade. As noted in a 2022 study by Guidehouse Insights:

"…VRFBs' flexible design enables large-scale and long-duration energy storage (i.e., the ability to increase energy storage capacity by adding more tanks of electrolyte). As such, utility-scale applications are one of the key use cases for VRFBs. Because of the size and complexity of the systems required for VRFBs, they are primarily suited for stationary applications where large systems can be accommodated. By pairing variable renewable energy sources such as wind turbines and solar PV arrays with VRFBs, large amounts of excess renewable energy can be captured and utilized later when the sun isn't shining or the wind isn't blowing, effectively turning them into dispatchable resources for peak periods. VRFBs could be crucial as the decade progresses with more renewable generation sources coming online and longer duration energy storage (i.e., longer than 4 hours) is required to balance the grid".

The outlook for BESS is highly positive. Project Blue expects cumulative energy storage installations to reach over 1,000GWh by 2032, by which point annual installations are expected to be higher than 200GWh per year.

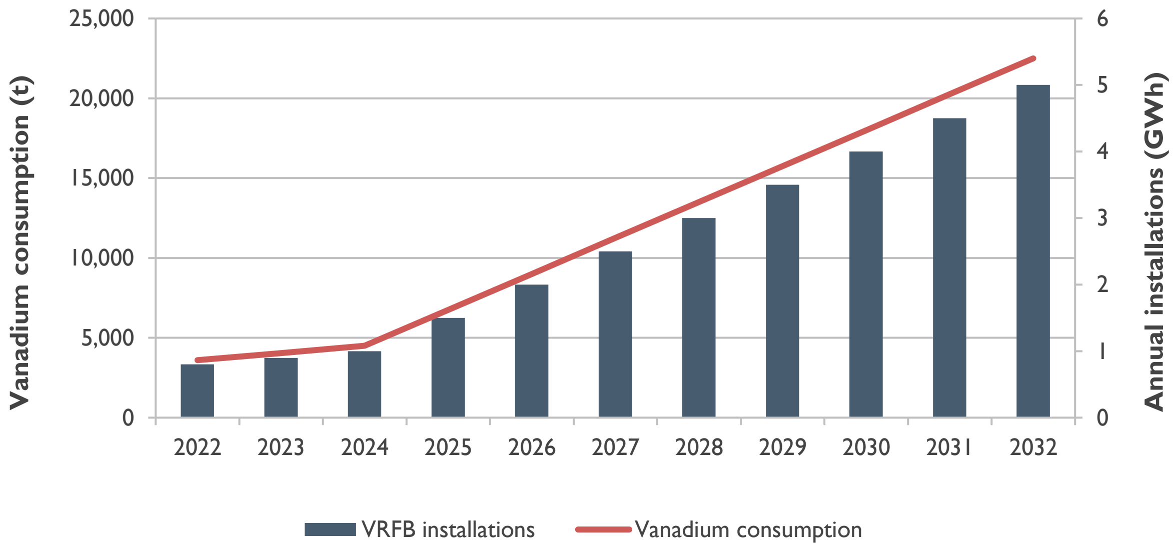
Figure 21: Outlook for annual ESS installations (GWh)



Source: Project Blue

Project Blue's base case outlook suggests that annual VRFB installations reach 5GWh by 2032 implying vanadium consumption in batteries of over 22kt that year.

Figure 22: Outlook for annual VRFB installations (GWh) and vanadium demand (t)

