Raw Materials in the Arctic
Challenges, Solutions and Business Opportunities

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Best Practices for Mining and Sustainable Development in the Arctic
Luleå, Sweden – October 13-14, 2016
Challenges that meet exploration/mining in the Arctic

Emerging markets (i.e. Greenland)
- No (or few) HEIs established with focus on RM
- Shortage of skilled labour
- Low population density, vast areas
- SLO and attractiveness of the sector to local communities questioned
- Immature legislation
- No or little infrastructure
- No established enterprises
- No established mining sector
- Indigenous peoples rights issues
- Competition for land mainly with Indigenous people

Mature markets (i.e. Nordic countries)
- HEIs established in the area with focus on RM
- Skilled labour exist, but remote locations
- Low population density, vast areas
- SLO and attractiveness of the sector to local communities increasingly questioned
- Legislation in place, but slow, unpredictable?
- Good infrastructure
- World leading industry in the sector
- Established mining sector
- Indigenous peoples rights issues
- Competition for land big issue
Arctic not only oil and gas:

- Many active mines
- Extremely under explored
- Climate changes also changes the logistics for extractive industry
From Boyd et al. (eds): Mineral resources in the Arctic
DEPOSITS REGISTERED
- STATUS 30.06.15

Circles -
(Grey): Ferrous metals (Cr, Fe, Mn, Ti, V)
(Blue): Base metals (Al, Co, Cu, Ni, Pb, Zn)
(Yellow): Gold, silver
(Red): Special metals (incl. Mo, Nb, REE, Sb, Sc, W)

Diamonds (orange): diamond deposits

Triangles (red): hydrothermal fields
(main source: InterRidge)

Deposit numbers (metal/diamond):
Alaska: 12/-
Canada: 38/6
Greenland: 13/-
Norway: 9/-
Sweden: 33/-
Finland: 23/1
Russia: 162/62 (including placers)

From Boyd 2015, Presentation FEM
Active vent
Extinct vent
Sulphide deposits
Hydrothermal plumes

Occurrences:
1) Grimsey,
2) Kolbeinsey,
3) quid Forest,
4) Seven Sisters
5) Soria Moria, Troll Wall, Perle & Bruse,
6) Copper Hill, Aegirs Kilde,
7) Mohns Treasure,
8) Loki’s Castle,
9) hydrothermal plume,
10) sulphide deposit,
11) sulphide deposit and hot waters,
12) hydrothermal plume
13) hydrothermal plumes

(From Boyd et al. (eds): Mineral resources in the Arctic; modified from Pedersen et al., 2010 b)
So why should we explore and extract in the Arctic?

- In general 2-3% increase in global consumption of metals per year
- Decrease in “world class” or “tier 1” mineral deposit discoveries
- For many of the “critical materials” the world demands are satisfied by 2-3 new mines
- Recycling rate of many infrastructure metals close to maximum in EU
- Recycling rate of CRM a.o. in its infancy
- Increased focus on LCA of metals, peak metal, scarcity, limits to growths etc.
Are we experiencing a Low Commodity Price Market?

Price 6th of October 215 cents/pound
Hi!
Did you know that each of us will, during our lifetime, use...

...more than **1700 tonnes** of metals and minerals!

*Is the world sustainable or are we running out of resources?*
Why metal consumption will continue to increase over the foreseeable future!
Metabolic rate (t/cap/yr)

Source: Steinberger et al., 2010

GDP per capita
Constant year 2000 US$
Cu-production and reserves reported by USGS in annual commodity reports 1995-2010

NO FIXED STOCK!
## Global production (tonnes) assuming 0% and 3% growth for Fe, Cu and Au

