Thursday, 18 November 2021

RESEARCH REPORT

CORPORATE CONNECT

Vanadium Industry Profile

Can vanadium emulate lithium's rise?

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Executive Summary

The green electrification mega-trend requires *many types of energy storage* to match intermittent renewable power generation to on-demand electricity needs. Strong growth in stationary storage capacity is expected with some tipping a 600% rise in just 7-years and reach US$55 billion in invested capital. While Lithium-ion currently has ~95% share, *capturing a modest portion of the storage trend can transform the small vanadium industry, worth just US$4billion in 2020.*

What is a Vanadium Redox Flow Battery?

A VRFB is an Australian invented power storage device has been under development globally over the last two decades. It is made up of two tanks filled with water-based vanadium electrolyte fluid and linked by pipes and pumps to a membrane separated power cell. Electron flows across the membrane to either store, or in reverse direction, to discharge electrical current. *VFRB's use a liquid vanadium electrolyte to store electrical charge, the larger the tank, the greater scale economies.*

While VRFB is at present more expensive up-front than Lithium-ion batteries, they can work our cheaper on full-cycle use over 20-years and 35,000 charge/discharge cycles. The VRFB does not degrade over time, can discharge 100% of its stored power and its vanadium electrolyte is fully recyclable that could realise ~1/3rd the value of a new VRFB. VRFB's can operate at high temperatures and cannot catch fire. They are suited to supporting utility-scale grids, mini-grids and teamed with renewables are ideal for remote power needs.

Vanadium's game-changer – learning from the lithium boom

In this report we focus upon the vanadium industry. Vanadium's price cycle has been highly volatile, captive to both the steel volume and the iron ore price cycle given most V production is in the form of ferrovanadium as a steel alloy input.

However, like lithium, the emergence of new energy storage demand is a game changer for high-purity vanadium, in this case to supply VRFB's.

Sustainability issues will favour low emissions producers

Low concentrations of vanadium are often associated with complex titanium and iron oxides ores. Most of the world's 110,000 tpa vanadium output is in the form of ferrovanadium with ~80% V as a Co-production from magnetite ores. Currently hi-grade 98% Primary mine producers only supply ~17% of the V market, have high emissions with some valuable co-products diverted to waste.

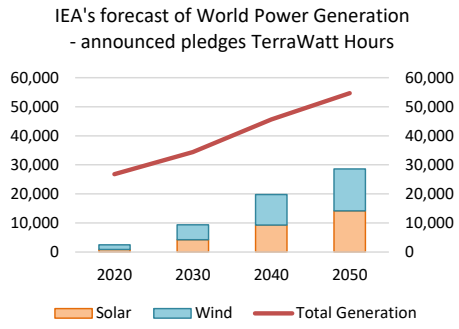
TNG's projected 6,000tpa of V2O5 has potential to be strategically significant in supplying >99% grade vanadium pentoxide, the primary ingredient for VRFB and with a low emissions footprint. This is because its patented TIVAN® process recovers hi-grade titanium dioxide and iron ore as well as V and is planning to incorporate solar generation and hydrogen as a reductant as soon as H2 volumes become available. *For more detail see*: *TNG Report link*.

Vanadium prices are consolidating prior to VRFB surge

The rise and then recent slowdown in China's steelmaking have seen vanadium prices double since last year and retrace around 25%. High iron ore prices allowed China's magnetite processers to boost ferrovanadium supplies. However, lower iron ore prices are now seeing a steadying in vanadium prices. New demand for hi-grade V is also starting to tighten the vanadium market.

China has announced over 1,500MWH of VRFB projects which amount to over 8,200 t of vanadium. This equates to ~7% of world V demand, and ~30% of high-grade vanadium supply. In aggregate, similar plans are being finalised in Europe, Japan, Brazil and South Africa over the next couple of years. *Clearly there is need for more hi-grade vanadium production that also meets sustainability credentials – to assist the energy transition to lower emissions.*

Growing intermittent power = battery need



[1]Source: IEA World Energy Outlook 2021 - page 302 table:

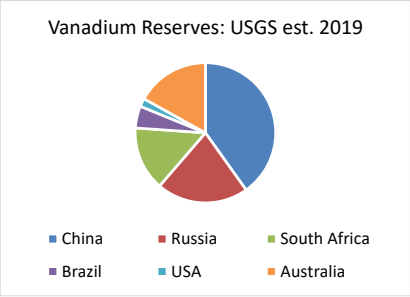
VRFB – ideal power storage teamed with solar generation & local power grid or off-grid

Source: Yadlamalka Energy is developing a 2 MW VRFB/ 6 MW solar project near Hawker, South Australia

