

The (Geo)Metallurgy of the Circular Economy

Markus A. Reuter

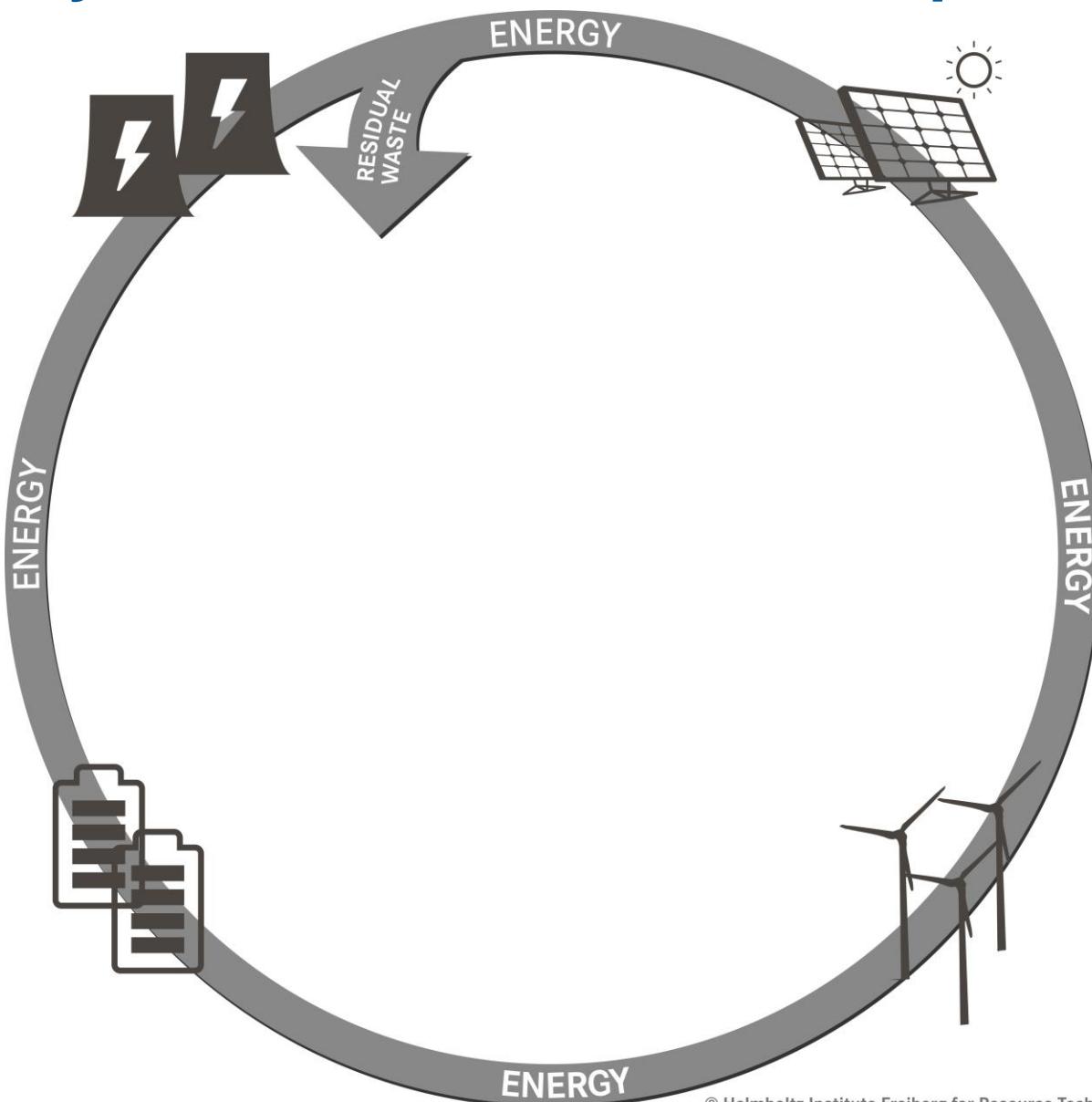
From: M.A. Reuter (2016): Digitalizing the Circular Economy-Circular Economy Engineering defined by the metallurgical Internet of Things-2016 TMS EPD Distinguished Lecture Award, USA, Metallurgical Transactions B (<http://link.springer.com/article/10.1007/s11663-016-0735-5>).

Prof. Dr. Dr. h.c. Markus A. Reuter

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Energy system often considered separately...

