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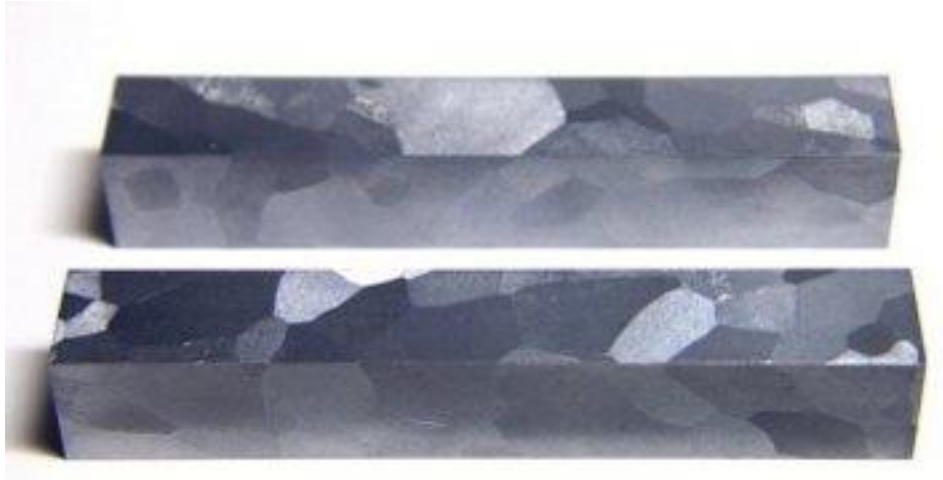


Pure vanadium metal

Syrah Resources Limited

Vanadium Overview – July 2014

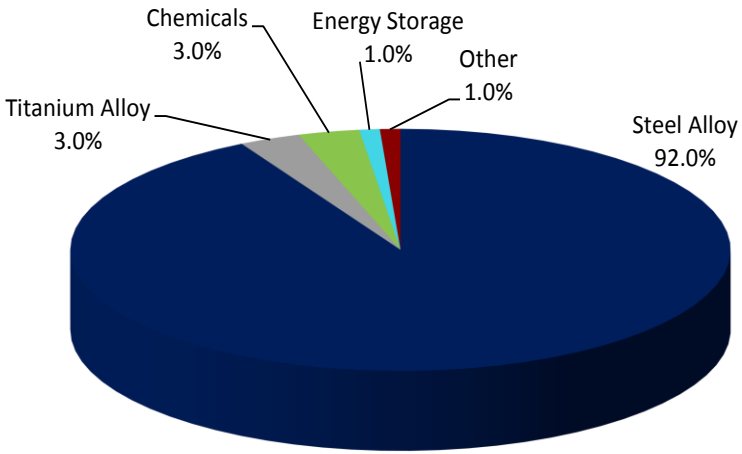
What is vanadium?

- Vanadium, named after the Scandinavian goddess of beauty and fertility, Vanadís (Freyja)
- First recognised as a chemical element with the symbol 'V' after vanadium chlorides were produced by Swedish chemist Nils Gabriel Sefstrom in 1830
- Vanadium is a soft silvery-grey mineral that is classified as a ductile transition metal
- It has good resistance to corrosion and is stable against alkalis, sulfuric and hydrochloric acids
- Metallic vanadium does not occur in nature, but vanadium compounds are found in about 65 minerals and in fossil fuel deposits
- Vanadium compounds have the ability to take on four oxidation states (V_{2+}, V_{3+}, V_{4+} and V_{5+}) which can be easily distinguished as the compound changes colour from lilac, green, blue, and yellow.

The four oxidation states of vanadium compounds.