Vanadium price likely to rise over time

Source Vanadiumprice.com – V2O5 pricing depicted US$/lb

Australia's opportunity – big resource, no production and critical mineral status



Source US Geological Survey

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Section 1: VRFB's and the global storage market

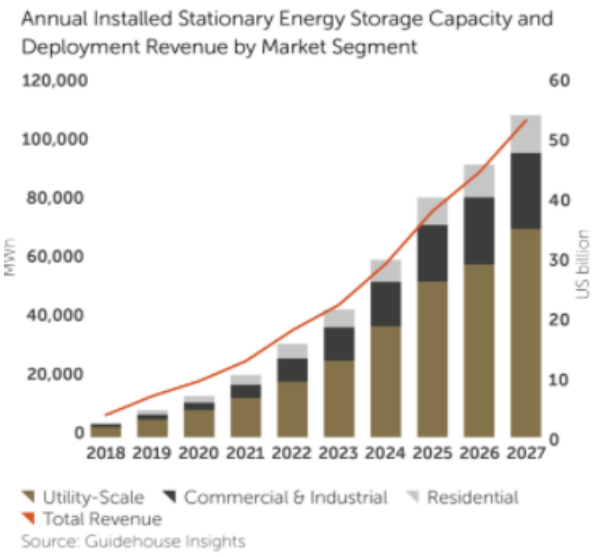
The 21st Century storage battery challenge

The current mega-trend for green electrification requires *many types of energy storage* to match intermittent renewable power generation to on-demand electricity needs.

Electricity itself cannot be stored and can only be transformed into potential energy, like mechanical energy in pumped hydro, or chemically such as within various batteries.

Electricity's share of the World's rapidly growing energy consumption has doubled from 10% in 1980 to 20% today. Specialist commentators expected electricity to exceed 40% of much larger energy use by 2050.

Strong growth in stationary storage capacity is expected with some tipping a 600% rise in just 7-years from 2020 and reach US$55 billion in invested capital. To date Lithium batteries have over 95% market share.



Capturing a small proportion of the energy storage trend can transform the relatively small vanadium industry that in 2020 was worth just US$4billion.

What is a Vanadium Redox Flow Battery?

The Vanadium Redox Flow Battery (VRFB) is power storage device. It is made up of two tanks filled with water-based vanadium electrolyte fluid and linked by pipes to a membrane separated power cell. Electron flows across the membrane to either store, or in reverse direction, to discharge electrical current. The tank size determines the battery's capacity. VRFB's use vanadium electrolyte's unique property that can exist in four *different oxidation states*; that is from an oxidation state of +2 (V^{2+}), +3 (V^{3+}), +4 (VO^{2+}) to +5 (VO_3^- or VO_2^+).

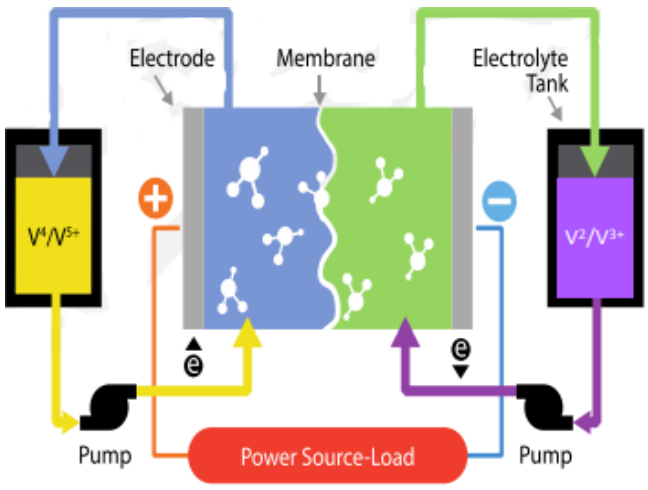
This simple, robust and scalable battery was invented in the 1980's at the University of NSW. It is increasingly being rolled out globally, particularly for power grid support and when teamed with renewables is ideal for utility-scale power providers, neighbourhood mini-grids and remote off-grid use.

Lithium-ion batteries store charge within the relatively small individual power cells. By contrast, *VRFB's use a liquid vanadium electrolyte to store electrical charge, the larger the tank, the greater the scale economy.*

Vanadium's 4-ionic states enable storage and transmission of electrical charge

When charging, positive blue V4 turns to yellow V5 and gives up an electron by crossing the power cell's membrane to the negatively charged green V3. The green V3 then turns into purple V2. This ionic reaction can be reversed to allow power to be discharged to perform work as required.

VRFB's – technically simple and scalable



Section 2: Can Vanadium emulate Lithium's rise?

