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FUNDAMENTAL LIMITS OF GREEN METAL AND MINERAL PROCESSING SUPPLY CHAINS WITHIN THE CIRCULAR ECONOMY

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Abstract

There is a lot of talk about greening society, greening the supply chain, circular economy etc. The question that needs to be answered, how green is all of this and what is the shade of green (or grey) is achievable. The circular economy integrates many stakeholders to possibly achieve this objective. To fully understand the performance of the systems an exergetic basis is required as shown in Figure 1 [1]. This implies all processes, streams, stakeholder activities etc., in the circular economy must be quantifiable in terms of the unit kW to fully understand the losses from the system. This means both the flow of mass and the exergy (both chemical and physical Ex=(H-H°)-T°(S-S°)) dissipation must be included. This should be the basis of any rigorous analysis. Life-Cycle Assessment (LCA) is too simplistic to fully understand the complex systems in these terms. Therefore, methods must be inclusive of thermochemistry, mass and heat transfer, technology etc., which all affect the economics of the circularity economy.

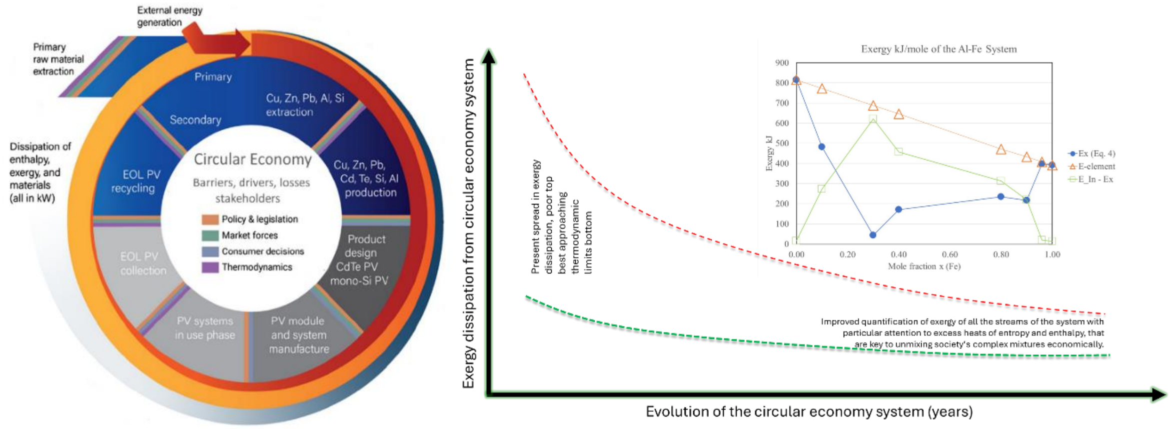


Figure 1. Various stakeholders in the circular economy, barriers as well as the exergetic downward spiral of the system [1,2].

This lecture will discuss the key role of metallurgy by applying its simulation methods and theory to understand the greenness of systems and in fact what the limits are of the system and thence of the circular economy, as reflected by Figure 2. To analyse the systems from, among others, an industry perspective, artificial intelligence (AI) techniques will be implemented, as well as simulation tools linked to LCA and similar types of methodologies [1,3].

