A Material Flow Analysis of cobalt: Observation of the evolutions of cobalt flows in Europe from 2008 à 2017

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30/04/2019
FRAMEWORK

- Forewords
- The value chain of cobalt
- Methodology of the Material Flow Analysis (MFA)
- Observations and conclusions
Forewords

What is a critical mineral?

- A significant importance for key economic sector (defence, space, electronic...)
- Geopolitical tensions on the supplies
- Few or no efficient substitute
- From a geological point of view, they are usually extracted as co-product

The Raw Materials Initiative (2008): three pillars

- Sustainable supply of raw materials within the EU
- Resource efficiency and supply of "secondary raw materials" through recycling
- Fair and sustainable supply of raw materials from global markets
- A criticality algorithm based on supply risk and economic importance
- A list of 27 minerals: Antimony, Fluorspar, LREEs, Phosphorus, Baryte, Gallium, Magnesium, Scandium, Beryllium, Germanium, Natural graphite, Silicon metal, Bismuth, Hafnium, Natural rubber, Tantalum, Borate, Helium, Niobium, Tungsten, Cobalt, HREEs, PGMs, Vanadium, Coking coal, Indium, Phosphate rock
Forewords

Critical minerals for the European union

European Commission, 2017
The value chain of cobalt

Value chain of cobalt

Study on the review of the list of Critical Raw Materials, Executive summary; Written by Deloitte Sustainability, British Geological Survey, Bureau de Recherches Géologiques et Minières, Netherlands Organisation for Applied Scientific Research; June 2017
The value chain of cobalt

Type of Deposits

- Canada
- China
- Russia
- South Africa
- Finland
- Australia
- Cuba
- Madagascar
- New Caledonia
- Papua NG
- Philippines
- DRC
- Zambia
- Morocco

Cobalt Production

- Magmatic sulphide (Cu-Ni-Co(-PGM))
- Lateritic (Ni-Co)
- Sediment hosted (Cu-Co)
- Hydrothermal and volcanogenic
The value chain of cobalt

Producing countries of mined cobalt

- DRC: 72%
- Phillipines: 4%
- Cuba: 4%
- Canada: 3%
- Russia: 3%
- PNG: 2%
- Australia: 2%
- New Caledonia: 2%
- Madagascar: 2%
- Others: 6%

Darton commodities, 2018-2019
134 500 tons
The value chain of cobalt

Producing countries of refined cobalt

- China: 65%
- Finland: 11%
- Canada: 5%
- Japan: 4%
- Norway: 3%
- Madagascar: 3%
- Other: 1%
- Morocco: 1%
- Belgium: 1%
- Russia: 2%
- Zambia: 2%
- Australia: 2%

Darton Commodities, 2018-2019

113,000 tons
The value chain of cobalt

From refining to transformation

Ore → Concentrates → Intermediates

Metal

Intermediates → Chemicals

- Alliage Blanc Cu-Co
- Mattes Ni-Co
- Oxide
- Hydroxide

Chemicals

- Sulphate
- Carbonate
- Chloride

Metal → Cathodes, Briquettes, Rounds, Powders
The value chain of cobalt

Cobalt Consumption by End Use - 2018
(in MT by end-use + year-on-year change)

- Others 3%
  - 2,850 MT
  - +3.6%
  - 3,500 MT
- Magnets 3%
  - 3,650 MT
  - +3.9%
- Tyres / Paint Driers 3%
  - 3,900 MT
  - +1.4%
- Hard Facing 4%
  - 5,550 MT
  - +2.8%
- Ceramics / Pigments 5%
  - 5,900 MT
  - +2.6%
- Catalysts 5%
  - 8,030 MT
  - +3.9%
- Hard metals 7%
  - 17,400 MT
  - +4.2%
- Superalloys 16%
  - Nickel / cobalt based (super) alloys
  - +9.4%
- Battery chemicals 54%

2018 Refined Cobalt Consumption (E)
- 111,300 MT
  - +6.6%

Darton commodities, 2018-2019
The value chain of cobalt

Type of recycling

- Recycling
  - Tailings
  - Manufacturing scraps
  - End-of-life scraps
  - Non functional recycling

