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

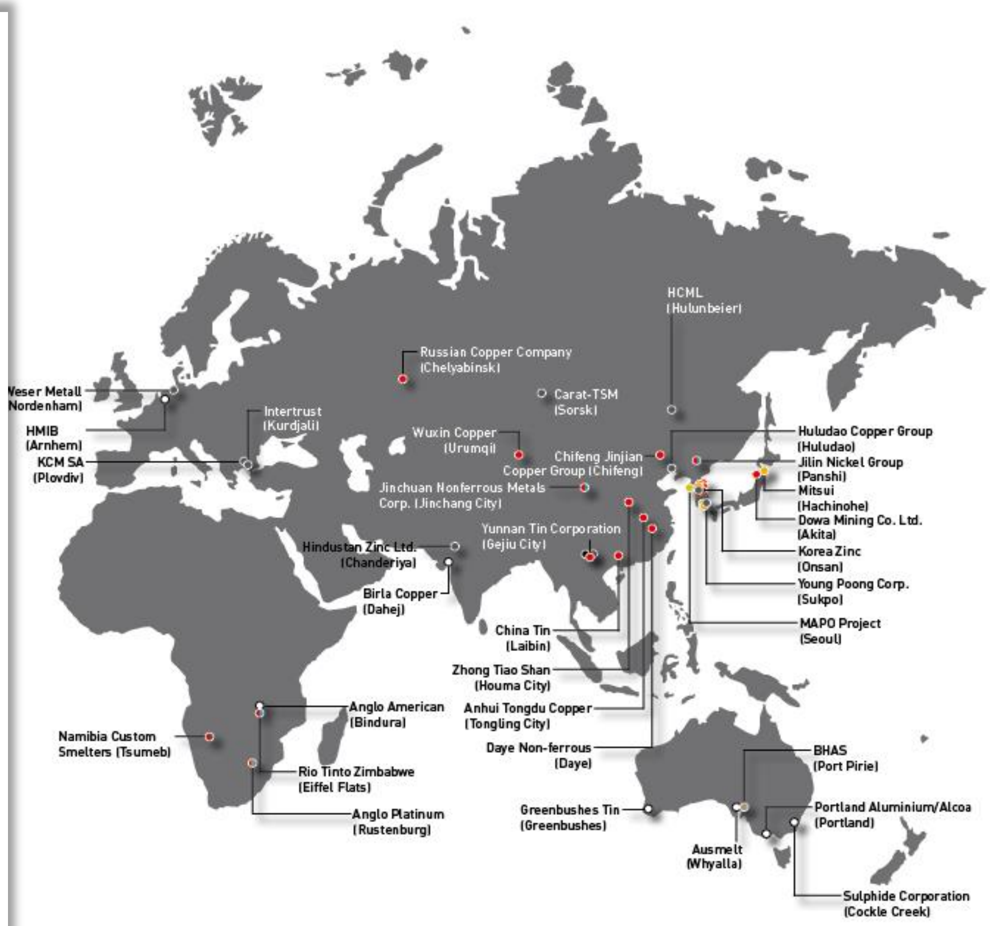
Circular Economy: CE

Understanding & quantification of entropy in the CE

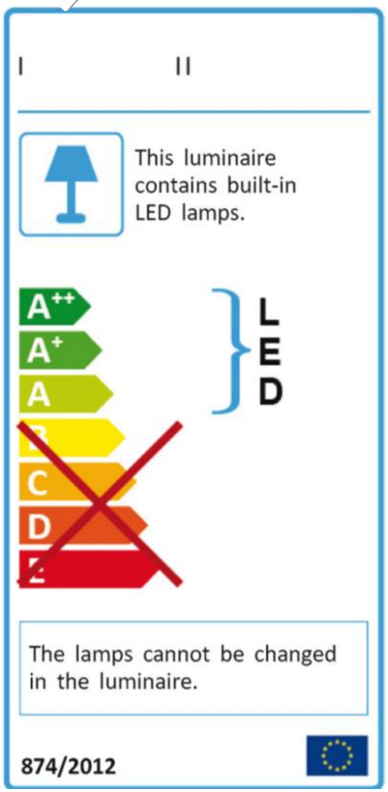
http://www.europarl.europa.eu/news/en/news-room/20151201STO05603/Circular-economy-the-importance-of-re-using-products-and-materials

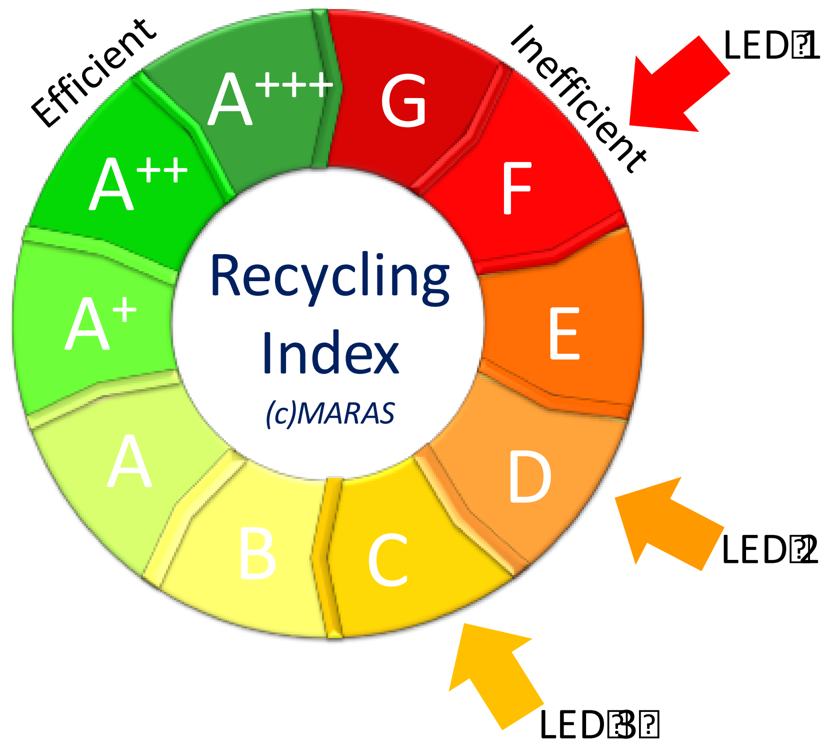
CE: Product Centric Recycling

Outotec Ausmelt
TSL Plants (65)



Is  sustainable considering both energy and materials for LED lamp designs?