Compared to Lithium-ion batteries – VRFB's are safe, simple and long life, though bulkier

Durability & 100% depth of discharge: Vanadium electrolyte's durability enables long lifespan operation of over 20-years and 35,000 charge/discharge cycles without significant performance degradation. Importantly VRFB's can discharge 100% of stored charge without damage. This contrasts with Lithium-Ion batteries where performance can be impaired if fully discharged and with accumulating charge/discharge cycles the battery performance wanes.

Unlike Lithium-Ion batteries, VRFB performance is largely unaffected by high or changing ambient temperatures.

Safety advantages: VRFB's cannot catch fire and are repairable, e.g., should say a pump fail. Lithium batteries under certain conditions can incur irreparable damage or result in intense fires. Further Lithium-Ion batteries are complex amalgams of materials, some toxic and many are expensive and in combination are difficult to recycle.

Ease of recycling: The vanadium is fully recyclable at the end of the vanadium redox flow battery's mechanical life. There is only one battery chemical element and there is no risk of cross-contamination. Production is likely to have a lower carbon footprint to produce than solid-state batteries.

Lithium-ion battery power cells have the advantage of greater density of charge compared to VRFB's electrolyte-based charge storage. This density enables Lithium-ion batteries to have the advantage where space is a premium and also for mobile applications such as electric vehicles and mobile devices and tools.

Strong R&D is driving lithium-ion battery performance improvements and cost reductions. We expect the less intensively researched VRFB's will over time exploit untapped latent efficiency and secure a significant market niche in storage. While upfront costs of VRFB's at present are higher that Lithium-ion batteries, over their life cycle VRFB's are as or more cost-effective. A further plus is an end-of-life re-sale of vanadium electrolyte.

VRFB's can transform the volatile vanadium market

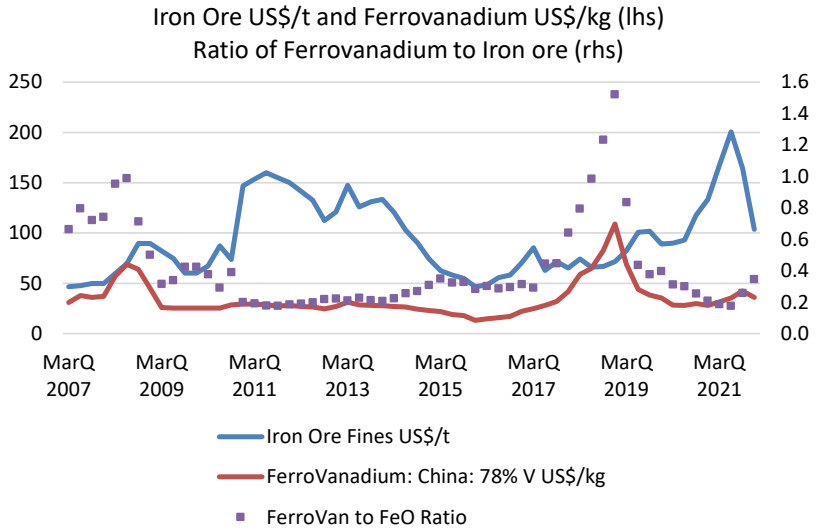
The vanadium market has been characterised by short boom and longer bust conditions often mirroring the volatile global steel industry ***output*** cycle and runs counter to iron ore's ***price*** cycle.

We see rising new-use battery demand for vanadium that requires high grade V. This can create an entirely new dynamic driver of the global vanadium market.

Source VanadiumPrice.com

Vanadium or V is a soft ductile metal that is not rare but generally occurs in low concentrations and is often associated with titanium and iron ores. Currently over 80% of V is used for alloying including with steel. Adding just 1kg of V to 1-tonne of steel increases its tensile strength by 84%. ***Adding more V to steel reduces the amount of steel needed in construction – enabling a reduction in this big sector's emissions***. Roskill consultants believe that the steel alloy market for V can drive over 2%pa growth in use to 2029. Adding in the

environmental and efficiency benefits of V could boost use further, particularly in fast-growing Developing Countries. *For example, India, that uses less than 30 grams/tonne of steel, while China uses nearly 75 g/t.*



In 2020, vanadium production rose 7.8% to 110,409 tonnes with China, Russia and South Africa producing 60%, 17% and 7% respectively.

Vanadium prices have gyrated over time as over 70% of output is derived as a Co-product of magnetite ores used for steel manufacturing.

Often, high iron ore pricing incentivises marginal magnetite producers, largely located in China, to also ramp-up output including co-product vanadium, *whether the V is needed or not.*

We observe that Ferrovanadium has a *negative correlation* to iron ore prices by around -9% on quarterly basis pricing.

