Metallurgical Internet-of-Things

$m$-IoT

Markus A. Reuter
Metallurgy enables the CE – An opportunity

• CE: Circular Economy
  – “Circular Economy within a Corporation”

• m-IoT: Metallurgical Internet-of-Things
  – Metallurgical infrastructure and knowhow are of key importance

• CEE: Circular Economy Engineering
  – Digitalized linking of stakeholders
  – Quantifying resource efficiency
  – Informing society in an understandable CE-paradigm
Circular Economy: CE
Understanding & quantification of entropy in the CE

\[ \Delta S = \frac{\Delta Q}{T} \]
CE: Product Centric Recycling

Outotec Ausmelt
TSL Plants (65)
Is sustainable considering both energy and materials for LED lamp designs?

CE: A key issue of recycling
CE: Complexity & creating entropy
Requires detail of particles to be able to optimize and simulate

Different appearances of PCB in (PCB) recyclates
CE: Optimization, Simulation, Big-data

Real-time data and evaluation of the complete chain
CE: Processing infrastructure

Secondary Feeds
(Low & High grade Cu materials & alloys, WEEE - PMs (Au) & PGMs containing residues & scrap, shredder residue)

Reductant
Fuel
Air (Oxygen)

Discard Slag
(Construction Material)

1-3 Stage TSL

Precious Metal Refining
Te, Se etc.

PGMs
PMs

Electrowinning & -Refining

Leaching
Slimes

Intermediate Pb-Rich Phases
Fumes

(Dust/Fume
(Zn rich)

Precipitates
(Pb/Sn rich)

Smelting/Refining

Leaching

Zn

Pb/Sn/Bi/Ag Products

Cathode Copper

Electrowinning

Offgas treatment

Gypsum

Precious Metal Refining

PMs

Gypsum

Te, Se etc.
CE: Processing infrastructure
Lead concentrates and residues YTCL (China) & KCM (Bulgaria)
Dowa (Japan): eWaste, Cu, residues (TSL)

Recylex (Germany): Lead Battery, Pb residues (TSL)

Young Poong Corporation (S. Korea): Pb/Zn residues (TSL)

Rönnskär Boliden (Sweden): Cu, slimes, eWaste (Kaldo)

JCC Guixi (China): Cu scrap, internal material (slags), residues (Kaldo)

Mitsui (Japan): ISF Slag fuming (TSL)

YTCL (China): 3 Stage lead smelting, Slag cleaning (TSL)

GRM – Danyang Smelter (S. Korea): Cu based residues, scrap etc. (TSL)

KCM (Bulgaria): Lead smelting and secondaries (TSL)
CE: Metallurgy a key enabler

https://www.youtube.com/watch?v=0WE72HB7asY
Metallurgical Internet-of-Things: m-IoT

GEOLOGICAL MINE
Geological Minerals (Au containing)

URBAN MINE
Designer "Minerals" and Functional Materials (Au containing)

Product Design
Remanufacture

Collection, Dismantling, Shredding

Unaccounted Losses & Theft

Physical Separation

Particle Properties Controls

Multi-material Recyclates

Complex Linkages/Connections

Losses & Stocks

Product Complexity

Market & Stocks

Recycling Index

© MARAS B.V.

Efficient

A+++ G

A++ F

A+ E

A D

A B C

Inefficient

Losses

Stocks & Losses

Functional Metal & Material Combinations

Pyro- & hydrometallurgy, Refining

Losses

Collection, Dismantling, Shredding

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Functional Metal & Material Combinations
M-IoT: Metallurgical Internet-of-Things
m-IoT: Recovering metals from residues, scrap etc.
Lead Concentrates & Zinc residues – Nyrstar (Zürich) installing TSL at Port Pirie, Australia 2016 (Outotec) – 65th Top Submerged Lance furnace
m-IoT: Zinc Residue processing
Xing’an China

Metals Recovered
Zn
Pb
Ag
Cu
In
Ge
Ga
Sb
Etc.
## M-IoT: Understanding metal distributions


Table IX Summary of previous work of trace valuable elements distribution in primary and secondary copper smelting

