More than recycling – challenges & potentials of the Circular Economy for metals

Mehr als Recycling - Herausforderungen und Potenziale der Kreislaufwirtschaft am Beispiel von Metallen

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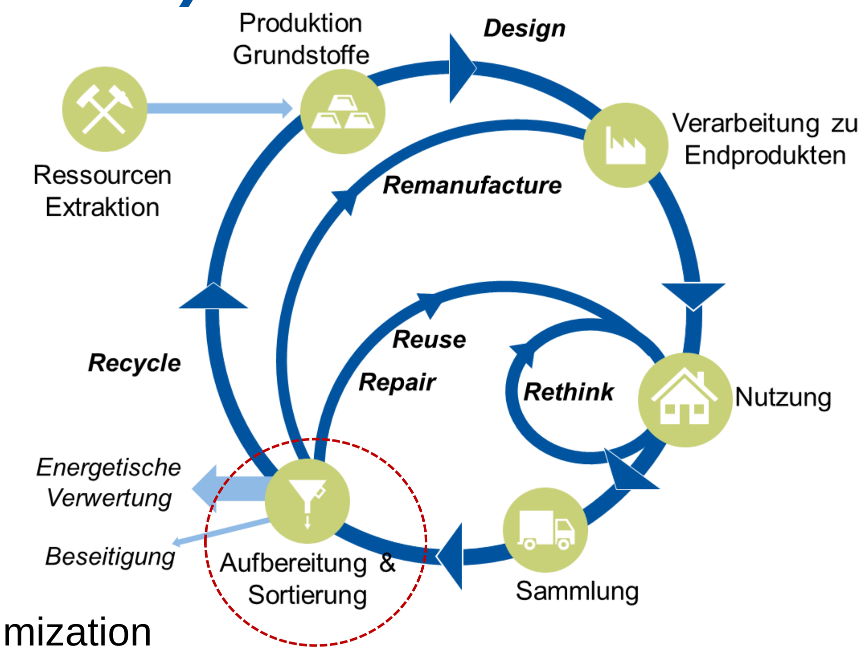
Department of anthropogenic material Cycles (ANTS)

- Reduce resource use and environmental impact
- Extend the useful life of anthropogenic substances



In the context of a sustainable circular economy, ANTS is searching for solutions and methods to keep anthropogenic material flows in cycles.

Processing & Sorting

- Material flow monitoring & process optimization
- Application of sensor technology
- Material flow characterization & process control

Modeling & Assessment

- Process simulation & product system modeling
- Life cycle sustainability assessment and material flow analysis

Circular raw material management

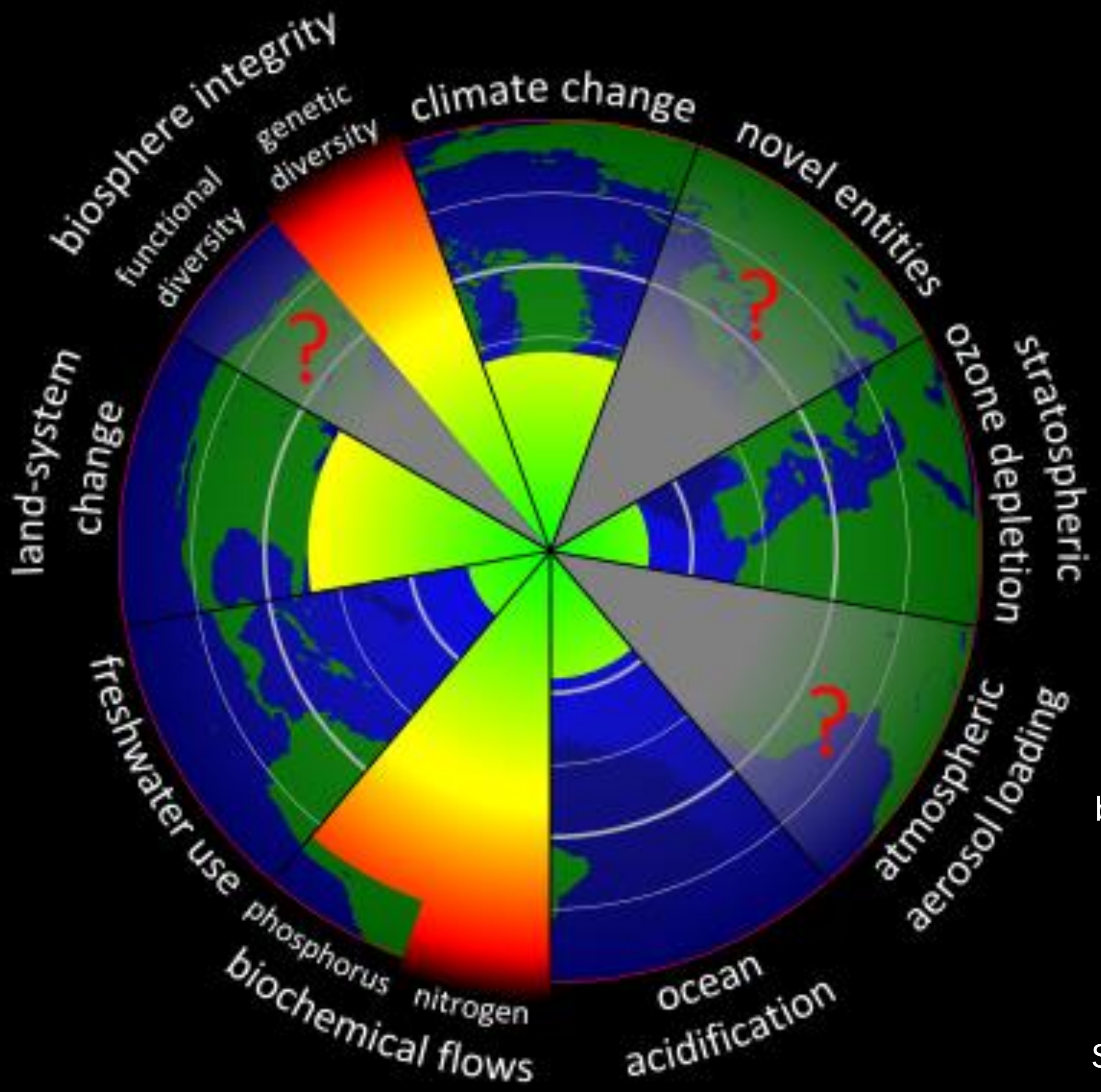
- End of Life in the focus of product development
- Development of holistic concepts
- Involvement of all stakeholders

More than recycling – challenges & potentials of the Circular Economy for metals

Agenda

- Global challenges and objectives
- The concept of Circular Economy
- Examples:
  - Reduce: New Alloys
  - Repurposing: Linking Value Chains
  - Recycling: Automated Quality Control in Metal Recovery Processes
- Conclusion

Source: https://pixabay.com/de/photos/erde-blauer-planet-erdkugel-planet-11008/



"The planetary boundaries framework defines a safe operating space for humanity based on the intrinsic biophysical processes that regulate the stability of the Earth System. […] Two core boundaries—climate change and biosphere integrity—have been identified, each of which has the potential on its own to drive the Earth System into a new state should they be substantially and persistently transgressed."

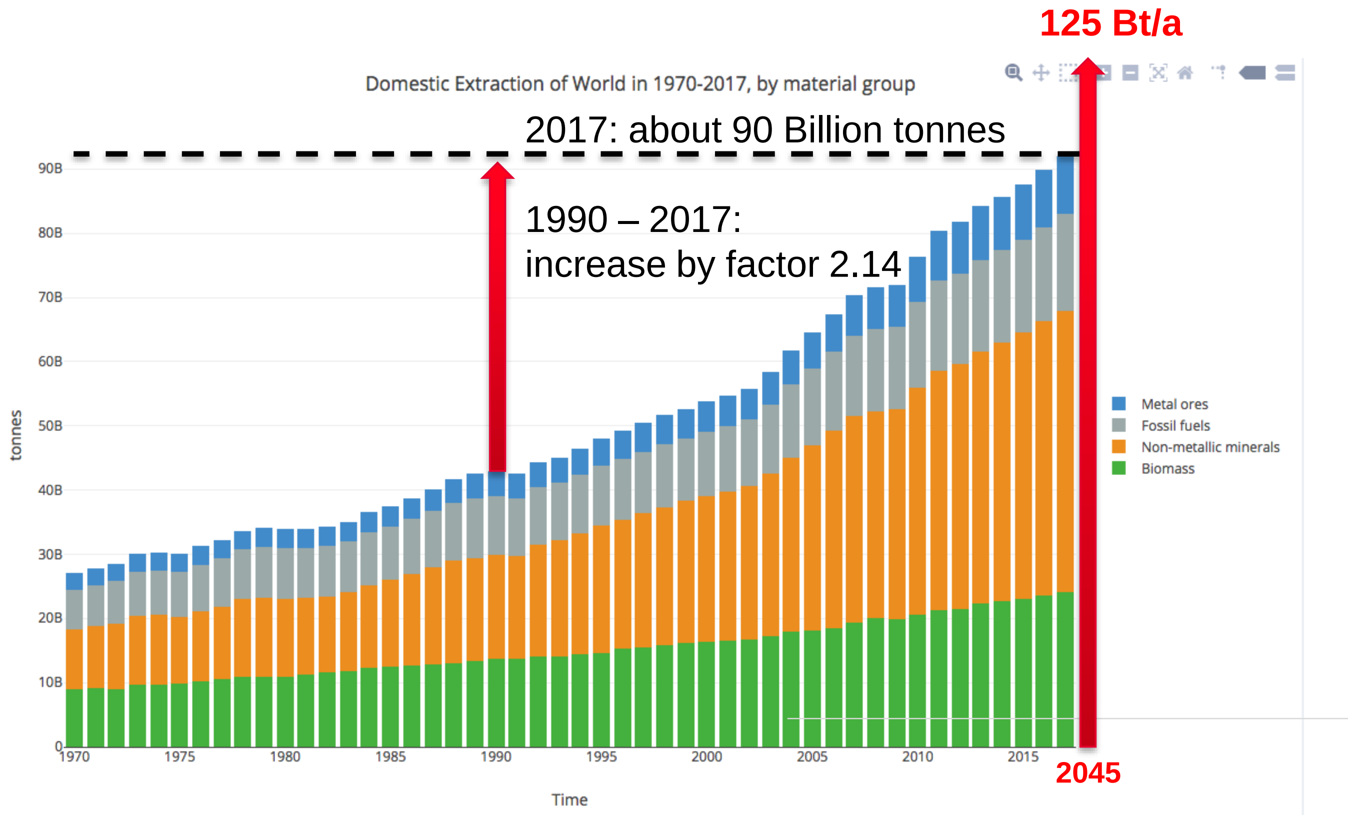
Steffen et al. 2015

Global domestic extraction

- Extraction & production of Materials: 23% global GHG emissions (2015)