- Non Recycling
  - Landfill
  - Dissipation
Methodology of the Material Flow Analysis (MFA)

A brief history

- The Material Flow Analysis (MFA) methodology has been primarily implemented by the Padua doctor Santoro Santoro during the 17th century in order to measure the human metabolism.
- In 1969 Ayres and Kneese, carried out the first MFA to measure the environmental consequences of economy.
- A few Cobalt MFA have been recently carried out. Harper et al in 2012 and Nansaï et al in 2014 using 2005 data, Deloitte in 2015 using 2012 data have brought valuable elements for the measurement of cobalt flows in the world.

A few paradigms

- A MFA is characterized by two main principles, the mass balance and the necessary boundaries (geographic, temporal and between the economical and natural system).
- It have been used to analyse the anthropogenic life cycle (Production, processing and manufacturing, use, waste management and recycling) of a substance or a good at each stage of it.
- A MFA can be used to calculate in use stock in order to estimate future waste streams, highlight the metal stocks and highlight the losses throughout the life cycle.
- By giving a geographical representation of the flows (their origin, their destination...) it also allows to understand better the vulnerabilities of the supplies of a material along the chain of production.
Methodology of the Material Flow Analysis (MFA)

Upstream of the value chain, nomenclatures and contained cobalt

<table>
<thead>
<tr>
<th>Nomenclature</th>
<th>Product</th>
<th>Contained cobalt</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS 26 05</td>
<td>Cobalt ores and concentrates</td>
<td>7 %</td>
</tr>
<tr>
<td>HS 28 22 20</td>
<td>Cobalt oxides and hydroxides ; commercial cobalt oxides</td>
<td>72 %</td>
</tr>
<tr>
<td>HS 28 34 29</td>
<td>Nitrates of barium, beryllium, cadmium, cobalt, nickel and lead</td>
<td>20-25 %</td>
</tr>
<tr>
<td>HS 28 33 29 30</td>
<td>Sulphates of cobalt and titanium</td>
<td>20-25 %</td>
</tr>
<tr>
<td>HS 28 27 39 30</td>
<td>Cobalt chlorides</td>
<td>20-25 %</td>
</tr>
<tr>
<td>HS 81 05 20 00</td>
<td>Cobalt mattes and other intermediate products of cobalt metallurgy ; unwrought cobalt ; cobalt powders</td>
<td>3-99 %</td>
</tr>
<tr>
<td>HS 81 05 30 00</td>
<td>Cobalt waste and scrap</td>
<td>3-60 %</td>
</tr>
<tr>
<td>HS 75 03 00 90</td>
<td>Waste and scrap of nickel alloys</td>
<td>3-40 %</td>
</tr>
<tr>
<td>HS 75 01</td>
<td>Nickel mattes</td>
<td>1-5 %</td>
</tr>
<tr>
<td>HS 75 02 10 00</td>
<td>Unwrought nickel alloys</td>
<td>0,5 %</td>
</tr>
<tr>
<td>HS 75 02 20 00</td>
<td>Nickel not alloyed, unwrought</td>
<td>1,5 %</td>
</tr>
</tbody>
</table>
### Methodology of the Material Flow Analysis (MFA)

**Downstream of the value chain, products, lost and recycling**

<table>
<thead>
<tr>
<th>Product</th>
<th>Contained cobalt</th>
<th>Scraps recycling</th>
<th>End of life recycling (Functional recycling/Non functional recycling/Landfill)</th>
<th>Manufacturing lost/Wear lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superalloys (Aerospace, landbased turbines)</td>
<td>5-60 % 250-500kg/pieces</td>
<td>70 %</td>
<td>50/30/20 %</td>
<td>66 %</td>
</tr>
<tr>
<td>Cemented carbides and hard metals</td>
<td>8-60%</td>
<td>5-35 %</td>
<td>15-75-10% 55-20-25%</td>
<td>5-16 %</td>
</tr>
<tr>
<td>Catalysts</td>
<td>0,5-5 %</td>
<td></td>
<td>75-90 %</td>
<td>6 %</td>
</tr>
<tr>
<td>Batteries (electronic)</td>
<td>5-14 % 1-3g</td>
<td></td>
<td>Collecting rate: 5-15 % Recovery rate: 40-80 %</td>
<td></td>
</tr>
<tr>
<td>Batteries (transport)</td>
<td>30-60kg</td>
<td></td>
<td>Collecting rate: 80 % Recovery rate: 40-80 %</td>
<td></td>
</tr>
<tr>
<td>Magnets</td>
<td>24-60 %</td>
<td></td>
<td>10/6/86 %</td>
<td>10 %</td>
</tr>
<tr>
<td>Chemicals (pigments, tyres, paint driers)</td>
<td>No data</td>
<td></td>
<td></td>
<td>100 %</td>
</tr>
</tbody>
</table>