<table>
<thead>
<tr>
<th>Metal</th>
<th>Primary Copper Processing</th>
<th>Ref.</th>
<th>Secondary Copper Processing</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag</td>
<td>Data available</td>
<td>[21-22,26,35-36,38, 40,42,44,51-54]</td>
<td>No data available</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Limited data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pt</td>
<td>available (matte-slag system)</td>
<td>[53,70-72]</td>
<td>No data available</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Limited data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pd</td>
<td>available (matte-slag system)</td>
<td>[53,70-72]</td>
<td>No data available</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Limited data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rh</td>
<td>available (matte-slag system)</td>
<td>[53,72]</td>
<td>No data available</td>
<td>-</td>
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<tr>
<td>Se</td>
<td>Data available</td>
<td>[26,34-36, 59-61,63-65]</td>
<td>No data available</td>
<td>-</td>
</tr>
<tr>
<td>Te</td>
<td>Data available</td>
<td>[26,34-36, 59,61,63-64]</td>
<td>No data available</td>
<td>-</td>
</tr>
<tr>
<td>Sn</td>
<td>Data available</td>
<td>[21,22,26,35-37, 40-45, 49-50]</td>
<td>One data available</td>
<td>[43]</td>
</tr>
<tr>
<td>In</td>
<td>Very limited data available</td>
<td>[29]</td>
<td>One data available</td>
<td>[13]</td>
</tr>
<tr>
<td>Pb</td>
<td>Data available</td>
<td>[21-22,26-27,35-36, 75-80]</td>
<td>No data available</td>
<td>-</td>
</tr>
<tr>
<td>Bi</td>
<td>Data available</td>
<td>[21-22,26-27,35-36,63,75,91,93-94]</td>
<td>No data available</td>
<td>-</td>
</tr>
<tr>
<td>As</td>
<td>Data available</td>
<td>[21-21,26-27,35-36,63,75-76,79, 91,93,95-96]</td>
<td>No data available</td>
<td>-</td>
</tr>
<tr>
<td>Sb</td>
<td>Data available</td>
<td>[21-22,26-27,35-36,41,63,75,76,79, 91,93-96]</td>
<td>No data available</td>
<td>-</td>
</tr>
<tr>
<td>Co</td>
<td>Data available</td>
<td>[35,81-85]</td>
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<td>-</td>
</tr>
<tr>
<td>Ge</td>
<td>No data available</td>
<td>-</td>
<td>No data available</td>
<td>-</td>
</tr>
<tr>
<td>Ga</td>
<td>No data available</td>
<td>-</td>
<td>No data available</td>
<td>-</td>
</tr>
</tbody>
</table>
CEE: Link CAD & Smelter to Recycling Index

Traditional Design for Recycling does not provide detail nor reveal the limits!

CEE: Comparing solutions relative to baseline


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**Potential competitive advantage**

**Neutral**

**Potential risk**
CEE: Real-time optimization & simulation

- Analytics & big data analysis platform
- Simulation and optimization platform
- Link back to product design – key innovation
Is sustainable in a CE?
Summary

• Digitalizing the CE

• Metallurgical Internet-of-Things
  – Metallurgical infrastructure key

• Circular Economy Engineering
  – Metallurgy’s contribution

• Quantified limits of a Circular Economy?
m-IoT: Metallurgical Internet-of-Things

Zinc-Metallurgy

- Zn Plant
  - Various configurations (Figure 2)
  - Zn Solution
  - Pb Residue
  - Other residues
  - Jarosite residue
  - Cu Speltes
- Waelz Kiln
- Feeds
  - Zn Concentrates
  - Washed roasted secondaries fumes (e.g., EAF dust)
- Direct Zn (TSL 2 stage)
- Pb/Speiss
- To lead plants
- Rotary Kiln
- Slag (low Pb)
- BULLION
  - Horizontal Bath (QSL, KIVCET, SKS 2 stage)
  - Discard Slag and Steam
  - Fume Leaching Plant
  - Ag Concentrate
  - Fume Zn/Pb (In, Ge)
  - H₂SO₄

Copper-Metallurgy

- Cu TSL Processing
  - Cu Removal
  - BULLION
  - Pb Refinery
  - Pb Slime
- Precious Metal Refinery
  - Pb, Sn, Sb, Te, Se, In
  - Cu, PGMs, various others

Lead-Metallurgy

- Vertical Bath (TSL 1.2 & 3 stage)
- Fume
  - BULLION
  - Pb/Speiss
  - To lead plants
  - Rotary Kiln
  - Slag (high Pb)
- Fume Leaching Plant
  - Ag Concentrate
  - Zn/Pb (In, Ge)
- Zn Plant
  - Various configurations (Figure 2)
  - Zn Solution
  - Pb Residue
  - Other residues
  - Jarosite residue
  - Cu Speltes
- Waelz Kiln
- Feeds
  - Pb Concentrates
  - Pb Secondaries (e.g., battery)
  - Ag Concentrate
- Blast Furnace
- Slag
  - Cu Removal
  - BULLION
  - Pb Refinery
  - Pb Slime
- Precious Metal Refinery
  - Pb, Sn, Sb, Te, Se, In
  - Cu, PGMs, various others
- Refinery
  - Pb, Sn, Sb, Te, Se, In
Circular Economy Engineering: CEE

BAT, Flow Sheets & Recycling System Maximizing Resource Efficiency – Benchmarks

- $US / t Product (CAPEX & OPEX)
- Recyclability Index (based on system simulation of whole cycle)
- Energy: GJ & MWh / t Product (source specific)
- Exergy: GJ & MWh / t
- kg CO₂ / t Product
- kg SOₓ / t Product
- g NOₓ / t Product
- m³ Water / t Product (including ions in solution)
- kg Residue / t Product (including composition)
- kg Fugitive Emissions / t Product
- kg Particulate Emissions / t Product
- Etc.

Environmental Indicators based on BAT Driving Benchmarks of Industry

ReCiPe (and similar) – Endpoint estimation

- Global Warming Potential (GWP)
- Acidification Potential (AP)
- Eutrification Potential (EP)
- Human Toxicity Potential (HTP)
- Ozone Layer Depletion Potential (ODP)
- Photochemical Ozone Creation Potential (POCP)
- Aquatic Ecotoxicity Potential (AETP)
- Abiotic Depletion (ADP)
- Etc...