Vanadium Market Fundamentals and Implications

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Abstract
1.0 Vanadium Demand

1.1 Vanadium Demand 2012

Global vanadium demand in 2012 is estimated at 81,000 metric tons vanadium contained (MTV). The vast majority (92%) of vanadium demand is from the steel industry. Vanadium is used to produce tool, high speed and high alloy steels containing as much as 20% vanadium (V), as well as high strength low alloy (HSLA) steels which contain typically less than 0.5%V.

Vanadium is also used in the production of titanium alloys for aerospace and industrial purposes. The workhorse titanium alloy used in aerospace applications is Ti6-4, which contains 4%V. There are also other titanium alloy compositions produced which use vanadium. Titanium alloys account for about 4% of consumption in 2012.

About 3% of global vanadium consumption is in petrochemical, catalyst and pollution control applications as well as ceramic pigments, special glasses and other chemical industry applications.

In 2012 about 1% of vanadium consumed was used in energy storage applications. Vanadium redox flow battery (VRB) systems for grid energy storage applications and lithium battery systems incorporating vanadium for mobility applications are under development today with potential to have a significant impact on future vanadium demand.

Global vanadium demand today is driven by two basic variables: global steel production rates, and the specific vanadium consumption rate (kilograms V used per metric ton of steel produced, or KgV/MT steel) within the steel industry. Changes in these two variables will be the main drivers for changes in global vanadium demand in the coming years.

Currently titanium alloy production is in a strong growth phase and this application will make a contribution to growth in vanadium demand in the next 5 years but the magnitude of the market impact pales in comparison to changes in the steel industry demand for vanadium. Vanadium chemical applications are for the most part mature applications with growth in vanadium consumption in this field projected to be close to global GDP growth. Energy storage applications do offer potential to have a significant impact on vanadium demand growth in the coming years.

1.2 Global Steel Production
Global steel production in 2011 was reported as 1,490,060 MT. Global steel production in January 2012 was well below January 2011. From February through May 2012 global steel production was roughly 2% higher than the corresponding period in 2011. More recently global steel production levels have dropped to levels close to 2011 production rates. Through September 2012 global steel production was 0.6% above 2011 production levels.

Steel production in the EU has been particularly weak in 2012 compared to 2011. EU Steel production through September is 4.4% below the same period in 2011.

North American steel production started the year very strong relative to 2011 but in recent months production levels have pulled back to close to 2011 levels. Year to date through September North American steel production is 4.1% ahead of the same period in 2011.

Our projection suggests that global steel production in October will be similar to September levels, and then November and December levels will run at 95% of the September/October production levels. This projection is in line with historical seasonal effects on steel production in the last quarter of the year. We therefore project global steel production in 2012 at just over 1.5 billion metric tons, or 0.8% growth from 2011 production levels.

Our longer term projection for global steel production suggests a compound annual growth rate (CAGR) of 3.9% from 2011-2017. Our projection assumes a CAGR of
4.6% for China, 1.1% for the EU and 3.2% for North America from 2011-2017.

1.3 Specific Vanadium Consumption

The global average specific vanadium consumption rate in 2011 was 0.052KgV/MT steel. We project the 2012 specific global average specific vanadium consumption rate at 0.054KgV/MT steel. Specific consumption rates for vanadium vary from 0.089KgV/MT steel in North America to 0.029KgV/MT steel in India.

Growth in specific vanadium consumption rates is a result of the replacement of relatively low strength carbon manganese (C-Mn) steel with HSLA steels which use small amounts of vanadium, niobium, titanium or some combination of these microalloying elements. In many cases a small amount of vanadium (typically 0.05%V) added to C-Mn steel can result in a 50% to 100% increase in yield strength. In applications where steel is a load bearing material – particularly in infrastructure development applications in the developing world which are driving global steel production growth rates - this efficient strengthening of the steel results in economic value for everyone in the supply chain. By using HSLA steel rather than C-Mn steels the steel producer is often able to produce steel with a less than 3% cost increase, but sell the high strength steel as a value added product at much higher margins. Steel users can pay higher prices for high strength steel but use significantly less steel for a given project leading to lower total cost. Less raw materials and energy are consumed, less pollution is generated, and less capital is deployed in steelmaking capacity for a given amount of infrastructure development.