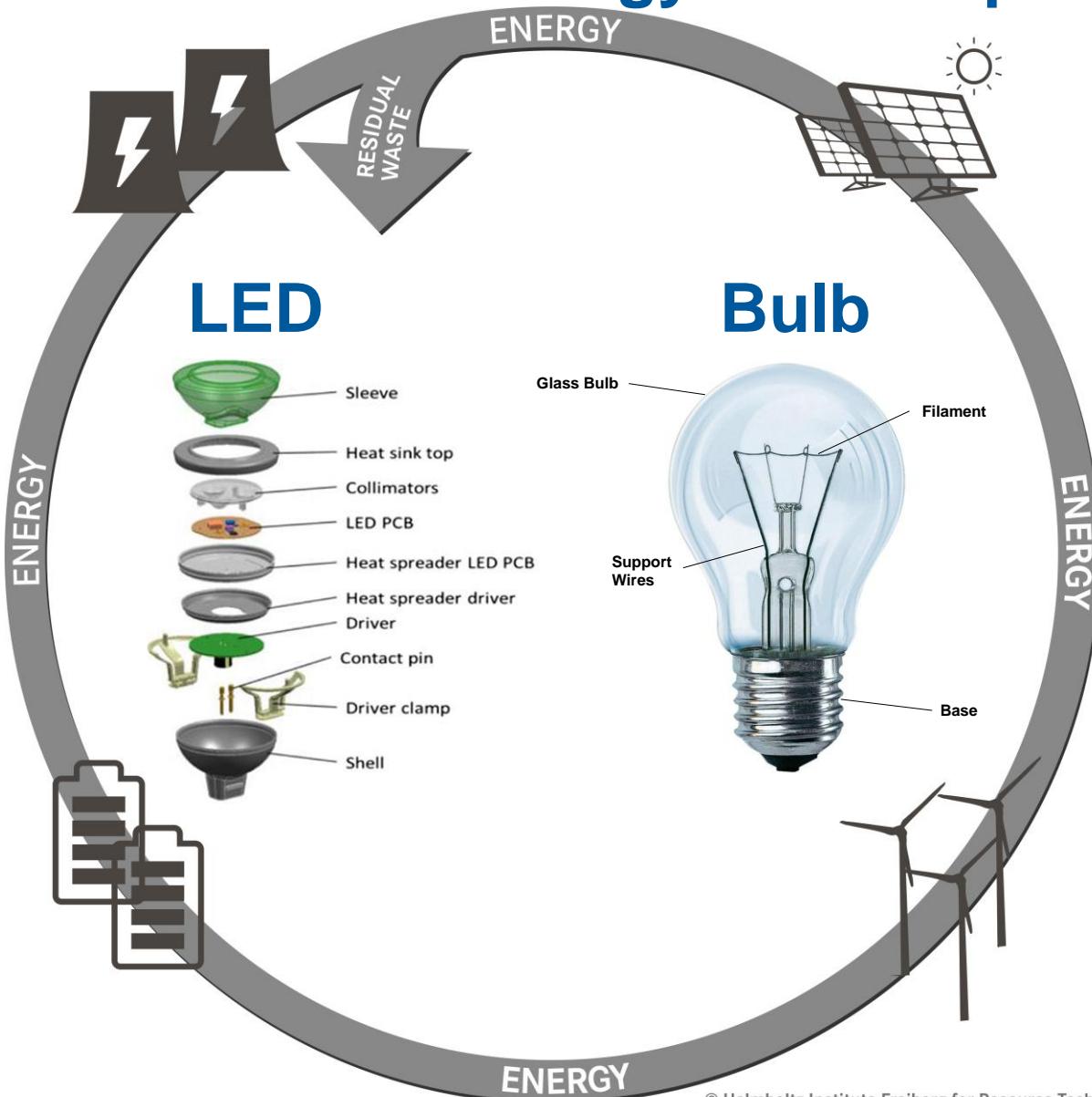


We talk about energy efficiency...



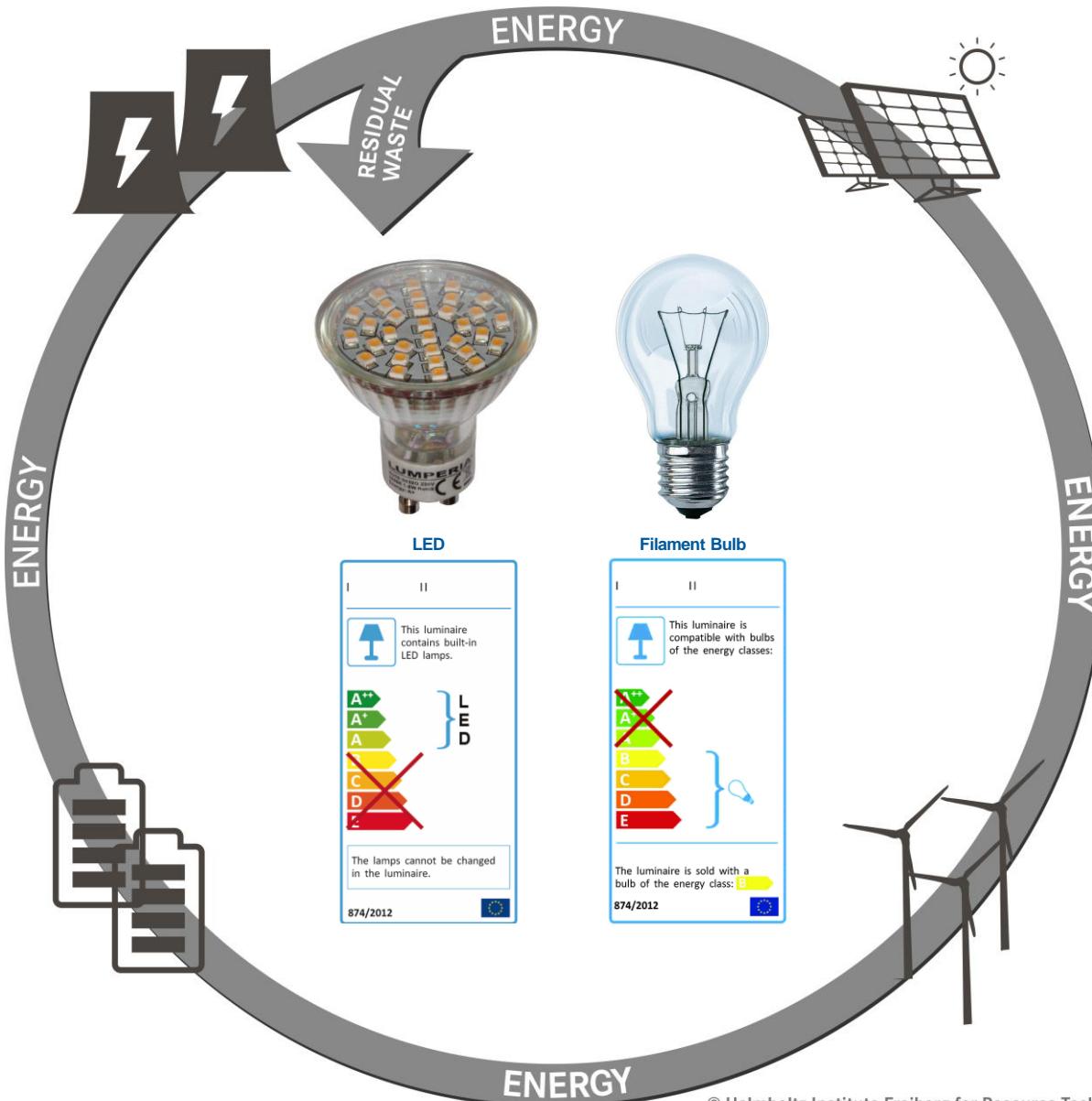
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Forgotten is the complexity of renewable energy systems + embodied energy and footprint...



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Which is more resource efficient?



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How does complexity affect resource efficiency?