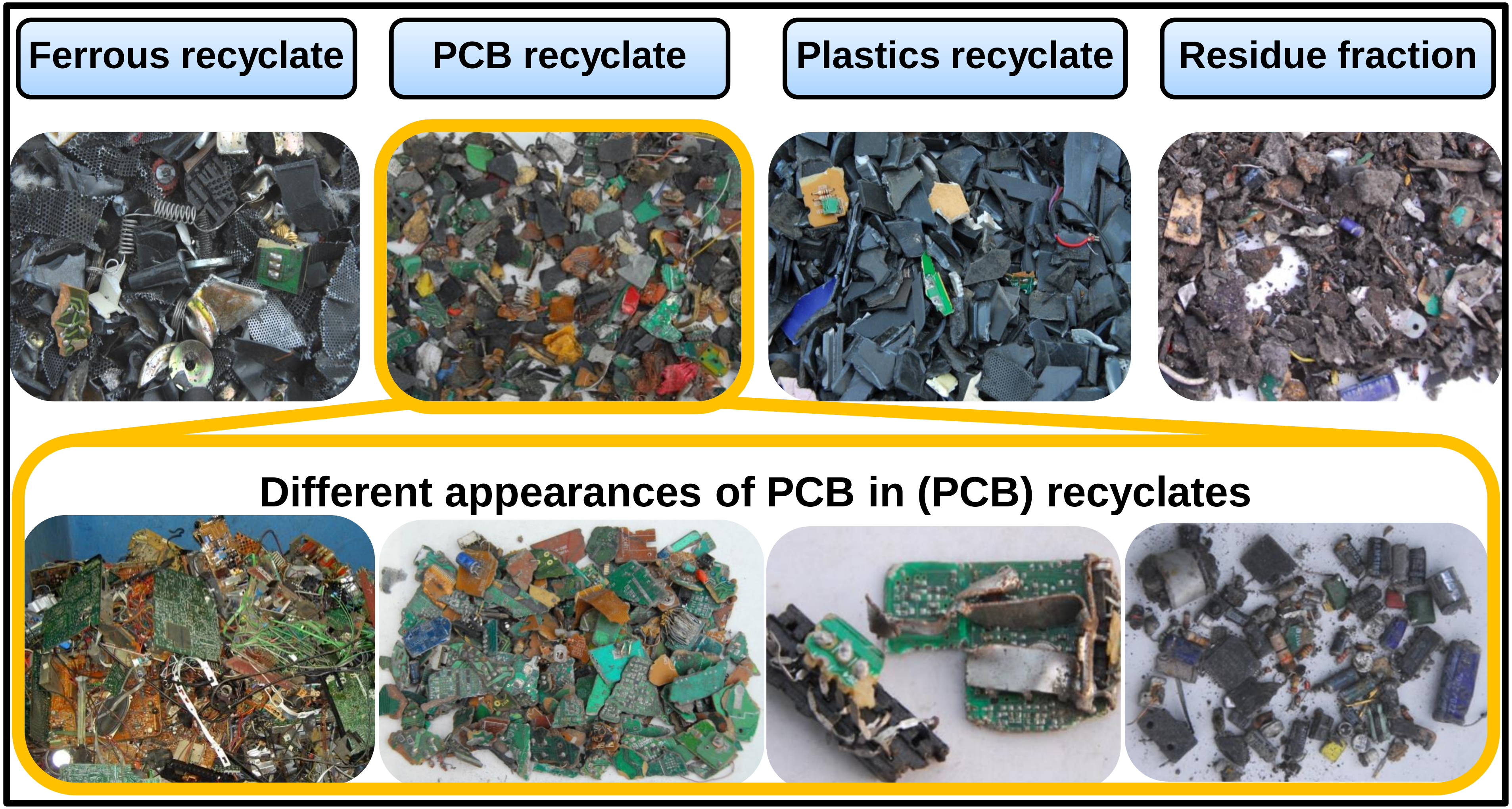


M.A. Reuter, A. van Schaik (2016): Strategic metal recycling: adaptive metallurgical processing infrastructure and technology are essential for a Circular Economy, RESPONSABILITÉ & ENVIRONNEMENT - AVRIL 2016 - N°82, pp. 62-66.

CE: A key issue of recycling

CE: Complexity & creating entropy

Requires detail of particles to be able to optimize and & simulate



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M.A. Reuter, A. van Schaik, O. Ignatenko (2006): Fundamental limits for the recycling of end-of-life vehicles, Minerals Engineering, 19(5), 433-449.
UNEP, 2013: Reuter (LEAD AUTHOR), United Nations Environmental Protection (UNEP) Report “Metal Recycling: Opportunities Limits Infrastructure” report: http://www.unep.org/resourcepanel/Publications/MetalRecycling/tabid/106143/Default.aspx

CE: Optimization, Simulation, Big-data

Real-time data and evaluation of the complete chain

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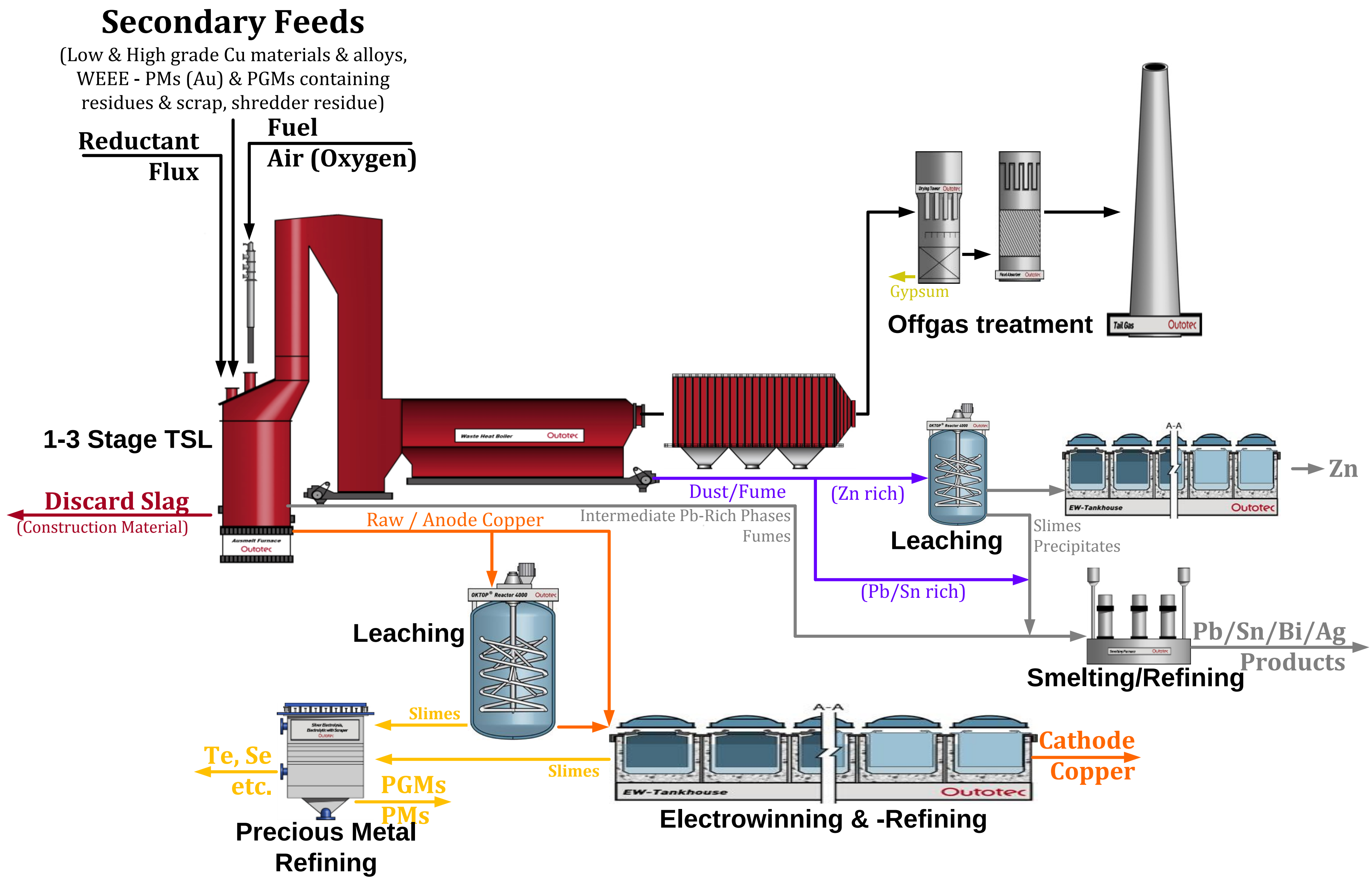
CE: Processing infrastructure