As a result there is value created at all stages of the value chain and this creates a strong driver for the ongoing replacement of lower strength C-Mn steel with HSLA steels. Today perhaps 60% of global steel produced is C-Mn steel, about 20% HSLA steels and about 20% special high alloy steels. There is no reason that the market share of HSLA steel to total steel cannot double or triple in the coming years as a result of the strong economic and sustainability drivers which result from the replacement of C-Mn steel with HSLA steels.

If we look at the time period 2004-2006 we see a period where the specific vanadium consumption rates actually decreased. This decrease was a reaction to extremely high vanadium market prices. At this time vanadium prices rose to extremely high
levels while prices for Nb and Ti were very stable. As a result there was some substitutional loss of market share as in some applications steel mills were able to substitute Nb and/or Ti or in some cases quench and temper (Q&T) processes for vanadium as a strengthening mechanism.

In each application there is a metallurgically best solution to achieving high strength in steel. In some cases Nb is best, in some cases V is best, in some cases Ti is best and in some cases a combination of the three alloy systems is best. If economic imbalances become too severe, some will use a less metallurgically sound solutions in order to address cost issues. However when relative prices of the various options come back into normal relationship we see those who have made this substitution return to their historical solution. Thus in the past the substitutional loss of market for vanadium was a direct but temporary result of extraordinarily high price levels.

Our projection suggests specific vanadium consumption rates will grow at a CAGR of 5.1% from 2011-2017. Assuming similar growth rates for Nb and Ti in HSLA steels then our projection suggests that HSLA steels will grow from about 20% of current steel production to about 28% of steel production by 2017, leaving plenty of market share growth potential in subsequent years before saturation begins to occur.

As the two thirds of the world’s population that lives in poverty today strive for a better life there will be continued pressure of governments to provide economic opportunity which requires industrialization of rural economies. Industrialization requires infrastructure and steel is the backbone of infrastructure. Thus we do not see the relatively high rate of growth in steel demand over the past decade as a China only phenomenon but one that will carry on for many more years.

This ongoing growth in steel demand puts tremendous pressure on global natural resources and the environment. To some extent the replacement of lower strength C-Mn steels with HSLA steels can create tremendous value for the world in terms of allowing the development of third world economies in the most efficient manner possible.

1.4 Vanadium Demand Forecast


Our vanadium demand forecast estimates changes in global vanadium demand based on projected changes in global steel production levels and projected changes in global specific vanadium consumption rates within the steel industry. It is presumed that these factors will also capture growth in vanadium demand from other applications.

It is possible that energy storage applications could develop and mature in the next few years to and make significant contributions
to the growth in vanadium demand. We do not incorporate those possibilities in this projection due to the difficulty in forecasting emerging technologies.

2.0 Vanadium Supply

2.1 Vanadium Production by Country

Vanadium production in 2012 is estimated at 70,000 MTV. For the purpose of this presentation vanadium production is defined as the manufacture of vanadium oxides or the first downstream product from oxides.

China produces about half of the global vanadium supply today. South Africa, Russia, Europe and the USA are also important vanadium producers in 2012.

2.2 Vanadium Raw Materials

There are three main sources of vanadium raw materials in the world. Slag from steel mills in China, Russia, South Africa and New Zealand make up the raw material for two thirds of global vanadium production. Vanadium bearing titaniferous magnetite ores are processed in these steel mills and a vanadium rich (typically 10%V) slag is generated as a coproduct in these mills.

These same vanadium bearing titaniferous magnetite ores are mined and processed directly for vanadium extraction in South Africa and Australia. There is also some vanadium bearing ores commonly referred to as Stone Coal mined in Shaanxi Hunan, Guansu and Hubei provinces in China. These primary vanadium mining projects supply the raw material for about 22% of the global vanadium production.