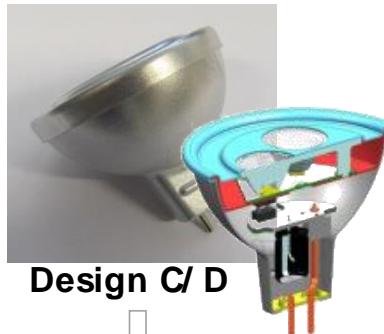
Different LED lamp (Re)Designs



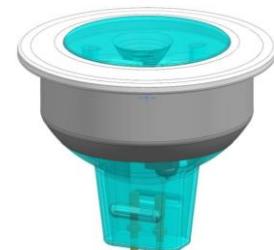
Design A



Design B



Design C/ D



Design E

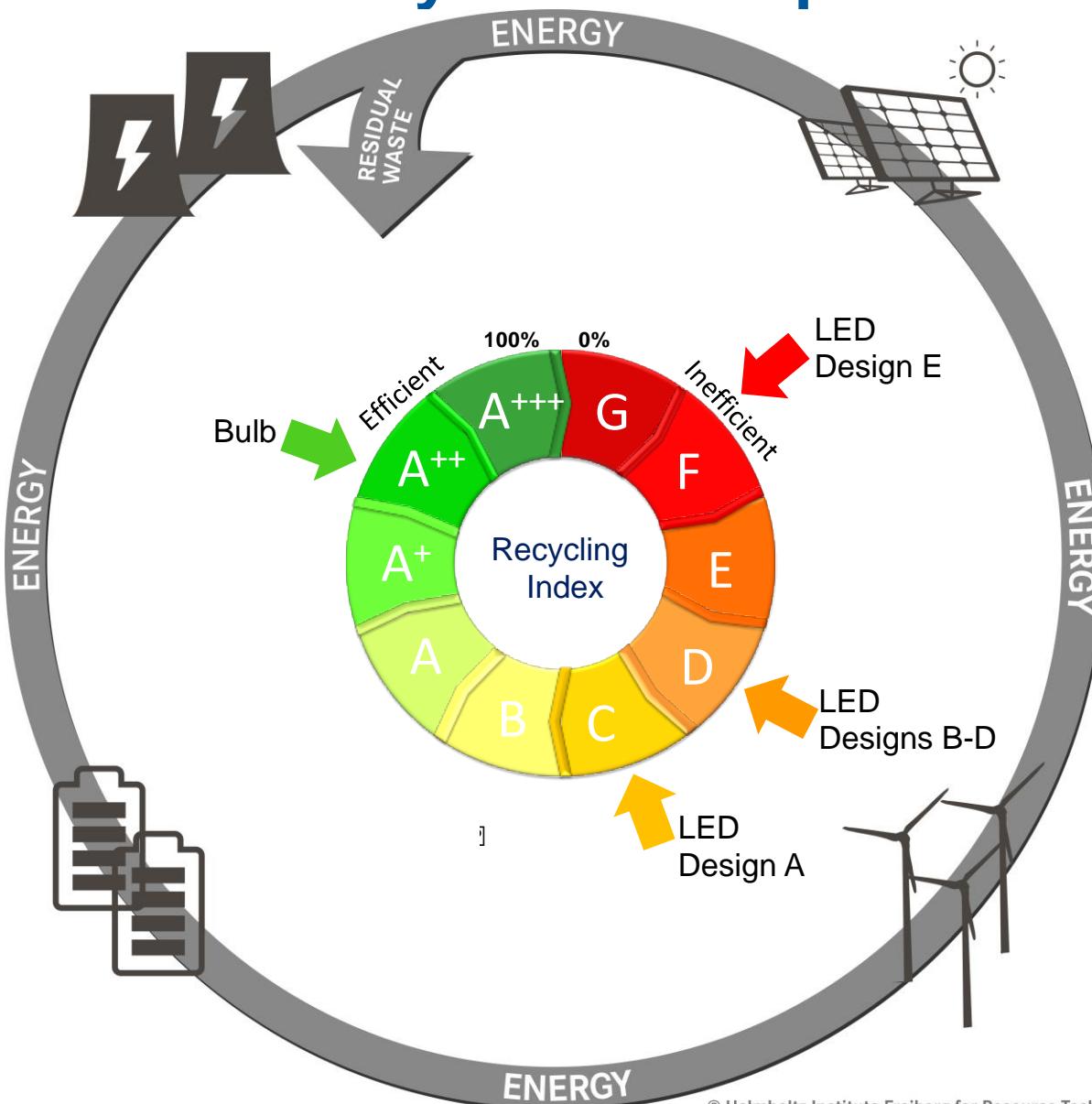
Particle/ fragment composition (liberation) after shredding



Different recyclates from LED lamp recycling : Ferrous, PCBA/ metal rich, plastics, aluminium

