MARAS

Material Recycling and Sustainability

Design for Recycling

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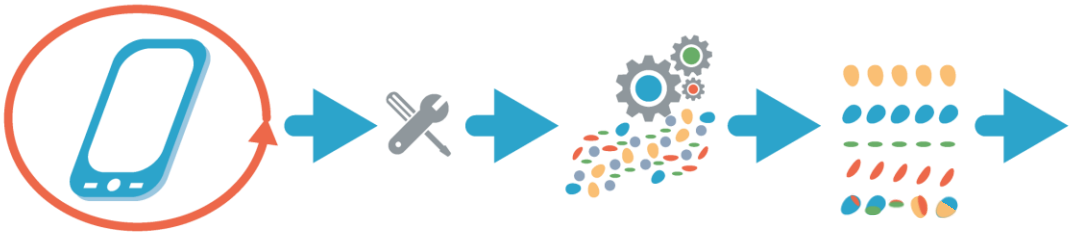
Material Recycling and Sustainability

Design for Recycling and Resource Efficiency

Product-Centric View

General initial question

How can we use a product as resource?



- Steel (Fe)
- Aluminium (Al)
- Cobalt | Nickel (Co | Ni)
- Precious metals | Copper (Co)
- Others, e.g. Indium (In)

EoL Product Design

Pretreatment
Dismantling/shredding/sorting

Chemical & Processing
Metallurgical processing
Less waste

How can we define DfR rules to optimise Resource Efficiency?

Design for waste stream sorting

Design for shredding/ liberation

Design for recovery in final treatment processing

Design for disassembly

Design for sorting

10 Design Rules and Simulation Derived Guidelines

Fundamental DfR rules

1. DfR rules are **product and recycling system specific**; oversimplification of recycling by defining general DfR rules will not produce the intended goal of resource efficiency

2. DfR needs model and **simulation based quantification**

3. **Design data** should be accessible/available in a format which is compatible with the **detail** required to quantify and optimise recycling performance of products for all metals, materials and compounds present

4. Economically viable **infrastructure and rigorous tools** must be in existence for realizing industrial DfR rules and methodologies

5. **CAD/Design** tools must be **linked** to recycling system process **simulation tools** to realise technology based, realistic and economically viable DfR

Note : All DfR rules/guidelines are subject to a mindful consideration of product/component functionality and should not impair these

10 Design Rules and Simulation Derived Guidelines

Possible DfR guidelines – Derived from Fundamental DfR Rules

Iteratively checked by simulation and validity

6. Identify and minimize the use of materials which will cause losses and contaminations in recycling due to **material characteristics** and **behaviour in sorting**

7. Identify components/clusters in a product, which will cause problems and losses in recycling due to **combined and applied materials**

8. Design clusters or sub-units in products that can be easily removed and which **match with the final treatment recycling options** (i.e. Metal Wheel)