Finally secondary materials resulting from the processing of vanadium bearing oil supply the raw material for approximately 11% of global vanadium production. Oil from Venezuela, parts of Mexico, Kuwait and Russia contains small amounts of vanadium which ends up in boiler slags and ashes or spent catalysts which are generated when these oils are either burned in power stations or processed in oil refineries

2.3 Future Vanadium Source
The Windimurra mine first started production of vanadium in 1999 but was shut down and the mill scrapped in 2003 due to horrible market conditions. The mill as now been rebuilt and production commenced earlier this year. Although some design flaws in the rebuilt mill caused delays in the project, the design issues have been resolved and the operation is now ramping up production. The parent company Atlantic, Ltd is well funded to see through the ramp up with a goal to be at full capacity of 6,300 MTV per year by early 2013.

China is in the process of a massive expansion of coproduct vanadium production as a result of growth in steelmaking from domestic vanadium bearing titaniferous magnetite ores. These ores, found in Sichuan and Hebei provinces primarily, are relatively low (less than 30%) iron bearing ores with high titanium and vanadium levels. Given China’s dependence on imported iron ores several years ago a strategy to support growing steel production from domestic ores was launched.

According to announced plans China will add another 20,000 MTV of final products to the market as coproduct vanadium from planned steel mill expansions over the next 5 years. Given the current situation in the Chinese steel industry there is some chance that some of this expanded capacity will be late to market or not occur. Our projection assumes all planned expansions take place according to the original time schedules.

In addition to Windimurra and the planned Chinese steel mills expansions there are other possible sources of increased vanadium supply in the next 5 years.

An estimated 9,000 MTV per year capacity from Chinese stone coal is currently idled due to high costs relative to the market. Some of this capacity may never come back on line due to environmental issues associated with chlorine contamination in effluent water. It is estimated that ferrovanadium prices will have to move above US$40/KgV for a protracted period in order to bring any of this capacity back on line.

Our projection assumes expansion at Highveld Vanadium and Steel in South Africa leads to an increase of 3,600 MTV per year in final products beginning in 2016. We also see an increase of about 700 MTV per year in final products coming from primary vanadium mining in South Africa in 2013. This represents production lost in

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**Figure 13: Chinese Coproduct Slag Expansion**

China Vanadium Supply fromCoproduct Slag

**Figure 14: Supply Increases 2012-2017**

<table>
<thead>
<tr>
<th>Source</th>
<th>2012</th>
<th>2017</th>
<th>Change</th>
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<tbody>
<tr>
<td>China Coproduct Slag</td>
<td>31,100</td>
<td>51,500</td>
<td>20,400</td>
</tr>
<tr>
<td>China Stone Coal</td>
<td>2,000</td>
<td>11,000</td>
<td>9,000</td>
</tr>
<tr>
<td>Unscheduled Primary Mine</td>
<td>-</td>
<td>6,000</td>
<td>6,000</td>
</tr>
<tr>
<td>Windimurra Primary Mine</td>
<td>500</td>
<td>6,300</td>
<td>5,800</td>
</tr>
<tr>
<td>Maracas Brazil Primary Mine</td>
<td>-</td>
<td>4,500</td>
<td>4,500</td>
</tr>
<tr>
<td>South Africa Coproduct Slag</td>
<td>6,000</td>
<td>9,600</td>
<td>3,600</td>
</tr>
<tr>
<td>New Zealand Coproduct Slag</td>
<td>1,000</td>
<td>2,600</td>
<td>1,600</td>
</tr>
<tr>
<td>South African Primary Mine</td>
<td>12,800</td>
<td>13,500</td>
<td>700</td>
</tr>
<tr>
<td>Coproduct Uranium Mining</td>
<td>150</td>
<td>550</td>
<td>400</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>52,700</td>
<td>72,700</td>
<td>20,000</td>
</tr>
</tbody>
</table>
2012 due to a strike at the Highveld Vanadium & Steel iron ore mine.

New Zealand Steel has plans for a possible expansion that could lead to another 1,600 MTV per year in Final products by 2017. We also see a modest increase of 400 MTV per year possible from resumption of processing of vanadium bearing uranium ores in the USA in the next few years.

The Maracas primary vanadium mining project in Brazil has broken ground and plans are for construction of the mine and mill over the next year. Our projection assumes that Maracas will reach full production of 5,200 MTV per year by 2017. We also forecast another as yet unfunded and not identified vanadium mining project to bring an additional 6,000 MTV per year to market by 2017.