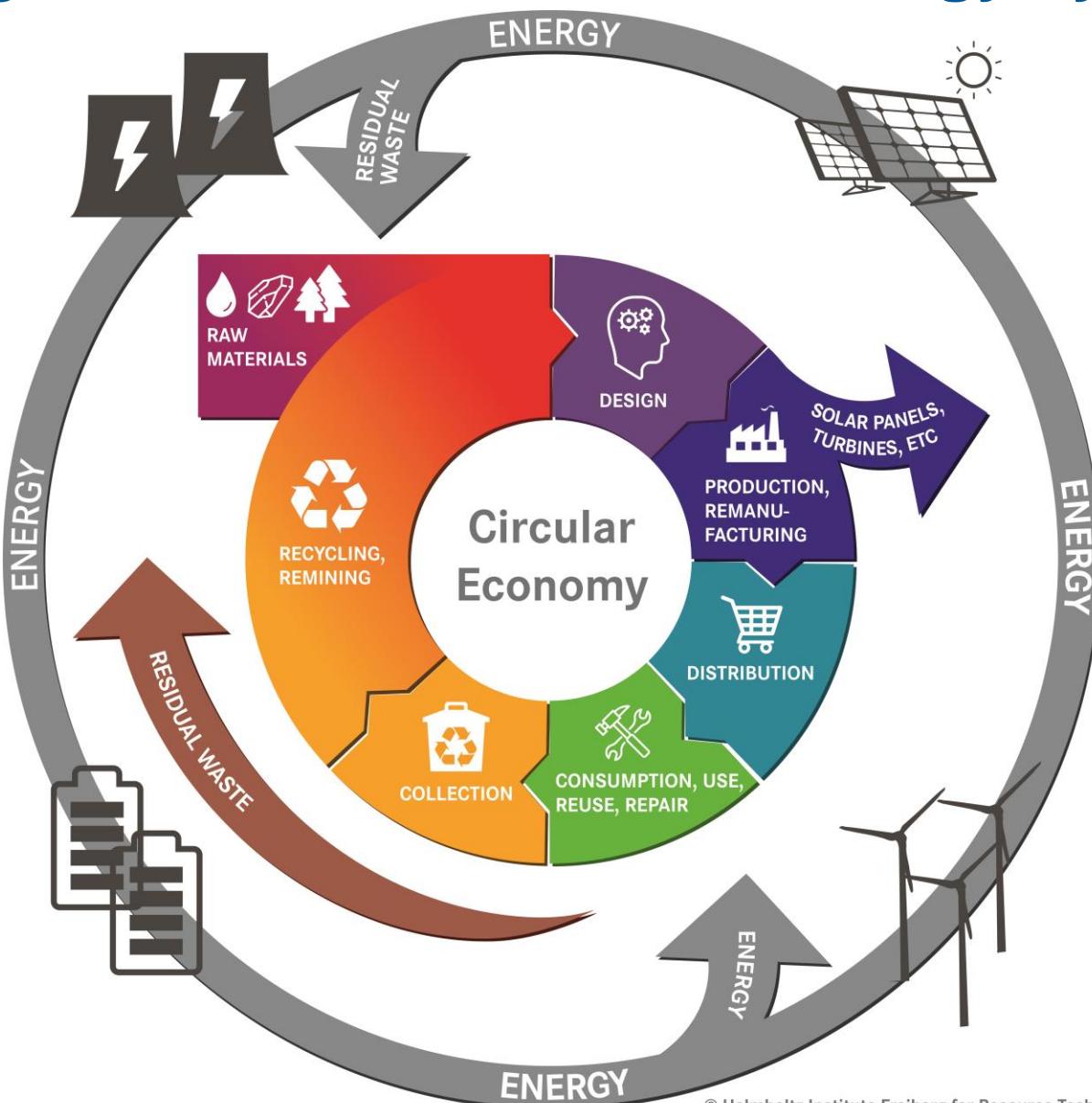


...and ultimately also how much material can truly flow back into the system to improve RE?



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Linking resources, materials & energy systems!



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So how do we optimize the “urban mine”?

(Geo)Metallurgy a key to the system?



Circular Economy Engineering – The tools...

The screenshot shows the main interface of HSC Chemistry 9. At the top, there is a navigation bar with icons for Outotec Technologies, HSC ver: 9.0.0, User: Antti Roine, and Licensee: Outotec. Below the navigation bar is the title "HSC Chemistry 9". The interface features a grid of tool icons, each with a name and a brief description. Some icons are highlighted with yellow boxes:

- Bal**: Heat & Material Balances
- Exergy**: Exergy Calculations
- Gem**: Equilibrium Computation
- Thermodynamic**: Thermodynamic Properties
- MLA**: Mineral Database
- Simulation**: Flowsheet Simulation
- Wat**: Water Calculator

Other visible icons include:

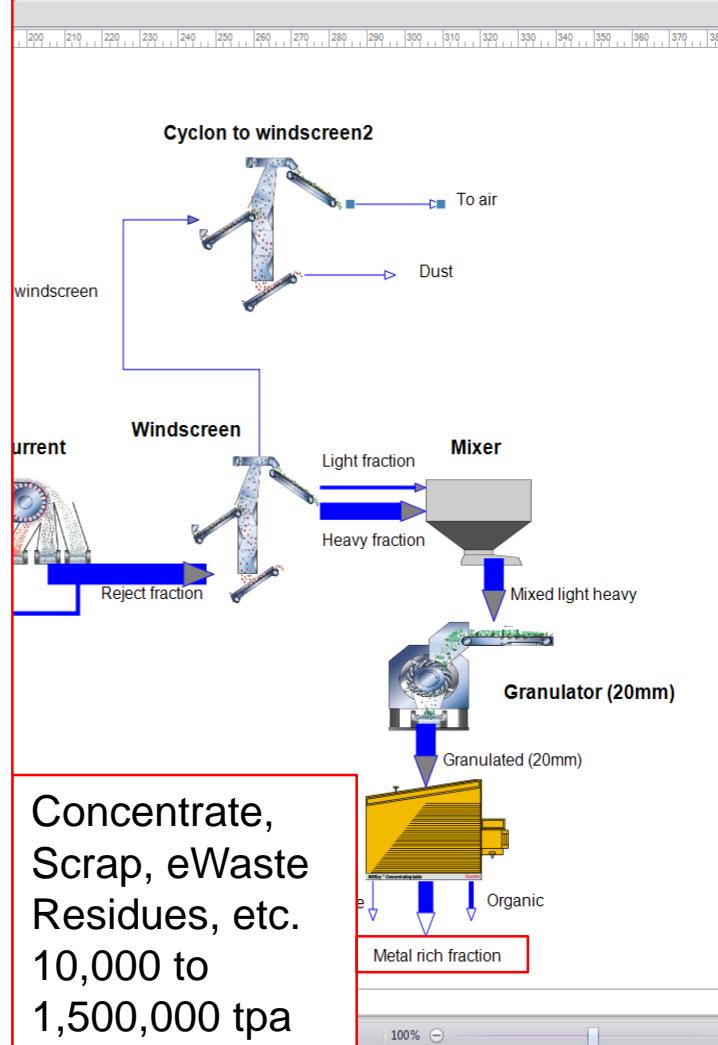
- Aqu**: Aqueous Solutions
- Ben**: Benson Estimation
- Con**: Species Converter
- Exe**: Exergy Calculations
- Ge**: Mineral Database
- HTr**: Heat Loss Calculator
- Dat**: Data Processing
- DB**: H, S and Cp Database
- Geo**: Mineral Database
- Map**: Stability Diagrams
- Dia**: H, S, Cp and G Diagrams
- Ele**: Periodic Chart
- Lpp**: Material Stock
- Wat**: Water Calculator
- Mea**: Measure Units
- Sam**: Sampler Module
- Tpp**: Stability Diagrams
- ?**: Help Module

On the left side, there are four large images with corresponding labels:

- Technologies**: An image of Earth from space.
- Products & Services**: An image of a modern city skyline.
- Sustainability**: An image of a green landscape with water.
- Research & Development**: An image of a red material being processed.