Vanadium demand by application

2012



80,733 tonnes

Source: TTP Squared, Inc & Metal Bulletin

Steel alloy applications

- Vanadium is predominately used as an alloy called ferrovanadium which increases the tensile strength and hardness of steel as well as reducing its weight.
- This makes ferrovanadium one of the most cost-effective additives in the production of alloy steel
- Alloy steel is used across multiple industries such as the aerospace, automotive, construction and machinery industries
- Generally, no more than 0.25% by weight is added to high carbon steel and between 1-5% is added to steel used in high speed tools

Ferrovanadium

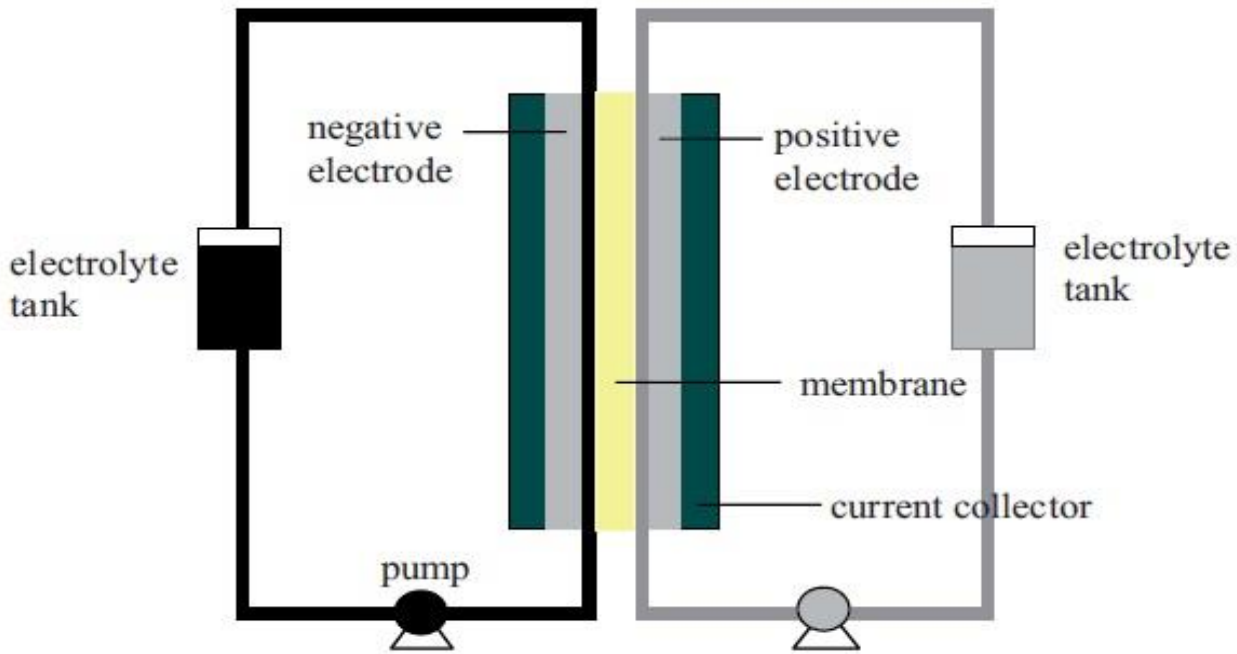
Stainless steel reinforcing bar (rebar)

Battery applications – vanadium redox battery

- The ability of vanadium compounds to take on four oxidation states (from 2+ to 5+) makes vanadium integral to the creation of the vanadium reduction-oxidation (redox) battery (VRB)
- VRBs require high purity V_2O_5 of ≥99%
- In addition, impurities such as nickel, cobalt or copper need to be reduced to negligible levels in the V_2O_5
- VRBs are a type of flow battery which is an electrochemical battery in which one or both of the reactants (or reactant products) is stored in tanks external to the battery stack.
- The cell stack itself contains the electrode, which serve as reaction sites and current collectors