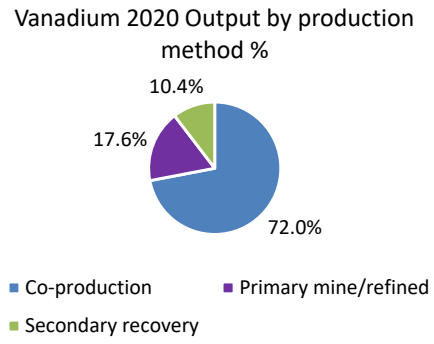
Falling iron ore prices can actually benefit pricing of commodity-grade 80% ferro-vanadium.

Post pandemic we see good pricing conditions for vanadium of robust steel production levels globally, supplied by moderately priced iron ore from Australia, a de-bottlenecked Brazil and new supplies from Simandou in Africa.

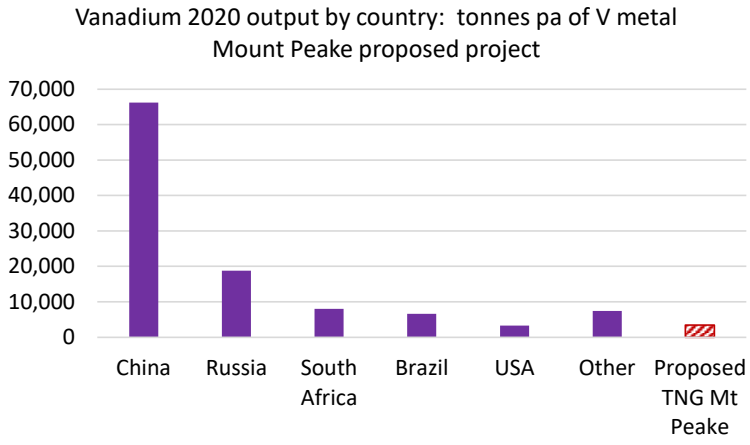
Primary production of vanadium involves roasting, leaching and precipitation to produce higher purity 98%+ V and accounts for 17.6% or just 19,400 tonnes in 2020.

A further 10% or 11,500 tonnes of vanadium is sourced from **Secondary production** from reprocessing fly ash, petroleum and alumina resides and spent catalysts. Higher purity vanadium has uses in chemical catalysts, as well as in the medical, aerospace and nuclear industries.

ASX-listed TNG plans to develop primary production of V in the Northern Territory at its Mount Peake mine and chemical complex. In this facility it aims to produce 6,000 tonnes pa of Hi-purity 99% vanadium pentoxide product, along with titanium pigment and hi-grade iron ore as co-products. *TNG's 6,000 tpa V2O5 production converts to ~3,350tpa of vanadium metal equivalent. While this is only ~3% of current global output of V, it represents a **~11% of hi-purity vanadium output**, making the Mount Peake project of global significance.*



Source: Bushveld Minerals



Source: Roskill and Bushveld Minerals

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New Use for hi-purity vanadium – enter the VRFB

VRFB's require high purity V in the form of vanadium pentoxide (V_2O_5). ***Each Mega-Watt hour (MWh) of storage requires around 5.5 metric tonnes of vanadium, equivalent to 9.8 tonnes of V_2O_5.***

China has announced over 1,500 MWh of VRFB projects in four provinces, which equates to over 8,200 tonnes of V over the next couple of years. This new V demand equates to over 7% of last year's global supply of vanadium units but is over 30% of hi-purity V production*. In a similar dynamic to the lithium market, new battery storage use appears to be transformative for the vanadium market.*

Largo, Brazil's biggest primary vanadium producer plans to have 1,400 MWh of VRFB's under a rental model by the end of 2022. This could use ~7,700 tonnes of V. Other companies have under construction and/or planned VRFB installations that span Japan, Europe and South Africa. These developments could match China's and Brazil's ambitions within the next two or three years. In South Australia, the Yadlamalka Sheep Station VRFB project near Hawker is investing A$20.3m to install a 6 MW solar farm and a 2 MW / 8 MWh storage facility with *41 VRFB modules* that would use over 40 tonnes of V and over 75 tonnes of V_2O_5.

Clearly, a big expansion of the hi-purity vanadium production for VRFB's is required over coming years.

These trends may result in increased price premium for hi-purity vanadium output versus ferrovanadium. This may parallel the experience of producers of LME-grade nickel who can sell to fast-growing battery uses, while lower grade ferronickel producers remain tied to the vagaries of the stainless-steel market.