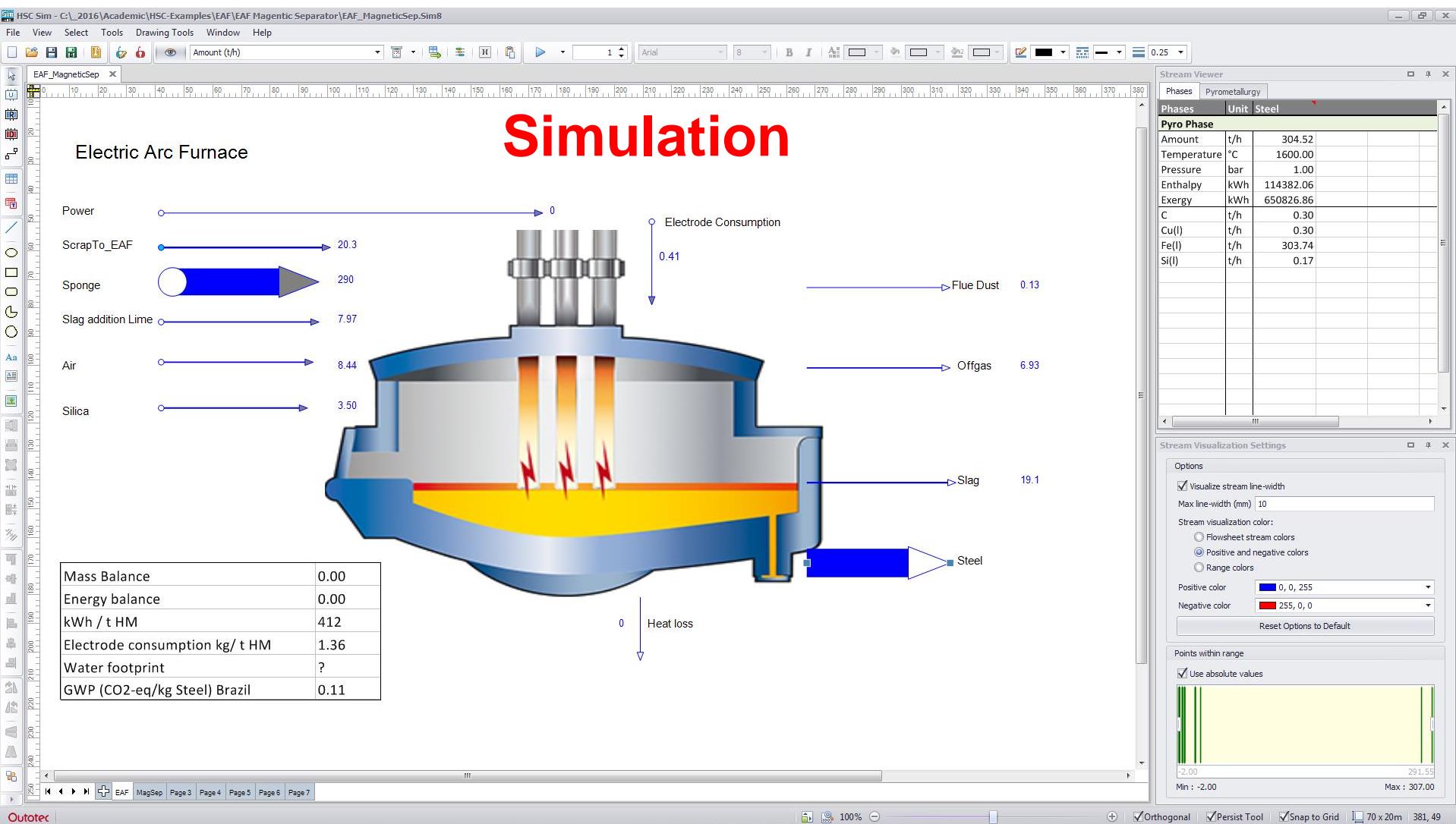
At the bottom left, there is a footer note: "Sustainable Process Technology and Engineering - Continuous Research and Development | © Outotec, Research Center, Antti Roine". At the bottom right, there is a logo for "Outotec".

Circular Economy Engineering – The tools...