Balama 99.9% vanadium pentoxide concentrate

Battery applications – vanadium redox battery



Schematic of a VRB

Source: Science Direct

Battery applications – vanadium redox battery

- VRBs have several key advantages over conventional batteries:
  - ✓ **Easy scalability** - energy and power ratings are independent which means a VRB can be upgraded for more energy by adding tanks and electrolyte, and upgraded for more power by adding cell stacks
  - ✓ **Long cycle life** - VRBs have a relatively long cycle life (up to 20 years) as the vanadium ions which act as the electrolytes do not degrade as quickly compared to solid electrodes
  - ✓ **Rapid charge/discharge** - direct current (DC) efficiencies are higher which along with more efficient thermal control, allows VRBs to be charged as quickly as they are discharged
  - ✓ **Operational stability and simplicity** - VRBS are less susceptible to conditions such as overcharge, undercharge and partial-state-of-charge cycling, simplifying operations in an utility environment
  - ✓ **Lower maintenance costs** - since all cells share the same electrolyte in VRBs, electrolytes can be monitored and managed on a system level without the requirement for individual cells to be inspected regularly.
- VRBs also have an advantage over other types of flow batteries as the positive and negative electrolytes are identical in their discharged states.
- Consequently, there is no risk of ions from one electrolyte diffusing into and contaminating the other.