2.4 Vanadium Supply Projection

Rolling up all the projection expansions we project vanadium supply could increase at a maximum rate of 8.7% CAGR 2011-2017. If there is any delay in the development of new coproduct capacity from Chinese steel mills the actual supply growth could be significantly lower. If vanadium prices do not justify the restarting of Chinese Stone Coal capacity than this supply source will not come to market. There is very little chance of any unforeseen new sources of supply emerging within the next five years but some fairly significant risk that all of the projected new sources of supply will not occur on schedule.

3.0 Supply/Demand Balance and Implications

3.1 Vanadium Supply/Demand

The projection indicates vanadium supply will grow by 8.7% and demand by 9.2% CAGR from 2011-2017.

If we look at the supply/demand balance with the detail of the source of supply we see an environment where coproduct steelmaking slag and primary mined vanadium alone cannot meet the needs of
the market. As a result all three source of production will be required in the coming years to fully meet demand. This has implications for production costs and therefore market equilibrium price levels.

3.2 Industry Cost Curve

If we look at the vanadium industry cost curve we see three distinct sections of the curve based primarily on the raw material source. Coproduct steelmaking slag represents the lowest cost production source. If the iron ore mine, the steel mill and the vanadium refinery are all part of the same group then in essence the vanadium slag is free and the cash cost of production is reflective of the cost to refine the slag to final products and bring the final products to market.

In the case of primary vanadium mines there is some incremental cash cost associated with the mining of ore and production of concentrate to feed to the vanadium refinery. Costs for primary vanadium mines are typically slightly above the cost for integrated slag producers and not subject to fluxuation with market conditions.

The final section of the industry cash cost curve is occupied by producers buying secondary vanadium bearing raw materials. These boiler ashes and slags and spent catalysts and residues are bought and sold at prices of typically 40% to 60% of vanadium market prices so the cost for this production is exposed to market fluxuations and limited by the availability of these raw materials.

Today the cash cost for production of ferrovanadium from secondary production is estimated at US$27.00/KgV. In theory this cash cost should determine the market equilibrium price assuming global stock levels are not excessive or insufficient.

The projection indicates that for the foreseeable future total demand will be greater than the total production from coproduct steel slag and primary ore. This would suggest that the cost of production from the least efficient portion of the supply base will drive market equilibrium prices going forward.

3.3 Vanadium Inventories

If we look at our Supply/Demand history and projection we can build a picture of the change in inventory globally year by year. This data shows that during 2001-2003 there was a significant increase in global inventories. In 2004 global inventories dropped as a result of the sudden increase in Chinese consumption. From 2004-2010
production ran ahead of consumption and there was a significant buildup in stocks of vanadium globally. There also appears to be a major destocking occurring in 2011-2013 before large supply increases lead to inventory rebuilding in 2014-2015. By 2016 growing demand is not met by limited new capacity available to come on line and we enter another destocking period.

Figure 20: Cumulative Inventory Change

If we look at the cumulative inventory change over this time period and measure inventory in months of consumption rather than MTV to address changing market size we see a situation where declining inventories in 2004 were followed by a price spike in 2005. Growing inventories in 2005 (due to high prices and loss of market to substitution) were followed by a decrease in price in 2006. A slight decrease in inventory levels in 2008 coincided with a price spike in 2008, and then a period of inventory declines from 2010-2012 with no corresponding price reaction.

The price spike of 2005 coincided with the adoption of grade 3 rebar standards in China. Overnight China became a net importer of vanadium and this had dramatic effects on western supply and prices.

The 2008 price spike appears to have been a bit of an anomaly as only a slight inventory reduction from relatively high levels occurred. There were however rampant rumors in the market at that time of power shortages in South Africa having a significant effect on the supply of all alloys and we believe the price spike to have been a result of speculation rather than fundamentals.

Looking at the current situation as well as the projection for the next several years it seems that global inventories are reaching a level last seen in 2004.

3.0 China Supply/Demand and Implications for the West

3.1 China Supply and Demand Trends

From 2001 until 2011 Chinese vanadium production grew by a CAGR of 16.5% while demand grew by 17.2% CAGR.