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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)

Rönnskår 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)

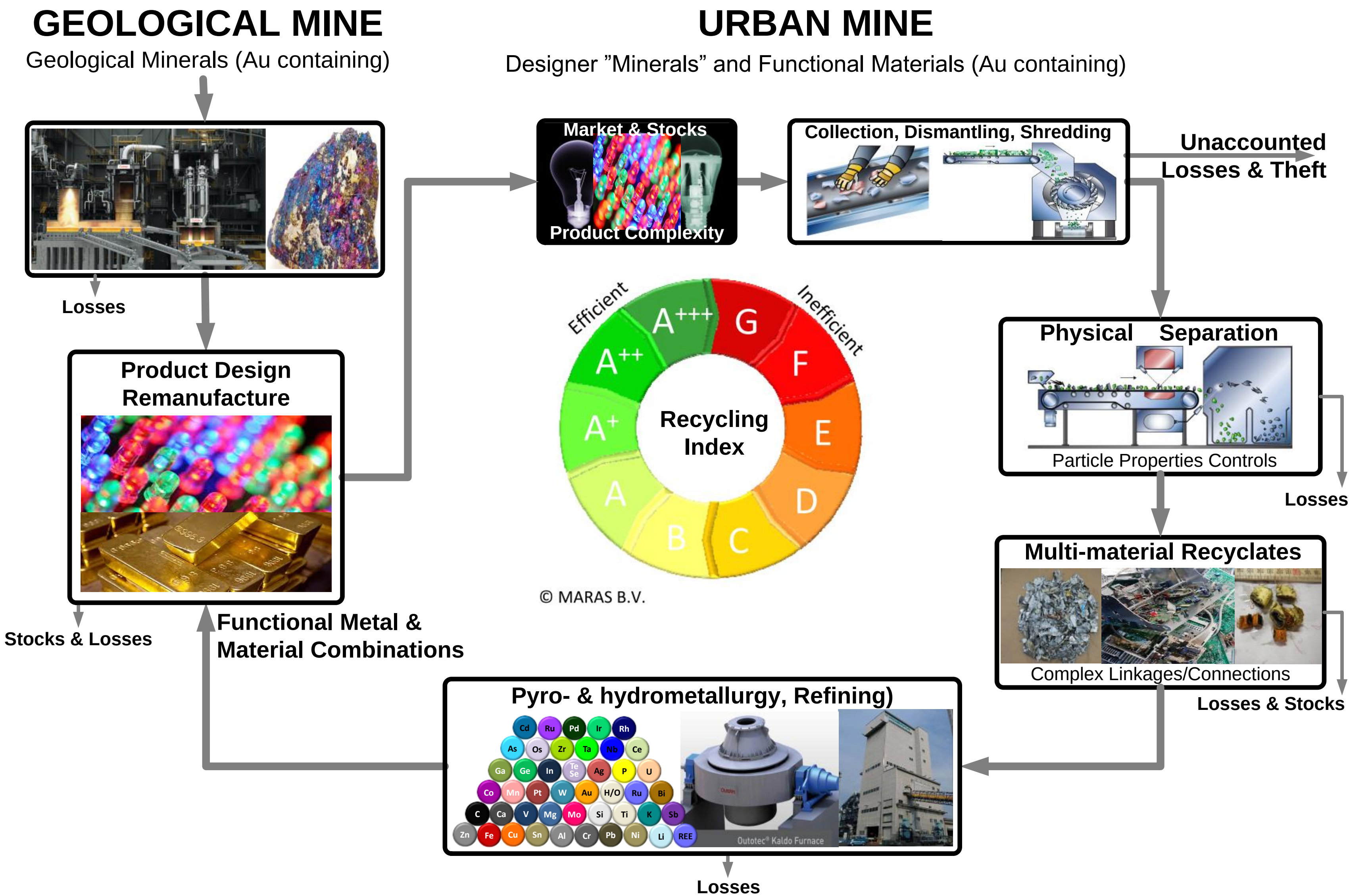
GRM – Danyang Smelter (S. Korea): Cu based residues, scrap etc. (TSL)