Given the still large influence of the alloy market, we believe the vanadium price cycle may continue to display high price volatility. This is akin to the hi-grade nickel market. In response, VRFB makers will likely seek to vertically integrate upwards to secure source of hi-purity V. Vanadium input represents around 30 to 45% of the cost of a VRFB, depending upon the price of this critical ingredient. The vertical integration driver would mirror the behaviour of pigment makers seeking to control the sources of rutile and refined titanium dioxide inputs**.** ***We expect competitive independent producers of hi-purity vanadium to be corporate targets in coming years from those manufacturers seeking to claim a portion of the growing power storage market.***

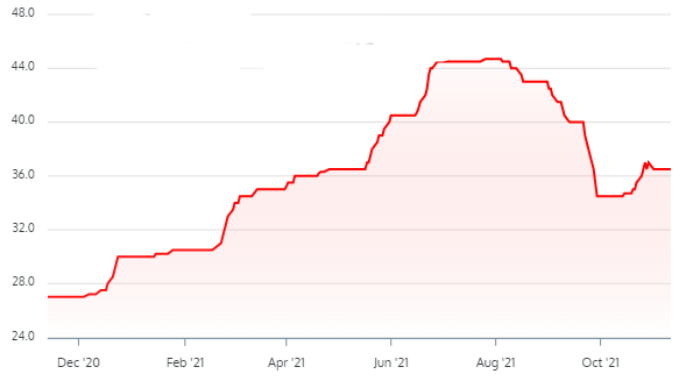
The short-term outlook and beyond is brightening for vanadium

2021 saw a doubling in vanadium prices as China's economy lead the advance out of Covid-19 restrictions. Enforcement of pollution restrictions in China plus a slowing in the property sector and in the general economy has seen commodity prices such as iron ore fall heavily. Interestingly, vanadium prices fell far less heavily.

We would expect to see vanadium co-product producers from marginal magnetite ores to curtail output as iron ore prices fall further below US$100/t and as power restrictions crimp processing. This may see ferrovanadium prices stabilise in coming months. In coming quarters, as China plus the rest-of-the-World steel output starts to recover, we would expect vanadium prices would rise and perhaps eclipse recent price highs.

Ferrovanadium prices in China (80% V) US$/lb

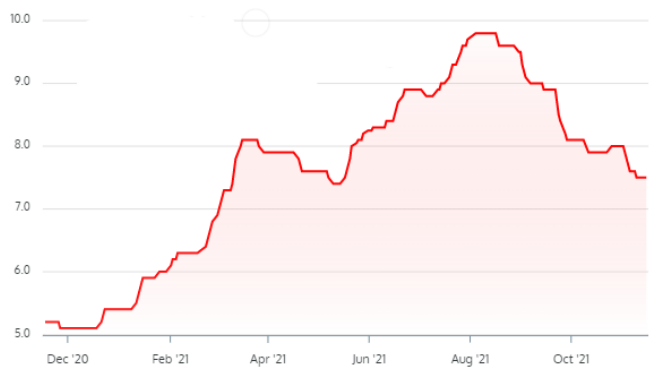
After retracing recent highs as steel output fell, prices start to stabilise as iron ore prices fell heavily



Source Vanadiumprice.com

Vanadium Pentoxide 98% Europe US$/lb

V2O5 still correcting as it rose more strongly than Ferrovanadium.



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Glasgow COP-26 – a spur to power storage growth, and the vanadium market

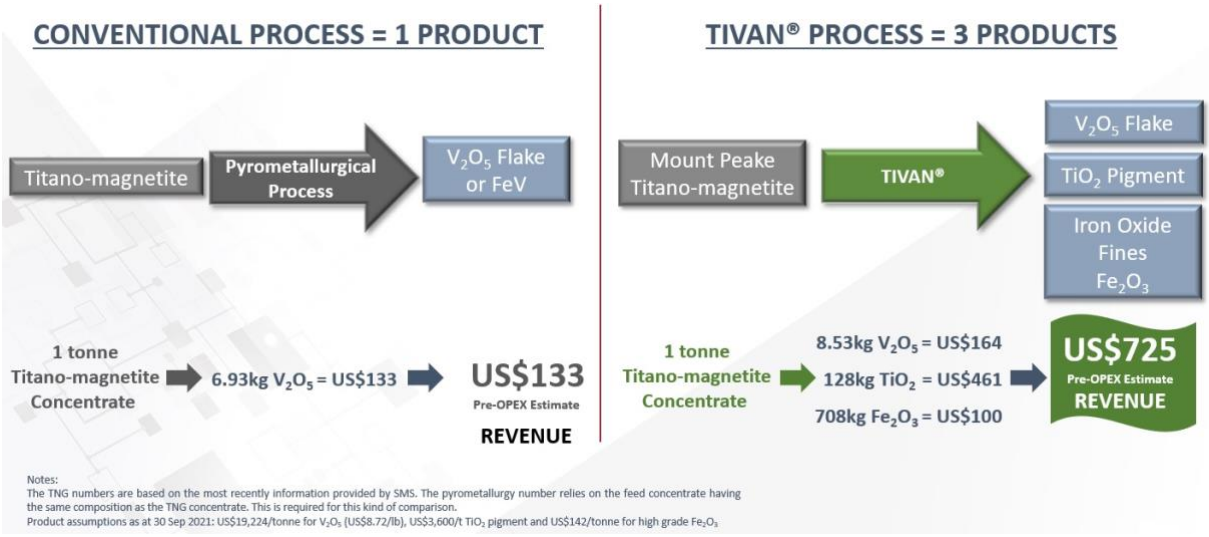
Beyond the vagaries of the steel market, hi-purity vanadium's market is tightening as the increasing number of VRFB projects move into construction and commission in China, Europe, Japan, South Africa, Brazil and beyond. Spurred on by Glasgow COP-26 national commitments to emission reduction, stationary power storage investment is likely to be turbo-charged with the aid of an *avalanche of finance looking for investments with solutions to reducing greenhouse gas emissions.*