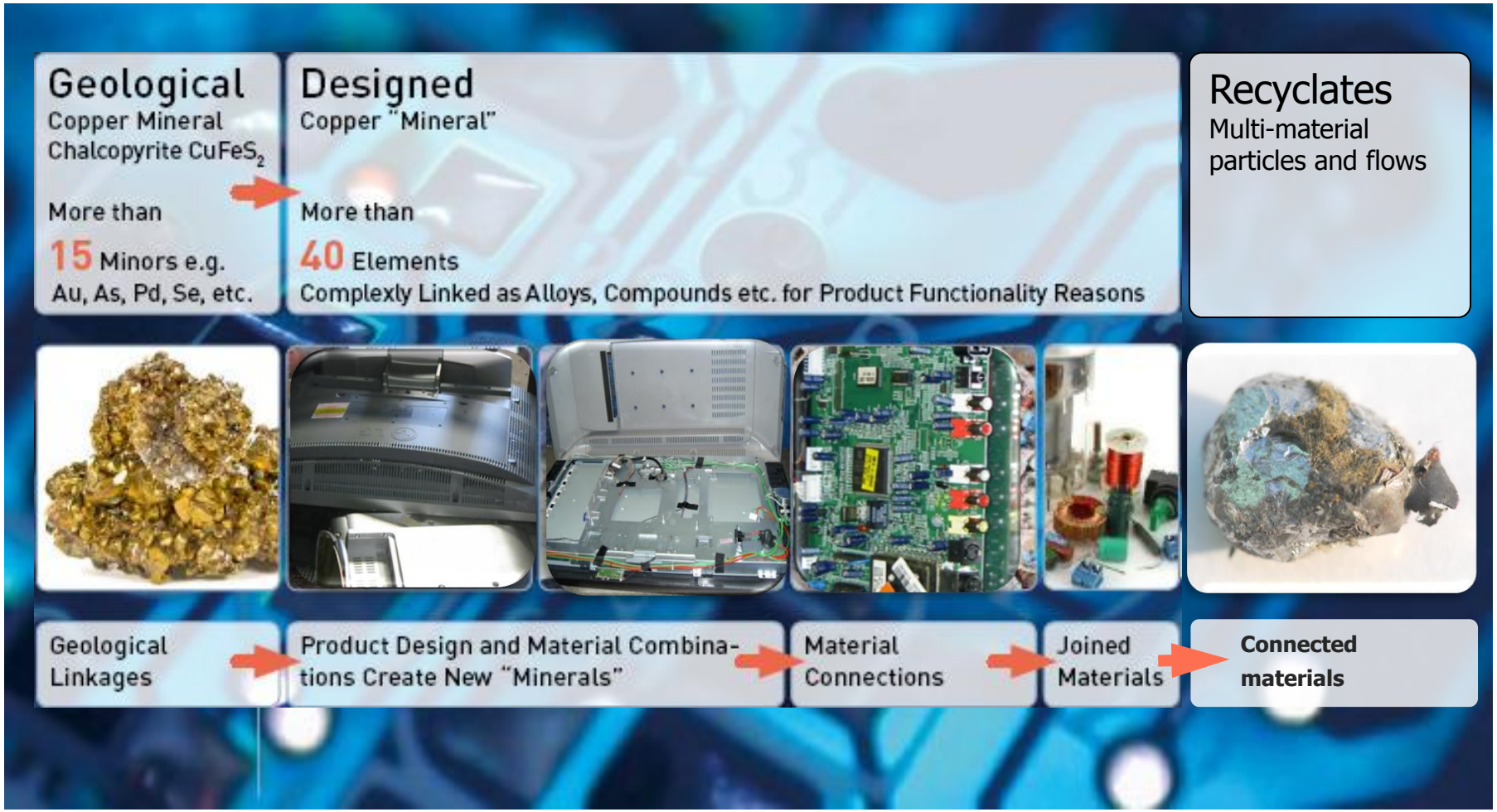
9. **Labelling** (including carefully considered standardisation) of products/components based on recovery and/or **incompatibility** for easy identification (and removal) from recyclates and waste streams