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



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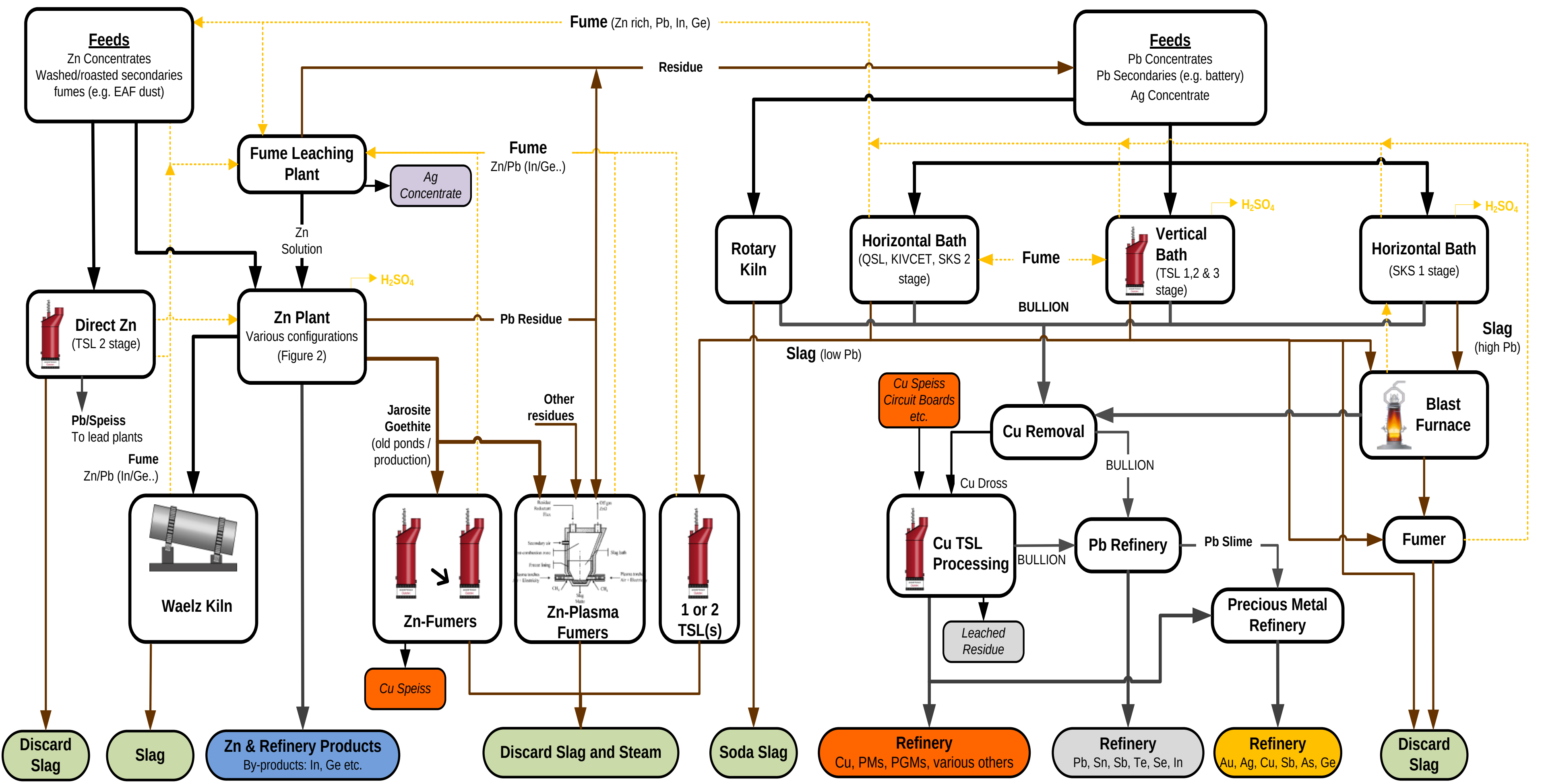
M-IoT: Metallurgical Internet-of-Things



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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

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m-IoT: Zinc Residue processing

Xing'an China

Metals Recovered

Zn
Pb
Ag
Cu
In
Ge
Ga
Sb
Etc.

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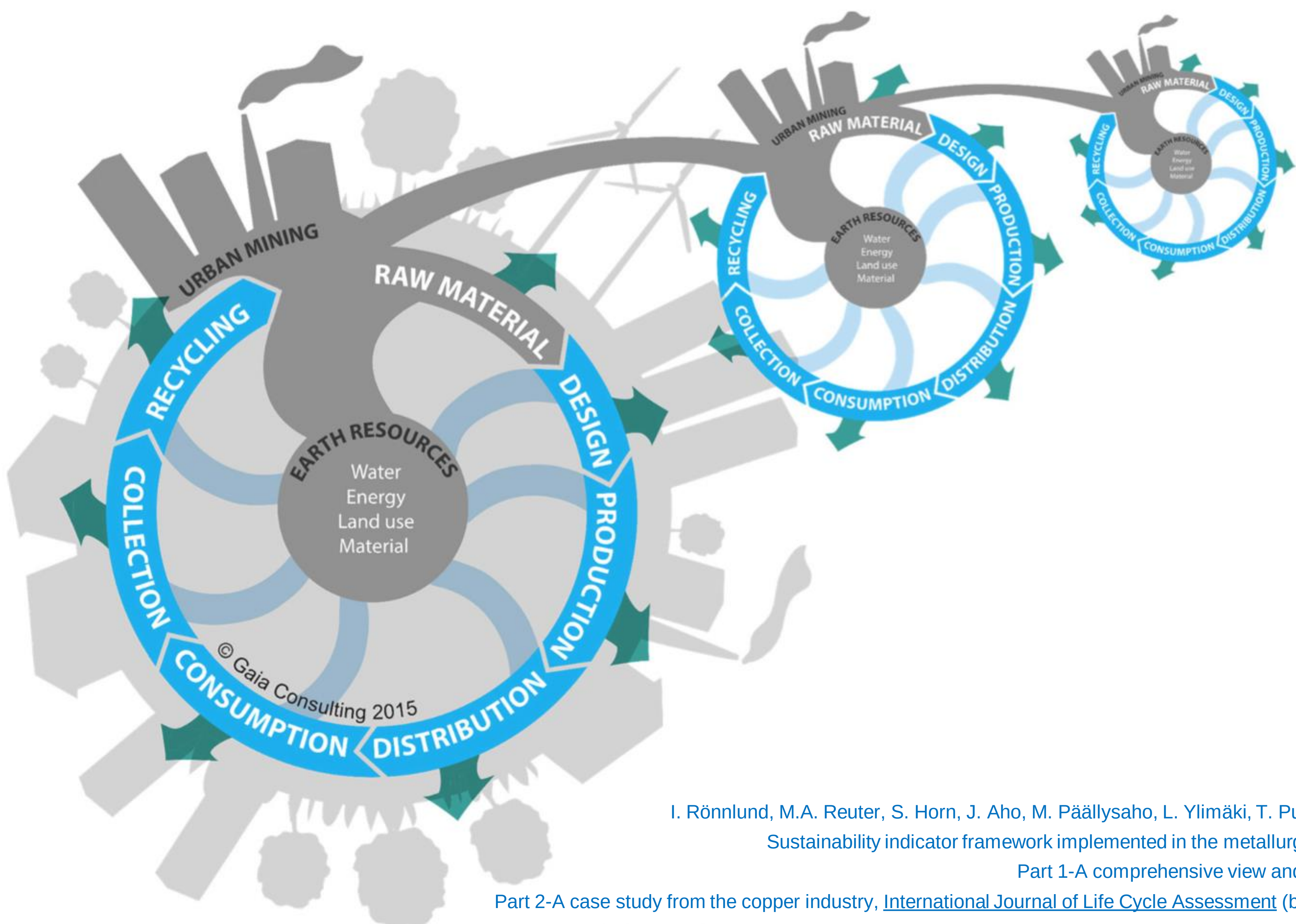
M-IoT: Understanding metal distributions

M.A.H. Shuva, M.A. Rhamdhani, G. Brooks, S. Masood, M.A. Reuter (2016) Thermodynamics data of valuable elements relevant to e-waste processing through primary and secondary copper production - a review, J. Cleaner Production (in press).