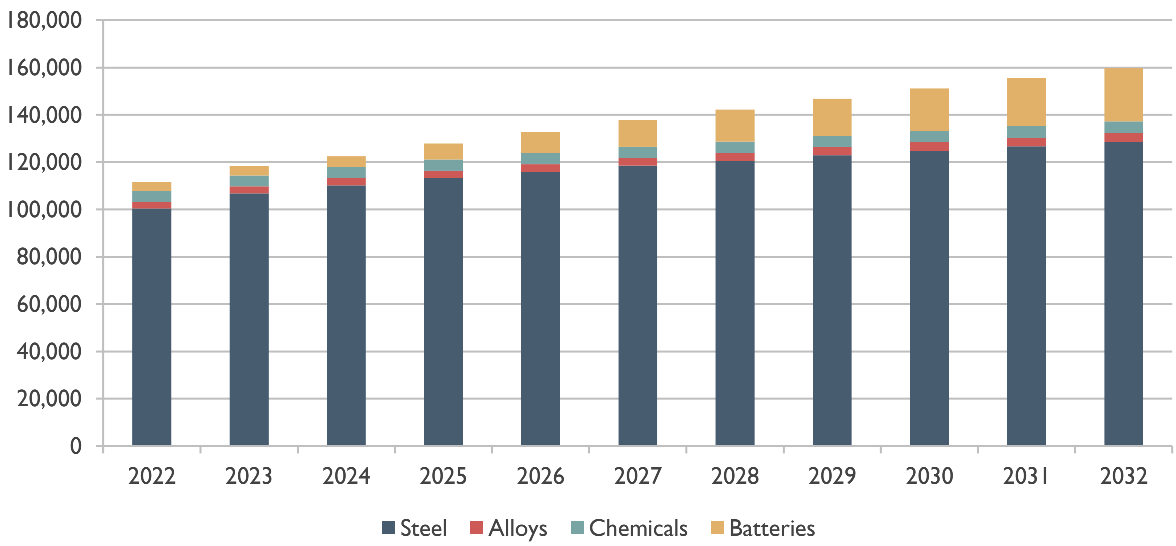


Source: Project Blue

2.5. Vanadium demand outlook

Overall, the vanadium market is expected to see growth of 3.7%py over the coming decade. A sizable portion of this growth is forecast to come from VRFBs, with steel, alloy and chemical demand set to see more modest consumption gains.

Figure 23: Outlook for vanadium consumption by key application (kt V)



Source: Project Blue

Project Blue expects Chinese steel output to plateau over the next ten years in line with a restructuring of the Chinese economy and Beijing's stated intention to curb production growth. In the ROW, output should continue to rise with countries including India and Indonesia expected to enjoy considerable growth. The result of these trends will be modest growth in global steel output over the coming decade (CAGR 0.7%). However, higher intensity of vanadium use in (mainly HSLA) steel, is forecast to see vanadium consumption in steel to increase at a higher rate of 2.5%py.

While growth is expected in alloys demand, the impacts of COVID-19 will impact consumption over the medium term. Demand is not expected to reach 2019 levels again until later in 2020s. Growth in chemicals demand will be moderate with no novel applications set to boost demand.

The outlook for BESS is highly positive. The 2022 Guidehouse Insights study forecasts annual installed VRFB utility scale and commercial and industrial battery deployment energy capacity to reach over 30GWh by 2032. Project Blue's outlook is more conservative (5 GWh in 2032), but nevertheless also anticipates substantial growth in VRFB installed capacity, which translates into over 22kt of vanadium in 2032 alone.

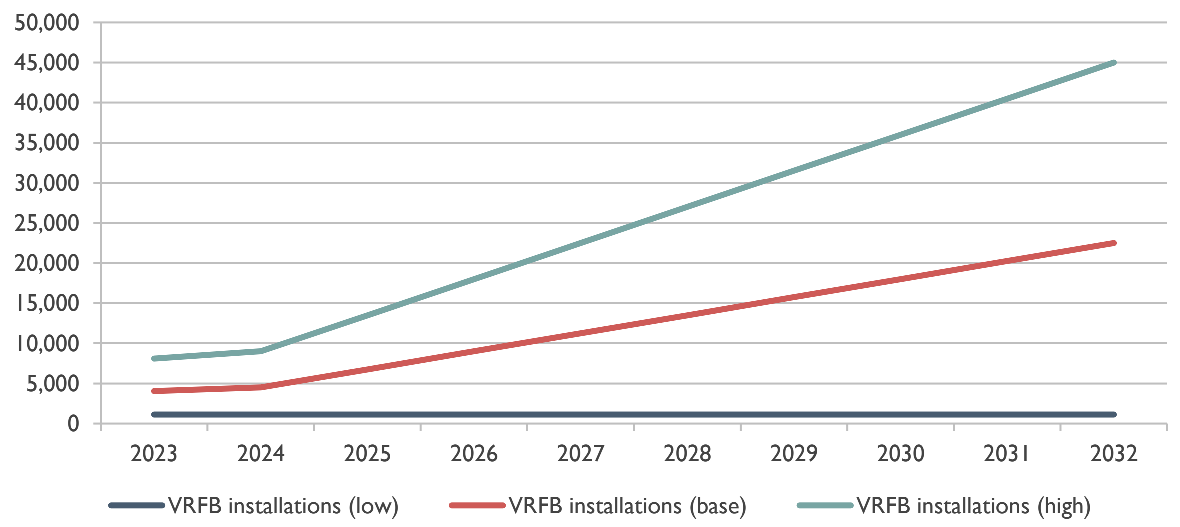
There is, of course, uncertainty over the scale and pace of VRFB commercialisation. Accurately predicting the size and location of new installations is challenging. Below, Project Blue has set out three scenarios for VRFB demand to 2032.

