Vanadium Supply Chain

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Vienna
June 15-16, 2010

Terry Perles
TTP Squared, Inc.
Outline

• Sources of vanadium
• Vanadium supply
• Vanadium Demand
• Vanadium production technology
• Vanadium electrolyte for V flow battery
• Economics of Vanadium Production
• Vanadium market supply/demand dynamics
• Summary
Vanadium Price History

V2O5 Market Price History
(London Metal Bulletin monthly midpoint averages)
Vanadium Sources

(source Vanitec)
2010 Vanadium Production by Source

- Slag: 56%
- V ores: 30%
- Secondary: 14%
2010 Vanadium Production by Country

- **China**: 48%
- **South Africa**: 25%
- **Russia**: 11%
- **USA**: 8%
- **Europe**: 5%
- **Japan**: 2%
- **Taiwan**: 1%
- **India**: 0%
2010 Vanadium Demand by Application

- Steel: 92%
- Titanium: 4%
- Chemicals: 4%
Vanadium Production Technology
Flowsheet for vanadium pentoxide production by Highveld Steel and Vanchem

- **Mapochs ore fines**
  - Milling
  - Roasting
    - Leaching
      - Polyvanadate precipitation
        - Deammoniation
          - Vanadium pentoxide powder
          - Vanadium pentoxide fused flake
Vanadium Production Process

Source: Stratcor, Inc.

**Diverse Feeds**
- Ores
- Residues
- Ashes
- Spent Catalysts
- Slags

**Grinding**
- Forming a water-soluble compound

**Leaching**
- Removing unwanted solids

**Decantation**
- Separating vanadium from other metallic impurities, yielding high-purity vanadium liquors

**Ion Exchange & Solvent Extraction**
- Driving off low melting-point contaminants and converting crystals to various high-purity vanadium oxides

**Calcination**
- Growing large ammonium-metavanadate crystals that minimize surface impurities and crystal inclusions

**Vanadium Oxides**
- For chemical customers and further processing

**Ammonium Metavanadate**
- For chemical customers and further processing

**Drying**
- Driving off moisture in ammonium-metavanadate crystals
Fused Flake V2O5 Specification

Source: Vanchem

V2O5% 98.5 min
Si% 0.20 min
Na2O 0.80 max
P% 0.05 max
S% 0.05 max
Fe% 0.55 max
Cr% 0.30 max

Packing: 250 kg steel drums on a pallet of 1'000 kg
# High Purity V2O5 Specification

**Source:** Stratcor, Inc.

## Chemical Properties

### Primary Elements, %

<table>
<thead>
<tr>
<th>Element</th>
<th>MIN.</th>
<th>MAX.</th>
</tr>
</thead>
<tbody>
<tr>
<td>VANADIUM (As V₂O₅) *</td>
<td>99.6</td>
<td></td>
</tr>
<tr>
<td>V₂O₄</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>IRON (Fe)</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>MOLYBDENUM (Mo)</td>
<td>0.025</td>
<td></td>
</tr>
<tr>
<td>POTASSIUM (K)</td>
<td>**0.01</td>
<td></td>
</tr>
<tr>
<td>SILICON (Si)</td>
<td>***0.005</td>
<td></td>
</tr>
<tr>
<td>SODIUM (Na)</td>
<td>**0.01</td>
<td></td>
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</tbody>
</table>

### Residual Elements, %

<table>
<thead>
<tr>
<th>Element</th>
<th>TYP.</th>
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</thead>
<tbody>
<tr>
<td>Aluminum (Al)</td>
<td>&lt;0.015</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>&lt;0.015</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Phosphorous (P)</td>
<td>&lt;0.015</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>&lt;0.02</td>
</tr>
</tbody>
</table>

## Physical Characteristics

### Sizing

**Nominal Size:**

US No. 20 X D (850μm x D)

### Physical Properties

- **Melting Range:** 1274 °F (690 °C)
- **Bulk Density:** 75 - 80 #/ft³ (1.2 - 1.28 g/cc)
- **Specific Gravity:** 3.36

### Appearance

Yellow/Orange Granules

### Typical Packaging

400 lbs. Net Weight in a 55-gallon drum. Drum is double lined with polyethylene liners.