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

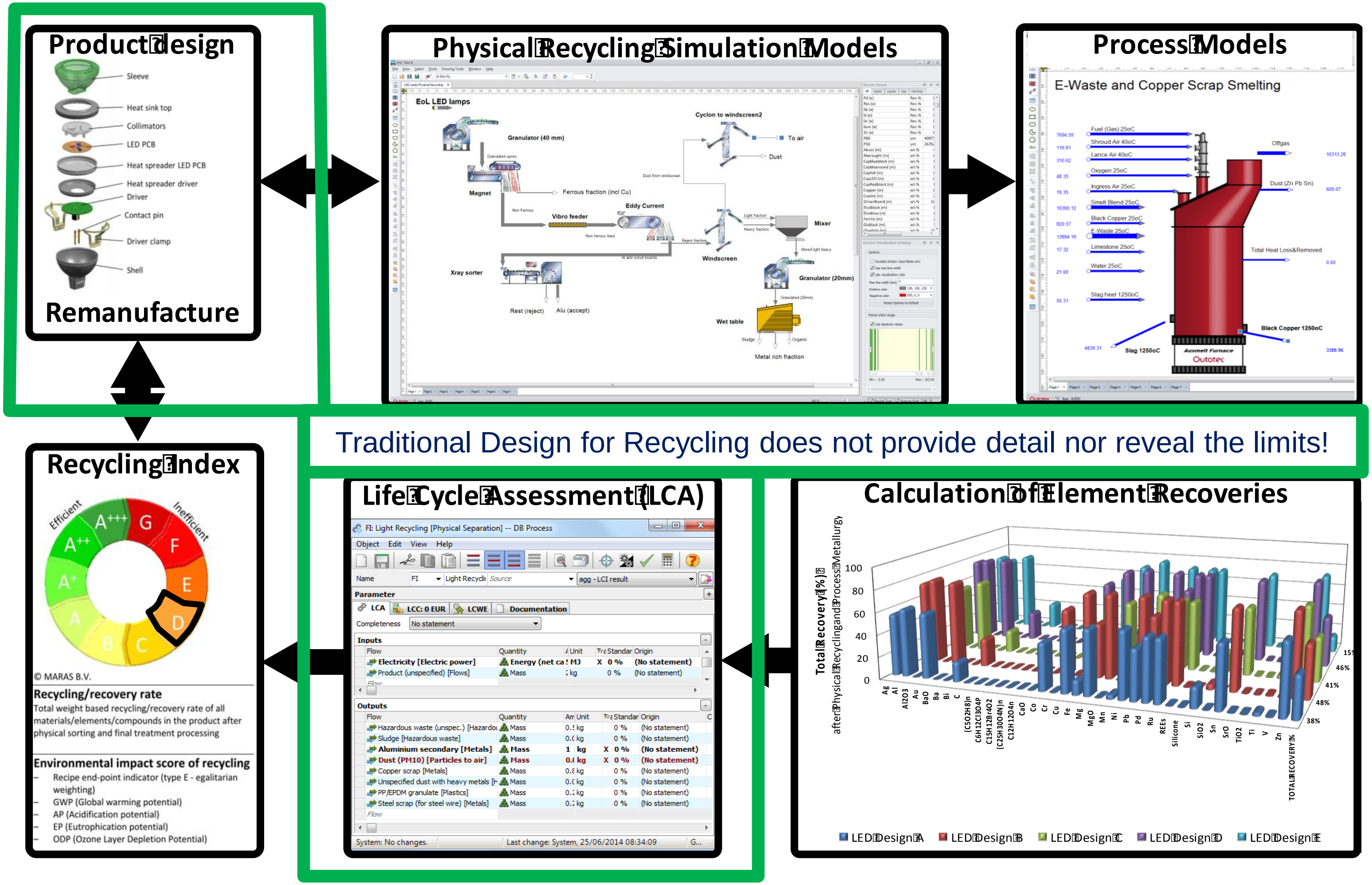
Metal	Primary Copper Processing	Ref.	Secondary Copper Processing	Ref.
Ag	Data available	[21-22,26,35-36,38, 40,42,44,51-54]	No data available	-
Pt	Limited data available (matte-slag system)	[53,70-72]	No data available	-
Pd	Limited data available (matte-slag system)	[53,70-72]	No data available	-
Rh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

Circular Economy Engineering - CEE



I. Rönnlund, M.A. Reuter, S. Horn, J. Aho, M. Päällysaho, L. Ylimäki, T. Pursula (2016):
Sustainability indicator framework implemented in the metallurgical industry:
Part 1-A comprehensive view and benchmark,
Part 2-A case study from the copper industry, International Journal of Life Cycle Assessment (both in press).

CEE: Link CAD & Smelter to Recycling Index



M.A. Reuter, A. van Schaik, J. Gediga (2015): Simulation-based design for resource efficiency of metal production and recycling systems, Cases: Copper production and recycling, eWaste (LED Lamps), Nickel pig iron, International Journal of Life Cycle Assessment, 20(5), 671-693.

