Trends in Supply of Feedstocks for the Kroll Process

David Moore & David McCoy
Presentations outline

- Global role of titanium minerals
- Titanium minerals in 2006
- Focus on sponge feedstocks
- Quality issues
- The emerging role of China
- Future outlook
Global role of titanium minerals

- 9th most abundant element
- 0.63% of earth’s crust
- 95% TiO₂ rutile highest quality but less abundant
- Dominated by ilmenite with its strong iron bond
- Major economic resources from sedimentary deposits on current and former coastlines
- Unweathered rock ilmenites less desirable
Titanium minerals schematic flowsheet

1. **Mining**
   - Overburden

2. **Mineral Processing**
   - Heavy mineral concentration
     - Gangue minerals

3. **Mineral Separation**
   - Ilmenite

4. **Beneficiation**
   - Rutile
   - Slag or synthetic rutile
   - Zircon
2006 titanium minerals: supply by product

- Sulfate grade ilmenite: 16%
- Chloride ilmenite/leucoxene: 5%
- Sulfate grade slag: 11%
- Chloride fines: 31%
- Chloride grade slag: 13%
- Upgraded slag: 3%
- Synthetic rutile: 13%
- Natural rutile: 8%
2006 titanium minerals: supply by country

- Australia: 21%
- Canada: 6%
- India: 20%
- Malaysia: 7%
- Norway: 6%
- South Africa: 1%
- US: 14%
- Other: 25%
2006 titanium minerals: end use demand

(expresssed in million TiO$_2$ units)

5.505   pigment
0.257   sponge
0.174   other markets
5.845   OVERALL

5.6% growth over 2005
Feedstocks for sponge production

- High TiO$_2$ materials – basically rutile, upgraded slag and synthetic rutile - for direct chlorination to produce TiCl$_4$ : in Japan, US & China
- Ilmenites for conversion to slag and then TiCl$_4$ by the molten salt process : in Russia, Kazakhstan, Ukraine & China
Schematic feedstock flowsheets

CIS & China
60% TiO₂ ilmenite
Pig iron → Smelter
80% TiO₂ slag
Reductant → Salt chlorination
TiCl₄
Mg reduction
Ti sponge

US & Japan
95% TiO₂ rutile, UGS or SR
Fluid bed chlorination
Reductant
TiCl₄
TiO₂ pigment production
Merchant TiCl₄

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US & Japan
95% TiO₂ rutile, UGS or SR
Fluid bed chlorination
Reductant
TiCl₄
TiO₂ pigment production
Merchant TiCl₄

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TiCl₄
TiO₂ pigment production
Merchant TiCl₄

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### Overview of sponge production

<table>
<thead>
<tr>
<th>Country</th>
<th>2004 ('000 tonnes)</th>
<th>2006 ('000 tonnes)</th>
<th>2008f ('000 tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>23.1</td>
<td>37.8</td>
<td>39.5</td>
</tr>
<tr>
<td>Russia</td>
<td>26.0</td>
<td>32.0</td>
<td>36.0</td>
</tr>
<tr>
<td>China</td>
<td>4.8</td>
<td>18.5</td>
<td>42.0</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>16.5</td>
<td>23.0</td>
<td>25.0</td>
</tr>
<tr>
<td>US</td>
<td>7.9</td>
<td>9.7</td>
<td>21.2</td>
</tr>
<tr>
<td>Ukraine</td>
<td>7.5</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>85.8</strong></td>
<td><strong>131.0</strong></td>
<td><strong>173.7</strong></td>
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</tbody>
</table>
## Overview of feedstock requirements

<table>
<thead>
<tr>
<th>('000 TiO₂ units)</th>
<th>2004</th>
<th>2006</th>
<th>2008f</th>
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</thead>
<tbody>
<tr>
<td>Rutile</td>
<td>22</td>
<td>37</td>
<td>47</td>
</tr>
<tr>
<td>UGS</td>
<td>4</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Synthetic rutile</td>
<td>33</td>
<td>42</td>
<td>42</td>
</tr>
<tr>
<td>Subtotal</td>
<td>59</td>
<td>97</td>
<td>107</td>
</tr>
<tr>
<td>Ilmenite</td>
<td>111</td>
<td>160</td>
<td>229</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>170</strong></td>
<td><strong>257</strong></td>
<td><strong>336</strong></td>
</tr>
</tbody>
</table>
Sponge feedstock quality requirements

Feedstocks for fluid-bed chlorination
1. High TiO₂ content
2. Low CaO and MgO levels
3. Low U + Th levels
4. Particle size >100 microns

Feedstocks for molten salt chlorination
1. Ilmenite with high TiO₂ content, preferably >65%
2. Wide tolerance for impurities
Historical FOB price trends: 1980-2006

High TiO₂ feedstocks

Index

0 50 100 150 200 250 300 350

80 82 84 86 88 90 92 94 96 98 00 02 04 06

Rutile
Chloride slag
Synthetic rutile
Sulfate slag
UGS
Historical FOB price trends: 1980-2006

Ilmenites

Index

0 100 200 300 400 500

80 82 84 86 88 90 92 94 96 98 00 02 04 06

Sulfate

Chloride (60% TiO2)
Future outlook

- Feedstock oversupply for some years
- No significant changes in real prices
- Similar trend for raw pigment
Titanium in China

Chengdu

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The emerging role of China

- Data uncertainty
- Which processes will be used?
- Quality issues
- Access to improved technology?
- Potential role equal to US by 2015?
Future outlook

- Kroll process will remain the major source of new Ti units as sponge for a significant time.
- Feedstock requirements would increase by over 90% from 2006 levels to meet potential 250,000 tonnes sponge production in 2015.
- The major uncertainty relates to China production demand and quality.
- Many of the potential new processes being studied would require new types of feedstocks.
Conclusions

- Continuing supply of quality rutile and ilmenite is required for the Kroll process
- Feedstock supply sources will not be a constraint to future production levels
- Reduction in cost of titanium metal products will to be driven by processing improvements and not rely on lower feedstock costs
TZMI & its strategic partners

The ChemQuest Group

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Helping the global titanium and zirconium industries to achieve maximum value from resources