Metals (Fe, Al, Cu etc.)	4.8 Gt CO_2eq
non-metallic minerals (Cement, lime, plaster etc.)	4.4 Gt CO_2eq
Plastics	1.5 Gt CO_2eq
Wood production	0.9 Gt CO_2eq

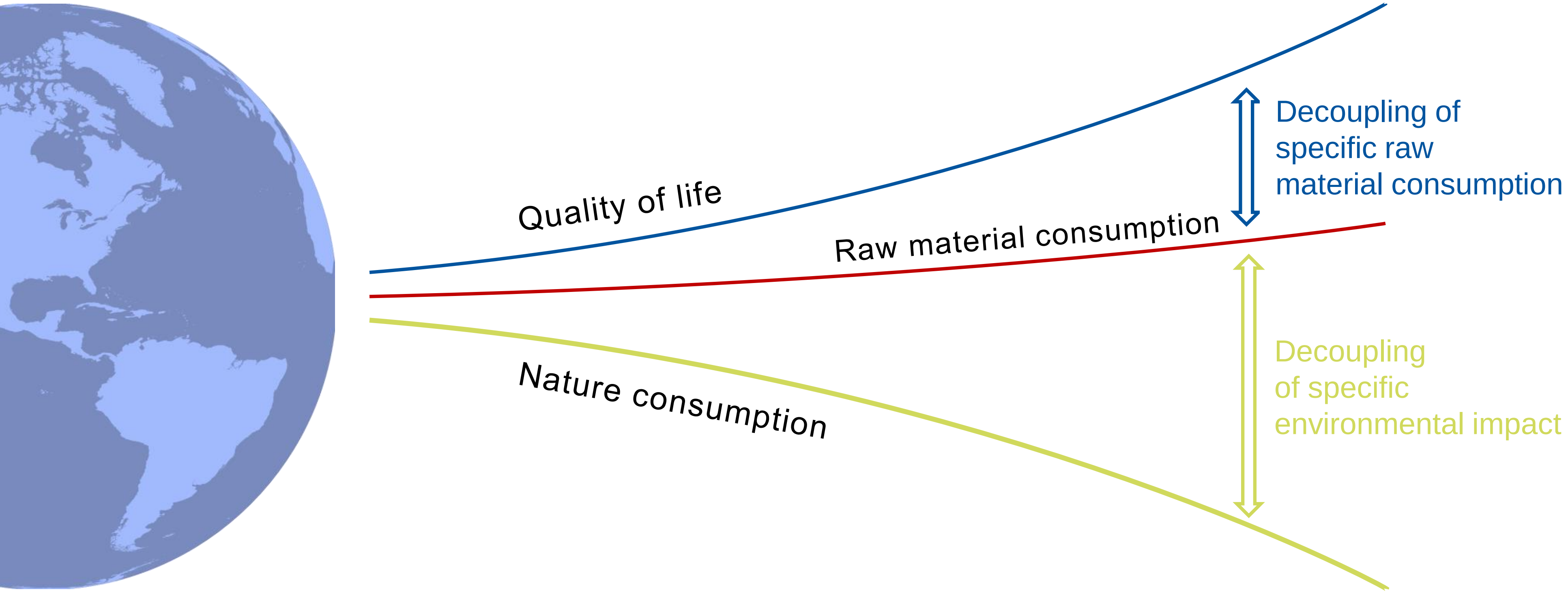
International Resource Panel 2019



http://www.materialflows.net/visualisation-centre/

Sustainable development

Twofold decoupling of resource consumption and quality of life/prosperity



Efficiency

- less resources – same function

Consistency

- Closing loops

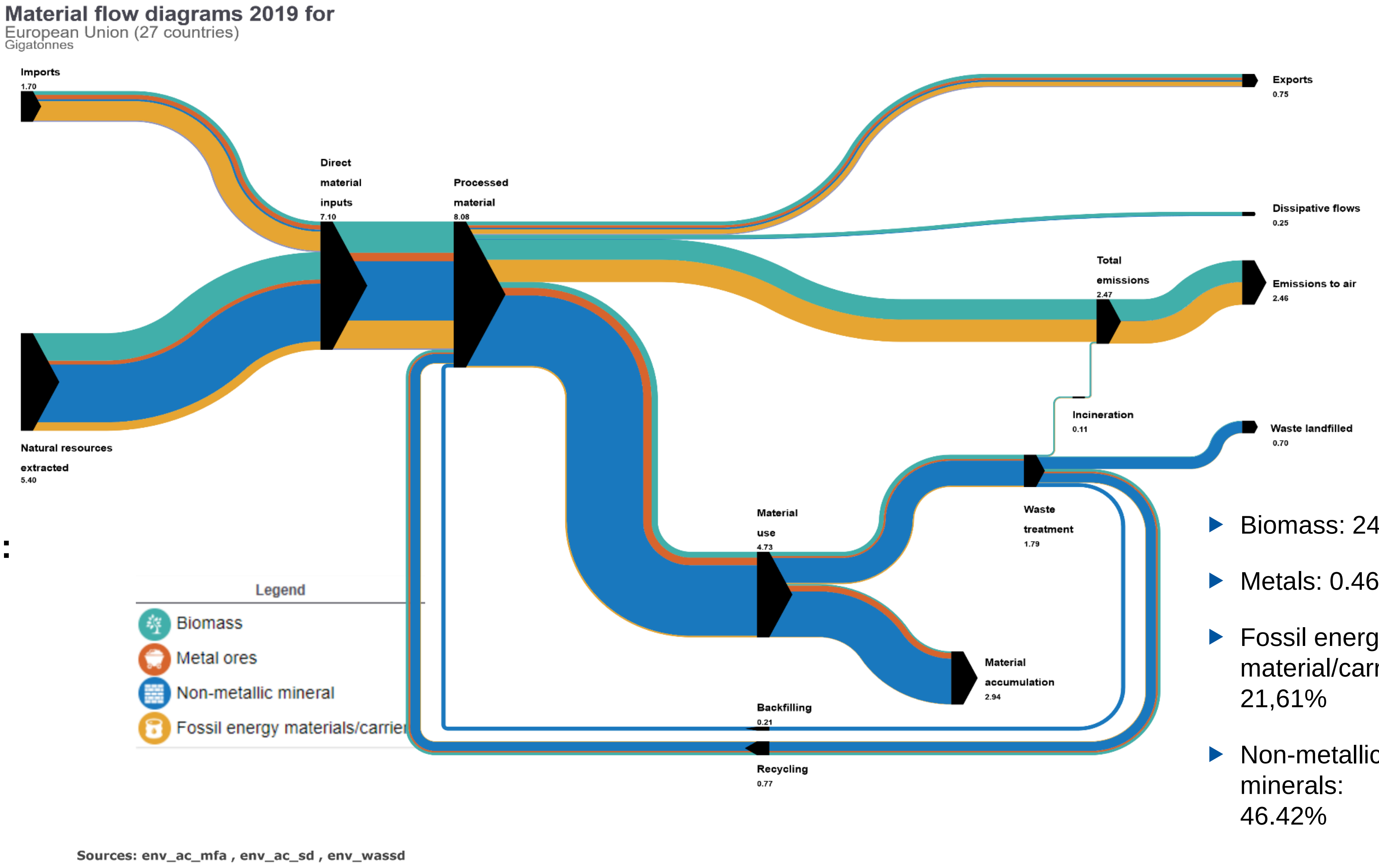
Sufficiency

- Slower, less, better, finer

changed after Wuppertal Institute; Fischer-Kowalski et al./UNEP, IRP 2011: „impact decoupling“

Material Flows in Europe (EU27) 2019

- DMI 2019:
  7.09 Gigatonnes/a
- Processed Material:
  8.08 Gt/a
- share of recycling in processed material: 10%
- Stagnation
  of high material demand
- **Challenges for Recycling:**
  - **Quantity**
  - **Accumulation**
  - **Quality**
  - **Losses**