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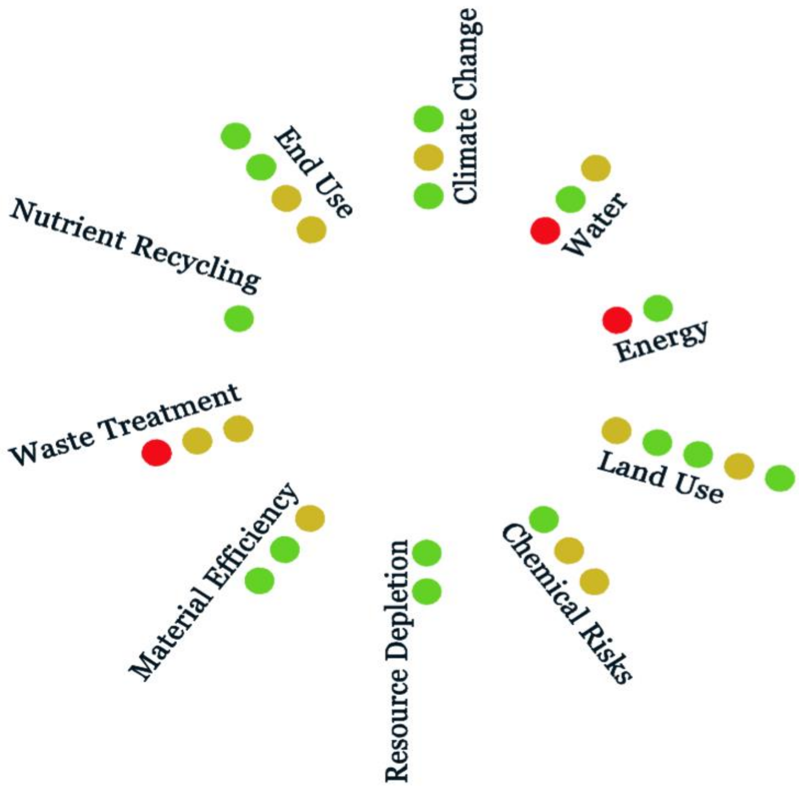
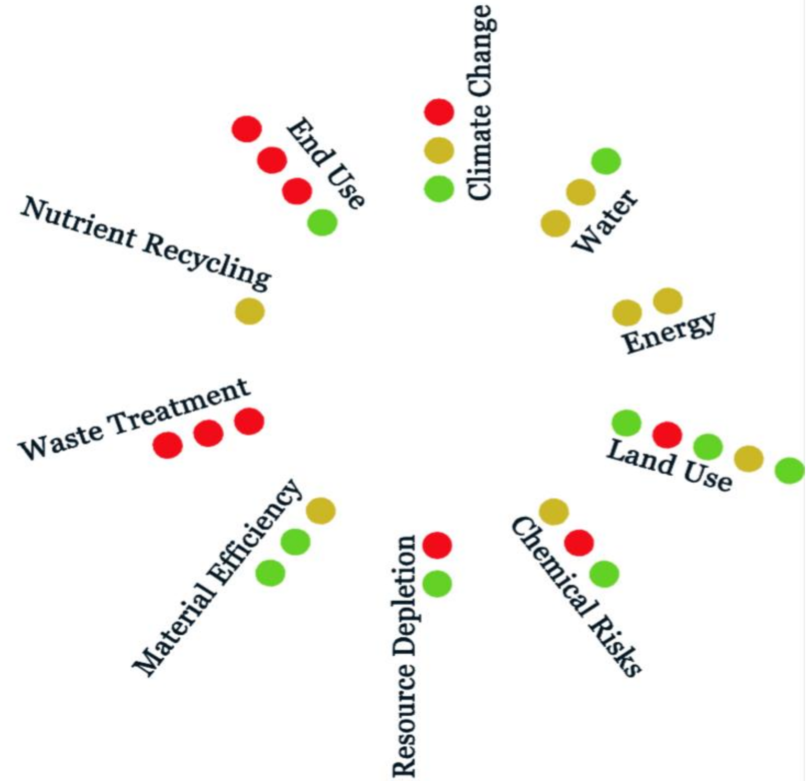
CEE: Comparing solutions relative to baseline

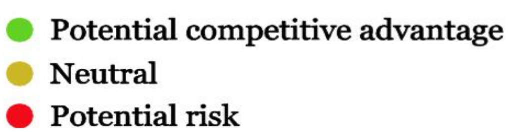
I. Rönnlund, M.A. Reuter, S. Horn, J. Aho, M. Päällysaho, L. Ylimäki, T. Pursula (2016): Sustainability indicator framework implemented in the metallurgical industry: Part 1-A comprehensive view and benchmark, Part 2-A case study from the copper industry, International Journal of Life Cycle Assessment (online).