Chinese vanadium supply grew dramatically following the 2005 vanadium price spike. The adoption of grade 3 rebar standards in China created a vast new market for vanadium and the Chinese invested in new capacity to meet the surging demand. In 2012 we see the production of vanadium in China decrease significantly as Stone Coal production has all but ceased. This high
cost capacity was reasonable when prices were above US$40.00/KgV but over the past few years prices have languished and this capacity has been for the most part brought off line.

In 2004 for a brief time China became a net importer of vanadium as the surge in demand from newly introduced grade 3 rebar overran production. High prices stimulated new sources of vanadium supply; in particular Stone Coal based supply. As a result since 2005 supply of vanadium has surged ahead of demand leading to a significant amount of excess production. In 2012 the amount of excess production has been drastically reduced with the shutdown of most Stone Coal capacity.

Looking at the world excluding China we see that until 2006 supply and demand were in relatively good balance. Starting in 2007 the western world demand has grown significantly faster than supply. In 2012 vanadium consumption ex China is projected to be 16,400 MTV more than production ex China.

The western world has become increasingly reliant on Chinese exports. Today about one third of western demand is supported by Chinese exports. To great extent future western vanadium market prices will be dictated by changes in the supply/demand balance in China and resulting availability of exports from China.

4.0 Energy Storage Applications

4.1 Lithium Vanadium Batteries

Vanadium is used in cathodes of lithium vanadium phosphate battery systems today.
This technology is being used in a limited number of commercial applications for portable electronics. The lithium vanadium phosphate battery technology is also being developed for automotive applications by companies including BYD (China) and Subaru (Japan). One source forecasts vanadium demand in lithium vanadium phosphate applications could reach 2,500 MTV per year by 2017.

4.2 Vanadium Redox Battery

Vanadium redox flow batteries (VRB’s) are being developed and commercially deployed today in industrial and grid storage applications. While relatively expensive compared to other technologies, VRB’s are being utilized in applications where their unique combination of energy density, power density, response time and flexibility in terms of power to energy configurations drive the decision making process.

It is projected the grid storage capacity will grow to 185 GWHr by 2017. One GWHr of storage capacity using VRB technology would require 5,000 MTV so even if VRB’s take only a small portion of this future market the impact on vanadium demand can be huge. Vanadium demand of at least 7,000 MTV per year in 2017 for VRB’s is projected by one source.

We do not make any effort to include energy storage applications in our projections due to the uncertainty in projecting developing technologies. Certainly there is a significant probability that significant amount of vanadium will be used in these technologies in the future but the impact is very difficult to quantify.

5.0 Summary

Vanadium demand expected to grow by 9.2% CAGR primarily due to increasing steel production rates (3.9% CAGR) and increasing specific vanadium consumption rate (5.1% CAGR).

Vanadium supply expected to grow at 8.7% CAGR 2011-2017 with early growth from increases in Chinese coproduct steel slag and the Windimurra primary mine followed by new primary mining in Brazil and elsewhere as well as incremental increases in coproduct slag from South Africa and New Zealand in 2015-2017.

Significant global excess inventory accumulated from 2005-2010 is depleted in 2011-2012 as demand continues to grow while production has decreased since 2010. Tight market conditions anticipated 2013-2017 as consumption runs slightly ahead of production with relatively low global inventory levels.

Growth in supply over the coming years is highly dependent upon increased coproduct vanadium slag from Chinese steel mills, some of which may be under pressure in current environment.

Western markets have become increasingly dependent upon Chinese exports to maintain market liquidity.
New demand in energy storage applications could add significantly to demand for vanadium in the coming years.

i World Steel Association

ii Jon Hykway, Byron Capital Markets, “Vanadium, The Supercharger”, Nov. 12, 2009, pg. 11,

iii Kevin Jones, Camelot Coal, Ryans Notes Ferroalloys Conference presentation, Oct. 30, 2012 Miami, Fl USA


v Kevin Jones, Camelot Coal, Ryans Notes Ferroalloys Conference presentation, Oct. 30, 2012 Miami, Fl USA