While the limelight has been upon lithium-ion batteries, we believe vanadium prices can emulate lithium to rise over coming years to meet the growing source of demand for V, particularly for VRFB's.

Vanadium supply expansion – Sustainability an increasing focus

The introduction of VRFB's into the market is spurring new supply of hi-quality vanadium production. However, traditional treatments of magnetite with vanadium ore with 0.3% to 1.3% content V have largely been based upon high emissions intensive production methods. In Brazil and South Africa traditional pyrometallurgical processes are driven by diesel and power derived from fossil-fuels like coal. The processes recover the vanadium but diverts potential co-products like titanium dioxide and iron oxides to waste dumps or to further emissions-intensive high temperature processing to make pig iron.

Newer processes such as TNG's patented TIVAN® Process is a multi-stage pyro-metallurgical and hydro-metallurgical chemicals plant for treating titano-magnetite with vanadium ores. The proposed plant progressively recovers titanium dioxide, vanadium pentoxide and iron oxide at purity levels above commodity grades. Recovering more of all potentially valuable product from ore also reduces the carbon footprint of each tonne of the various products.



The TIVAN® Process is a potential game changer because it produces three premium purity products, while competing conventional pyrometallurgical processes create a single product often with average grade V_2O_5 or a Ferrovanadium. The TIVAN® Process utilises natural gas initially, though TNG is actively considering incorporation of solar generation and battery support including VRFB's at its Central Australian site near Alice Springs. Also, TNG are planning to replace fossil fuel reductant for hydrogen as H2 volumes become available, or possibly install an electrolyser for onsite green-H2 making.

TNG - an example of a sustainable vanadium supplier of the future

TNG Limited (TNG) is an Australian company listed on the ASX. It is a mineral processing technology company and project developer of its 100% owned world-class Mount Peake Vanadium-Titanium-Iron Project in the Northern Territory. The decade-long work on the mine, technology and process has culminated in a FEED study that focussed on a Darwin sited processing facility. TNG are now engaged on an amended FEED study with an integrated mine/processing facility at the Mount Peake Mine. Next steps are to finalise site approval, final investment decision and a funding over the coming year.

The defining feature of TNG is its ownership and intended deployment of the patented TIVAN® treatment process that combines both pyro- and hydro-metallurgical processes. This extracts from magnetite a concentrate with three premium high purity products (V2O5, TiO2 and Fe). TiO2 is further processed to make a paint-grade pigments with the trademark TNG360™.

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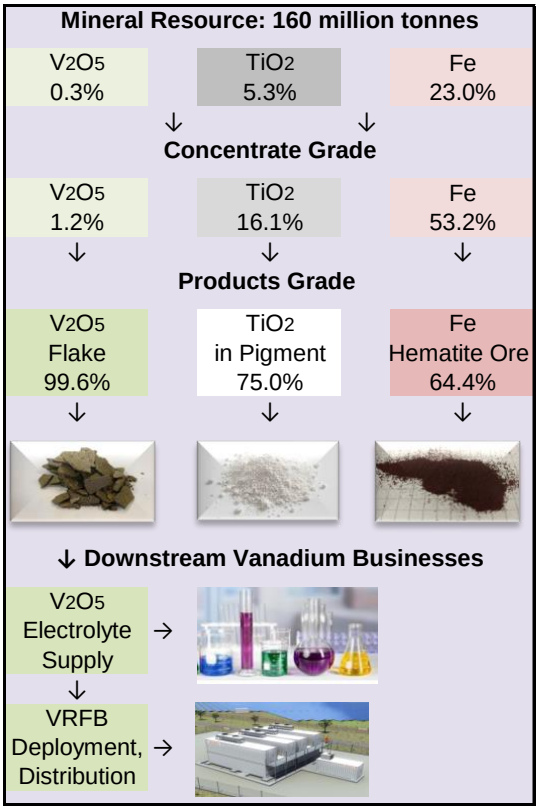
Product	Est Production	Product usage	Off-take	Est. Revenue Split	Est. Price Premiums
Vanadium Pentoxide V_2O_5	6,000 tpa ~3% of world demand of V	Steel alloys, chemicals, catalysts & Vanadium Flow Batteries	Woojin – Korea up to 60% LOM Gunvor – Singapore for up to 40%.	30%	Product 99.6% versus standard 98%. Expect 10-15% premiums
Titanium Dioxide Pigment TiO_2	100,000 tpa 1.5% of world demand	Steel alloys, chemicals, catalysts and emerging Vanadium Flow Batteries	DKSH – up to 100% LOM	60%	TiO2 75% & Fe 2.3% versus Fe 9% for hi-quality TiO2 slag Expect ~3% premiums
Hematite Iron Ore Fines Fe_2O_8	500,000 tpa <0.5% of world fines demand	Steel making	Vimson – India up to 100% LOM	10%	Product fines 64.4% Fe versus standard 62% Expect ~10 % premiums