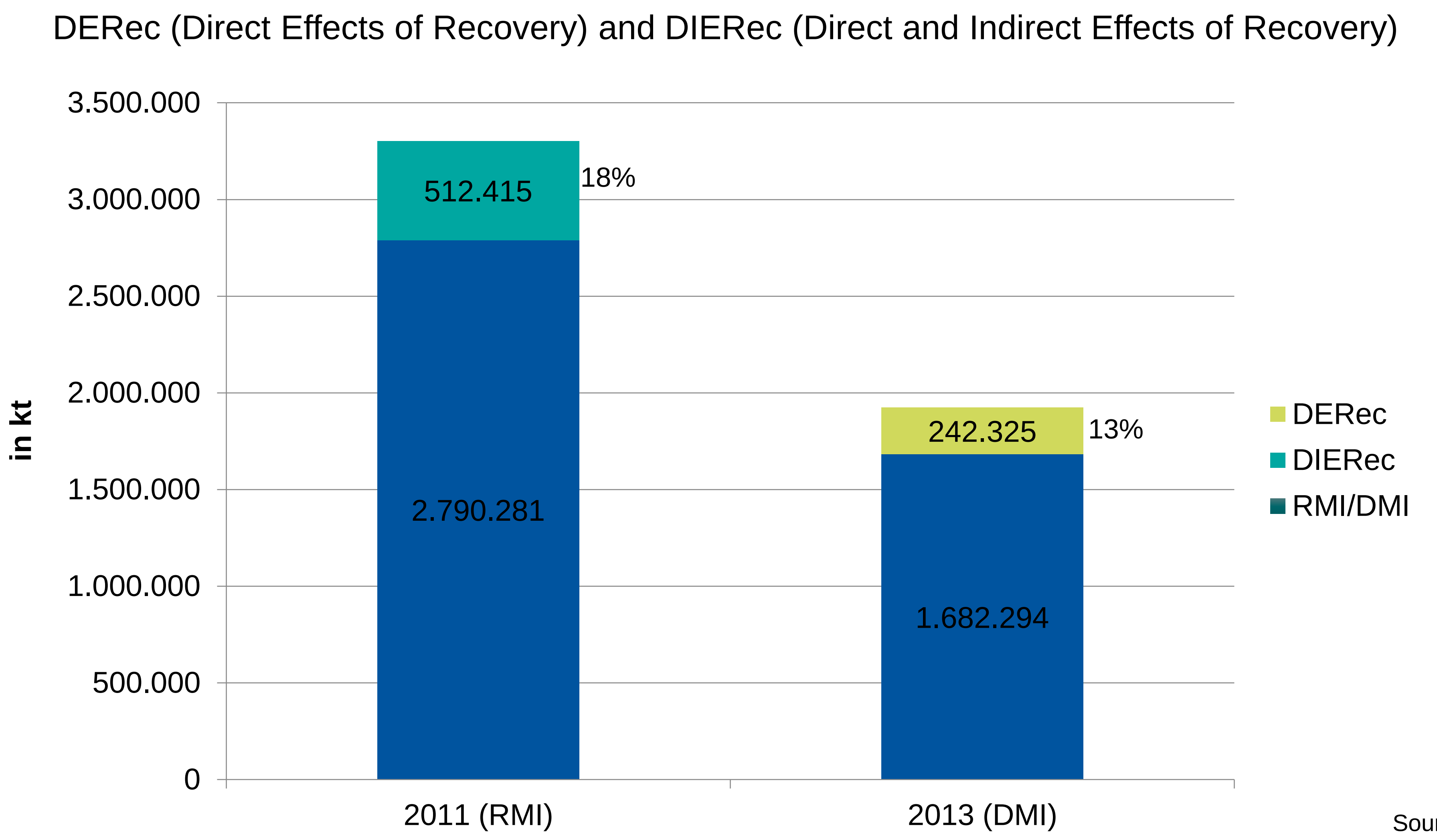


- Biomass: 24.41%
- Metals: 0.46%
- Fossil energy material/carriers: 21,61%
- Non-metallic minerals: 46.42%

eurostat

Quantity // Accumulation

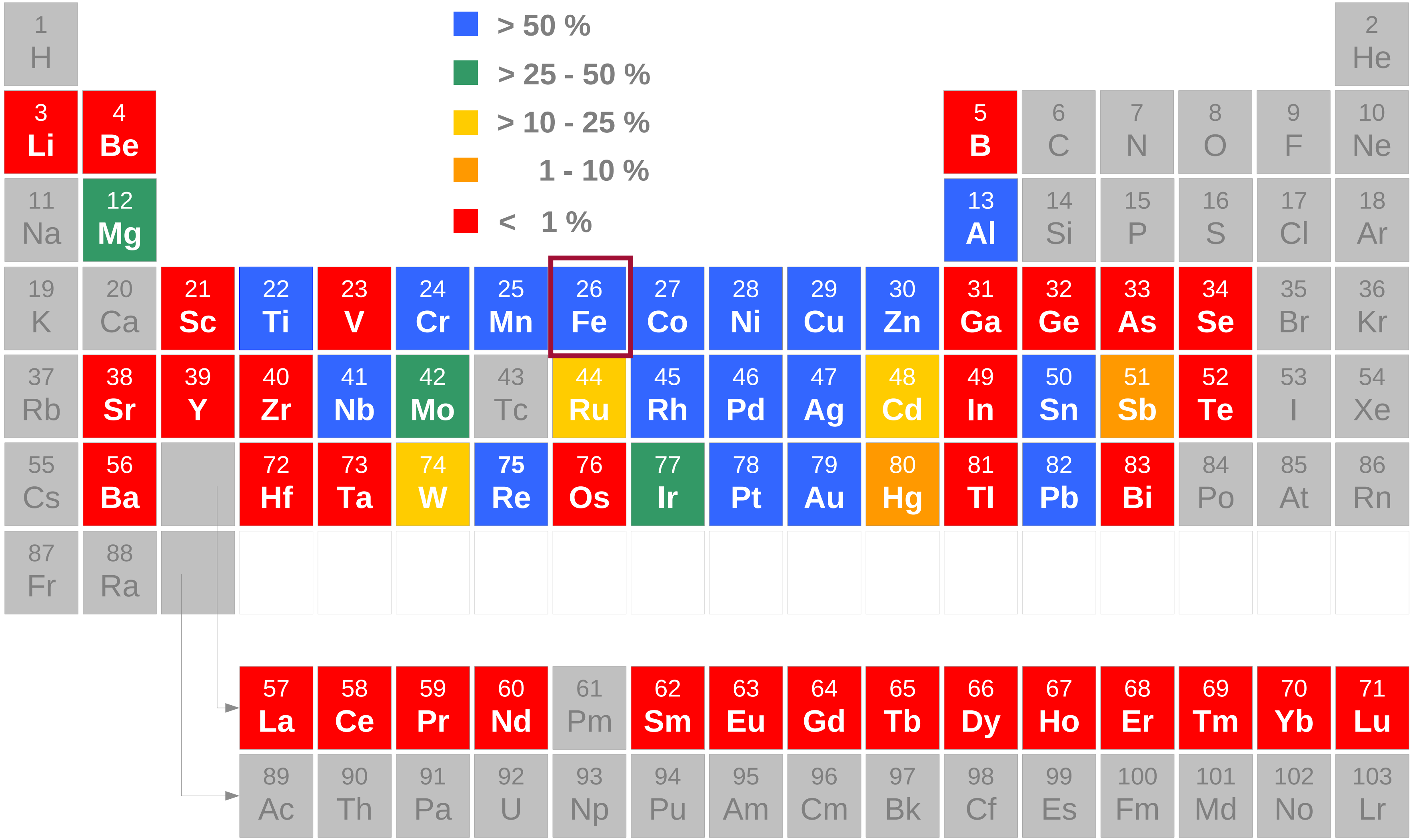
Substitution effect recycling Industry Germany



