Sustainable resource availability.

Ge, Ni, Al three contrasting stories

Eric PIRARD
GeMMe operates on the characterization, valorization, transformation, use and recycling of mineral materials at any stage of their life cycle.

- 3 research units – 40+ researchers
  - Building materials
  - Minerals engineering & recycling
  - Georesources & Geo-Imaging

2.5 M€ annual turnover
- 40% contracts with private partners
Future products will not only be optimized with regard to their functionality but also their recyclability and the sustainable availability of resources.
Resource Availability

A sudden awakening
Resource Availability

A sudden awakening

- < 1985
  - Compilation of Mineral/Metal Statistics
    - Market vs. Non-market driven economies
- 1985-2008
  - Complete disinterest
    - Minimum data through USGS Mineral Commodity Summaries
- > 2008
  - China declares REE export quota
    - EU Raw Materials Initiative (2009)
    - Critical Raw Materials for the EU (2010)
Resource Availability

• Supply Risk vs. Importance in Use
  - 14 metals list (2010 snapshot!)
Resource Availability

• Components of Supply Risk
  • Geological, Technological, Economic (Graedel et al., 2012)
    o 1. Spatial Component
      • Variable geological environments
        ✓ Bauxite distribution
    • Geopolitical strategies
      ✓ Not in My Continent
Resource Availability

Components of Supply Risk

2. Geological Component

- Average abundance in earth crust
- Existence of deposits

<table>
<thead>
<tr>
<th>Metal</th>
<th>Grade (ppm) earth crust</th>
<th>Concentration factor in ores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>78 000</td>
<td>3 x</td>
</tr>
<tr>
<td>Fe</td>
<td>36 000</td>
<td>7 x</td>
</tr>
<tr>
<td>Ti</td>
<td>4700</td>
<td>20 x</td>
</tr>
<tr>
<td>Cr</td>
<td>70</td>
<td>1000 x</td>
</tr>
<tr>
<td>Ni</td>
<td>44</td>
<td>100 x</td>
</tr>
<tr>
<td>Cu</td>
<td>30</td>
<td>100 x</td>
</tr>
<tr>
<td>Li</td>
<td>30</td>
<td>150 x</td>
</tr>
<tr>
<td>Sn</td>
<td>3</td>
<td>600 x</td>
</tr>
<tr>
<td>Ge</td>
<td>1,7</td>
<td>100 x</td>
</tr>
<tr>
<td>Au</td>
<td>0,002</td>
<td>1250 x</td>
</tr>
</tbody>
</table>

In Bauxite as Al(OH)$_3$

In Massive Sulphides as (Fe,Ni)$_9$S$_8$

In Laterites as (Mg,Fe,Ni)$_3$Si$_2$O$_5$(OH)$_4$

As by-product in Pb-Zn-Cu deposits
As by-product in coal seams...
Resource Availability

Components of Supply Risk

2. Geological Component

- Hypothetical Grade/Tonnage distribution (Bimodal or Lognormal?)

Gerst, 2008, Economic Geology Yale Center for Industrial Ecology
Resource Availability

Components of Supply Risk

3. Technological Component

- Innovation in mineral processing
  - New technologies make new resources available
  - Bioheapleaching in Talvivaara (FIN)
    1.3 Mt @ 0.23 % Ni; 0.02% Co; 0.13 % Cu; 0.5 % Zn

- Innovation in deep exploration (> 300m)
  - Potential increase in Ni sulphides deposits and expected higher Ge grades with depth
CF for Resource Availability

How to build them?

• Characterization Factors for LCA
  o # Metal price (Krautkraemer, 1998)
  o # Ore grade (Vieira et al., 2012; Swart et al., 2013)

  • Ore grade, metal price and extraction costs are intimately linked

(Vieira et al., 2012)
Sustainable
Resource Availability

A glimpse into circular economy
Sustainable Resource Availability
Towards a circular economy

EXTRACTION & CONCENTRATION
Fragmentation/Sorting

PRODUCTION
Materials/Design

GEO-RESOURCES
Exploration/Evaluation

ECO-RESOURCES
Collect/Storage

Urban Mines

Mines
Sustainable Resource Availability
Towards a circular economy

• Promote Best Mining Practices
  o Major mining operations meet strict guidelines
    ✓ Rehabilitation; Biodiversity; Tailings monitoring;...
    ✓ Social responsibility;...
  o Indicators to reflect environmental impact
    • NORILSK (RUS) 1,5% Ni
      ✓ Above Arctic Circle
      ✓ Underground – Grinding
      ✓ Pyrometallurgical process
      ✓ Ni sulphides (SO$_2$)
      ✓ Cu, Co, PGE as byproducts
Sustainable Resource Availability
Towards a circular economy

• Promote Best Mining Practices
  o Major mining operations
    • Meet strict guidelines
      ✓ Rehabilitation; Biodiversity; Tailings monitoring;...
      ✓ Social responsibility;...
  o Indicators to reflect environmental impact
    • TIEBAGHI (N CAL) 1.5% Ni
      ✓ Tropical Ecosystem (Coral Reefs)
      ✓ Surface Mining (Land Use)
      ✓ Ni silicates
      ✓ Pressure Acid Leaching
Sustainable Resource Availability
Towards a circular economy

- Promote Shorter Supply Circuits
- Promote by-production

  - Privileged source for Germanium
    - CHINA
      - Ge in coal seams
      - Leaching from power plant residual ashes
    - EUROPE
      - Ge from lignite or zinc deposits
      - Poorly documented resources
      - No incentives for extraction

Gunn, 2014
Sustainable Resource Availability
Towards a circular economy

- Help closing the Loop
  - Put enough material in the loop
    - ✓ 4000 t of Ge in cycle
  - Limit dispersive uses
    - ✓ Ge as a catalyst of PET
  - Collect end-of-life products
    - ✓ Collection of Ge doped optical fibers (14mg/km)
  - Build optimal urban mines
Sustainable Resource Availability
Towards a circular economy

- Building Mines for the Future
  - 1. Metal concentrations
    - Maintain grade above a technological cut-off
      - Often only precious metals (Au, PGM) pay for recycling
  - 2. Metal speciation
    - Metal, alloy, salt, organic compound,…
      - Wide variety of Ni, Al alloys
  - 3. Metal paragenesis
    - Unexpected metal assemblages,…, contamination
      - Copper coated aluminium wires
  - 4. Textural assemblage
    - Liberation and dismantling
      - Separate core from cladding and jacket in optical fibers
  - 5. Volume of mine
    - Make sure large enough quantities can be collected
  - 6. Homogeneity
    - Zonation, Blending
      - Technological evolution with time changes deposit
What is progress?

*Future products will not only be optimized with regard to their functionality but also their recyclability and the sustainable availability of resources*

<table>
<thead>
<tr>
<th>Luminous Source</th>
<th>Energy Efficiency (lm/W)</th>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescent</td>
<td>12-20</td>
<td>Tungsten, Glass,…</td>
</tr>
<tr>
<td>Halogène</td>
<td>18-25</td>
<td>Tungsten, Iodine, Bromine,… Glass,…</td>
</tr>
<tr>
<td>Fluocompact</td>
<td>60-80</td>
<td>Tungsten, Mercury, Rare Earths,… Glass, Plastics,…</td>
</tr>
<tr>
<td>LED</td>
<td>25-140</td>
<td>Gallium, Indium, Cerium, Yttrium, Copper, Silver, Silicium,… Plastics,…</td>
</tr>
</tbody>
</table>