Link to TNG Limited Initiation Report October 2021: *TNG Report link*.

TNG and others – exploring vertical integration & parallel businesses



While TNG's focus is on final assessment for decision to proceed to develop the Mount Peake integrated project, it is advancing ways to leverage its technology and operations in three ways:

To enter the supply of VRFB's to the Australian power storage market. In August 2021, TNG engaged Perth-based mineral process engineering group METS Engineering to undertake a process design study for a vanadium electrolyte production facility. This builds upon its November 2020 announcement on the establishment of Vanadium Redox Flow Battery ("VRFB") business unit to be a prime mover in supplying Australia with this battery system. In April 2021, TNG announced its collaboration with Singaporean-based battery technology development company V-Flow Tech that could supply and construct advanced VRFB designs.

TNG would also look to licence its process technology internationally. This becomes an option upon a successful commissioning the TIVAN® process that demonstrates superior recoveries, product and economic returns with substantially lower unit carbon emissions compared to vanadium industry norms.

In September 2021, the TNG executed a Project Development Agreement with Malaysian-based green energy company AGV Energy & Technology to develop green hydrogen production projects jointly and exclusively in Australia. The plan is to utilise AGV's "HySustain" technology. This can deepen TNG's sustainability credentials at site and beyond, in 3rd party businesses.

Looking overseas we see vanadium producing companies scaling operations to include VRFB opportunities.

In South Africa, Bushveld Minerals' subsidiary Bushveld Energy has committed US$20m and has a pipeline of up to 250MWh projects that they intend to roll out VRFB integrated power projects. This is in ventures with VRFB manufacturer Enerox, and VRFB maker, installer and electrolyte rentals manager InVinity Energy Systems. South Africa's main power generator Eskom has started a massive 1,400 MWh energy storage system which includes pump hydro and increasingly with batteries. It has issued a tender for an 80 MW / 320 MWh storage system.

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Selection of listed companies with vanadium exposure

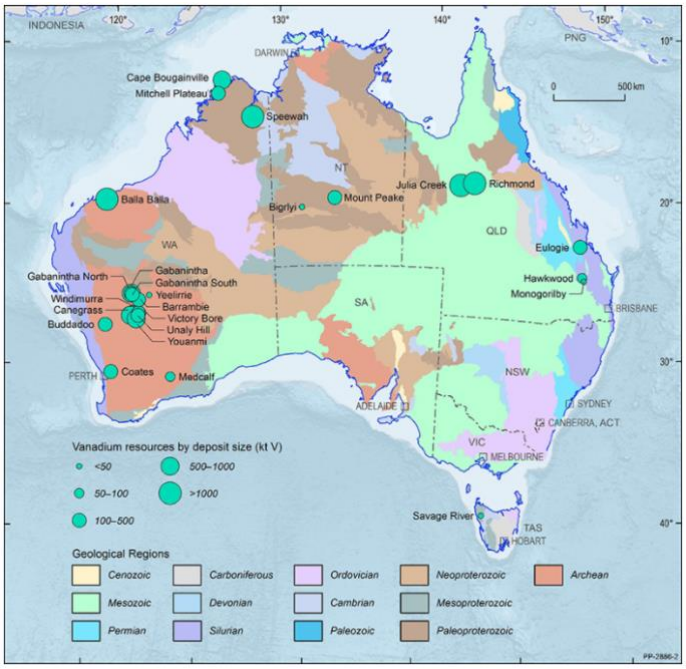
A selection of Listed companies with vanadium exposure.