Source: Steger et al. 2019

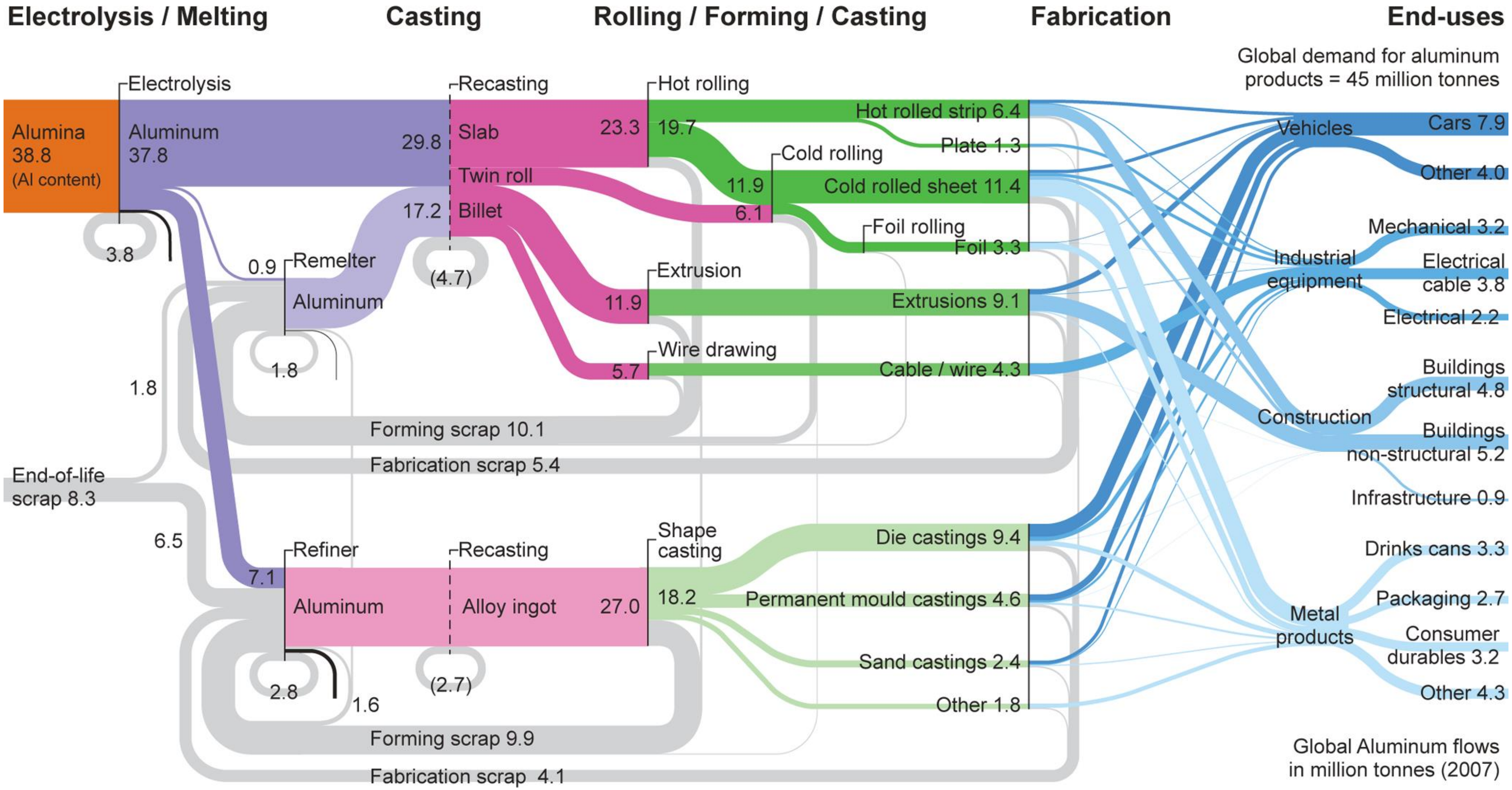
Quality // losses

Resource efficiency: metal recycling globally



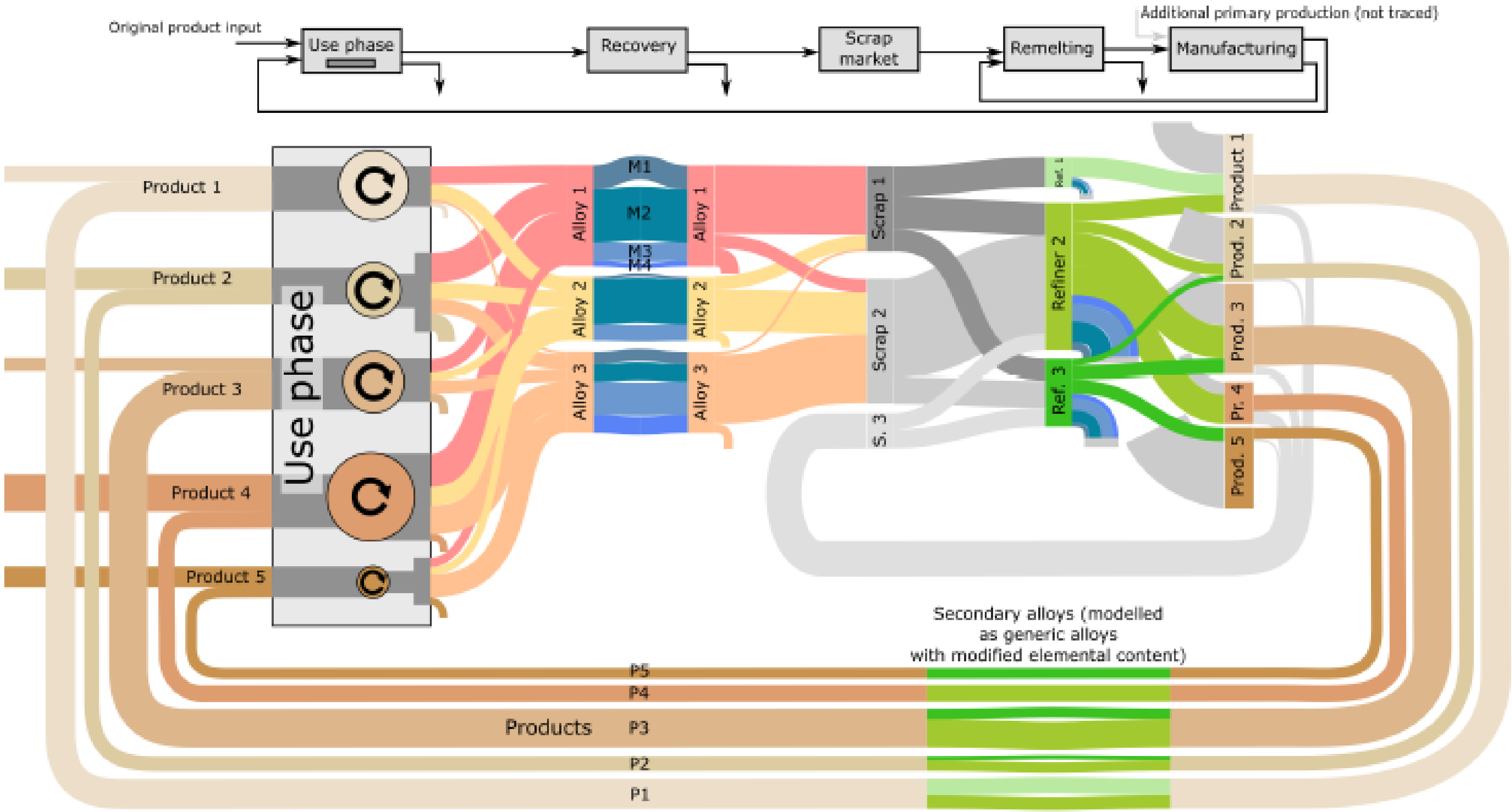
UNEP 2011, Hagelüken 2011

Global Material Flows – Alluminium



Cullen et al. 2013

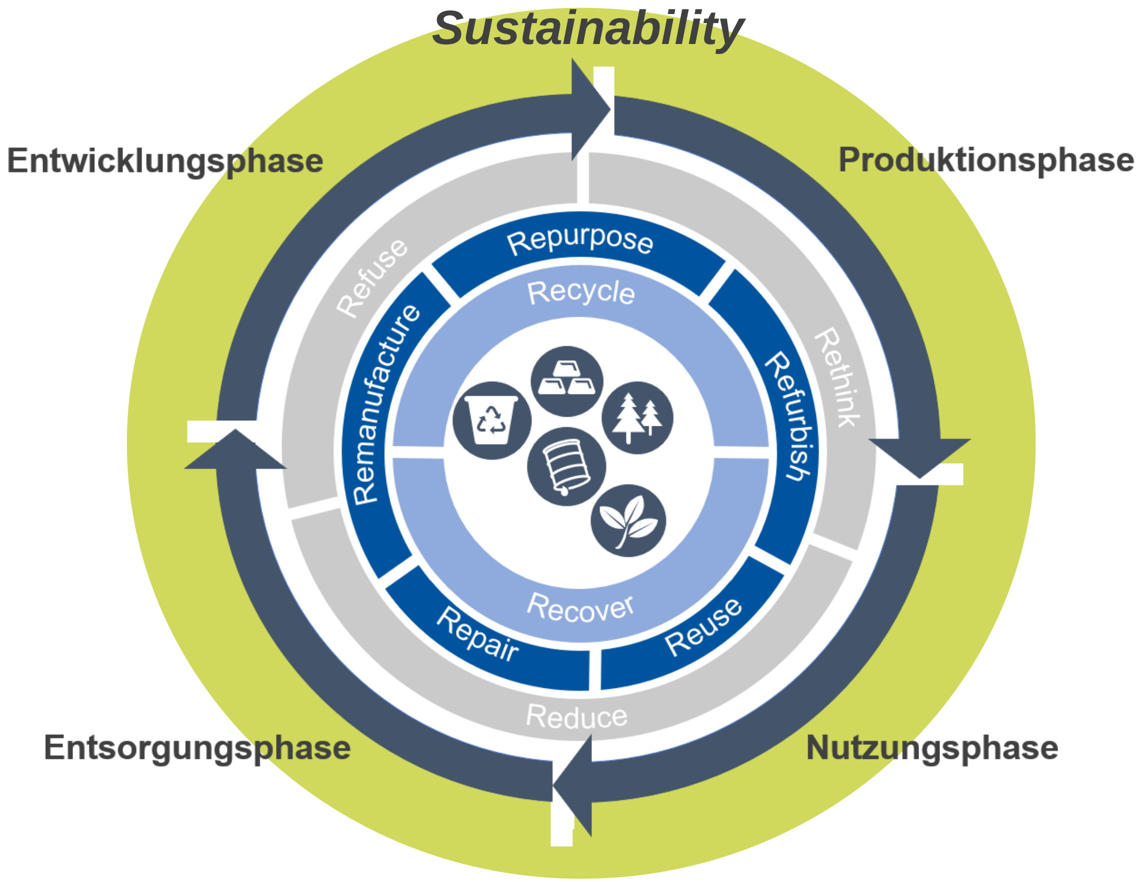
Alloy-specific material flow model – Alluminium



(Nakamura et al. 2017)

Circular Economy – Definition

Objective: Achieving longer material service lifetime



Circular Economy:

*„(…)The value of products, materials and resources is **maintained** in the economy for **as long as possible**, and the generation of **waste is minimised** (…), to develop a **sustainable, slow carbon, resource efficient and competitive** economy.“*
(EC, 2015)

R- Strategies

Circular Economy ↑ Increase in circularity ↑ Linear Economy

	R-Strategy	Description	objective
Smart/ Innovative manufactur-ing and use of products	Refuse	Replacement of previous products with new PDL systems	Narrowing
	Rethink	Intensification of product use (e.g. by sharing)	
	Reduce	Increase material efficiency	
Increased lifetime of products and product parts	Reuse	Further use of existing products by other consumers	Slowing
	Repair	Repair/maintenance of defective products and further use	
	Refurbish	Reconditioning of defective products and further use	
	Remanufacture	Usage of modules/components of a defective product in a new product with the same function	
	Repurpose	Usage of modules/components of a defective product in a new product with modified function	
Usage of materials and substances	Recycle	Processes for production of materials with the same or lower quality	Closing
	Recover	Combustion of materials with energy recovery	

