Oakdene Hollins

Study of By-Products of Copper, Lead, Zinc and Nickel

- Peter Willis, Senior Economist
- 2nd October 2013
Agenda

• What are the by-product metals?
• Why are they considered critical?
• Recap of by-products project:
  • Production estimates
  • Economic impact
  • End-uses, REACH
• Further work: Selenium
• General conclusions
• Questions & answers
What are the by-product metals?

Source: Reuter et al. (2005)
What are the by-product metals?

<table>
<thead>
<tr>
<th>Copper:</th>
<th>Nickel:</th>
<th>Lead and Zinc:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>Copper</td>
<td>Silver</td>
</tr>
<tr>
<td>Silver</td>
<td>Cobalt</td>
<td>Gold</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Platinum group</td>
<td>Tin</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>Gold</td>
<td>Bismuth</td>
</tr>
<tr>
<td>Nickel</td>
<td>Silver</td>
<td>Indium</td>
</tr>
<tr>
<td>Zinc</td>
<td>Selenium</td>
<td>Germanium</td>
</tr>
<tr>
<td>Platinum group</td>
<td>Tellurium</td>
<td>Selenium</td>
</tr>
<tr>
<td>Rhenium</td>
<td>Scandium</td>
<td>Tellurium</td>
</tr>
<tr>
<td>Selenium</td>
<td></td>
<td>Arsenic</td>
</tr>
<tr>
<td>Tellurium</td>
<td></td>
<td>Cadmium</td>
</tr>
<tr>
<td>Bismuth</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Those in red can be worth >10% of overall revenue!
World Non-Ferrous Metal Production (tonnes)

- Aluminium: 34%
- Chromium: 21%
- Copper: 15%
- Zinc: 10%
- Lead: 4%
- Nickel: 1%
- Manganese: 9%
- Boron: 4%
- Other Metals: 2%
- Other Metals: 2%

Source: Resnick Institute (2011)
Policy Context – Critical Raw Materials

Studies in EU, US, Japan, China, Korea, Russia, UNEP, Major Corporates etc.

Sources: KITECH, General Electric, EU RMI, US Dept. of Energy
## Critical Metals for EU Decarbonisation

### EU demand for decarbonisation technologies, as % of projected supply 2020-30

<table>
<thead>
<tr>
<th>High</th>
<th>High-Medium</th>
<th>Medium</th>
<th>Medium-Low</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>REE: Dy, Eu, Tb, Y</td>
<td>Graphite</td>
<td>REE: La, Ce, Sm, Gd</td>
<td>Lithium</td>
<td>Nickel</td>
</tr>
<tr>
<td>REE: Pr, Nd</td>
<td>Rhenium</td>
<td>Cobalt</td>
<td>Molybdenum</td>
<td>Lead</td>
</tr>
<tr>
<td>Gallium</td>
<td>Hafnium</td>
<td>Tantalum</td>
<td>Selenium</td>
<td>Gold</td>
</tr>
<tr>
<td>Tellurium</td>
<td>Germanium</td>
<td>Niobium</td>
<td>Silver</td>
<td>Cadmium</td>
</tr>
<tr>
<td></td>
<td>Platinum</td>
<td>Vanadium</td>
<td></td>
<td>Copper</td>
</tr>
<tr>
<td></td>
<td>Indium</td>
<td>Tin</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chromium</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: EC JRC-IET (2013)
Recap of Joint Study Groups’ Project 2012

- Aim: to produce in depth information on production, use and trade of by-products

### Germanium Refined Production

<table>
<thead>
<tr>
<th>Company</th>
<th>Country</th>
<th>Production (tonnes pa)</th>
<th>Contact</th>
<th>Source/Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outokumpu Asset S</td>
<td>Finland</td>
<td>7</td>
<td>tel: +35 86 881 0111 fax: +35 8-818-1260 website: <a href="http://www.outokumpu.com/">www.outokumpu.com/</a></td>
<td>Zinc and lead by-product Production</td>
</tr>
<tr>
<td>Yunnan Chihong Zn &amp; Ge</td>
<td>China</td>
<td>18</td>
<td>tel: +86 874 896 9688 fax: +86 874 8666789 email: <a href="mailto:chz@chz.com">chz@chz.com</a> website: <a href="http://www.chz.com">www.chz.com</a></td>
<td>Zinc and lead ore by-product Capacity</td>
</tr>
</tbody>
</table>
## Worldwide Production Estimates, 2012

<table>
<thead>
<tr>
<th>Principal Metal</th>
<th>Mine Production (tonnes)</th>
<th>By-product Metal</th>
<th>Production (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lead</strong></td>
<td>4,500,000</td>
<td>Bismuth</td>
<td>8,500</td>
</tr>
<tr>
<td><strong>Zinc</strong></td>
<td>12,400,000</td>
<td>Germanium*</td>
<td>118</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indium*</td>
<td>640</td>
</tr>
<tr>
<td><strong>Nickel</strong></td>
<td>1,800,000</td>
<td>Cobalt</td>
<td>98,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Platinum Group Metals</td>
<td>472</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scandium*</td>
<td>10#</td>
</tr>
<tr>
<td><strong>Copper</strong></td>
<td>16,100,000</td>
<td>Cobalt</td>
<td>98,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Molybdenum</td>
<td>250,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rhenium</td>
<td>46#</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Selenium*</td>
<td>2,600#</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tellurium*</td>
<td>450#</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rare Earth Elements</td>
<td>130,000</td>
</tr>
</tbody>
</table>