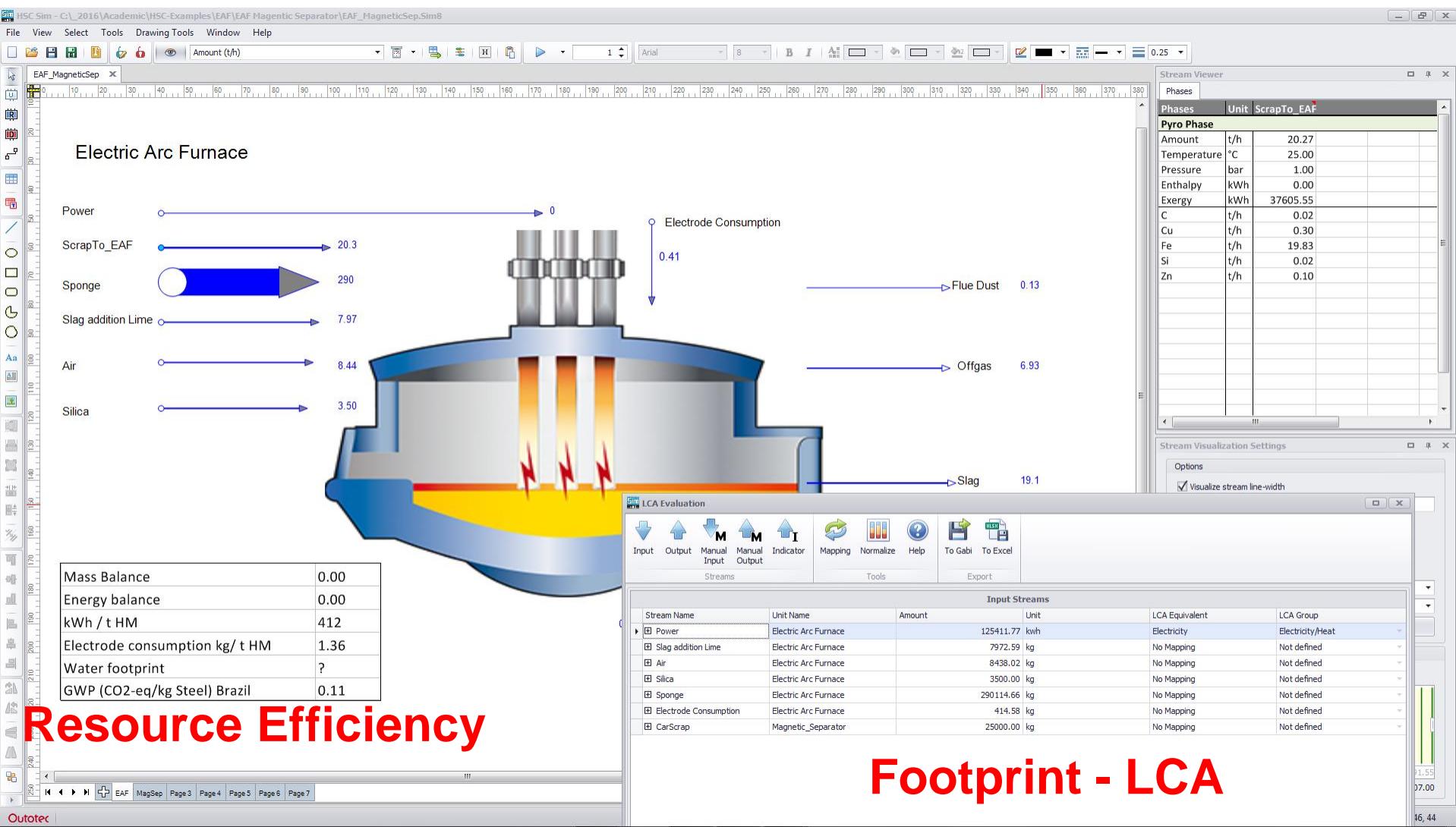


Stream Viewer		
Phases		Minerals Processing
		To air
Summary		
Total Solids	t/h	0.01
Total Gas	t/h	0.00
Total Liquid	t/h	0.05
Pulp Flowrate	t/h	0.06
Pulp Volumetric Flow Rate	m ³ /h	0.05
Solids SG	g/cm ³	2.81
Liquid SG	g/cm ³	1.00
Pulp SG	g/cm ³	1.12
% Solids	%	16.84
Solids Recovery	%	0.00
Liquid Recovery	%	0.00
Ag	wt-%	0.01
Al	wt-%	5.42
As	wt-%	0.00
Au	wt-%	0.01
Be	wt-%	0.00
Bi	wt-%	0.00
Br	wt-%	0.01
C	wt-%	17.81
C12H10xCx	wt-%	26.39
Ca	wt-%	1.27
Cd	wt-%	0.00
Cl	wt-%	0.01
Co	wt-%	0.00
Cr	wt-%	0.27
Cu	wt-%	7.89
Fe	wt-%	2.43
H	wt-%	2.99
N	wt-%	1.19
Ni	wt-%	0.91
O	wt-%	15.37
Pb	wt-%	0.18
Pd	wt-%	0.01
Res	wt-%	0.02
Sb	wt-%	0.03
Si	wt-%	17.23
Sn	wt-%	0.33
Sum	wt-%	100.12
Zn	wt-%	0.34
Alcast	wt-%	4.43
Alwrought	wt-%	0.00
Capblueblock	wt-%	1.56