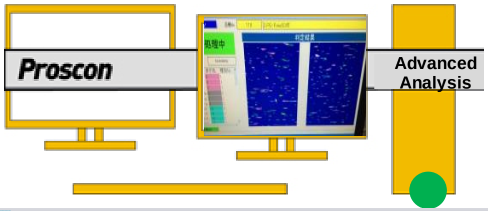
CE Product 1



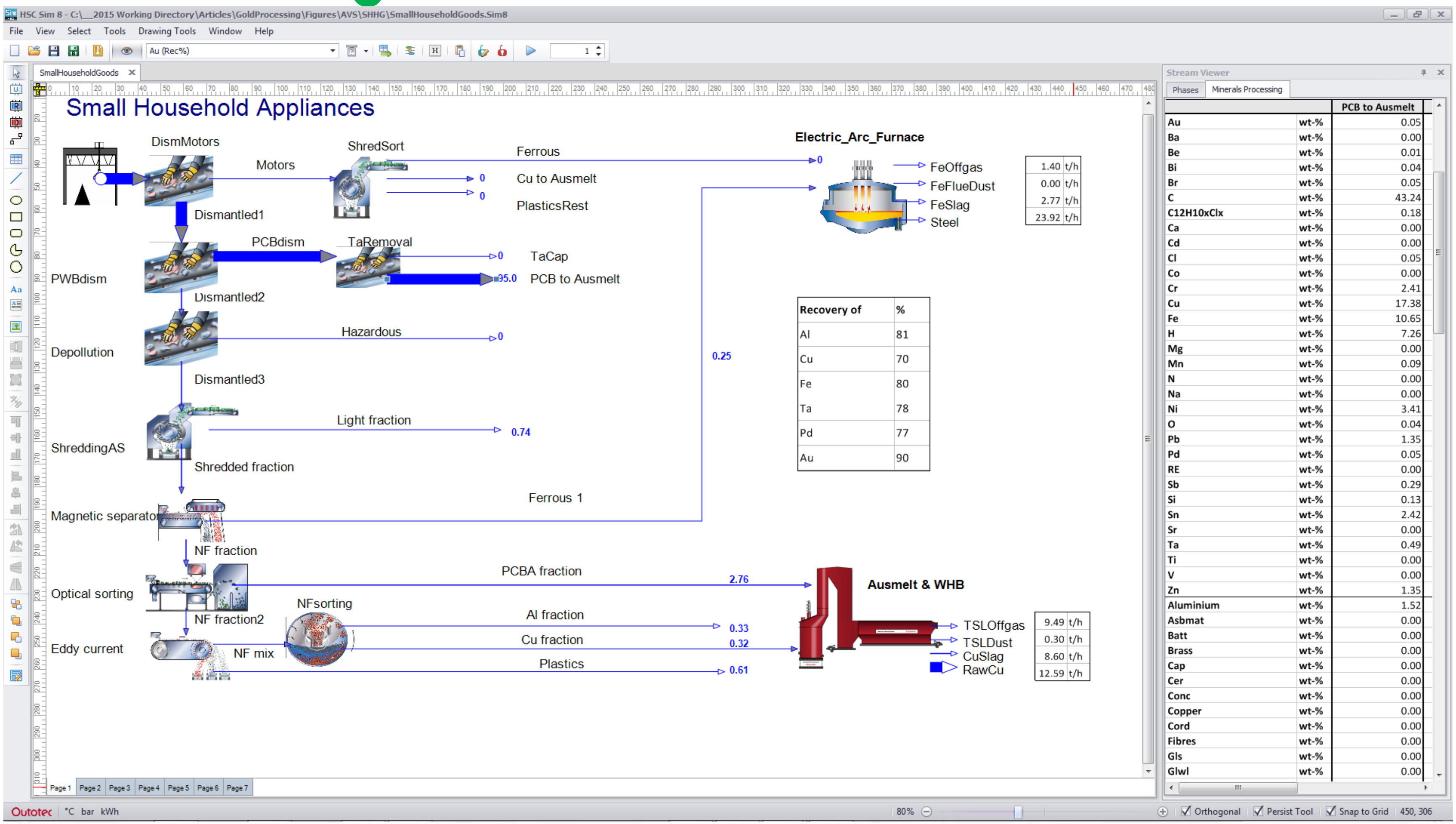
CE Product 2



CEE: Real-time optimization & simulation



- ❖Analytics & big data analysis platform
- ❖Simulation and optimization platform
- ❖Link back to product design – key innovation



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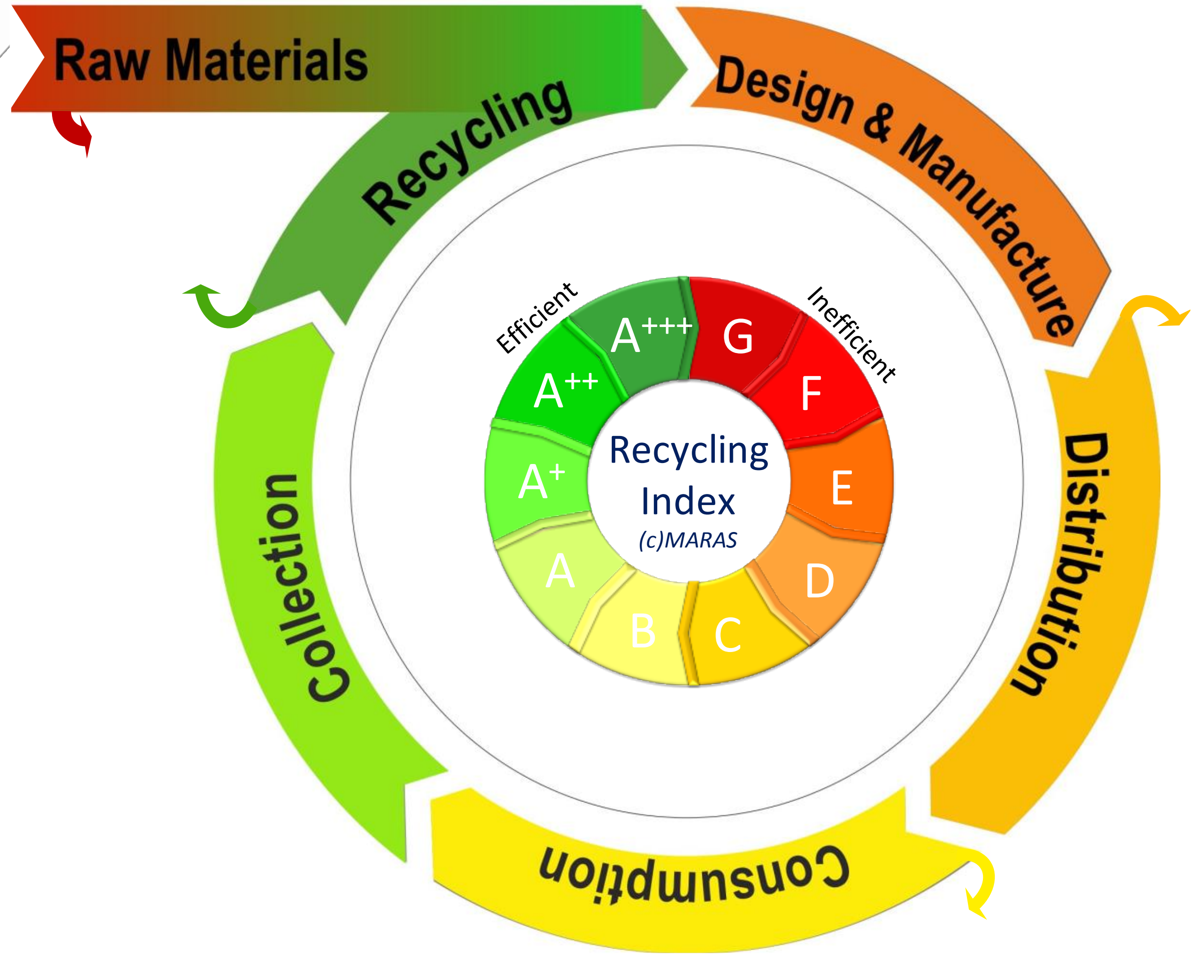
Is  sustainable in a CE