- In addition, having identical electrolytes reduces shipment costs and simplifies electrolyte storage and management during operations.

Battery applications – vanadium redox battery

- Due to its relative mechanical complexity, space requirements and economies of scale, VRBs are most suited for use in the utility industry. Primary applications are:

  - ✓ **Peak load support and infrastructure upgrade deferral** – instead of constructing new substations or upgrading capacity in existing substations, VRBs can be used to serve peak loads in the short term and be relocated if and when a capacity upgrade is actually installed. In 2003, a 250 kW VRB was installed in Castle Valley, Utah for this purpose

  - ✓ **Integration of alternative energy into the grid** – VRBs can mitigate the effects of power fluctuations from alternative energy sources (e.g. wind, solar, etc.) by storing electricity generated and then discharging to match power supply and demand under varying weather conditions. Sumitomo Electric Industries is currently working with Hokkaido Electric Power on a 60 MWh device that will allow Hokkaido to add increasing amounts of renewable energy to its grid

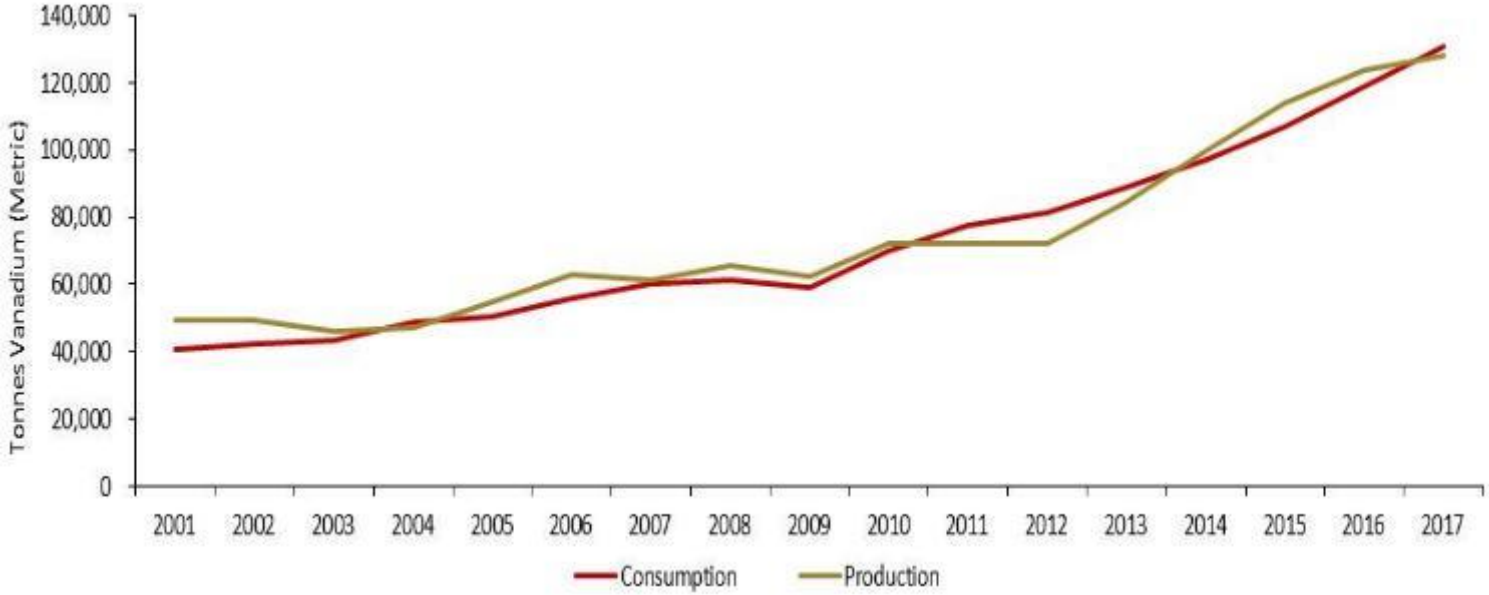
  - ✓ **Increased grid stability** – in order to maintain grid stability in the event of a loss of generation units, grid operators need to rely various sources of power generation reserves. VRBs are an ideal source of reserve generation given its ability to transition from zero to full output in microseconds.