In the low case, VRFB installations fall back from historic levels and sit at ~250MWh per year. To come to pass, this scenario would require very high vanadium prices making VRFBs uneconomic. It is unlikely that the scenario could be seen based on technological reasons.

In the base case, as set out above, installations reach 5GWh in 2032 translating into 22kt of vanadium consumption in that year. This forecast considers Project Blue's view of long-term prices (expected to be at a level to make VRFBs economic) and the viability of new supply being made available to meet the new demand.

In the high case, annual installations are doubled reaching 10GWh in 2032. Under this scenario, 45kt of vanadium are required by 2032. This would require a sizable increase in supply and need capacity expansion from existing producers as well as supply from new entrants. Project Blue notes that under this scenario, prices would need to be much higher (to incentivise new supply) which would in turn put pressure on the economics of VRFBs.

Figure 24: Scenarios for VRFB demand (t)

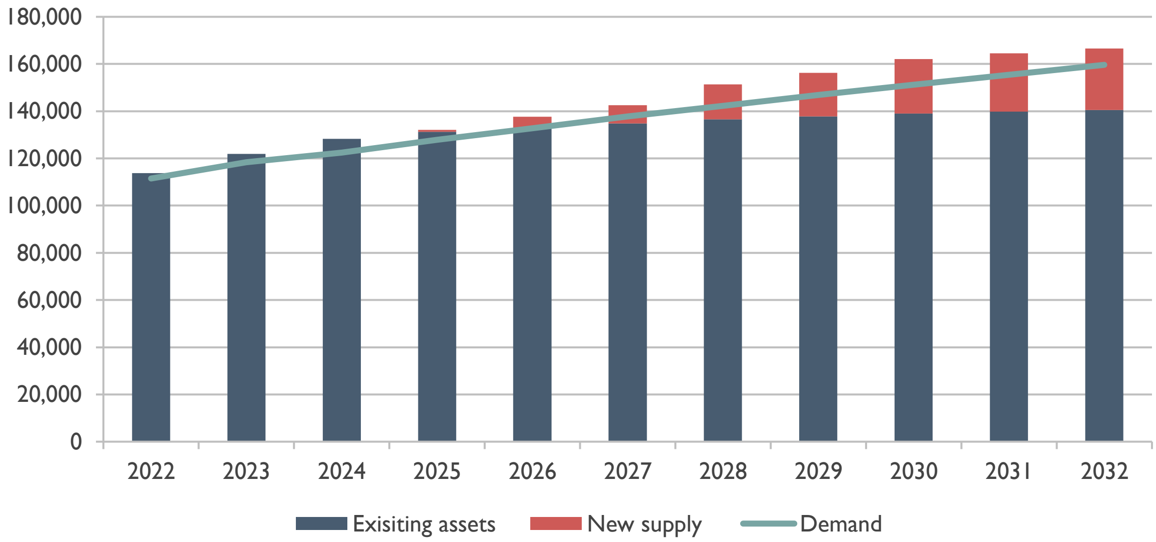


Source: Project Blue

2.6. Vanadium supply outlook

Project Blue's expectation is that the market could almost be supported by existing assets over a five-year horizon, but that ultimately new sources of supply will be required after the middle of the decade. Over the period to 2032, increased supply will come from both existing primary, secondary and co-producers as well as new operators looking to bring projects into production.

Figure 25: Overview of ten-year vanadium market balance



Source: Project Blue

Project Blue expects Chinese co-production to grow over the coming decade although significantly increased capacity expansion or utilisation isn't viable, especially in the context of plateauing steel output in China. We estimate that co-production output in China will not rise beyond 70ktpy by 2032. Outside China, Evraz is set to increase output via Uzlovaya facility from 2025.

Primary output will see small increases form established producers in Brazil and South Africa. Meanwhile, coal stone producers in China act as the market's swing producer, increasing output when prices are high. In theory, there is considerable idle capacity in Chinese coal stone, but much of this capacity has fallen into disrepair, and many idle producers would struggle to conform to increasingly stringent environmental standards. We expect cost and environmental factors to limit coal stone output to a small number of larger producers.

Secondary output is also expected to increase. In January 2020, a new global cap by the International Maritime Organisation (IMO) on sulphur content in marine fuels came into effect. Known as "IMO 2020", the rule limits the sulphur in the fuel oil used on board ships operating outside designated emission control areas to 0.5% mass by mass, a significant reduction from the previous limit of 3.5%. The regulation has led to growth in refinery catalyst consumption, which in turn implies a growth trend in vanadium-bearing spent catalysts available for recycling. We expect output to increase in China, South Korea, and the USA.