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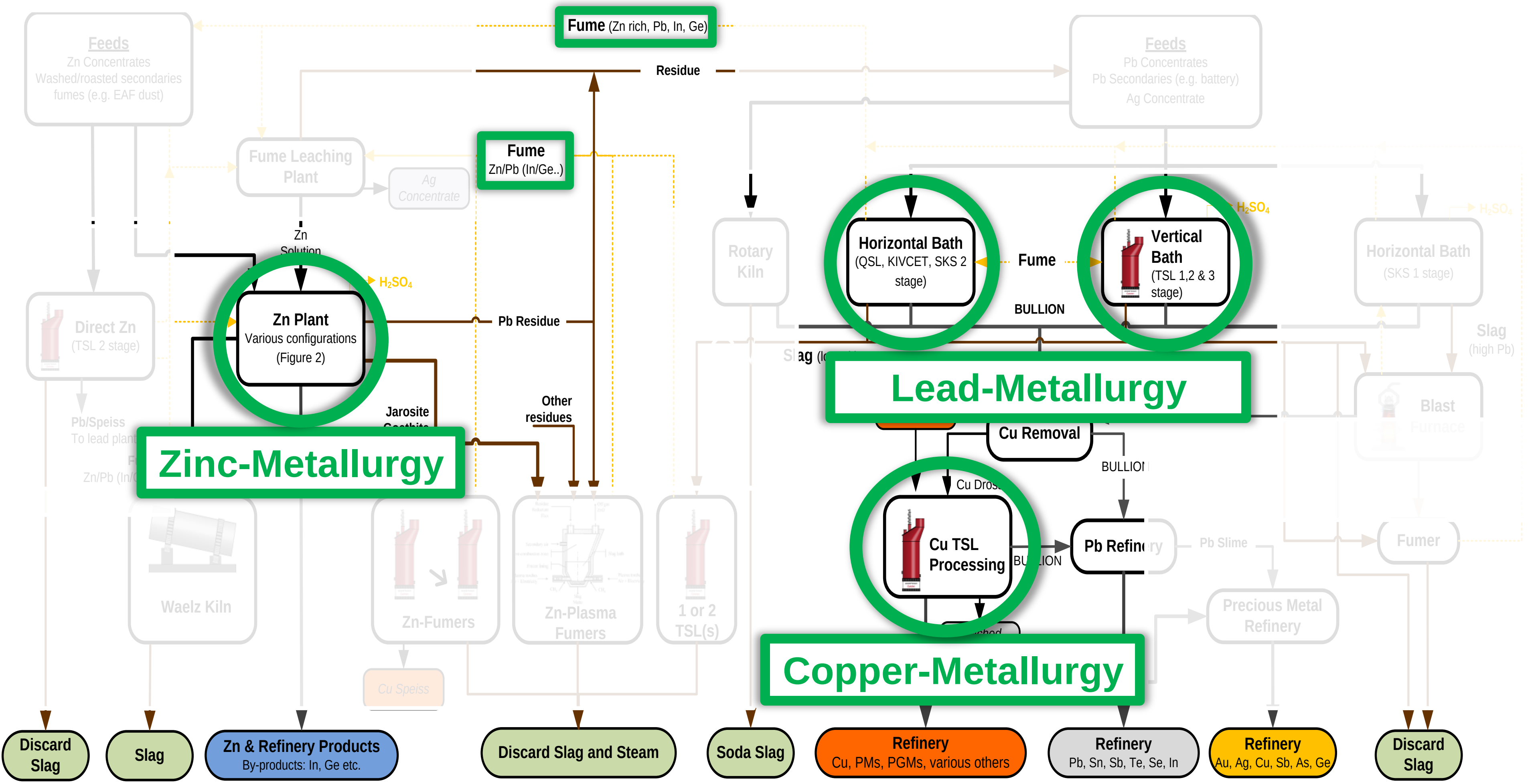
Summary

- 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



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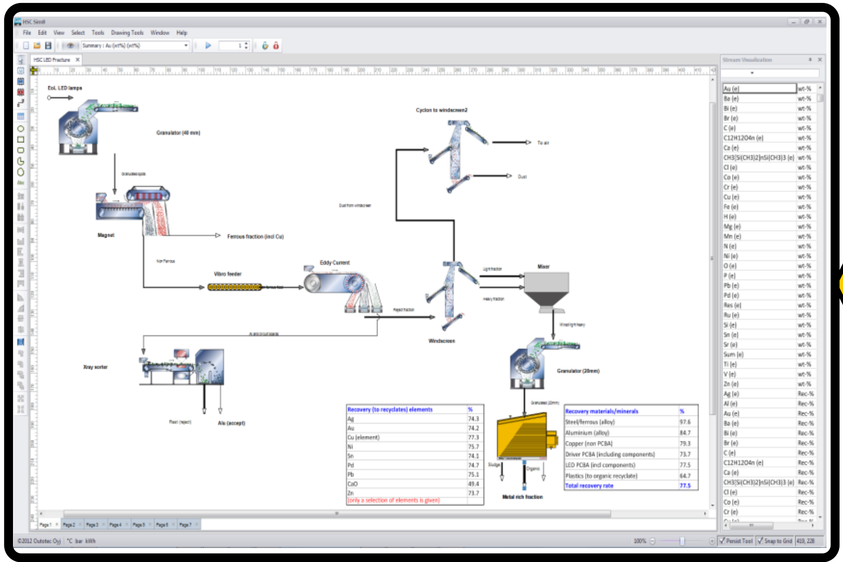
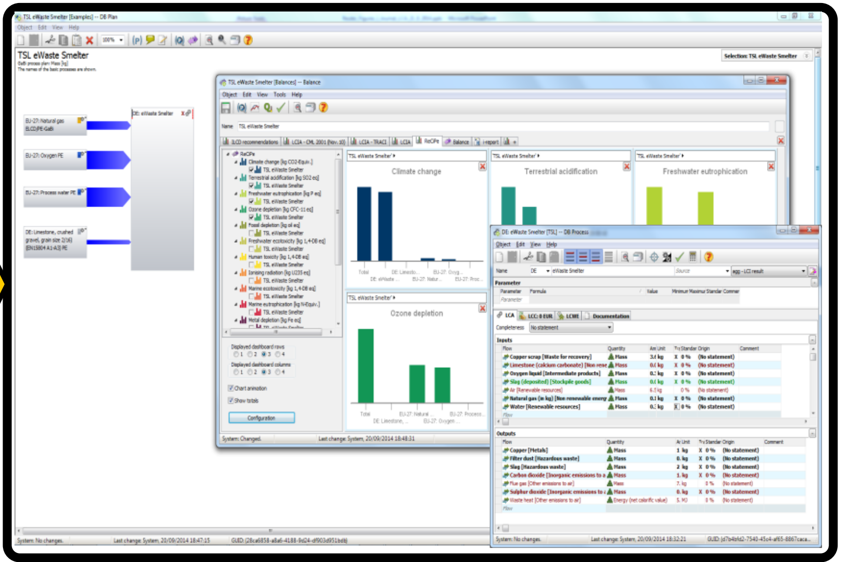
Circular Economy Engineering: CEE





<u>BAT, Flow Sheets & Recycling System Maximizing Resource Efficiency – Benchmarks</u>

$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 CO_2 / t Product

kg SO_x / t Product

g NO_x / t Product

m^3 Water / t Product *(including ions in solution)*

kg Residue / t Product *(including composition)*

kg Fugitive Emissions / t Product

kg Particulate Emissions / t Product

Etc.

<u>Environmental Indicators based on BAT Driving Benchmarks of Industry</u>

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...

M.A. Reuter, A. van Schaik, J. Gediga (2015): Simulation-based design for resource efficiency of metal production and recycling systems, Cases: Copper production and recycling, eWaste (LED Lamps), Nickel pig iron, <u>International Journal of Life Cycle Assessment</u>, 20(5), 671-693.