Master Alloy Market Trends & Analysis

International Titanium Association Annual Meeting
Las Vegas, Nevada
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Agenda

• Vanadium
  • Production
  • Consumption
  • Demand Drivers
  • Inventory Change

• Molybdenum
  • Production
  • Consumption
  • Inventory Change

• Role of Master Alloy Suppliers in the Ti Alloy Industry
Vanadium Production
Definition of Production

Vanadium Industry Flow Chart

Source: TTP Squared, Inc.

International Titanium Association North American Meeting
Oct. 10, 2018 Las Vegas  TTP Squared, Inc.
Vanadium Production

Historical Production

Source: TTP Squared, Inc.
Vanadium Production
Sources of Raw Material 2017

- Coproduct Steel Slag: 71%
- Primary V Ore: 18%
- Secondary: 11%

Source: TTP Squared, Inc.
Vanadium Production
Production by Country 2017

Source: TTP Squared, Inc.
Vanadium Production

Chinese Production by Raw Material Source

source: TTP Squared, Inc.
Vanadium Production
Production from Chinese Steel Slag

source: TTP Squared, Inc, and Metal Bulletin
## Vanadium Production

### Vanadium Production by Country (metric tons V)

<table>
<thead>
<tr>
<th>Country</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018e</th>
<th>% of Total 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>40,234</td>
<td>39,630</td>
<td>49,706</td>
<td>53,013</td>
<td>48,562</td>
<td>45,718</td>
<td>47,258</td>
<td>53,635</td>
<td>59%</td>
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<tr>
<td>Russia</td>
<td>7,725</td>
<td>7,900</td>
<td>8,300</td>
<td>7,807</td>
<td>8,400</td>
<td>7,975</td>
<td>8,300</td>
<td>8,300</td>
<td>9% 22%</td>
</tr>
<tr>
<td>South Africa</td>
<td>13,324</td>
<td>13,143</td>
<td>11,971</td>
<td>11,070</td>
<td>10,101</td>
<td>7,954</td>
<td>7,854</td>
<td>8,205</td>
<td>9% 22%</td>
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<tr>
<td>North America</td>
<td>4,163</td>
<td>3,990</td>
<td>4,861</td>
<td>5,763</td>
<td>5,526</td>
<td>3,400</td>
<td>3,000</td>
<td>3,000</td>
<td>3% 8%</td>
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<tr>
<td>Europe</td>
<td>6,650</td>
<td>5,700</td>
<td>6,350</td>
<td>7,000</td>
<td>6,950</td>
<td>8,452</td>
<td>7,785</td>
<td>9,675</td>
<td>11% 25%</td>
</tr>
<tr>
<td>Japan</td>
<td>1,000</td>
<td>1,000</td>
<td>1,250</td>
<td>1,500</td>
<td>1,750</td>
<td>1,750</td>
<td>1,950</td>
<td>1,950</td>
<td>2% 5%</td>
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<tr>
<td>Korea</td>
<td>1,200</td>
<td>1,200</td>
<td>1,200</td>
<td>1,200</td>
<td>700</td>
<td>250</td>
<td>250</td>
<td>450</td>
<td>0% 1%</td>
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<tr>
<td>Taiwan</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>400</td>
<td>400</td>
<td>400</td>
<td>300</td>
<td>0% 1%</td>
</tr>
<tr>
<td>India</td>
<td>700</td>
<td>700</td>
<td>700</td>
<td>700</td>
<td>700</td>
<td>700</td>
<td>700</td>
<td>700</td>
<td>1% 2%</td>
</tr>
<tr>
<td>Australia</td>
<td>-</td>
<td>58</td>
<td>400</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0% 0%</td>
</tr>
<tr>
<td>Brazil</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>500</td>
<td>3,250</td>
<td>4,462</td>
<td>5,433</td>
<td>5,433</td>
<td>6% 14%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>75,296</td>
<td>73,621</td>
<td>85,038</td>
<td>88,953</td>
<td>86,339</td>
<td>81,061</td>
<td>82,929</td>
<td>91,647</td>
<td>100% 100%</td>
</tr>
<tr>
<td><strong>ex China</strong></td>
<td>35,062</td>
<td>33,991</td>
<td>35,332</td>
<td>35,940</td>
<td>37,777</td>
<td>35,343</td>
<td>35,672</td>
<td>38,013</td>
<td>41% 100%</td>
</tr>
</tbody>
</table>
Vanadium Consumption
Vanadium Consumption By Region 2017