VRB cell stacks at Castle Valley, USA (Source: VRB Power Systems)

VRB cell stacks at Tomamae Wind Farm, Japan (Source: J-Power)

Drivers of demand for vanadium

- Vanadium demand growth over the past ten years has been mainly driven by Asian demand, particularly in China.
- World consumption of vanadium was estimated at about 40,000 tonnes in 2001, rising to about 80,000 tonnes currently.
- TPP Squared Inc. estimates that vanadium demand will rise to about 120,000 tonnes by 2017.



Historical and forecast vanadium demand and supply

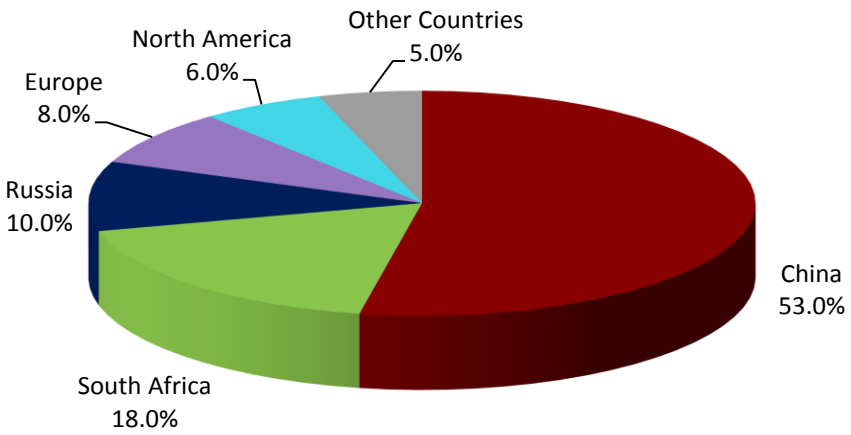
Source: TPP Squared, Inc

Drivers of demand for vanadium

- In 2006, China accounted for about 20% of world vanadium demand, rising to 34% by 2012 (Source: TPP Squared Inc)
- This was mainly driven by increased steel production in China over that period
- New design codes implemented in China are phasing out Grade 2 rebar (reinforcing bars) which have no vanadium, in favour of Grade 3 rebar which require about 0.35 kg vanadium per tonne of steel
- An upgrade of rebar from Grade 2 to Grade 3 would require an additional 30,000 tonnes of vanadium per year (Source: TPP Squared Inc)
- Another potential large driver of vanadium demand is VRBs for grid storage applications
- According to Lux Research, VRBs is forecast to account for 34% of the global large-scale storage battery market by 2017 which equates to US$38 billion in revenues
- According to the University of Tennessee, approximately 46 tonnes of V_2O_5 is required for 1 megawatt power capacity using vanadium redox flow batteries for grid storage
- Credit Suisse Equity Research (Japan) estimates the global market for energy storage could be approximately US$400 billion assuming power networks worldwide adopt load-levelling and battery storage is used for 10% of current electricity consumption
- Industry analyst, Kema Inc. forecast that the global market for energy storage over the next 10-20 years could be upwards of 300 gigawatts in size and US$200-US$600 billion in value

Global vanadium production

2012

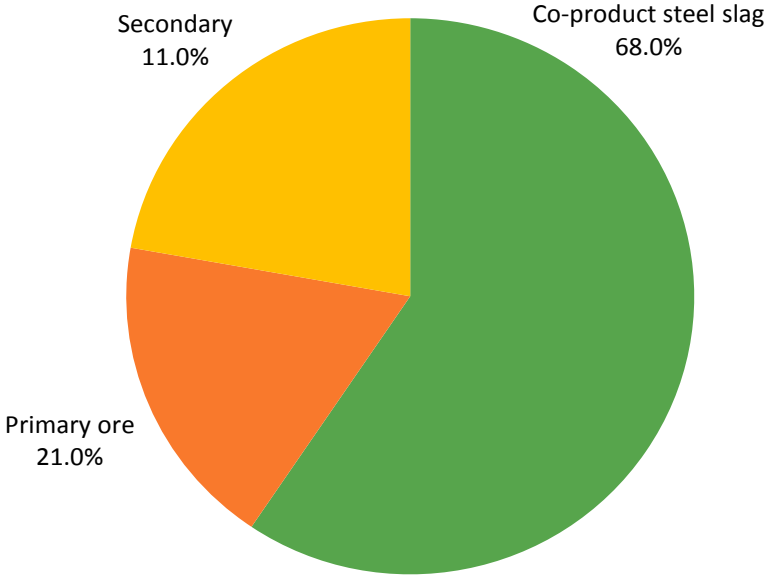


71,508 tonnes

Source: TPP Squared, Inc

Global vanadium production

- China is currently the world's largest producer of vanadium and accounts for over half of the world's supply
- Most of China's vanadium is consumed in China with some exports to regional neighbours such as Korea and Japan.
- The only other major suppliers of vanadium are South Africa (18%) and Russia (10%)
- Rhovan in South Africa (majority owned by Glencore) is currently the world's largest operating vanadium deposit (Source: Glencore annual report)
- In 2013 Rhovan produced ~9,800 tonnes of V_2O_5 in the form of ferrovanadium
- Vanadium producers can be classified as either co-product steel slag, primary ore or secondary producers