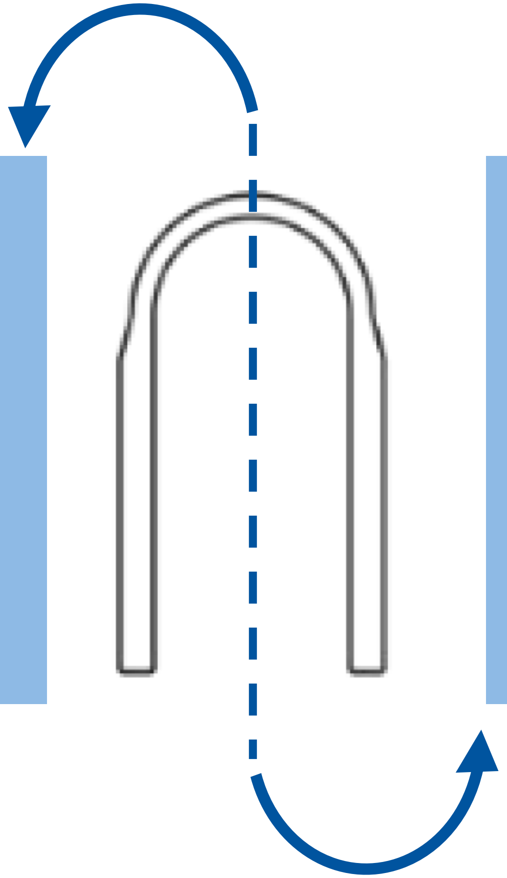
Source: Own illustration according to Potting et al. 2017

Reduce: New alloy enables lightweight construction

» Reduction of Carbon Footprint

Original

Material	42CrMo4
Weight	2 kg
Funktion	Component of the axle beam of trucks
Manu-facturing	Forging process and heat treatment



New

Material Air-Hardening Steels

+ Double cyclic strength
+ Weight reduction possible
+ Tempering not required

Own calculation; Gramlich, Hagedorn, Krupp, Greiff 2021

Reduce: New alloy enables lightweight construction

» Reduction of Carbon Footprint

Environmental Performance compared

Adaption	42CrMo4	33MnCrB5-2	LHD	Δ CF*	Δ CED*
Material Level				-	↑ 11-13%
Process Level				↓ 17-22%	↓ 16-19%
Product Level				↓ 29-32%	↓ 29-32%

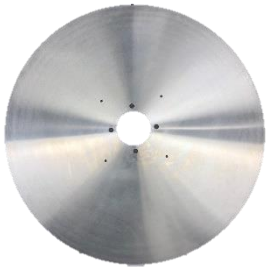
*LHD im Vergleich zu Szenarien mit 42CrMo4 und 33MnCrB5-2