- Europe: 18%
- North America: 12%
- Japan: 7%
- China: 9%
- CIS: 6%
- India: 4%
- Other: 44%

source: TTP Squared,
Vanadium Consumption

History

source: TTP Squared, Inc.
Vanadium Consumption

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td>Europe</td>
<td>16,310</td>
<td>16,213</td>
<td>16,100</td>
<td>16,461</td>
<td>14,988</td>
<td>15,084</td>
<td>15,145</td>
<td>15,448</td>
<td>17%</td>
<td>32%</td>
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<tr>
<td>North America</td>
<td>10,360</td>
<td>10,853</td>
<td>10,815</td>
<td>11,480</td>
<td>10,429</td>
<td>10,573</td>
<td>10,635</td>
<td>10,848</td>
<td>12%</td>
<td>22%</td>
</tr>
<tr>
<td>Japan</td>
<td>6,000</td>
<td>6,100</td>
<td>6,415</td>
<td>6,549</td>
<td>5,352</td>
<td>5,297</td>
<td>5,439</td>
<td>5,548</td>
<td>6%</td>
<td>11%</td>
</tr>
<tr>
<td>China</td>
<td>25,391</td>
<td>28,578</td>
<td>36,248</td>
<td>44,894</td>
<td>43,865</td>
<td>35,685</td>
<td>37,962</td>
<td>42,981</td>
<td>47%</td>
<td></td>
</tr>
<tr>
<td>CIS</td>
<td>6,370</td>
<td>6,374</td>
<td>6,310</td>
<td>6,308</td>
<td>5,436</td>
<td>5,446</td>
<td>5,546</td>
<td>5,657</td>
<td>6%</td>
<td>12%</td>
</tr>
<tr>
<td>India</td>
<td>1,900</td>
<td>2,221</td>
<td>2,586</td>
<td>3,031</td>
<td>3,138</td>
<td>3,249</td>
<td>3,411</td>
<td>3,479</td>
<td>4%</td>
<td>7%</td>
</tr>
<tr>
<td>Other</td>
<td>9,481</td>
<td>9,198</td>
<td>8,131</td>
<td>8,011</td>
<td>7,448</td>
<td>6,965</td>
<td>7,679</td>
<td>7,833</td>
<td>9%</td>
<td>16%</td>
</tr>
<tr>
<td>Total</td>
<td>75,812</td>
<td>79,536</td>
<td>86,605</td>
<td>96,735</td>
<td>90,655</td>
<td>82,299</td>
<td>85,818</td>
<td>91,794</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>ex China</td>
<td>50,421</td>
<td>50,958</td>
<td>50,357</td>
<td>51,841</td>
<td>46,790</td>
<td>46,614</td>
<td>47,856</td>
<td>48,813</td>
<td>53%</td>
<td>100%</td>
</tr>
</tbody>
</table>
Vanadium Consumption
Chinese Rebar

Assumption:
• Total hot-rolled rebar production: ~200 million tons
• % of HS rebar: 80%, ~160 million tons
• HS Rebar Structure: 60% Gr.3 + 20% Gr.4
• Average V content:
  0.03%V in Gr.3 rebar
  0.06%V in Gr.4 rebar
  0.10%V in Gr.5 rebar

Source: China Iron & Steel Research Institute (CISRI)
Vanadium Consumption
Demand Drivers