10. Be mindful of **liberation** of materials in design (Design for Liberation)

DESIGN FOR RECYCLING RULES

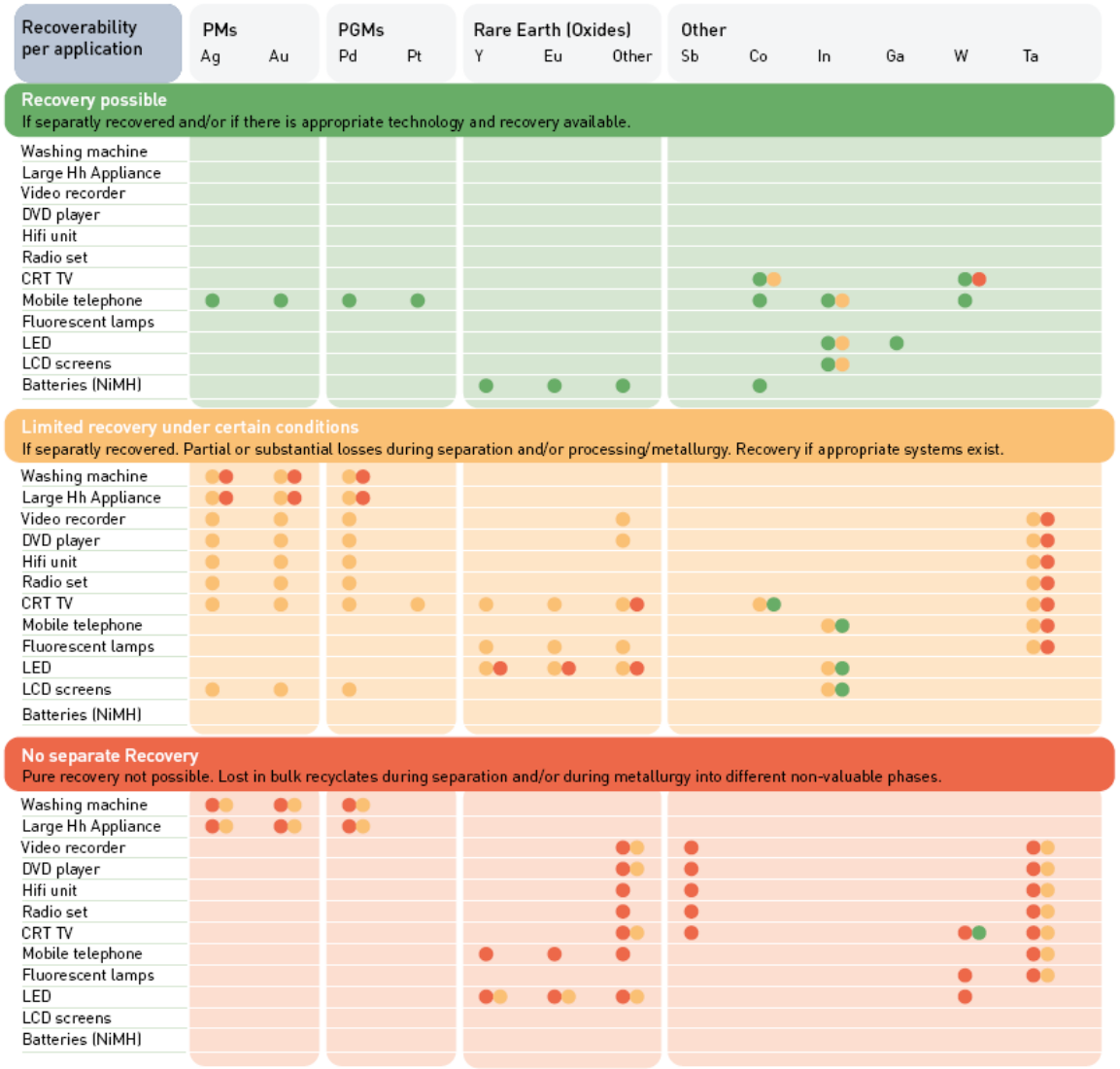
DfR Rule 1 : DfR is product specific

DfR rules are product and recycling system specific - each product has a unique recyclability profile



DfR Rule 1 : DfR is product specific

Each product has a recyclability profile and a set of product and recycling system specific DfR guidelines



DfR Rule 1 : No oversimplification

Oversimplification of recycling by defining general DfR rules will not produce the intended goal of resource efficiency

DfR Rule 2 : Quantification

Quality of recyclates : design, shredding and sorting determines recoverability and recycling of product and components (example on Printed Circuit Board)