Gramlich, Hagedorn, Krupp, Greiff 2021

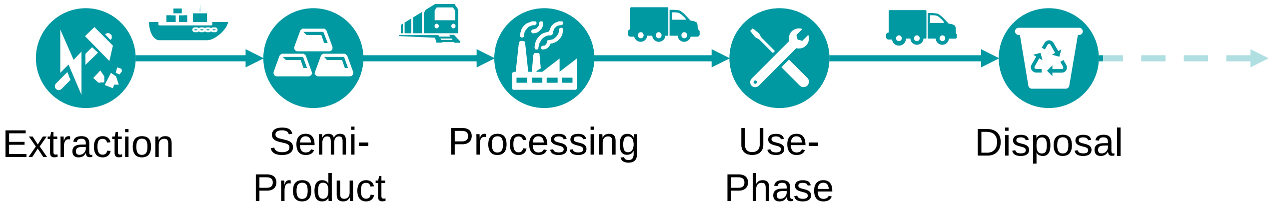
Repurposing: Linking Value Chains

Linear Production Machining Knife and Turning Tool

Machining Knife

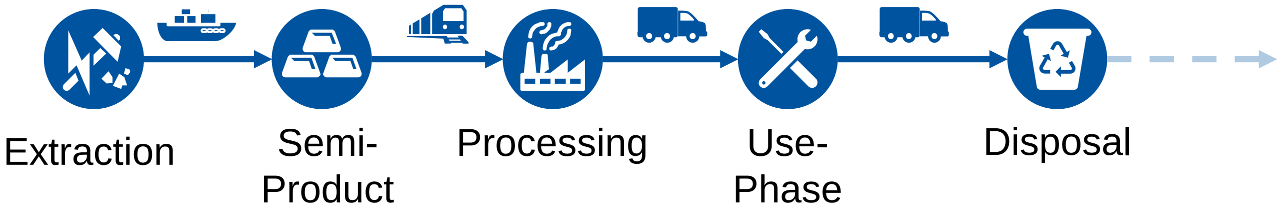


Own Picture



Turning Tool

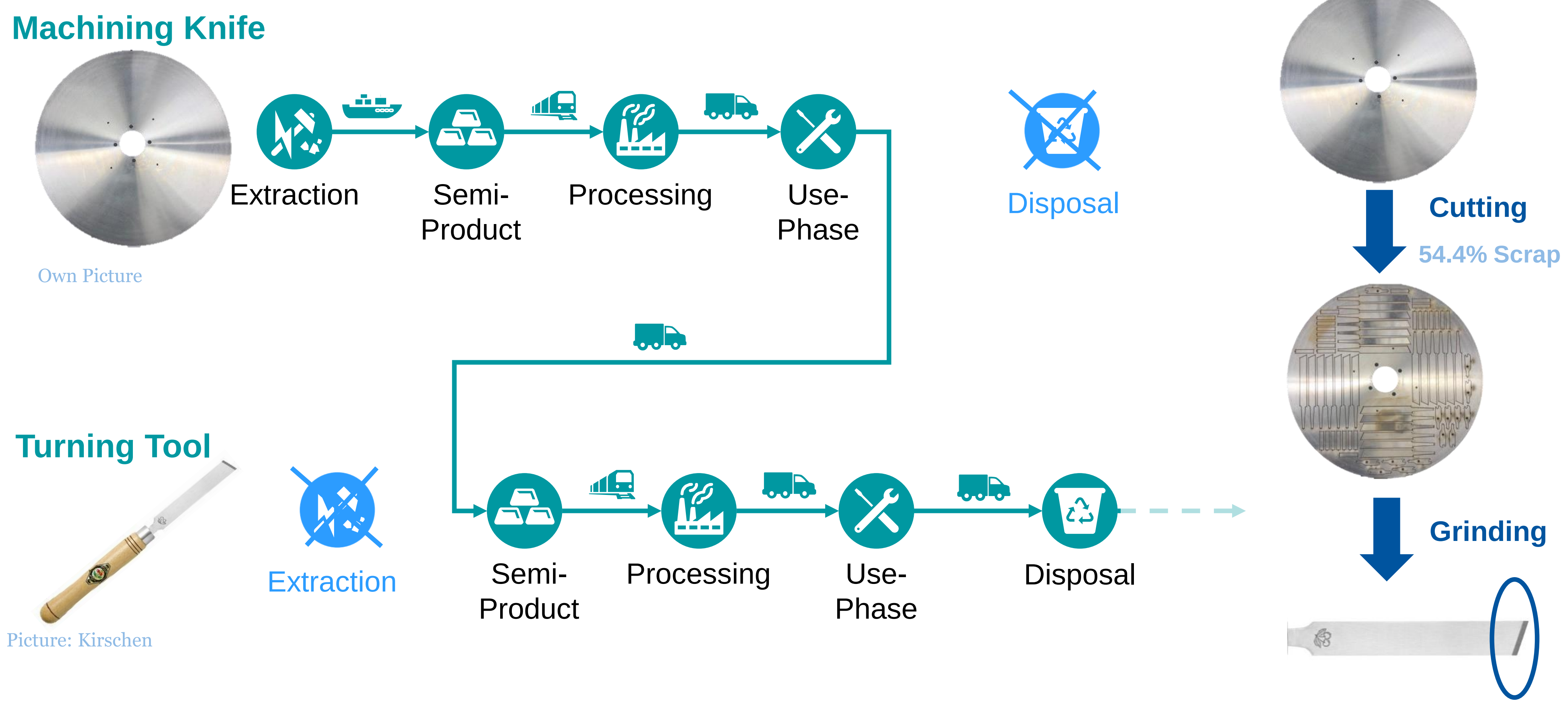
Picture: Kirschen



Hagedorn et al. 2021

Repurposing – Linking Value Chains

Circular Production

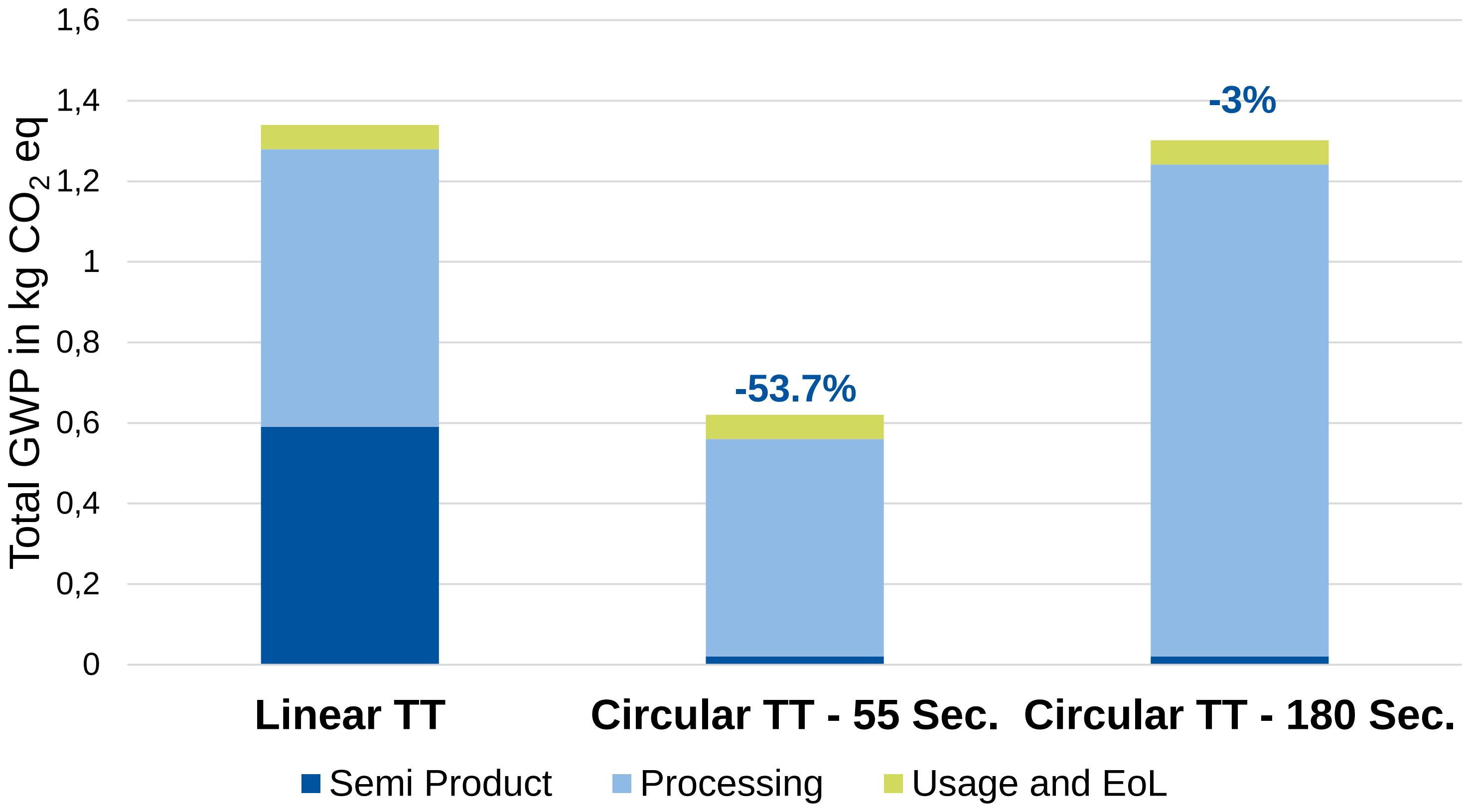


Hagedorn et al. 2021

Repurposing

Environmental Assessment

Carbon Footprint of One Turning Tool



→ **If the circular tools are environmentally beneficial depends on the grinding process**

Hagedorn et al. 2021

Bundesministerium für Bildung und Forschung

FONA Ressourceneffizienz BMBF

ReziProK Ressourceneffiziente Kreislaufwirtschaft – Innovative Produktkreisläufe

TKM

Wuppertal Institut

FREUND ... Dein Werkzeug

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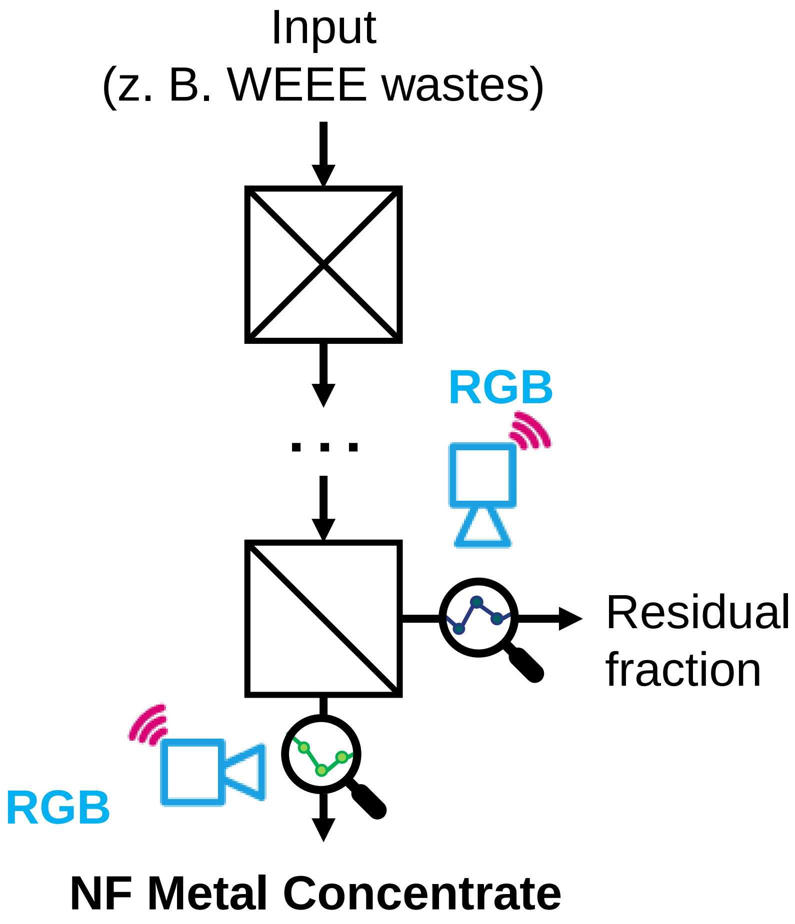
Recycling: Automated Quality Control in Metal Recovery Processes

Objectives



State of the Art: Manual Sorting

- ✗ Limited sample sizes
- ✗ High costs, time consuming
- ✗ Subjective influences of manual sorters

Sensor-Based Material Flow Monitoring

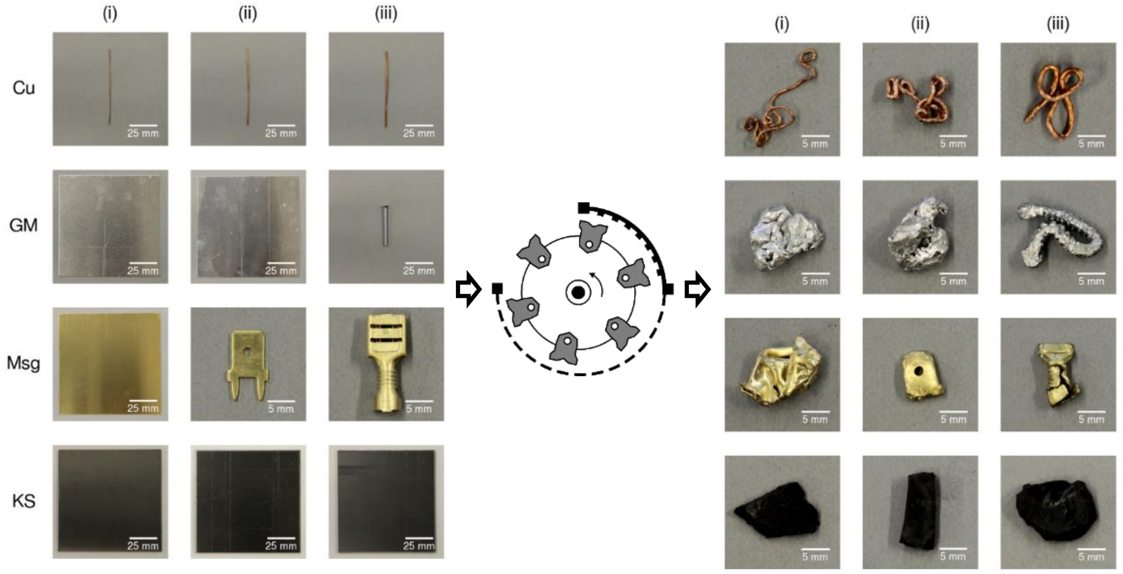
- ✔ Inline: Full material flow is monitored
- ✔ Automated approach, low costs
- ✔ Reproducable results

NF: Non-Ferrous

Case Study 2: Automated Quality Control in Metal Recovery Processes
Sample Preparation

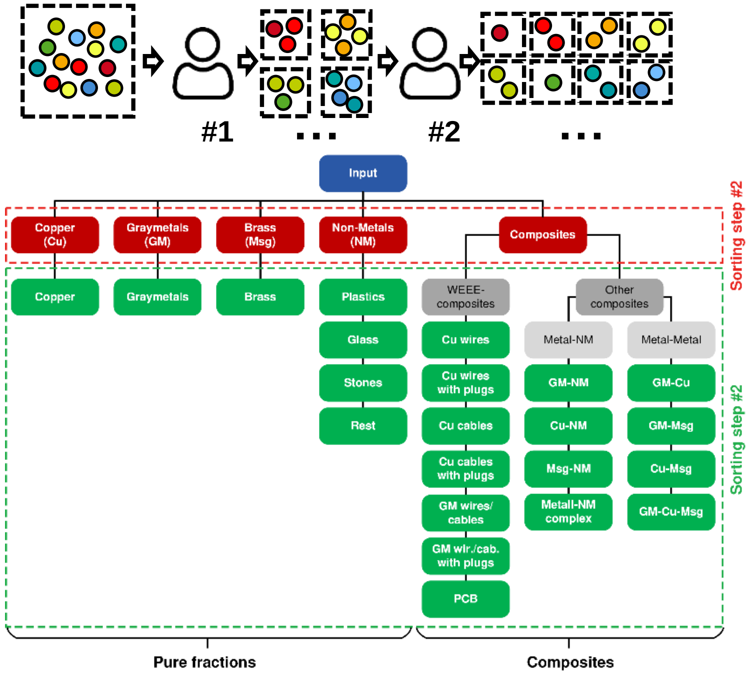
A Dataset A: Sample mix

- Show technical feasibility
- Shredded standard components (2 – 10 mm)
- 4 material classes: Copper (Cu), gray metals (GM), brass (Msg), plastics (KS)



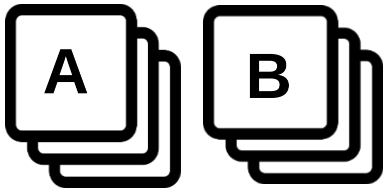
B Dataset B: Metal-containing fine fractions