Given the fact that roughly 90% of vanadium consumption today occurs in the steel industry, we can focus on two variables that will be the key drivers to changes in vanadium consumption in the coming years:

• Changes in global steel production rates

• Changes in specific vanadium consumption rates – Kg vanadium consumed per MT steel produced
Vanadium Consumption
vs. Steel Production
Vanadium Consumption
Forecast Assumptions

• Surge in new demand 2018-2020 as a result of the revised rebar standard in China

• Specific vanadium consumption growth rate equal to historical levels (1.9% CAGR) post 2020

• Modest growth in global steel production – CAGR 2.5%
Vanadium Consumption
History and Forecast

source: TTP Squared, Inc.
Growth in Vanadium Consumption in the past has been primarily driven by growth in global steel production volumes. Looking forward the majority of growth in vanadium consumption will be driven by increasing specific vanadium consumption rates rather than by growth from steel production as the world steel industry continues to mature and growth rates decrease while product quality increases.
Vanadium Inventory
Vanadium Inventory
Production and Consumption History

2003-2017 CAGR
Production 4.5%
Consumption 5.0%

source: TTP Squared, Inc.
Vanadium Inventory
Annual Change (Metric Tons Vanadium)
Vanadium Inventory
Cumulative Change (Metric Tons Vanadium)

source: TTP Squared, Inc.
Forecast Assumptions

• Restart of all idle capacity on a global basis by 2021
  • Windimurra – Western Australia
  • Vanchem – South Africa
  • Stone Coal mines – China

• Significant Expansions at existing primary vanadium mines
  • Largo Resources - Brazil
  • Glencore Rhovan – South Africa
  • Bushveld Minerals – South Africa

• Increase in recovery of vanadium from secondary sources
• No new primary sources of vanadium
Vanadium Supply and Demand

Existing Capacity includes restart of currently idle capacity at Windimurra and Vanchem
Vanadium Summary

- Historically high prices in 2005 combined with exploding steel production in China from 2004-2010 lead to massive increases in vanadium supply, primarily from Chinese steel mills utilizing vanadium bearing ores.
- Historically weak vanadium prices in 2014-2016 lead to significant reduction in supply with some past sources being liquidated and thus unable to restart under any condition.
- Excess inventories built from 2005-2010 kept downward pressure on the market even after the major closures of 2014-2015.
- Today it appears excess inventory is depleted and the supply base will struggle to meet demand in the next few years.
- Clearly there is a need for new sources of vanadium to meet the growing market demand, particularly from 2022 onward.
- This analysis does not assume any increase in vanadium consumption from energy storage applications (batteries) which may be erroneous.
Metal Bulletin V2O5 Monthly Midpoint Average Price
Sept. 2003- August 2018
Inflated to November 2017 US$
China V2O5 Monthly Price

Source: ferroalloynet.com
Molybdenum
Molybdenum Production by Source

<table>
<thead>
<tr>
<th>Year</th>
<th>Primary Production</th>
<th>Coproduct/Byproduct</th>
</tr>
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<tbody>
<tr>
<td>2010</td>
<td>264.6</td>
<td>233.1</td>
</tr>
<tr>
<td>2011</td>
<td>272</td>
<td>266.1</td>
</tr>
<tr>
<td>2012</td>
<td>299.7</td>
<td>249.4</td>
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<tr>
<td>2013</td>
<td>308.5</td>
<td>249.4</td>
</tr>
<tr>
<td>2014</td>
<td>310</td>
<td>280</td>
</tr>
<tr>
<td>2015</td>
<td>257</td>
<td>272.3</td>
</tr>
<tr>
<td>2016</td>
<td>231.3</td>
<td>284.5</td>
</tr>
<tr>
<td>2017</td>
<td>259.8</td>
<td>322.5</td>
</tr>
</tbody>
</table>
Mo Production by Region