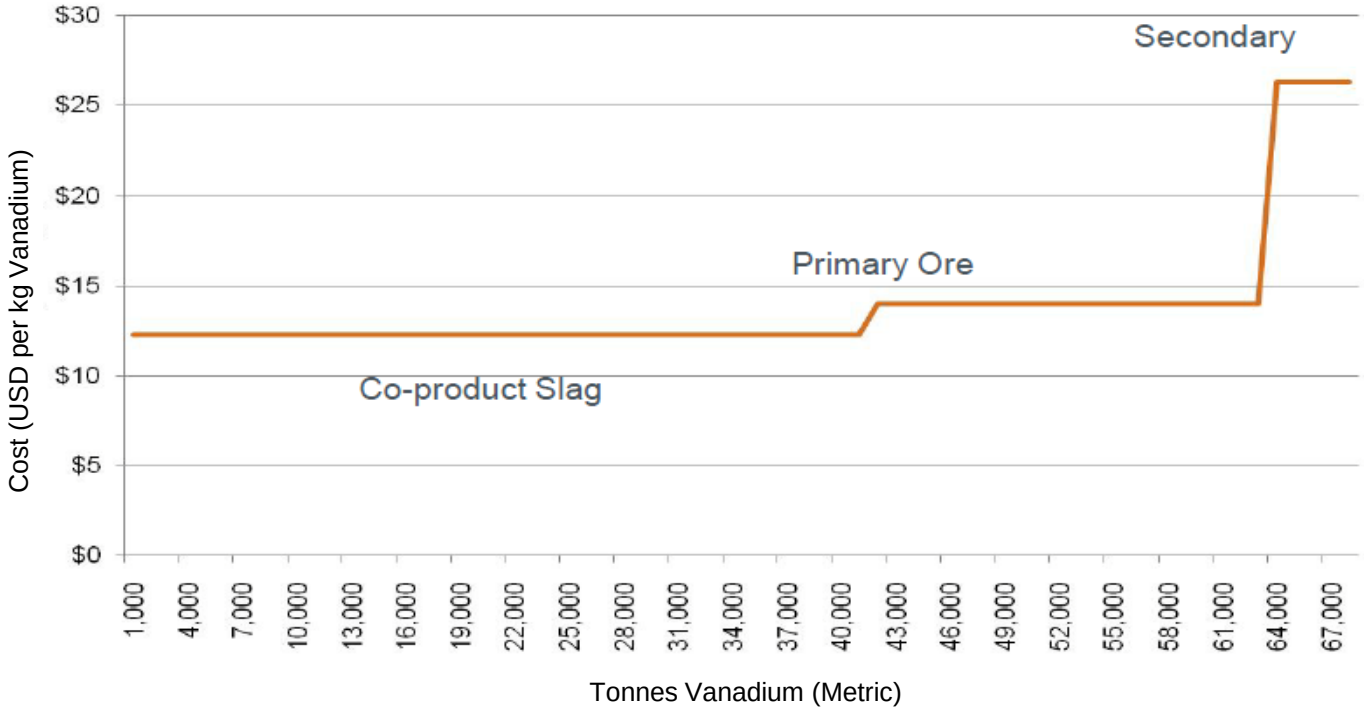


Vanadium supply by raw material

Source: TPP Squared, Inc

Vanadium industry cash cost curve

- The following figure shows the average cash costs for co-product slag, primary ore and secondary vanadium producers in 2012



Source: TPP Squared, Inc

Potential sources of new supply

- The following table shows the known vanadium projects currently being developed by listed entities around the world