Overall, Project Blue expects existing producers to increase output at a CAGR of 2% over the period to 2032. With demand forecast to grow at 3.7%py over the coming decade, there is a requirement for new primary or secondary projects to enter production in Project Blue's base case. We estimate that these projects would need to bring 120kt of cumulative production (ramping up to 26kt of annual production in 2032).

2.7. Vanadium price outlook

The table below sets out our extended outlook for vanadium pentoxide and ferrovanadium prices in Europe. Project Blue's forecasts consider expectations for the global economy, vanadium supply and demand balance, our understanding of the marginal cost of production in the supply chain, and our view of market incentive prices.

Table 1: Forecast vanadium pentoxide prices (Europe) (US$/lb)

	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Real	7.50	8.20	8.15	8.09	8.09	8.09	8.09	8.09	8.09	8.09
Nominal	7.68	8.59	8.72	8.84	9.02	9.21	9.39	9.58	9.78	9.98

Source: Project Blue

Table 2: Forecast ferrovanadium prices (Europe) (US$/kg)

	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Real	33.20	35.95	35.76	35.53	35.53	35.53	35.53	35.53	35.53	35.53
Nominal	33.99	37.64	38.26	38.81	39.62	40.43	41.25	42.09	42.95	43.82

Source: Project Blue

The near-term price outlook largely depends on macroeconomics and geopolitics. The most likely scenario is a recessionary environment in Europe and possibly in the USA which will keep steel production and consumption at relatively low levels.

Any rebound is unlikely to take place before H2 2023, although the outcome of the Ukrainian conflict remains a wildcard. Therefore, prices of both European V_2O_5 and FeV are expected to be subdued in 2023. Project Blue does not anticipate any economic rebound in China until Chinese New Year. A recovery in Q2 2023 in line with the traditional construction season could translate into a stronger steel production and vanadium consumption. Prices could rebound, depending on how strong the recovery would be.

Although uncertainty remains for H2 2023, Project Blue's base case is for gradual global economic improvement accelerating in 2024 and 2025, with a tamed inflation and lower interest rates. However, a structural inflation higher than the average recorded during the past decade cannot be ruled out. That would translate into higher production costs which could be reflected on prices, assuming that demand is strong enough.

Aside from the macroeconomic environment, there are various vanadium-specific upside and downside risk factors which could impact price levels. Possible upside scenarios include the Russia-Ukraine conflict impacting material flows (most likely Evraz material), multiple large-scale VRFB projects being announced, and higher steel demand in China (which could be brought about by construction-related stimulus). Any supply disruptions at key producers, or logistics issues, could also push up prices. Key downside factors include high-than-expected vanadium production and lower-than-expected VRFB demand.

Below Project Blue has set out some price scenarios. The high case would require strong demand from the VRFB segment, although Project Blue believes that demand will trigger new supply and eventually keep the market balanced at a price that keeps VRFB technology economic and competitive. We consider that a >US$10 pentoxide price would not be positive for VRFB economics over the long run. The low case would require much lower-than-expected demand with prices being supported by production costs. Under a scenario of low steel demand and low case VRFB demand, prices could conceivably fall back to US$6/lb.

Table 3: Scenarios for vanadium pentoxide prices (Europe) (US$/lb)

	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
High	9.00	9.50	9.80	10.00	10.10	10.10	10.10	10.10	10.10	10.10
Base	7.50	8.20	8.15	8.09	8.09	8.09	8.09	8.09	8.09	8.09
Low	9.00	7.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00

Source: Project Blue

Table 4: Scenarios for ferrovanadium prices (Europe) (US$/kg)

	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
High	38.15	40.00	40.50	41.00	41.50	41.50	41.50	41.50	41.50	41.50
Base	33.20	35.95	35.76	35.53	35.53	35.53	35.53	35.53	35.53	35.53
Low	38.15	35.00	32.50	30.00	28.00	28.00	28.00	28.00	28.00	28.00

Source: Project Blue

The base case forecast (US$8.09 in real terms) is in line with the 2015-2022 V_2O_5 average price and above the average level of 2010-2022 prices. While this is the expected long-term price trend, Project Blue notes that the vanadium price has been volatile historically and there is every expectation that the market will see large swings in prices in the future. Price volatility is more induced by factors impacting prices on the upside, while prices are supported on the downside by production costs. Project Blue notes that in any given year, prices could record average levels well in excess of the high case. Vanadium pentoxide prices reached over US$25/lb at points in 2018 and averaged US$18/lb that year.

It is also worth noting that historic price spikes have been limited in terms of time scale and the market has always reacted accordingly to return prices to typical levels. There is every expectation that this will also be the case going forward.

Index **Pg**

List of Tables **Pg**

List of Figures **Pg**