- Sampling at metal recovery plant
- NF concentrate + residual fraction (2 – 10 mm)
- Manual sorting in 22 material classes

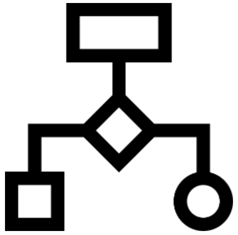


Case Study 2: Automated Quality Control in Metal Recovery Processes
Proceeding

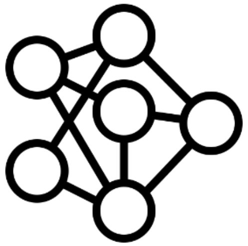
Datasets



Classification Methods



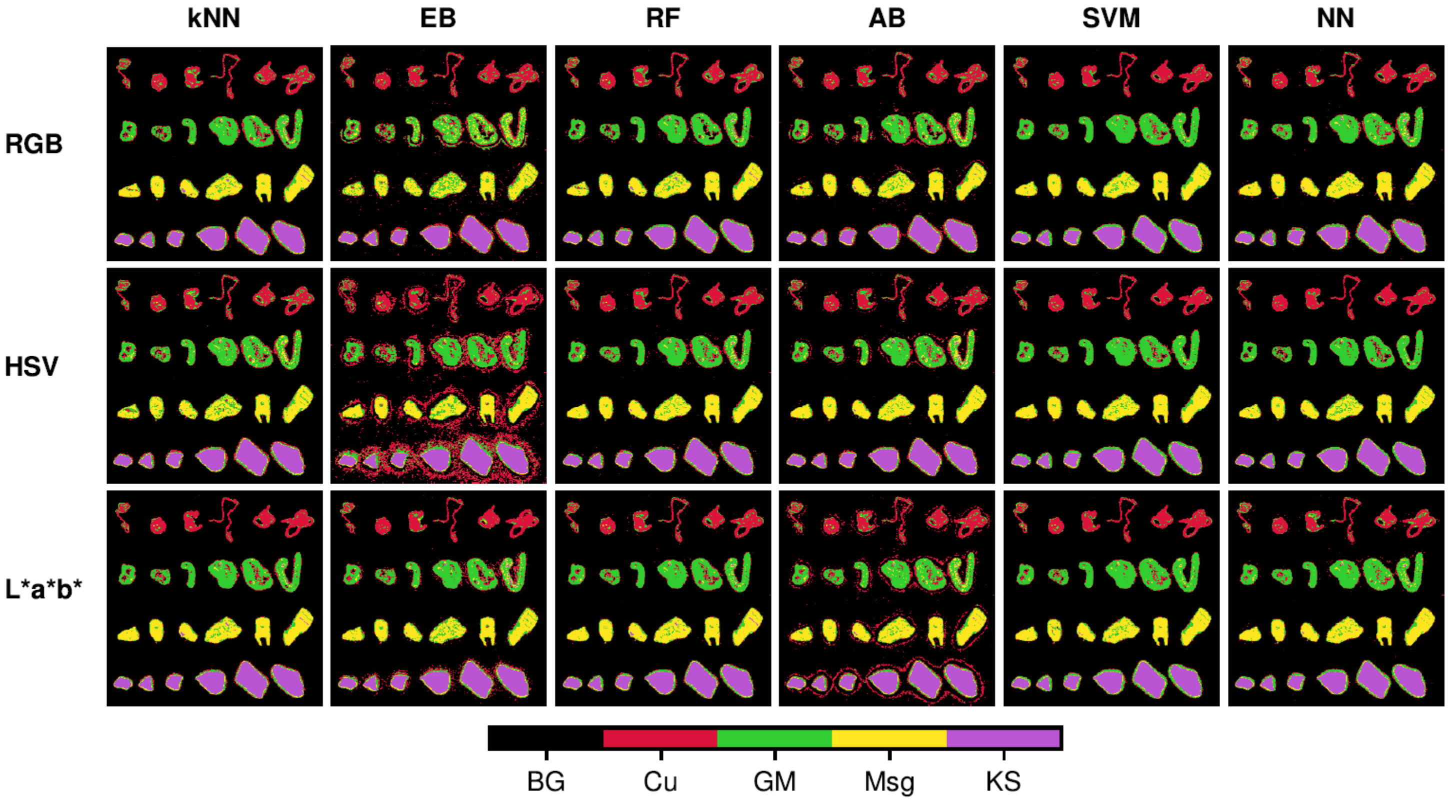
Approach I:
Feature-Based Machine Learning



Approach II:
Convolutional Neural Networks (CNNs)

Case Study 2: Automated Quality Control in Metal Recovery Processes
Results: Approach I – Dataset A

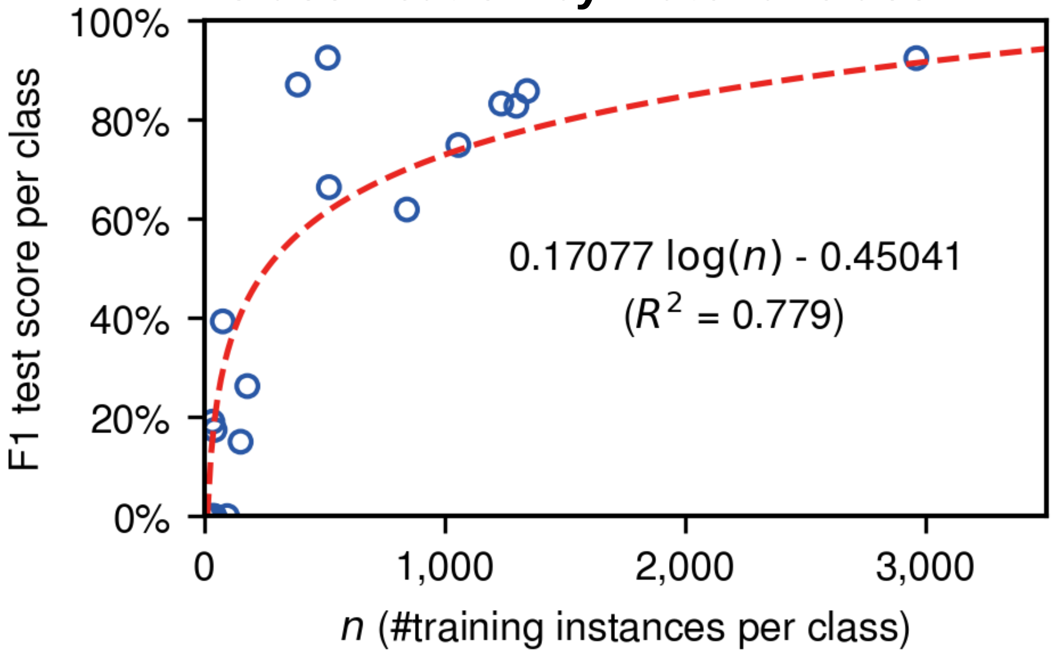
Prediction accuracy (test set):
Pixel-based: **86.7 %,** Objekt-based: **100 %**

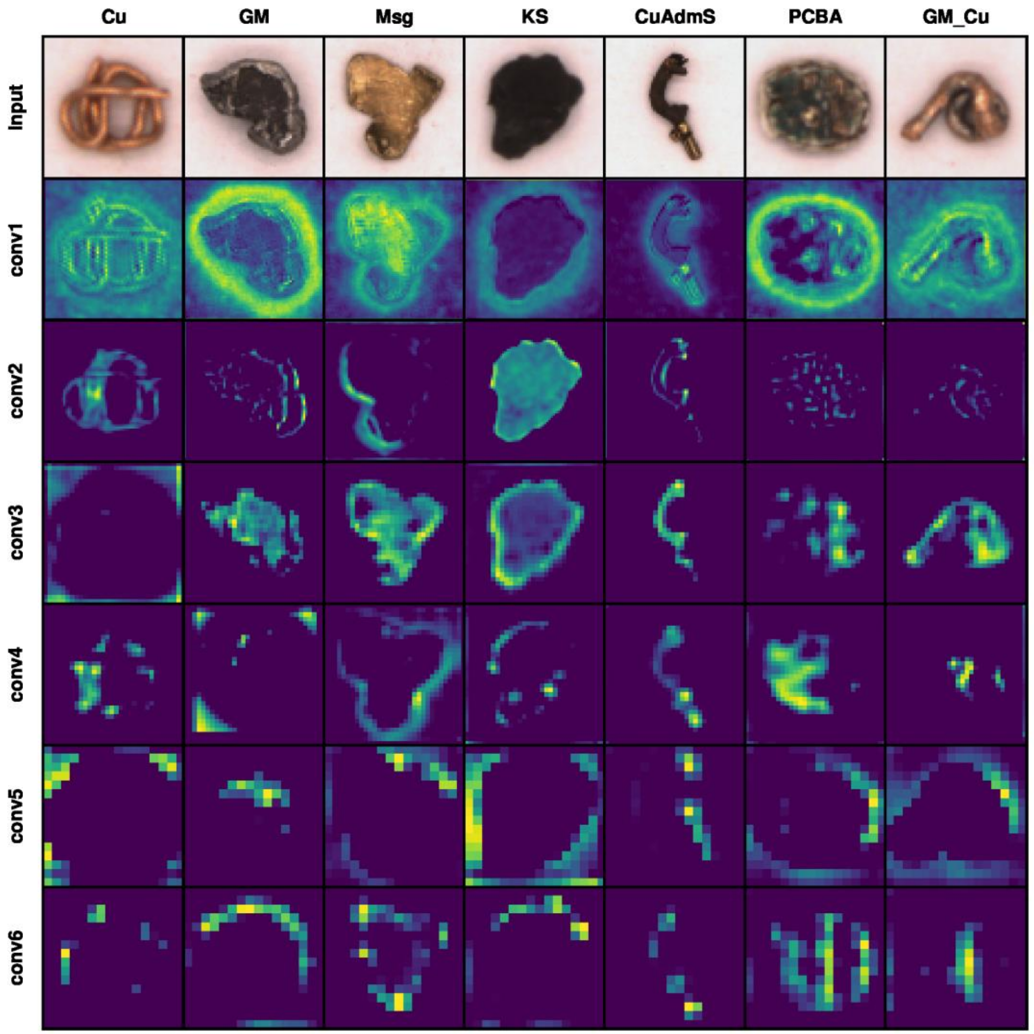


Case Study 2: automated Quality Control in Metal Recovery Processes
Results: Approach II – Dataset B