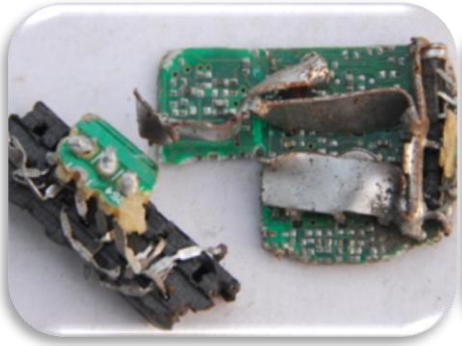
Ferrous recyclate

PCB recyclate

Plastics recyclate

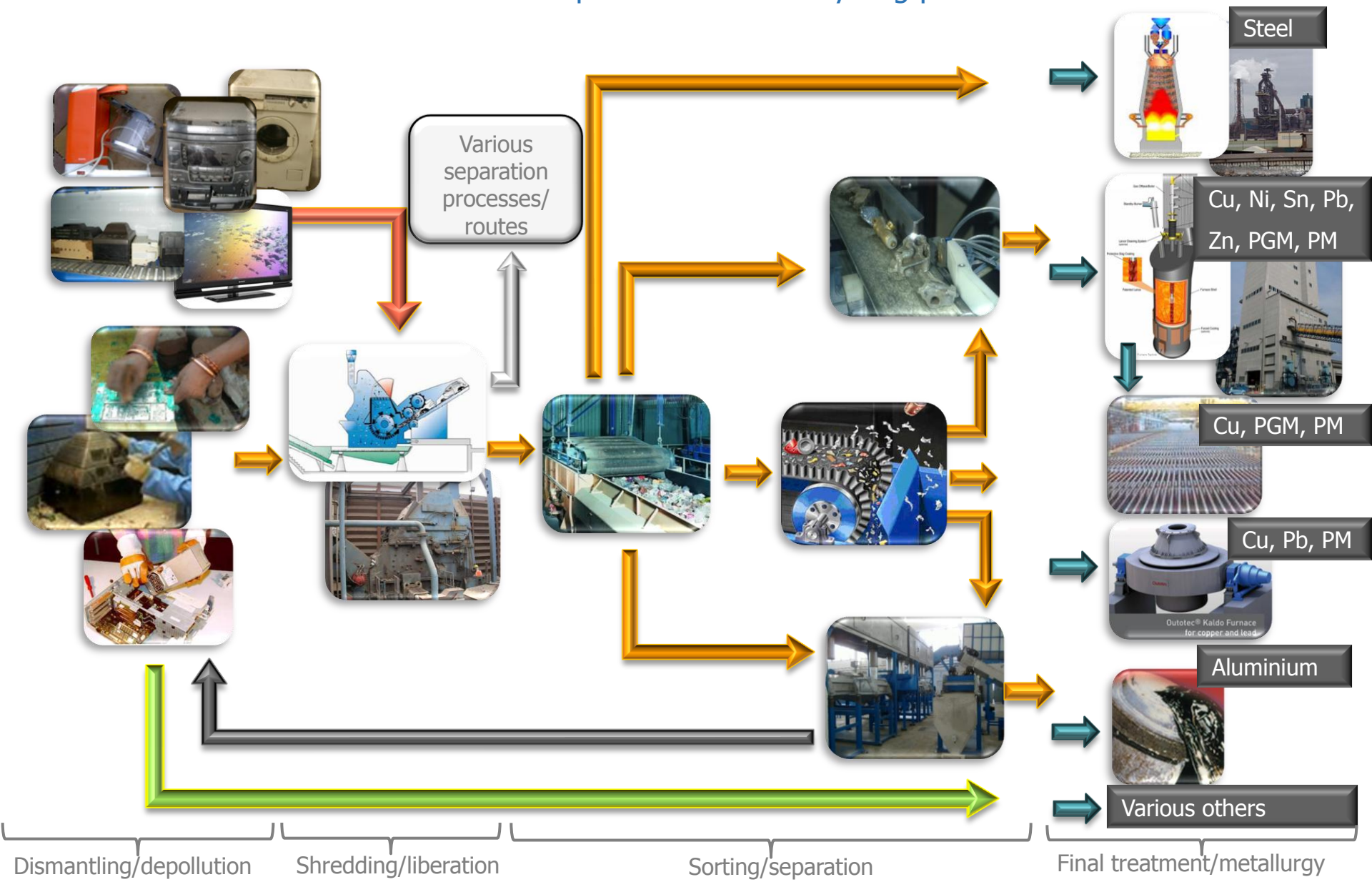
Residue fraction

Different appearances of PCB in (PCB) recyclates



DfR Rule 2 : Quantification

DfR needs model and simulation based quantification of recycling performance