Resource efficiency of industrial systems

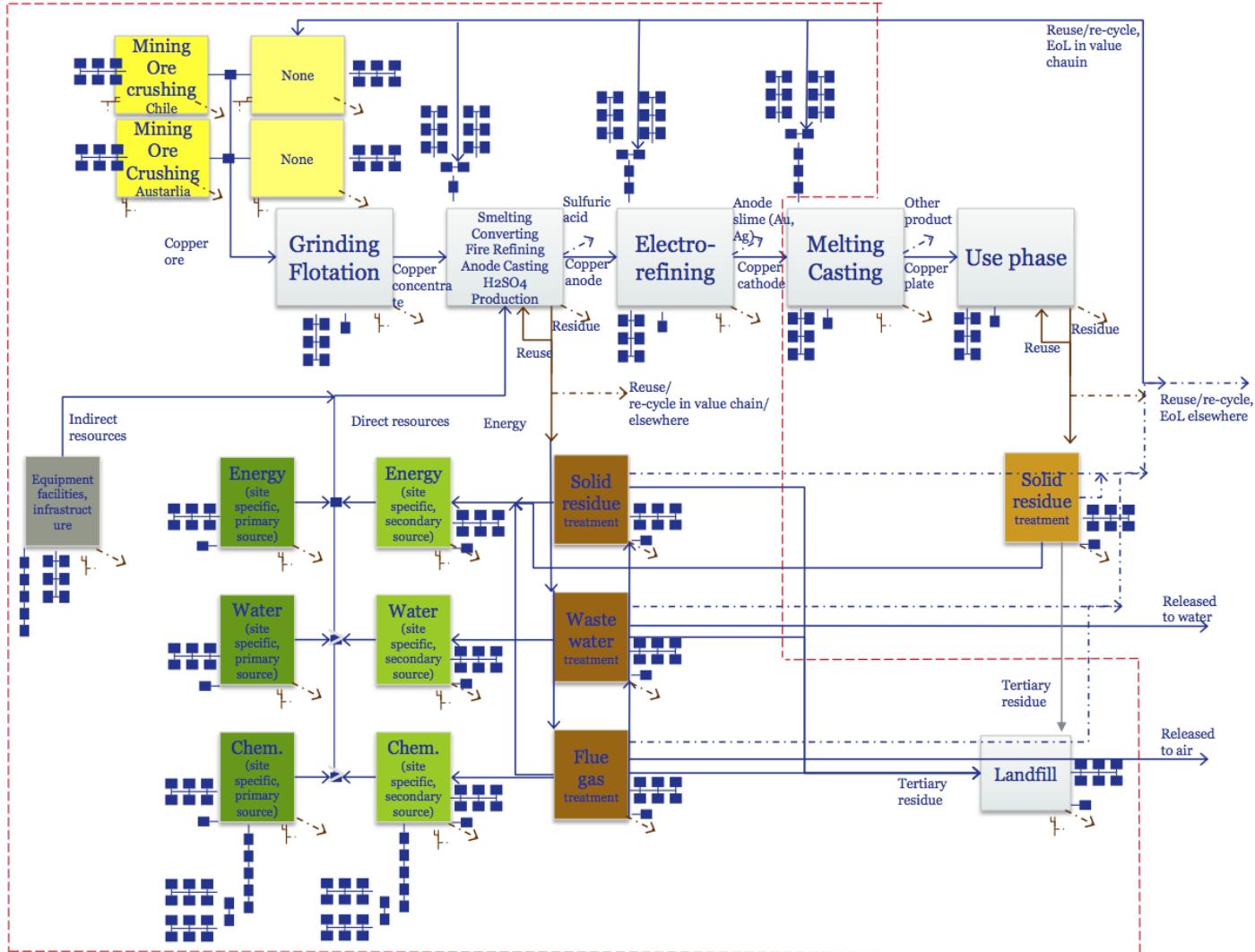


Resource efficiency of industrial systems



Resource efficiency of industrial systems - Copper

General system boundaries for case study



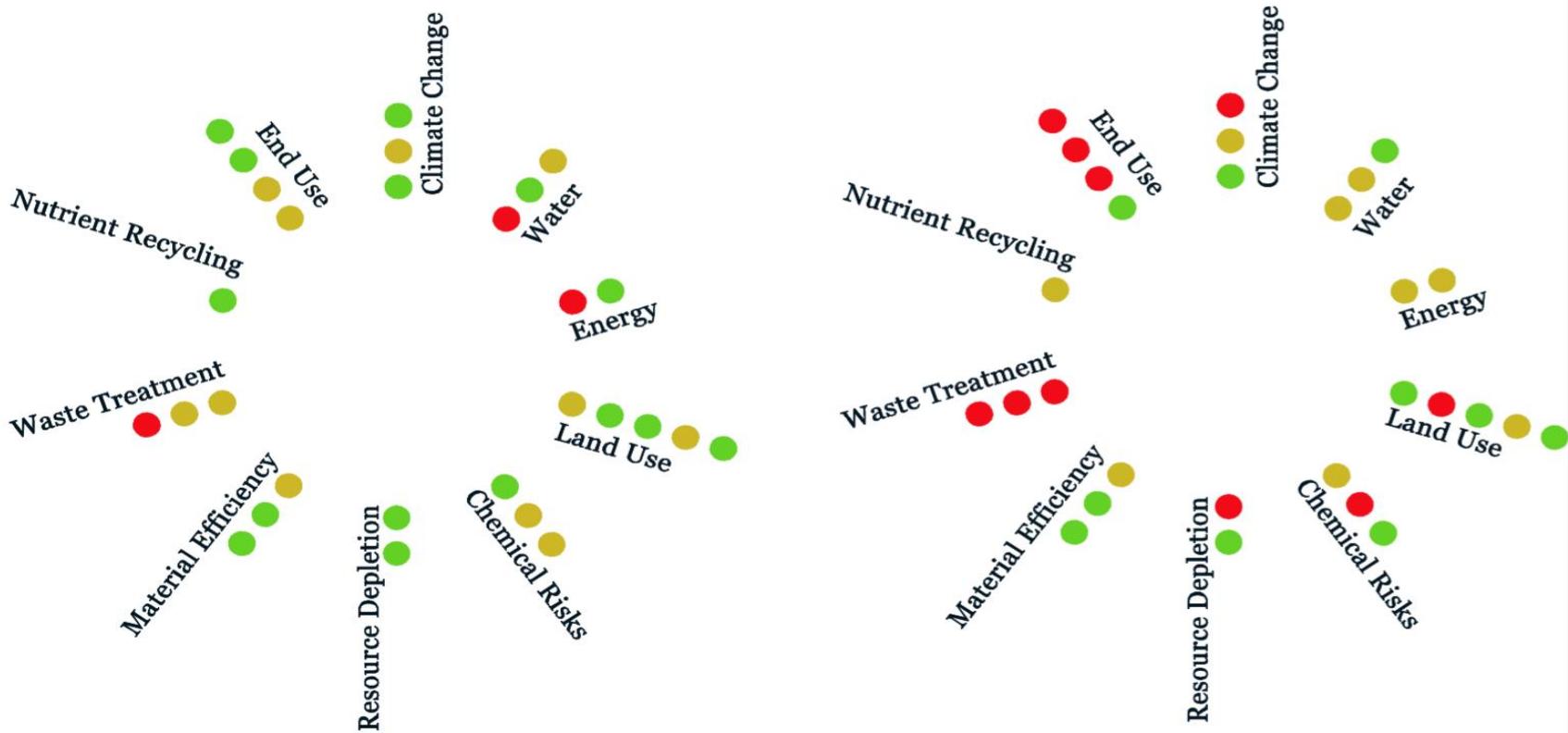
Symbols

	Value chain step: Raw material production or processing step
	Dotted arrow exits the system boundaries
	Fugitive emissions
	Other product
	Residue, recycle and reuse
	Direct resources
	Indirect resources
	Other value chain
	Direct resources used in process step: Energy, water, chemicals (site specific, primary or secondary source)
	Residue treatment step: Solid, waste water, flue gas (site specific)
	Indirect resources used in process step: Equipment, facilities, infrastructure (site specific)

