Extractive metallurgy of man-made minerals: opportunities for short-loop processes.

Ir David Bastin

Cross section EDS mapping of a Nokia Lumina 925
Giaro & Al at Hi-Tech Metals’18, Cape Town.

Journées scientifiques du GDR Prométhée
23/05/2024, IFPEN Rueil-Malmaison
Extractive metallurgy originally developed for natural metals paragenesis.
<table>
<thead>
<tr>
<th>End Of Life Equipements and opportunities for specific short-loop urban extractive metallurgies</th>
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<tbody>
<tr>
<td><strong>Spent Automotive Catalytic Converters</strong></td>
</tr>
<tr>
<td><img src="image1" alt="Spent Automotive Catalytic Converters" /></td>
</tr>
</tbody>
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**KIC RM Upscaling CEBRA**  
**MSCA-RISE ChemPGM**  
**Regional Innovation Partnership REVERSE METALLURGY**  
**Next Generation EU CISTEMEEC**  
**HE MAGELLAN**
Spent Automotive Catalytic Converters

<table>
<thead>
<tr>
<th>Application</th>
<th>ACC Type</th>
<th>PGMs Associations</th>
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<tbody>
<tr>
<td>Gasoline &amp; HEV cars</td>
<td>TWC</td>
<td>Pt/Pd/Rh</td>
</tr>
<tr>
<td></td>
<td>cGPF</td>
<td>Pt/Pd/Rh</td>
</tr>
<tr>
<td>Diesel Light and Heavy</td>
<td>DOC</td>
<td>Pt/Pd</td>
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<tr>
<td>Duty Vehicles</td>
<td>cDPF</td>
<td>Pt/Pd</td>
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</table>

Ceramic (Cordierite), Metallic and SiC supports
### PGEs Primary Ores and Metallurgy

<table>
<thead>
<tr>
<th></th>
<th>Pt</th>
<th>Pd</th>
<th>Rh</th>
<th>Ru</th>
<th>Ir</th>
<th>Os</th>
<th>Au</th>
<th>PGM total</th>
<th>Cu</th>
<th>Ni</th>
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<tr>
<td></td>
<td>[g/t]</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td>Merensky Reef</td>
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<td>0.04</td>
<td>0.24</td>
<td>4-10</td>
<td>0.08</td>
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<td>1.3</td>
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<td>1.9</td>
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<td>0.03</td>
<td>0.21</td>
<td>4-5</td>
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<td>0.21</td>
<td>k.A.</td>
<td>k.A.</td>
<td>k.A.</td>
<td>0.47</td>
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<td>-</td>
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<td>0.03</td>
<td>0.04</td>
<td>0.01</td>
<td>0.01</td>
<td>0.09</td>
<td>1-2</td>
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<tr>
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<td>k.A.</td>
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<td>2-3</td>
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<td>Russia (Norilsk)</td>
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<td>k.A.</td>
<td>k.A.</td>
<td>0.25</td>
<td>&gt;10</td>
<td>3</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Impurities: Si, S, Mg, As, Pb, Sb, Bi, Fe, Sn – Cr, Se, Te
PGEs ores, from Mine to Metals

### Steps
- **Mining**
- **Concentration**
- **Smelting**
- **Refining**

### Activities
- **Mining**
- **Crushing and grinding**
  - Froth flotation
- **Smelting**
  - Converting
  - Sulphur removal
- **Base metal refining**
  - Precious metal refining (PMR)

### Output
- **Run of mine ore**
  - 3-6 g/t 4E [11]
- **Flotation concentrate**
  - 100-500 g/t 4E [11]
- **Converter matte**
  - >2800 g/t 4E [11]

- **Tailings**
- **Chromite recovery**
- **Nickel/nickel sulphate**
- **Copper**
  - Cobalt/cobalt sulphate
  - Sodium/ammonium sulphate
- **Individual PGMs**
  - Gold
  - Cobalt/cobalt sulphate
Figure 2. Simplified flow sheet of Rustenburg Base Metals Refinery (adapted from Hofirek & Halton [20]).
PGM – precious metal refining

Mixed PGM feed

Dissolution – HCL/Cl2 system preferred

Pt, Pd, Au, Rh, Ir, Ru, (Os) – chloride solution

Selective precipitation

Ion-exchange

Solvent extraction

Separated PGMs, Au

Prof. Jochen Petersen, University of Cape Town, shortcourse on PGM Metallurgy
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Pure Metals Handling (Level 3)

- Calcination of salts and sponges.
- Reduction of metal oxides (cracked ammonia).
- Acid (HF + HCl) washing to remove base metals and silica.
- Screening and milling.