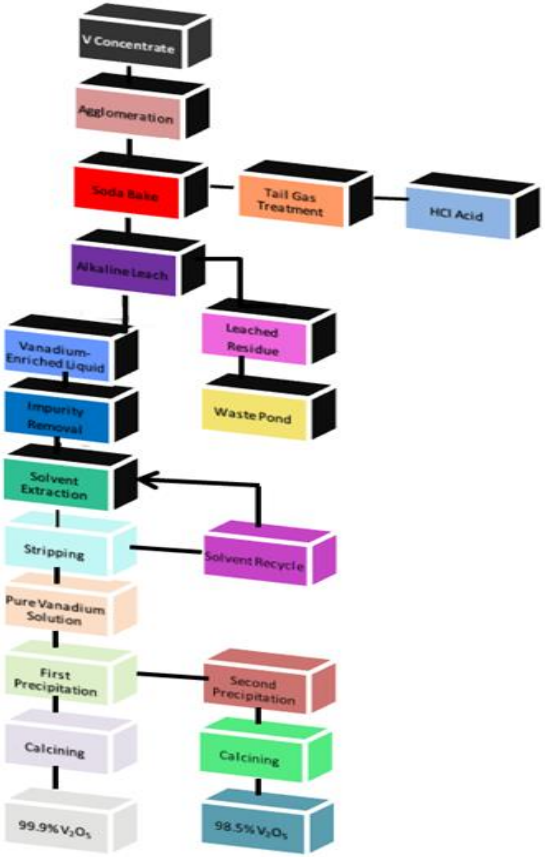
Metric	Unit	Syrah Resources	Largo Resources	TNG Limited	American Vanadium
Project		Balama	Maracas	Mount Peake	Gibellini
Location		Mozambique	Brazil	NT, Australia	Nevada, USA
Ownership	%	100	100	100	100
Life of mine	years	20	29	20	Unavailable
Strip ratio		0.11 : 1	6.27 : 1	0.95 : 1	0.22 : 1
Concentrate throughput	V_2O_5 %	2.5	3.4	1.0 to 1.5	Unavailable
Production	tpa tpa tpa	3,804 V_2O_5 (Min. 98%) 1,245 V_2O_5 (99.9%)	6,376 V_2O_5 4,899 FeV	11,000 V_2O_5 (99%) 290,000 TiO_2 900,000 Fe_2O_3 (99.9%)	5,171 V_2O_5
Price assumption	US$/kg US$/kg US$/kg	12.0 V_2O_5 (Min. 98%) 50.0 V_2O_5 (99.9%)	14.0 V_2O_5 28.0 FeV	20.3 V_2O_5 (99%) 0.4 TiO_2 (55%) 0.2 Fe_2O_3 (99.9%)	24.1 V_2O_5
Total costs	US$/kg US$/kg	8.3 V_2O_5 (Min. 98% & 99.9%)	7.0 V_2O_5 15.6 FeV	75.5 V_2O_5, TiO_2 & Fe_2O_3	9.0 V_2O_5
Total capex	US$ m	80.0	235.0	563.0	95.5
Discount rate	%	10.0	8.0	8.0	7.0
NPV	US$ m	330.0 Post tax	554.0 Post tax	2,600 Pre or post-tax not specified	170.1 Pre or post-tax not specified
IRR	%	59.2 Post tax	26.3 Post tax	38.0 Pre-tax	43.0 Pre or post-tax not specified
Payback period	years	3.4	Unavailable	Potentially 4	2.4

Source: Company presentations and stock exchange announcements

Balama Graphite and Vanadium Project

- In July 2014, Chalieco (the international engineering arm of the Chinalco Group) completed the Vanadium Scoping Study for Syrah's Balama Graphite and Vanadium Project
- Chalieco was selected by Syrah based on its experience in undertaking the engineering work on eight vanadium projects in China with a similar ore assemblage to that of Balama (vanadium hosted in graphitic schists)
- Metallurgical testwork to date has shown that the vanadium reports to the tailings during the graphite flotation process
- Magnetic rich mineralisation (mainly magnetite and limonite) can be upgraded by 8-11 times to achieve a V_2O_5 grade of 4-5% by a WHIMS (Wet high Intensity Magnetic Separator)
- Non-magnetic mineralisation (mainly roscoelite) can be upgraded by 4-5 times to achieve a V_2O_5 grade of 2-2.5% by flotation. These two processes have been demonstrated to produce a combined concentrate grade of >3% V_2O_5
- Chemical processing of this initial vanadium concentrate had shown that a 98.5% purity vanadium pentoxide can be produced
- Additional metallurgical testwork has now successfully produced a 99.9% high purity vanadium pentoxide by solvent extraction
- **The ability to produce a 99.9% concentrate is a significant differentiating factor for Balama when compared to the majority of graphite projects outside of China, which are generally ferro-magnetite style deposits for which it may not be economic to upgrade to these levels.**
- **As a potential major supplier of high purity vanadium outside of China, Syrah is well positioned to take advantage of forecast future growth in vanadium battery manufacture (including VRBs)**