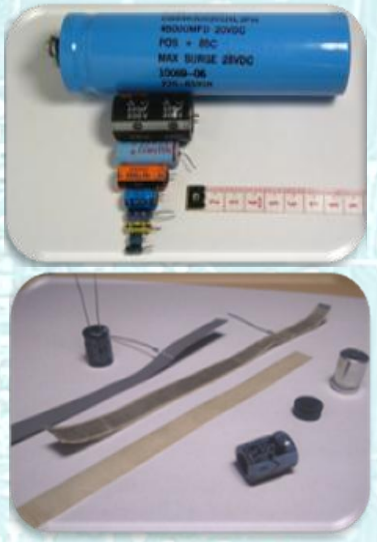
DfR Rule 3 : Design data

Design data on product composition and construction should be available in a consistent format that matches with the detail required to quantify and optimise recycling

Material usage and material combinations in products

Connection of complex components to structural parts/materials

Material usage, chemical compounds and combinations in components and its variations



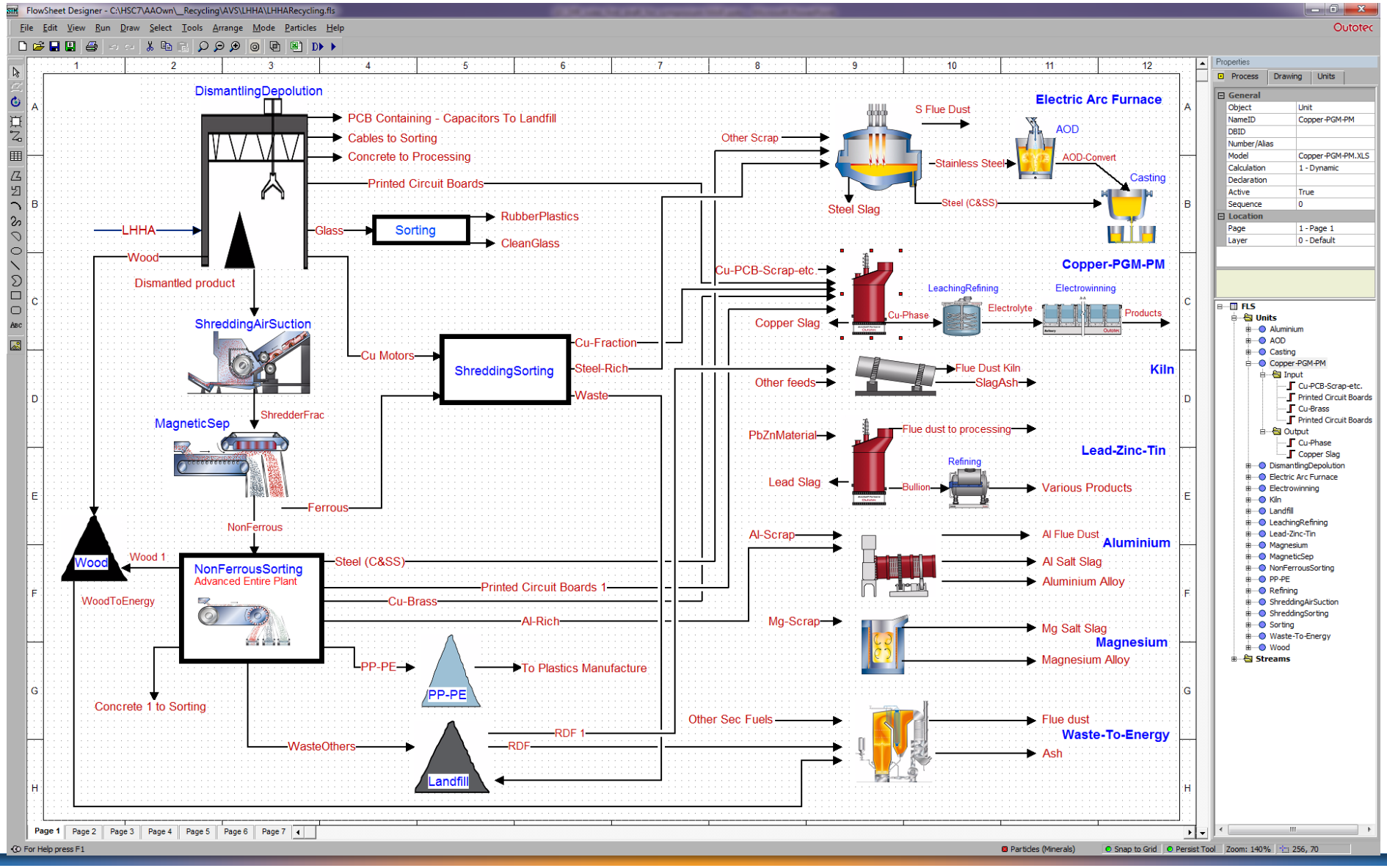
Chemical composition and compounds in e.g. electrical components and its variations