Prof. Jochen Petersen, University of Cape Town, short course on PGM Metallurgy
Co-processing of e-scrap, catalysts and multiple feedstocks

Principal flowsheet of Umicore’s smelter and refinery at Hoboken, Belgium.
Figure 21. Classical Refining Process for Au, Pt, Pd - Inco Acton Refinery

Figure 18. Degussa dmC² Process to Recover PGE’s from Autocatalysts
Spent Automotive Catalysts
Is there a room for dedicated flowsheets shortening the recycling process loop from EOL equipments to new catalysts?

Sensor Based Sorting
- Pt
- Pt/Pd
- Pt/Pd/Rh

Pretreatments
- Calcination
- Dry chlorination

Leaching

Solution Purification
- PGE Grade correction
- Direct support Impregnation and catalysts synthesis

Pt/Pd/Rh Co-extraction
- Pt/Pd/Rh Nitrates production
- PGE Grade correction
- Support Impregnation and catalysts synthesis

Close the gap between Recyclers/Metallurgists and Material Scientists.
Smart sorting to unlock short-loop recycling.
### After grinding

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<th>Stationary calibrated XRF</th>
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<td>8588</td>
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<td></td>
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<td>8390</td>
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<tr>
<td>Mean</td>
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### After grinding

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<td>2438</td>
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<td>4173</td>
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<tr>
<td>Mean</td>
<td>4195</td>
<td>2518</td>
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GeMMe’s on-line XRF analysis and robotic sorting prototype
The PICKIT concept and technology: **SINGLE PASS MULTI-CLASS SORTING**

https://matvision.eu
PICKIT – MULTIPICK: Investissement de 9.4 M€ sur le site industriel d’Obourg – Capacité de traitement de 20 000 t/an de Zorba (Valeur métal > 30M€/an) - Création de 15 emplois.
EOL Rare Earth Permanent Magnets from e-Mobility.

### e-Scooters

<table>
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<th>LREEs</th>
<th>HREEs</th>
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<td>Pr Wt %</td>
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<td>19</td>
<td>5</td>
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### e-Bikes

<table>
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<th>HREEs</th>
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<td>Pr Wt %</td>
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<tr>
<td>24</td>
<td>-</td>
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### BEV – HEV - FCEV
Exploring short-loops for EOL Rare Earth Permanent Magnets.

Figure 10 MAGELLAN choice of recycling process: “Magnet-to-alloy”
The Li-ion batteries case study.

Blackmass from Spent Li-ion NMC Batteries

Leaching

PLS Purification

Ni-Mn-Co mixed salts Precipitation

Ni-Mn-Co grades and Ratio Adjustment with pure salts

New CAM Synthesis methods from mixed salts

Close the gap between Recyclers/Metallurgits and Material Science Actors.
• Close the gap between Recyclers, Metallurgists, Materials Scientists and Products Designers.
• Explore the Designed from Recycled options.
• Do we always have to go back to pure elements or do we have to keep the maximum of the energy embedded in man-made minerals and anthropic elemental associations.
• Develop Smart Sorting Solutions to chanel the EOL products to the shortest recycling loop.

• No sustainable Circular Economy and Urban Mining without Primary Mining.
• Stop using slogans like Zero Waste, 100 % recycled, carbon neutral and climate neutral.
• Mitigating and minimizing the environmental impacts of our societies require to think in terms of systems.
Mini means 600kg in 1960

Mini SE means 1440 kg in 2021
Université de Liège hosts the GeMMe, a Research Unit specialized in georesources, mineral engineering and extractive metallurgy.

The GeMMe contributes to the development of innovative processes for the efficient management of mineral and metallic resources while providing unparalleled upscaling experience in urban ore characterization and processing (with a focus on innovative sorting techniques and hydrometallurgy) derived from a long research tradition in primary ores mining and processing.