Fig. 1 The scope of the analysis is signified by the golden dashed line

Quantifying Resource Efficiency

Footprint of industrial solutions relative to baseline



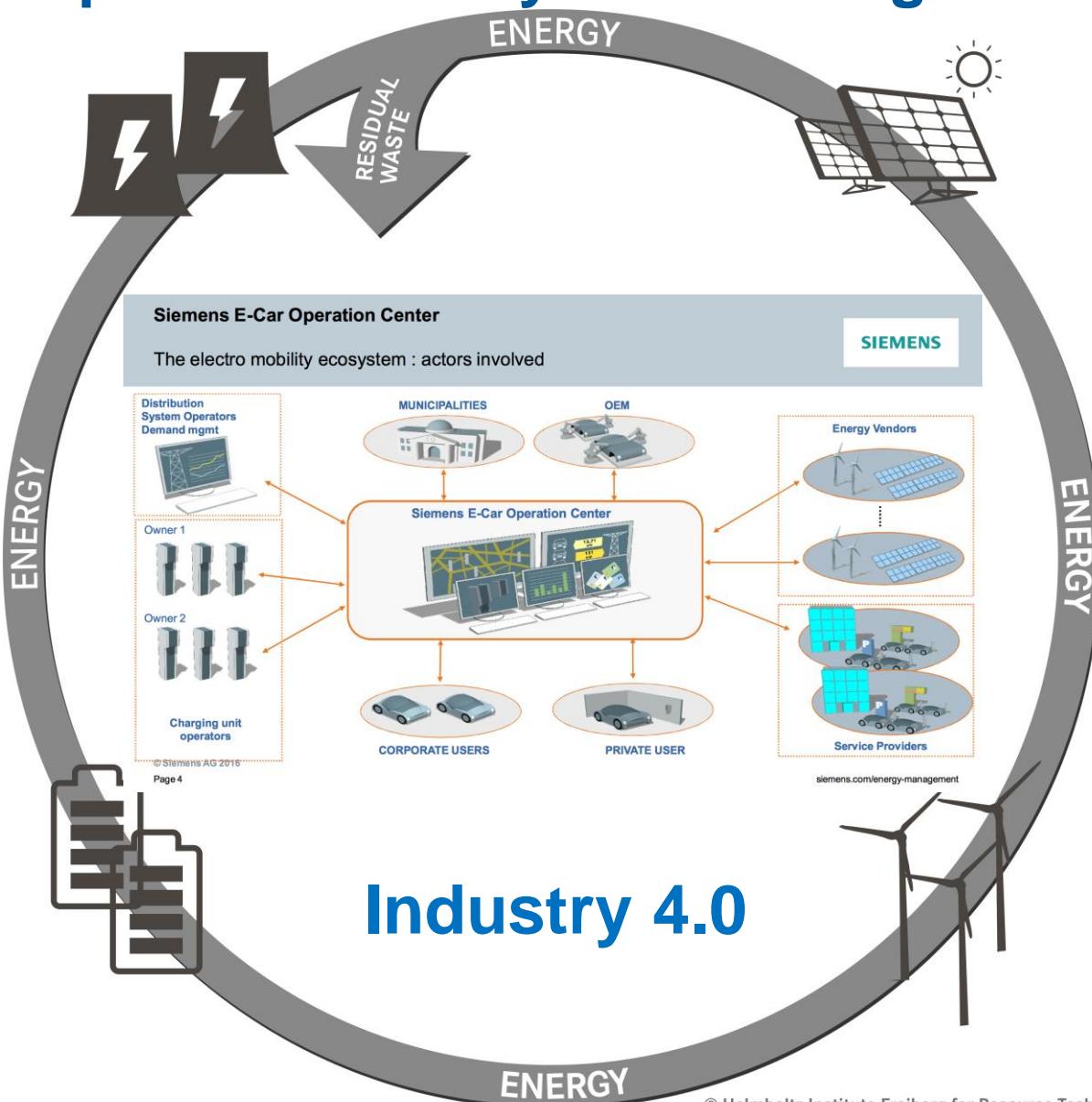
Copper System 1

- Potential competitive advantage
- Neutral
- Potential risk

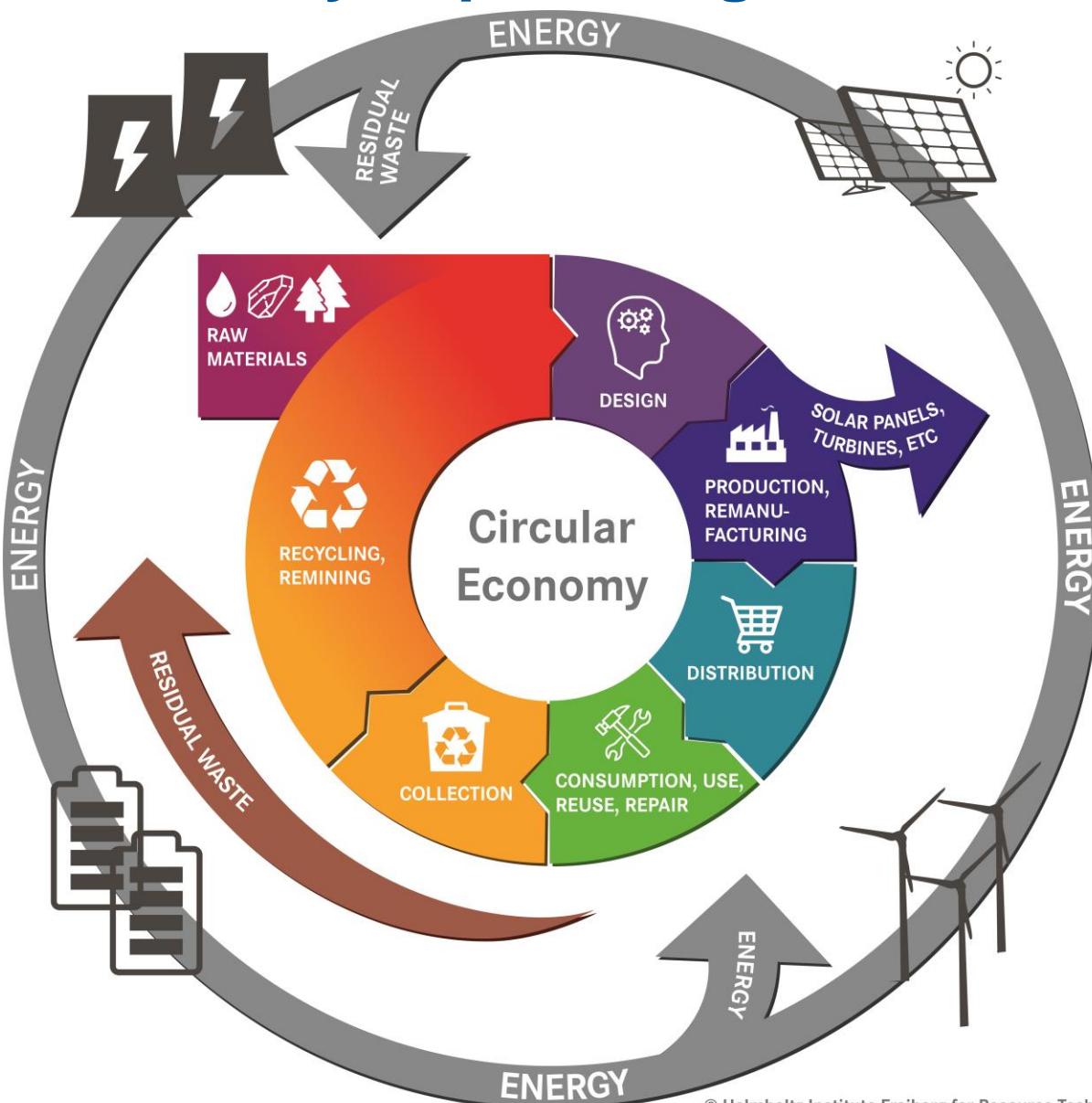
Copper System 2

I. Rönnlund, M.A. Reuter, S. Horn, J. Aho, M. Päälysaho, 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).

Has anybody spoken about the footprint & embodied energy impact of Industry 4.0? Ecological break-even?



Circular Economy: Optimizing Resource Efficiency



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