DfR Rule 4 : Infrastructure and tools

Robust metallurgical infrastructure should be in place to ensure maximum recovery

DfR Rule 4 : Infrastructure and tools

Rigorous tools for recycling simulation and DfR



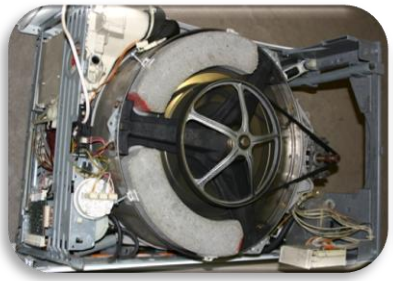
SIMULATION DERIVED GUIDELINES

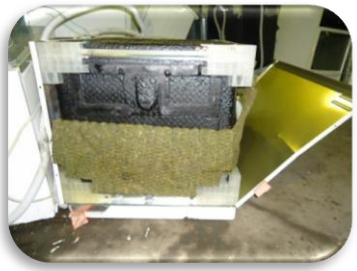
Guideline 6 : Material characteristics

Identify and minimize the use of materials which will cause losses in recycling due to material characteristics and behaviour in sorting

Problematic materials in design

Concrete in washing machines	Glass in fridges	Isolation materials	Colored Printed Wire Boards





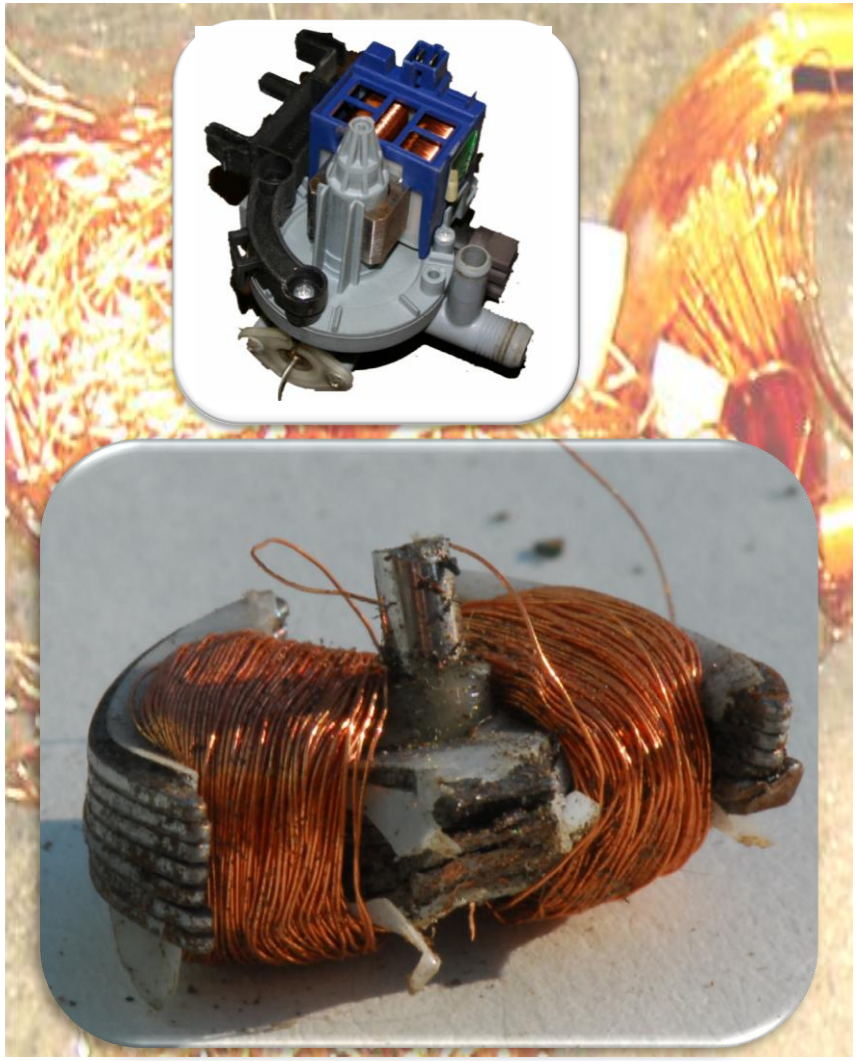

Problems/consequences in sorting/separation

Difficult to dismantle & distributes over recyclate fractions	Process waste, decreases recycling performance	Contaminates recycle fractions - material losses	Losses of PCB to other recyclates - contamination of PCB fraction