* Refinery Production;  # Industry Estimates

Sources: USGS & Industry Estimates
Geographic Distribution of By-Products

Heat Map of Production of By-Product Metals Production, 2012 (%)

Canada:
- Germanium
- Indium

USA:
- Germanium
- Molybdenum
- Rhenium

Mexico:
- Bismuth

Peru:
- Bismuth
- Molybdenum

Chile:
- Molybdenum
- Rhenium

European Union:
- Rhenium
- Selenium
- Tellurium

Congo:
- Cobalt

South Africa:
- Palladium
- Rhodium

China:
- Bismuth
- Germanium
- Indium
- Molybdenum
- Selenium
- Tellurium
- Scandium

Korea:
- Indium

Russia:
- Palladium
- Scandium

Japan:
- Indium
- Selenium
- Tellurium

Source: Oakdene Hollins
EoL Recycling Rates for By-Product Metals

Source: UNEP
Economics: Lead and Zinc

Estimated revenues of Teck Trail Refinery, Canada, 2011

- Zinc, 38%
- Lead, 12%
- Silver, 46%
- Cadmium, 0.18%
- Germanium, 1.84%
- Indium, 2.70%
- Other, 4.7%

Source: By-products Report
Economics: Nickel and Copper

Estimated revenues of Norilsk Russian Operations, 2011

- Nickel: 43%
- Copper: 27%
- Palladium: 16%
- Platinum: 9%
- Gold: 1.5%
- Cobalt: 0.8%
- Rhodium: 1.2%
- Se: 0.1%
- Te: 0.01%
- Other: 3.7%
- Ru: 0.1%
- Ir: 0.1%

Source: By-products Report
By-products: More valuable but more volatile

Copper

Nickel

Zinc

Molybdenum

Cobalt

Selenium

Indium

Source: USGS, year averages, data in real $/tonne, indexed 1998
Major End-uses of By-Products, 2012 (%)

Indium
Tellurium
Germanium
Ruthenium
Molybdenum
Bismuth
Cobalt
Selenium
Rhodium
Palladium
Rhenium
Rare Earths
Scandium

Electronics
Materials
Transport
Chemicals
Other

Sources: Oakdene Hollins using various sources
## EU REACH Registrations for By-Products

Most by-products already or soon to be affected:

<table>
<thead>
<tr>
<th>Metal</th>
<th>World Production (tonnes)</th>
<th>No. Substances Registered</th>
<th>No. Substances Forthcoming</th>
<th>No. SVHCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molybdenum</td>
<td>250,000</td>
<td>15</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Rare Earths</td>
<td>130,000</td>
<td>8</td>
<td>25</td>
<td>-</td>
</tr>
<tr>
<td>Cobalt</td>
<td>98,000</td>
<td>27</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>Bismuth</td>
<td>8,500</td>
<td>5</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>Selenium</td>
<td>2,600</td>
<td>7</td>
<td>6</td>
<td>-</td>
</tr>
<tr>
<td>Indium</td>
<td>640</td>
<td>-</td>
<td>12</td>
<td>-</td>
</tr>
<tr>
<td>PGMs</td>
<td>472</td>
<td>1</td>
<td>68</td>
<td>-</td>
</tr>
<tr>
<td>Tellurium</td>
<td>450</td>
<td>3</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>Germanium</td>
<td>118</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Rhenium</td>
<td>46</td>
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<td>-</td>
</tr>
<tr>
<td>Scandium</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: By-products report
Example of Selenium

• By-product of copper, recoverable from slimes (concentration varies)
• Incomplete official data – industry estimates
• Diverse supply, but fewer high purity refiners
• Often not recovered
• China as main consumer: Electrolytic Mn production

Source: By-products report
STDA – Selenium Tellurium Development Association

• Survey of members:
Barriers to By-Product Recovery

- **All**
  - Not present in ore/concentrate: 50%
  - Outside core business: 40%
  - Technology not available: 10%
  - Extraction not economic: 0%
  - Processing techniques prohibit extraction: 0%

- **Lead/Zinc**
  - Not present in ore/concentrate: 20%
  - Outside core business: 30%
  - Technology not available: 10%
  - Extraction not economic: 5%
  - Processing techniques prohibit extraction: 5%

- **Nickel**
  - Not present in ore/concentrate: 0%
  - Outside core business: 0%
  - Technology not available: 0%
  - Extraction not economic: 0%
  - Processing techniques prohibit extraction: 0%

- **Copper**
  - Not present in ore/concentrate: 10%
  - Outside core business: 20%
  - Technology not available: 5%
  - Extraction not economic: 5%
  - Processing techniques prohibit extraction: 5%

Source: By-products report
General Conclusions

- Many are critical with strong market outlook e.g. In, Te, Re
- Economics of by-production:
  - Co, PGMs, Mo, REEs with (some) primary production
  - In, Ge, Bi, Sc, Re, Se, Te solely as by-products
- The availability of data is patchy for some metals:
  - Government, industry could collaborate to improve it (greater Study Group involvement?)
  - Better trade statistics could be recorded
- Considerable opportunities to increase the recovery of certain by-products or its efficiency:
  - Wastes can sometimes be sold for by-product recovery.
  - What about revisiting tailings/spoils?
Questions & Answers

Thank-you for listening!