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<tr>
<td>Fe 3%</td>
<td>$2.36 \times 10^9$</td>
<td>$2.73 \times 10^9$</td>
<td>$3.17 \times 10^9$</td>
<td>$3.66 \times 10^9$</td>
<td>$4.25 \times 10^9$</td>
<td>$4.93 \times 10^9$</td>
<td>$5.71 \times 10^9$</td>
<td>$6.62 \times 10^9$</td>
<td>$7.68 \times 10^9$</td>
<td>$1.88 \times 10^{11}$</td>
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<td>Fe 0%</td>
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<td>$9.32 \times 10^9$</td>
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<tr>
<td>Cu 3%</td>
<td>$16.3 \times 10^6$</td>
<td>$18.9 \times 10^6$</td>
<td>$22.0 \times 10^6$</td>
<td>$25.4 \times 10^6$</td>
<td>$29.5 \times 10^6$</td>
<td>$34.2 \times 10^6$</td>
<td>$40.0 \times 10^6$</td>
<td>$46.0 \times 10^6$</td>
<td>$53.2 \times 10^6$</td>
<td>$1.30 \times 10^9$</td>
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<tr>
<td>Cu 0%</td>
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<td>$0.65 \times 10^9$</td>
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<tr>
<td>Au 3%</td>
<td>2398</td>
<td>2780</td>
<td>3222</td>
<td>3735</td>
<td>4330</td>
<td>5020</td>
<td>5819</td>
<td>6746</td>
<td>7821</td>
<td>190934</td>
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<tr>
<td>Au 0%</td>
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Source production data 2008: USGS
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<tr>
<td>World Mine Production</td>
<td>15,959</td>
<td>16,051</td>
<td>16,056</td>
<td>16,778</td>
<td>18,272</td>
<td>18,715</td>
<td>6,089</td>
<td>6,263</td>
<td>1,611</td>
<td>1,452</td>
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<tr>
<td>World Refined Production</td>
<td>18,241</td>
<td>18,987</td>
<td>19,600</td>
<td>20,186</td>
<td>21,043</td>
<td>22,480</td>
<td>7,147</td>
<td>7,355</td>
<td>1,881</td>
<td>1,739</td>
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<td>(Secondary+Primary)</td>
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<td>World Refined Usage</td>
<td>17,903</td>
<td>19,137</td>
<td>19,705</td>
<td>20,441</td>
<td>21,370</td>
<td>22,887</td>
<td>7,582</td>
<td>7,293</td>
<td>1,858</td>
<td>1,623</td>
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<tr>
<td>Refined Balance</td>
<td>338</td>
<td>-150</td>
<td>-105</td>
<td>-255</td>
<td>-328</td>
<td>-407</td>
<td>-436</td>
<td>62</td>
<td>23</td>
<td>116</td>
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**Demand forecast**

- 9 billion people 2050,
- USGS production forecast 2050 copper $53 \times 10^6$ tonnes
- Intensity of use 5 kg/cap/year (all world, western standard= best case scenario for decoupling), all fully industrialized, $45 \times 10^6$ tonnes
- Assumption: Copper demand will stabilize around 45-55$x10^6$, when can we produce this from recycled materials?
- Assuming a 90% recovery of primary production and anthropogenic life length of copper at 30 years it could be theoretically possible to sustain the world with copper from recycling (assuming current production rate from primary resources) with **best case scenario** at around **2090** (substitution not included)
- A **realistic assumption** would be that we possibly reach an equilibrium not until a long **way in to the 22nd century**
What about the society of tomorrow?

- What commodities will we use?
- What commodities will be to a large extent substituted or phased out?
- How much can we decouple?
- How much can we dematerialize the society?

Think back 30 years…
Led lighting, TV:s, solar panels, wind turbines, smartphones, lap tops…
much has happened that uses new raw materials…
WIND TURBINES

Material Composition

SMARTPHONE

Material Composition

LED LIGHTING

Material Composition

COMMERCIAL BUILDING

Material Composition

The transformation of our energy systems through the expanded use of renewable energy sources including wind power is not possible without innovative new materials. As an example, wind turbines largely depend on highly engineered steels, making it possible for the wind energy industry to meet the technical performance requirements of the turbines. This is an example of a green energy needed to address climate change that relies on a traditional industry with high technology solutions.

Whilst the blades are often made of other materials, such as carbon fibre or fiberglass, steel holds the blades as they can carry a high tensile load or fail safely. Electrical steel is used in the machinery of the generator because it is tailored to produce the specific magnetic properties which optimally convert wind energy into electric energy.