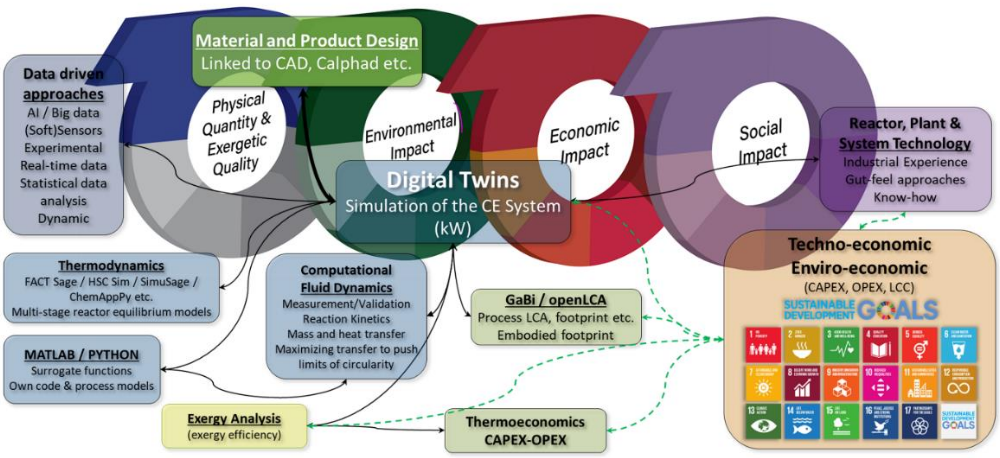
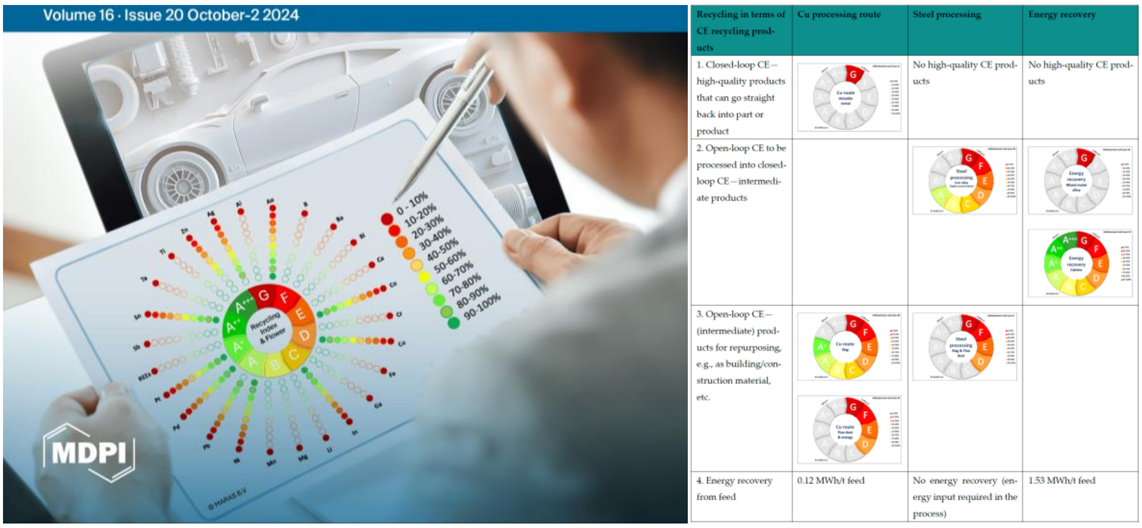


Figure 2. An overview of tools that need to be integrated to evaluate green systems on a fundamental basis [1].

As illustrations, various cases will be shown how methods and techniques have been applied to understand the fundamental limits of supply chains as a part of the circular economy. A large body of published information will be highlighted rooted in industrial practice to illustrate how far the industry has also progressed to address green issues fundamentally, while bringing a simulation basis to footprint analysis. For example, the presentation will discuss:

- *Various examples showing the simulation of metallurgical and recycling systems to understand their exergetic limits in an industrial and applied context as shown by Figure 2 [1,2].*
- *Show the analysis of supply chains including their critical metals on system performance using simulation tools. Integration of AI methods into simulation and process control in industry to push processes and systems to their physics as well as mass and heat transfer limits and thence obviously also economic limits [3].*
- *Use of Finite Element Method (FEM) to understand the liberation of particles from products [4], thus showing true design for recycling using physics to understand liberation linked to material properties.*
- *EU projects that are applying these techniques for design for recycling and show the link to product design with example from automotive and consumer electronics [5, 6]. A typical result of design for recycling of modules from the automotive industry is given by Figure 3, showing different recyclabilities of car parts as well as a recyclability label.*

In conclusion, the methods can be used to fundamentally describe the supply chains of the circular economy and quantify the exergetic limits of the circular economy. For this we advanced the theory of exergy [2] to include the thermodynamic approaches such as represented by FactSage [9] and discuss how this must be used in the analysis of supply chains within the circular economy.



Recycling in terms of CE recycling products	Cu processing route	Steel processing	Energy recovery
1. Closed-loop CE—high-quality products that can go straight back into part or product	Cu route Valuable metal	No high-quality CE products	No high-quality CE products
2. Open-loop CE to be processed into closed-loop CE—intermediate products		Steel processing Iron alloy	Energy recovery Mixed metal alloy; Energy recovery Calcine
3. Open-loop CE—(intermediate) products for repurposing, e.g., as building/construction material, etc.	Cu route Slag; Cu route Flue dust & energy	Steel processing Slag & Flue dust	
4. Energy recovery from feed	0.12 MWh/t feed	No energy recovery (energy input required in the process)	1.53 MWh/t feed

Figure 3. Recyclability of different car parts using different recycling options and flowsheets with the definition of a recycling label for products [5-8].

Keywords: *Circular economy; green metal and mineral processing; AI simulation*

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