## Notes:

- * V, wt% equal to or greater than 55.8%
- ** (K₂O + Na₂O) less than or equal to 0.025%
- *** SiO₂ less than or equal to 0.011%
# Vanadyl Sulphate Specifications

Source: Stratcor

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
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<tbody>
<tr>
<td>Vanadium</td>
<td>9%</td>
<td>11%</td>
</tr>
<tr>
<td>Iron</td>
<td>0.005%</td>
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<tr>
<td>Sodium</td>
<td>0.003%</td>
<td></td>
</tr>
<tr>
<td>Potassium</td>
<td>0.002%</td>
<td></td>
</tr>
<tr>
<td>Specific gravity</td>
<td>1.36 gm/cc</td>
<td>1.47 gm/cc</td>
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<tr>
<td>Bulk density</td>
<td>11.3 lb./gal</td>
<td>12.3 lb./gal</td>
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<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
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<tbody>
<tr>
<td>Vanadium</td>
<td>17%</td>
<td>23%</td>
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<tr>
<td>Iron</td>
<td>0.010%</td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td>0.006%</td>
<td></td>
</tr>
<tr>
<td>Potassium</td>
<td>0.004%</td>
<td></td>
</tr>
<tr>
<td>Specific gravity</td>
<td>3.0 gm/cc</td>
<td></td>
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<tr>
<td>Bulk density</td>
<td>60 lb./ft³</td>
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</table>
Economics of Vanadium Production
Vanadium Pentoxide Industry Cost Curve
LMB = $6.50

Variable Cost (US$/pound V2O5)

Primary V Ore

Secondary

V Bearing Slag from Steelmaking

MT V2O5

1,000, 5,000, 9,000, 13,000, 17,000, 21,000, 25,000, 29,000, 33,000, 37,000, 41,000, 45,000, 49,000, 53,000, 57,000, 61,000, 65,000, 69,000, 73,000, 77,000, 81,000, 85,000, 89,000, 93,000, 97,000, 101,000, 105,000, 109,000, 113,000, 117,000, 121,000, 125,000, 129,000, 133,000
Vanadium Supply/Demand Dynamics
Vanadium Production vs. Consumption

Global 12-Month Moving Average Annual Rates

Vanadium Production

Vanadium Consumption

Source: Stratego Minerals Corporation

Rational Vanadium Price 2010-2015

• Low - US$5.00/pound V2O5 based on cash cost of production
• High – US$9.00/pound V2O5 based on value to major end users
## Primary Vanadium Projects

*Source – Mining Journal Feb. 19, 2010*

<table>
<thead>
<tr>
<th>Company</th>
<th>Project</th>
<th>Location</th>
<th>Capacity (MTV2O5/yr)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral Resources Ltd./Atlantic Ltd.</td>
<td>Windamurra</td>
<td>Australia</td>
<td>10,000</td>
<td>Construction on hold</td>
</tr>
<tr>
<td>Largo Resources</td>
<td>Maracas</td>
<td>Brazil</td>
<td>8,000</td>
<td>Feasibility study completed, sourcing finance</td>
</tr>
<tr>
<td>Aurox Resources</td>
<td>Balla Balla</td>
<td>Australia</td>
<td>10,000</td>
<td>Feasibility study completed</td>
</tr>
<tr>
<td>Reed Resources</td>
<td>Barrambie</td>
<td>Australia</td>
<td>11,000</td>
<td>Feasibility study completed</td>
</tr>
<tr>
<td>Sino Vanadium</td>
<td>Daquan</td>
<td>China</td>
<td>16,000</td>
<td>Preliminary economic assessment completed</td>
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<tr>
<td>Adriana Resources</td>
<td>Mustavaara</td>
<td>Finland</td>
<td>N/A</td>
<td>Early stage</td>
</tr>
<tr>
<td>Apella Resources</td>
<td>Lac Dore</td>
<td>Canada</td>
<td>N/A</td>
<td>Early stage</td>
</tr>
<tr>
<td>Baobab Resources</td>
<td>Tete</td>
<td>Mozambique</td>
<td>N/A</td>
<td>Early stage</td>
</tr>
<tr>
<td>Energizer Resources</td>
<td>Green Giant</td>
<td>Madagascar</td>
<td>N/A</td>
<td>Early stage</td>
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<tr>
<td>TNG Ltd.</td>
<td>Mount Peake</td>
<td>Australia</td>
<td>N/A</td>
<td>Early stage</td>
</tr>
<tr>
<td>Yellow Rock Resources</td>
<td>Gabanintha</td>
<td>Australia</td>
<td>N/A</td>
<td>Early stage</td>
</tr>
</tbody>
</table>
VANADIUM USAGE PER MT OF STEEL

North America

Western Europe

FSU / CIS

China

Kg V PER MT OF STEEL

0.09

0.08

0.07

0.06

0.05

0.04

0.03

0.02

0.01

0

177.4 Million Lbs. V2O5
Summary

- There are abundant vanadium resources available globally.
- The vast majority of vanadium production capacity is designed to supply the steel industry with low cost vanadium units.
- The VRB system requires high purity vanadium compounds which can be produced by a smaller number of suppliers due to quality issues.
- Vanadium market fundamentals suggest a near term rational price of US$5.00/pound V2O5 to US$9.00/pound V2O5.
- Longer term prices could fall below US$5.00/pound V2O5 depending upon the balance between global demand and supply from V slag and primary ore mining.