Welding steel is used for bearings and rings, which are important structural and connecting elements in wind turbines. These bearings are made to the highest standards and are very well designed, ensuring high performance, long-term reliability, and low maintenance and repair costs. The steel used in the tower is engineered to enhance its longevity and performance under wide-ranging weather conditions, airborne debris, or other factors. This is achieved through the use of metallurgy to harden the steel and add to a corrosion-resistant coating.

In total, a single wind turbine can contain up to several hundred tons of steel, compared to several tons of copper and aluminium, as well as steel riveted connectors for the blade. The increasing demand for wind energy infrastructure is a new demand on the supply chain. Furthermore, the steel used in wind turbines is placed over a period of 40 years, which is longer than for a conventional high building.

Lightweight, strong, and uncommon light materials are generally used in construction and as part of the building envelope towards greater urbanisation. These materials are a key feature of competitive and high-performance building projects due to their technical performance in building applications, durability, and, because these materials can be recycled, their full cycle cost of quality.

Steel and aluminum alloys are created by adding small amounts of other metals such as copper, magnesium, nickel, manganese, and zinc. These are used in buildings because they are weatherproof and corrosion-resistant and ensure optimal performance over many decades.

They can be tailored to specific performance criteria that are integrated into an entire system design. They can also define efficiency goals for a building's overall energy output and energy consumption. These materials range from heavy for high-rise buildings, auditoriums and auditorium buildings, window frames, and structural support for solar heating and cooling systems.

The trend towards increased urbanisation coupled with climate change challenges will lead to an increase in demand for these base metals for the construction of new more environmentally sustainable buildings. The recycling of metals used in buildings will contribute to reducing pressure on the supply.

With continuous research and innovation, European base metal industries, like aluminium, provide new high-performance solutions for the construction sector enabling Europe to reach its ambitious emission, energy and climate goals. The continuous evolution of lightening solutions in terms of the possibilities of our materials together with advanced technologies, we create energy efficient buildings.

Sven Richard Brandt

Managing Director of Metalcaurom
Outlook exploration

- Exploration down more than half since all time high in 2012 (c. 30B USD)
- Exploration shift towards LA, Africa and China
- Around 50 significant discoveries per year but perhaps less than 1 world class
- Expenditure increasing but discovery rate not
- New discoveries increasingly at depth – mature mining areas need deep penetrative exploration technologies
- Junior companies drivers, hard to raise capital
- Exploration short sighted, driven by commodity prices, economic growth and funding for junior companies
Non-Bulk exploration spend and discoveries World: 1975-2013

No:

150

100

110

60

50


2013 US$ Billion

$30

$20

$10

$0

Number of Discoveries

Exploration Spend

Note: Based on Moderate, Major and Giant discoveries. Excludes satellite deposits within existing Camps. Also excludes Bulk Mineral discoveries and expenditures.

Source: MinEx Consulting © September 2014
Significant mineral deposits: World
All years

Source: Richard Schodde, MinEx consulting, 2011
Significant mineral deposits: World
Discovered since 2000

N = 223

Source: Richard Schodde, MinEx consulting, 2011
Critical raw materials in Europe


Deposit classes according to the tonnage expressed in metric tons (1,000 kg).
District maturity and the need to chase deep targets

Depth to top of ore body for (>0.1 Moz) gold discoveries made in the Western World

Note: Chart refers to the initial discovery in a camp and so excludes subsequent brownfield discoveries which are often deeper

Source: Richard Schodde, MinEx Consulting Jan 10
Boundary conditions for future primary extraction

- CSR, Social license to operate, LCA responsibilities, low environmental impact
- Deeper, more extreme environments ARCTIC!
- Lower grades
- More complex ores, different commodities
- Less waste
- Less or more energy/kg? - pricing
Resource efficiency in Arctic mining

Case studies

• *Aitik* – low grade open pit Cu-mine north of arctic circle
• *Kankberg* – complex base metal massive sulphide underground mine
• *Kiirunavaara* – large scale underground Fe-mine north of arctic circle
**Aitik 45**

45 (38) Mt annually, +20%

Reserve grade 0.22 (0.24)
- Reserves 1 085 (633) Mt
- Life of mine 2040 (2030) years
- Copper life of mine 2 348 (1 471) kt