For the calculation of a dynamic recycling rate, take into account the lifespan:
- Hard metals (1 year), superalloys (5 years), catalysts (5 years), batteries (1-5-8 years), magnets (5 years), chemicals (un year)
Observations and conclusions

**IMPORTATION OF COBALT, 2008**

- **Waste and scrap (Cobalt and nickel)**: 8.46%
- **From nickel flows**: 19.11%
- **Article of cobalt NES**: 3.23%
- **From iron flows**: 0.26%
- **Cobalt oxides and hydroxides; commercial cobalt oxides**: 2.55%
- **Chemicals**: 0.88%
- **Cobalt mattes and other intermediate products of cobalt metallurgy; unwrought cobalt; cobalt powders**: 56.54%

**IMPORTATION OF COBALT, 2017**

- **Waste and scrap (Cobalt and nickel)**: 7.93%
- **From nickel flows**: 31.47%
- **Article of cobalt NES**: 6.20%
- **From iron flows**: 0.26%
- **Cobalt oxides and hydroxides; commercial cobalt oxides**: 3.15%
- **Chemicals**: 0.64%
- **Cobalt mattes and other intermediate products of cobalt metallurgy; unwrought cobalt; cobalt powders**: 50.27%

**Total Importation of Cobalt, 2008**: 20,254.27 tons

**Total Importation of Cobalt, 2017**: 16,439.4 tons
Observations and conclusions
Observations and conclusions

EUROPEAN IMPORTATION, 2017

RUSSIAN FEDERATION (RUSSIA) 24%

UNITED STATES 11%

MADAGASCAR 9%

NORWAY (incl.SJ excl.1995,1996) 10%

CHINA (PEOPLE'S REPUBLIC OF) 6%

COUNTRIES AND TERRITORIES NOT SPECIFIED FOR COMMERCIAL OR MILITARY REASONS IN THE FRAMEWORK OF TRADE WITH THIRD COUNTRIES 5%

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COUNTRIES AND TERRITORIES NOT SPECIFIED FOR COMMERCIAL OR MILITARY REASONS IN THE FRAMEWORK OF TRADE WITH THIRD COUNTRIES 5%
Observations and conclusions

**IMPORTATION EN PROVENANCE DE RUSSIE (2017)**

- Nickel Mattes: 72%
- Waste and scraps of nickel alloys: 3%
- Cobalt mattes and other intermediare product of cobalt metallurgy: 19%
- Unwrought nickel alloys: 9%
- Cobalt waste and scraps: 2%
- Oxydes and Hydroxydes: 1%
- Article of cobalt N.E.S: 1%
- Nickel not alloyed, unwrought: 6%

**IMPORTATION EN PROVENANCE DES ETATS-UNIS (2017)**

- Waste and scraps of nickel alloys: 9%
- Cobalt mattes and other intermediare product of cobalt metallurgy: 64%
- Unwrought nickel alloys: 2%
- Nickel not alloyed, unwrought: 2%
- Nickel Mattes: 9%
- Article of cobalt N.E.S: 18%
- Cobalt waste and scraps: 7%
- Chlorides: 3%
- Sulphides: 1%
- Ores and concentrates: 1%
- Oxydes and Hydroxydes: 1%
- Nitrides: 1%

30/04/2019
University of Orleans
Observations and conclusions