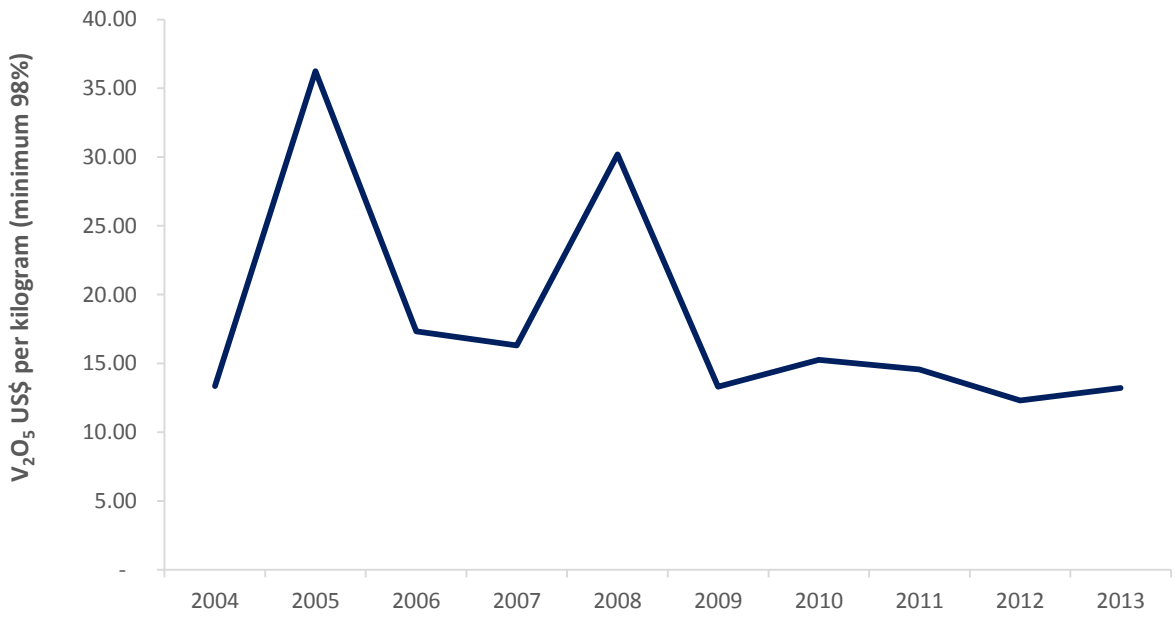
Balama Graphite and Vanadium Project



Simple flow sheet for the processing of Balama vanadium

Vanadium pricing

- 98.5% V_2O_5 sells for between US$12.5 to US$15 per kilogram
- 99.9% V_2O_5 can sell for about US$50 per kilogram



Average annual V_2O_5 (minimum 98%) prices from 2004 to 2013

Source: Bloomberg

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The information in this report as it relates to geology, geochemical, geophysical and exploration results was compiled by Mr Tom Eadie, FAusIMM, who is a Competent Person and Chairman of Syrah Resources Ltd. Mr Eadie has more than 20 years of experience in the activities being reported on and has sufficient expertise which is relevant to the style of mineralisation and type of deposit under consideration and to the activity undertaken to qualify as a Competent Person as defined in the 2012 Edition of the 'Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves'. Mr Eadie consents to the inclusion of this information in the form and context in which it appears in this report.

The information in this report as it relates to mineral processing and metallurgical testing was compiled by Mr Michael T.N. Chan, MAusIMM, who is a Competent Person and General Manager of Project Development at Syrah Resources Ltd. Mr Chan has more than 20 years of experience in the activities being reported on and has sufficient expertise which is relevant to the style of mineralisation and type of deposit under consideration and to the activity being undertaken to qualify as a Competent Person as defined in the 2012 Edition of the 'Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves'. Mr Chan consents to the inclusion of this information in the form and context in which it appears in this report.

Roscoelite (bearing vanadium) in broader graphite host from Balama

Thank you