Capex
- New crushers with improved reliability
- Lower stripping, approx. 0.5
- TMF
<10% costs per ton of ore
- Economies of scales

Source: Boliden AB webpages
Copper- open pit with mill 2014

Source: Moström 2015
Key productivity drivers at mine
Minimizing lead time between work processes faces, stopes and benches

**Aitik - productivity**

<table>
<thead>
<tr>
<th>Open pit Cu mines</th>
<th>Percentile **</th>
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<tbody>
<tr>
<td>Head grade % Cu</td>
<td>99</td>
</tr>
<tr>
<td>Mine t ore/hour</td>
<td>1</td>
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<tr>
<td>Mill t ore/hour</td>
<td>0</td>
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<tr>
<td>G&amp;A t ore/hour</td>
<td>0</td>
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<tr>
<td>Overall t ore/hour</td>
<td>0</td>
</tr>
<tr>
<td>Wage rate $/hour</td>
<td>87</td>
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<tr>
<td>Labour cost $/t</td>
<td>12</td>
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<tr>
<td>Cash cost, Normal C1* - All c/lb Cu mines</td>
<td>42</td>
</tr>
</tbody>
</table>

* Cash cost Normal C1, Wood Mackenzie Q3 2014 estimate for 2014
** All mines in Woodmackenzie model, Q2 2014 estimates for 2014

Source: Moström 2015
Integrated control system drives efficiency

Integrated control system for mine and mill
  • Increased efficiency
  • Lower costs

Mobile control room
  • Enables operators to monitor and adjust in real time

Control system integrated with maintenance system
  • Only one original document
  • All share same info
  • Improved surveillance
  • Easier to spot errors
  • Diary improves visibility over time

WLan
  • Enable status control and operational guidance

Source: Moström 2015
**AITIK**

- Mo as by-product content 0.0025%
- Recovery 85% to copper conc.
- Annual prod 36 Mt
- Annual prod 544 tonnes Mo/year (9 MUSD/year)
- Additional resources Co in pyrite (reports to tailings)

**Source:** Wanhainen et al. 2014
**Kankberg - a ”New” Gold Mine**

- Ore reserve 2.9 Mton
- Average Grades
  - Gold 4.1 g/ton
  - Tellurium 186 g/ton
- Average production 320 kton/a
- Gold 1 150 kg
- Tellurium 41 ton

Source: Boliden AB webpages
**Kankberg – Technology breakthrough**
leaching of gold and tellurium from gold tellurides, turning a non profit “VMS” into a profitable mine

**Conceptual study initiated 2008**
A hot leaching process developed
  - Boliden patent
  - Gold recovery 85% (without 45%)
Tellurium leaching process developed
  - Tellurium recovery 65%

*Source: Boliden AB webpages*
**Kiirunavaara Iron ore**
Potential of P and REE in Iron ores

- Apatite Iron ore, mined underground in northern Sweden, >100 km north of the arctic circle
- Production from two large underground mines and two open pits 25.5 Mt 2015
- Iron ores contain 1-5% P in apatite
- REE in apatite (av. 0.25%), monazite (c. 70%), allanite (c. 22%) a.o.
- Approx. 30 000 tonnes TREE in tailings
- Approx. 2 000 t/a goes to tailings
- Global annual production c. 110 000 tonnes

Source: Pålsson et al. 2014
Summary

• Global consumption of metals will continue to increase
• There is a huge untapped potential for new discoveries in the Arctic
• Innovation in exploration, mining, processing, metallurgy towards systemic thinking and integration
• Digitalization, automation; measure & analyse in real time
• Cash cost control and lean production leads to economic and sustainable mining of low grade deposits in extreme environments
• Automation, systemic integration, resource characterization key factors
• Technological breakthroughs in especially mineral processing and metallurgy leads to economic extraction of by-products
• Economic extraction of by-products leads to resource efficiency
• Resources efficiency leads to increased economically viable primary extraction
• Needs to involve not only industry, research institutes and academia, but also decisions makers, NGOs and stakeholders at large