- China
- South America
- North America
- Mongolia
- CIS

Years: 2011-2017

Production in Million lbs. Mo:
- 2011: ~150
- 2012: ~150
- 2013: ~150
- 2014: ~150
- 2015: ~150
- 2016: ~150
- 2017: ~150

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TTP Squared, Inc.
Molybdenum Consumption
Mo Consumption 2017
Including Scrap

Total 751 million lbs. Mo
Scrap represent 26% of total Mo consumption

Engineering steel: 222 million lbs.
Stainless Steel: 126 million lbs.
Tool Steels: 44 million lbs.
Chemicals: 73 million lbs.
Foundries: 46 million lbs.
Nickle Alloys: 20 million lbs.
Mo Metal: 31 million lbs.
Titanium Alloys: 2 million lbs.

First Use
Scrap

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Molybdenum First Use by Application
2017

558 million pounds Mo

- Engineering steel: 40%
- Stainless Steel: 23%
- Tool Steels: 13%
- Chemicals: 8%
- Molybdenum metal: 8%
- Nioble Alloys: 6%
- Foundries: 2%
- Titanium Alloys: 0%
- Other: 0%
Mo Consumption by Region

First Use

Million Pounds Mo


China Europe Other USA Japan CIS

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Molybdenum Inventory
Mo Production and Consumption

Production
First Use Consumption

Million lbs. Mo


International Titanium Association North American Meeting
Oct. 10, 2018 Las Vegas
TTP Squared, Inc.
Molybdenum Summary

• Global market was in severe over-supply following demand collapse in 2015.
• 2015 saw large demand and supply falls, but still a surplus market.
• 2016 and 2017 a tighter market following 2015/16 supply cuts then strong demand recovery in 2017.
• First half-2018 very strong demand
• Oil and gas investment collapse in 2015/16 –now recovery
• Following consumption decline in 2015/16, strong bounce-back in 2017/18 followed by reversion to trend or even weaker in 2019/20?
• China potential to surprise on upside given its low per capita use in 316 stainless (there was surprising stainless strength in 2017, especially in 300 series)
• Large supply shortfalls projected in 2018/19, which will have to be met by destocking.
Master Alloys

• Master Alloys in the titanium industry are binary, ternary or multi-component alloys used to efficiently and effectively allow the melting of titanium alloys.

• Vanadium and molybdenum master alloys account for approximately 90% of the total annual demand volume

• More than 40 master alloys are regularly used by the titanium industry including master alloys of Co, Cu, Cr, Nb, Ni, Si, Sn and Zr
Master Alloys

• Quality is an absolutely critical attribute for master alloys given their use in critical applications.
• A critical and highly variable cost component in master alloy production is the market price of raw materials – primarily V and Mo.
• Assurance of supply of the broad range of master alloys necessary is an important issue.
• The ability of the master alloy supplier to design solutions for titanium alloy producers is a critical value added factor in the relationship.
Master Alloys

• Master Alloy producers can create value for the titanium alloy producers by bringing several capabilities to the table:

  • All necessary quality certifications
  
  • Upstream supply of V and Mo to provide competitive prices and minimize market risk
  
  • The experience and ability to bring metallurgical solutions to the table to improve existing alloy production methods and develop alloy systems for new titanium alloys.
BHN Special Materials Ltd.
Where are we? – HYK, Huayuankou Economic Zone, Dalian, Liaoning Province, PR China
### How well we do it: Management

<table>
<thead>
<tr>
<th>Certification</th>
<th>since</th>
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<tr>
<td>EN 9100:2009</td>
<td>Oct. 2010</td>
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<tr>
<td>Aerospace Quality Management System</td>
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<tr>
<td>ISO 9001:2008</td>
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<td>Quality Management System</td>
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Comparison of Melting Temperatures and Densities

VAR, standard raw material input for Ti 10-2-3, Ti-10V-2Fe-3Al:

<table>
<thead>
<tr>
<th>Material</th>
<th>Raw material input ratio (wt%)</th>
<th>Melting temperature (°C)</th>
<th>Density (kg / dm³)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAL 85:15</td>
<td>12.47</td>
<td>1,890</td>
<td>5.14</td>
<td>standard raw material input</td>
</tr>
<tr>
<td>Titanium metal</td>
<td>85.26</td>
<td>1,668</td>
<td>4.51</td>
<td>standard raw material input</td>
</tr>
<tr>
<td>Iron metal</td>
<td>1.81</td>
<td>1,538</td>
<td>7.87</td>
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<td>Aluminum metal</td>
<td>0.79</td>
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<td>2.70</td>
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<table>
<thead>
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<th></th>
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<tbody>
<tr>
<td></td>
<td>1,890</td>
<td>7.87</td>
<td></td>
</tr>
<tr>
<td>weight average</td>
<td>1,685</td>
<td>4.63</td>
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<tr>
<td>min</td>
<td>660</td>
<td>2.70</td>
<td></td>
</tr>
<tr>
<td>STDEV</td>
<td>539</td>
<td>2.14</td>
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<tr>
<td>Δ min-max</td>
<td>1,230</td>
<td>5.17</td>
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</tbody>
</table>
## Comparison of Melting Temperatures and Densities

**VAR, sophisticated raw material input for Ti 10-2-3, Ti-10V-2Fe-3Al:**

<table>
<thead>
<tr>
<th>Material</th>
<th>Raw material input ratio (wt%)</th>
<th>Melting temperature (°C)</th>
<th>Density (kg / dm³)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAlFe 69:19:12</td>
<td>15.00</td>
<td>1,730</td>
<td>5.03</td>
<td>sophisticated raw material input</td>
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<tr>
<td>Titanium metal</td>
<td>85.26</td>
<td>1,668</td>
<td>4.51</td>
<td>standard raw material input</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>max</th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>VAlFe 69:19:12</td>
<td>1,730</td>
<td>5.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight average</td>
<td>1,677</td>
<td>4.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>1,668</td>
<td>4.51</td>
<td></td>
<td></td>
</tr>
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</table>

<table>
<thead>
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<td>44</td>
<td>0.37</td>
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</table>

<table>
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<tr>
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<th>Δ min-max</th>
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<th></th>
</tr>
</thead>
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<tr>
<td></td>
<td>62</td>
<td>0.52</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Advantages of VAlFe 69:19:12

✓ The standard recipe for Ti 10-2-3 has a delta in melting temperature of $1,230^\circ\text{C}$ and a delta in density of $5.17 \text{ kg} / \text{dm}^3$ for the raw material input

✓ The characteristics of VAlFe 69:19:12 is closer to denominator Titanium metal by temperature, density and morphology

✓ The parameters of BHN’s ternary master alloy improve:

  ▪ the handling of the pressed electrode [ for VAR consolidation melt ]
  ▪ the melting and dissolution activity of alloying components in the Titanium matrix
  ▪ homogeneity of the 1st VAR ingot [ consolidation melt ], minimize VAR defects, and may even result in saving 1 VAR melting step for industrial application
The perfect Master Alloy for Titanium Alloys

- pseudo binary alloy, *theoretical* approach: Ti-V, Ti-Mo, Ti-Nb, Ti-etc.
  * highly flexible but expensive
    - in volume utilizing the same or similar, expensive equipment, e.g. VAR, VIM, EB
  * technically tough to make
    - in quality [homogeneity, contamination-free and size]

- binary alloy, *pragmatic* approach: Al-V, Al-Mo, Al-Nb, Al-etc.
  * but not all oxides can be reduced by ATR – see Mr. Ellingham
  * but not all compositions can satisfy every defined final Ti-Al alloy

- BHN master alloys, *the solution*
  * just kindly provide your RFQ and BHN will advise the best option
Thanks!