Prediction accuracy (test set):
Objekt-based: **80.4 %**

Classification by material class:





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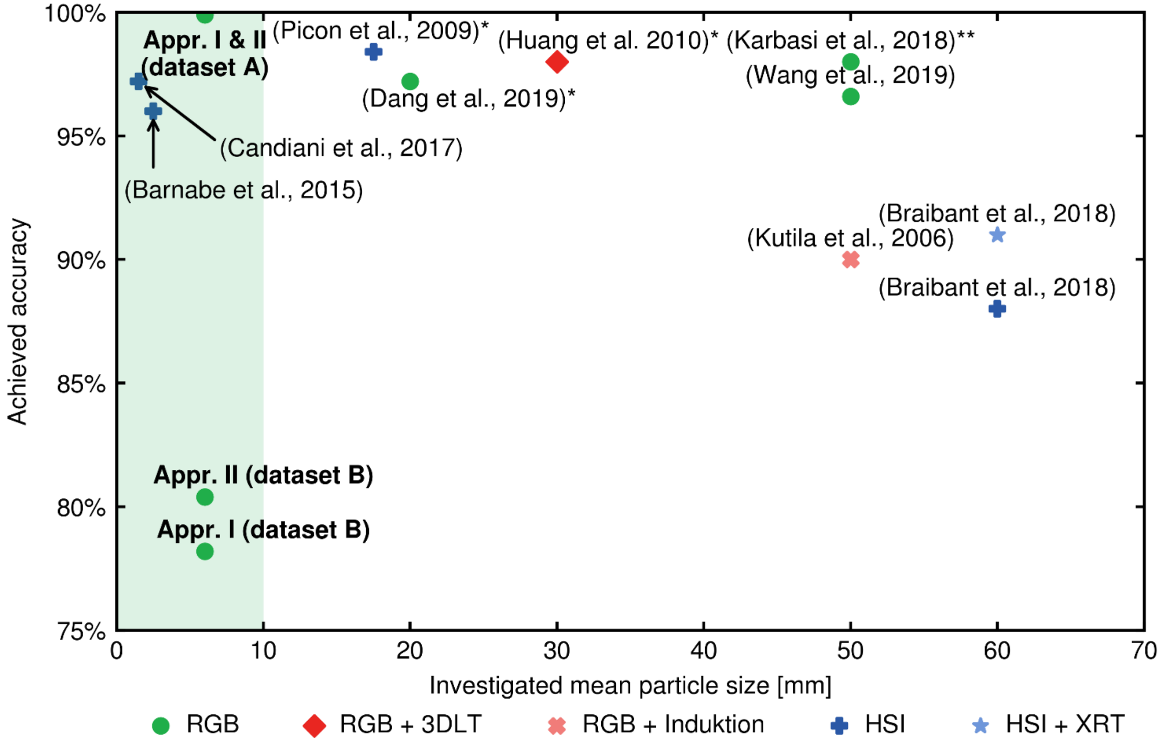
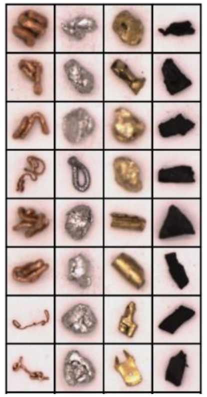
Case Study 2: automated Quality Control in Metal Recovery Processes
Conclusion

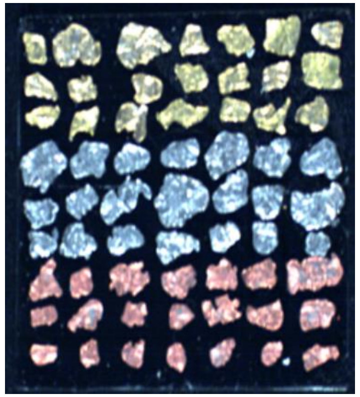
- Results of fine fractions **comparable** with existing results coarse fractions
- Similiar classification results compared to HSI studies
- Dataset B: Complex composites + 22 material classes → **challenging**



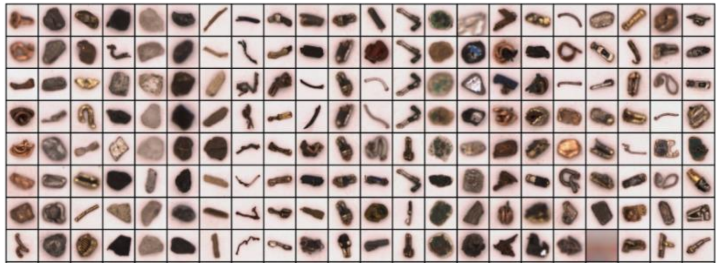
Dataset A:



(Candiani, 2017)



Dataset B:



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Life cycle step	Aspects for resource efficient resource management
Design for Circularity and Sustainability	▪ Optimization of **product design** – Focus on service design/*user needs* and circularity ▪ Integration of **indicators for sustainable circularity** in the design process: focus on **longevity, reparability and recyclability** ▪ Focus on product-service systems combined with **new business models**
Resource extraction	▪ Concentrations of useful materials will decrease while environmental impact will increas ▪ Resource efficiency can be improved by **mining fewer raw materials in a more sustainable way**
Production of primary material	▪ Technically **optimization of production process** within thermodynamic equilibriums ▪ Noticeable increases in efficiency by **substituting materials** ▪ Closing and decreasing **internal material loops** along the life cycle or value chain
Production of Goods	▪ Optimization of production processes ▪ Material efficiency through **Remanufacturing or Refurbishment** ▪ Legal requirements e.g. for the content of recycled materials
Use of Goods	▪ **Extension of service life** through technical and design aspects and new business models ▪ Use of **reparable and recyclable products** ▪ Shift in demand patterns towards consumption of less material-intensive goods or services via **product information and labeling**
End-of-Life (EoL) Management	▪ Monitoring of EoL Management success by expressive indicators, **implementation of standards** ▪ **High collection and separation rates** by optimization of infrastructure ▪ Consideration and **cooperation with design phase / product development**

The key is the networking of the different life cycle phases

–

innovations must be developed together

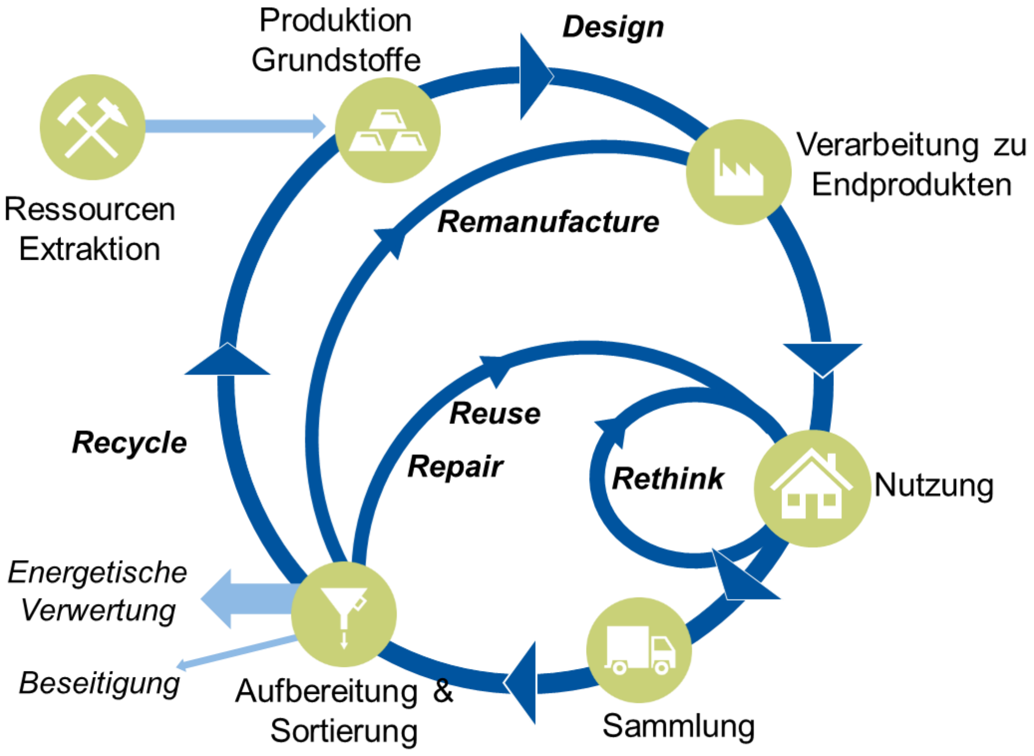
-

Potentials are still high

Greiff et al. 2020

Conclusion Circular Economy for metals

- Recycling
  → high potential but limits in
  - Quantity – still increasing stock amounts (globally)
  - Quality / inefficiencies – loss of material, alloying elements –
    → need of primary materials
- CE strategies
  → environmental benefit seems to be high –
  potential depends on single processes
- Recycling processes:
  high potentials using sensor technology
  and machine learning techniques
- Outlook: further investigation of CE strategies & impacts



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Thank you for your attention.
Any questions?

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