	ASX-Listed Company in A$	Local Price	Market Capitalizn. fd. $m	Enterprise Value (EV) $m	Net Cash (Debt)
NMT-AU	Neometals Ltd.	1.100	603.2	504.8	95.1
TNG-AU	TNG Limited	0.086	119.4	99.4	18.9
AVL-AU	Australian Vanadium Limited	0.027	88.6	73.2	3.4
VR8-AU	Vanadium Resources Ltd.	0.078	36.7	28.1	1.8
	Overseas listed - in US dollars		US$	US$	US$
000629-CN	Pangang Group Vanadium Titanium and Resources (	3.400	4,579.3	4,084.1	501.2
LGO-CA	Largo Inc.	13.750	709.5	657.2	54.4
BMN-GB	Bushveld Minerals Limited	0.099	167.4	228.1	-14.7
WUC-CA	Western Uranium & Vanadium Corp.	2.780	84.7	78.3	0.6
893-HK	China Vanadium Titano-Magnetite Mining Co., Ltd.	0.180	52.0	110.2	-9.0
VRBFF-US	Vanadiumcorp Resource Inc	0.043	23.4	23.1	0.3

Source: FactSet as at 15 Nov'2021

Australian vanadium deposits and critical mineral status

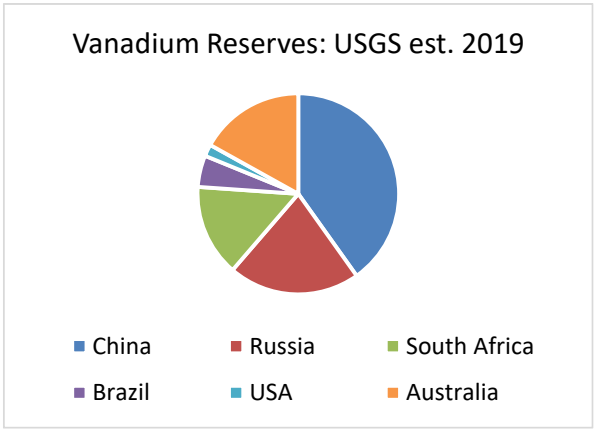
Vanadium has been listed as a "critical mineral" input to the development of Australia's next generation industries.



Source: Geoscience Australia – Resource status as of 2017

[Vanadium | Geoscience Australia (ga.gov.au)]

Currently, Australia has no commercial output of segregated vanadium. With a substantial reserve endowment there is potential for Australia to take a sizable share of the hi-purity vanadium output, just as in the production of lithium products.



Source: United State Geological Survey for 2020

[Vanadium Data Sheet - Mineral Commodity Summaries 2020 (usgs.gov)]

The key to project vanadium development in Australia is the deployment of new processing technology that increases returns per tonne of ore and chemical refining processes that also reduce the emissions footprint.

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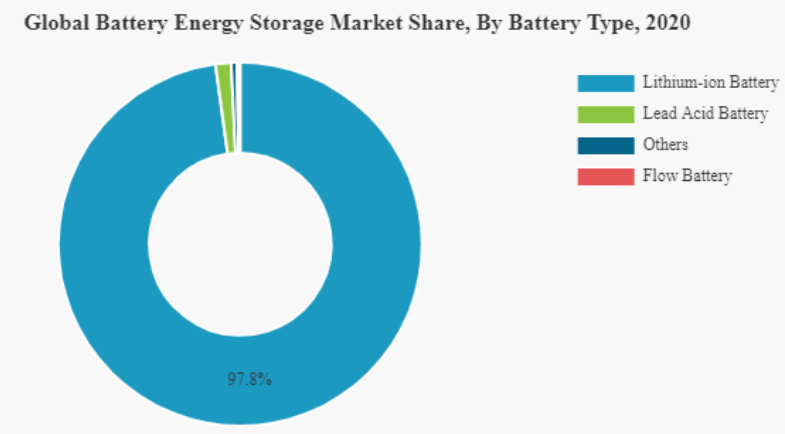
Fortune Business Insights estimate: 2020 energy storage market



Battery Energy Storage Market Size, Share | Growth [2028] (fortunebusinessinsights.com)

Various versions of the Lithium-ion battery have undergone extensive research, development and deployment. This has encouraged investment in scale manufacturing facilities that are leading to falling costs. Lithium-ion batteries currently dominate the stationary power storage market.

A third-generation development Vanadium Redox Flow Batteries is providing greater efficiencies that will attract attention of ultimate users.

The move to integrate the vanadium production chain to the critical VRFB battery ingredient is enabling construction of manufacturing capacity with greater scale economies.

This promises to reduce VRFB's installed cost and see the flow battery segment grow strongly within a strongly growing segment, over time.

VRFB's appear to be securing a strategic role in stationary power storage. In turn, this may see vanadium be viewed as a further critical mineral to assist the World's energy transition.

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