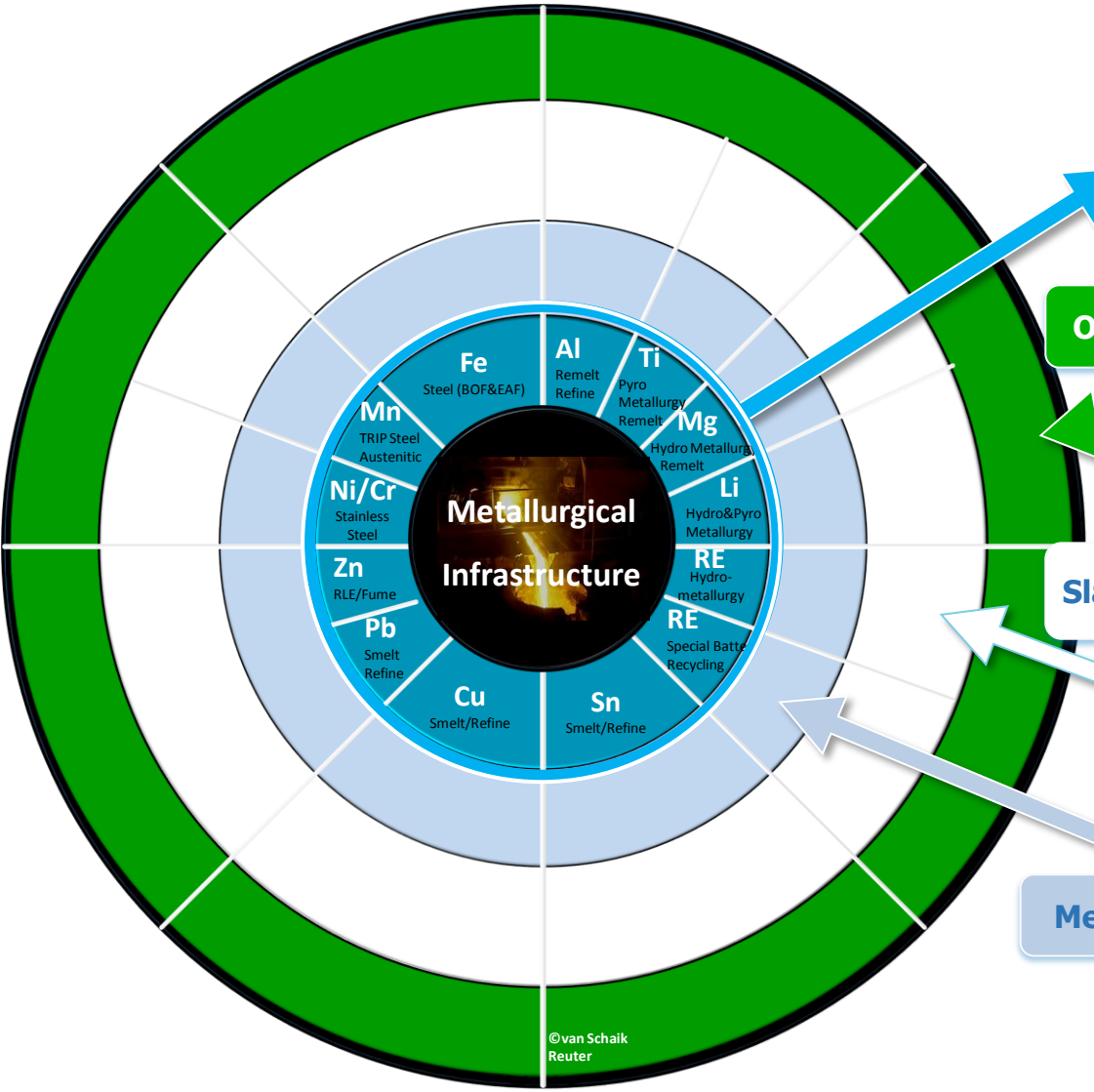

Guideline 7 : (In) compatibility of combined materials

Identify and minimize the use of materials which will cause losses due to combined & applied materials



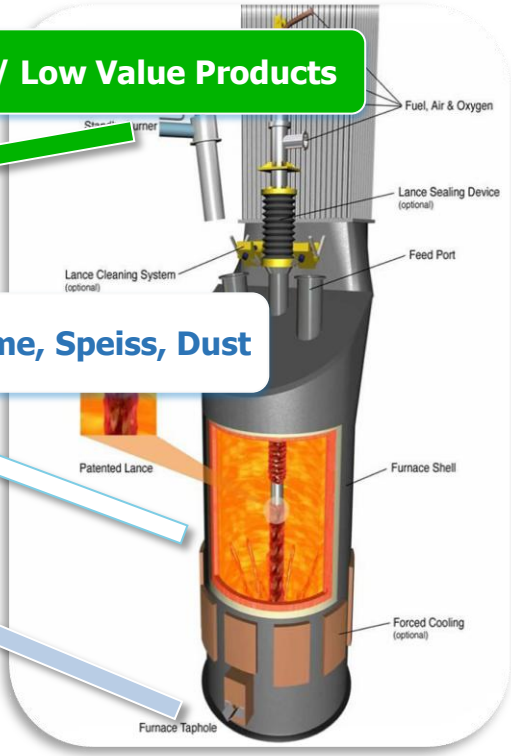
Guideline 7 : (In) compatibility of combined materials

Society's Essential Carrier Metals: Metal recycling products, by products & residues



Carrier metals :
Primary and recycling metallurgy infrastructures

Off gas / Low Value Products



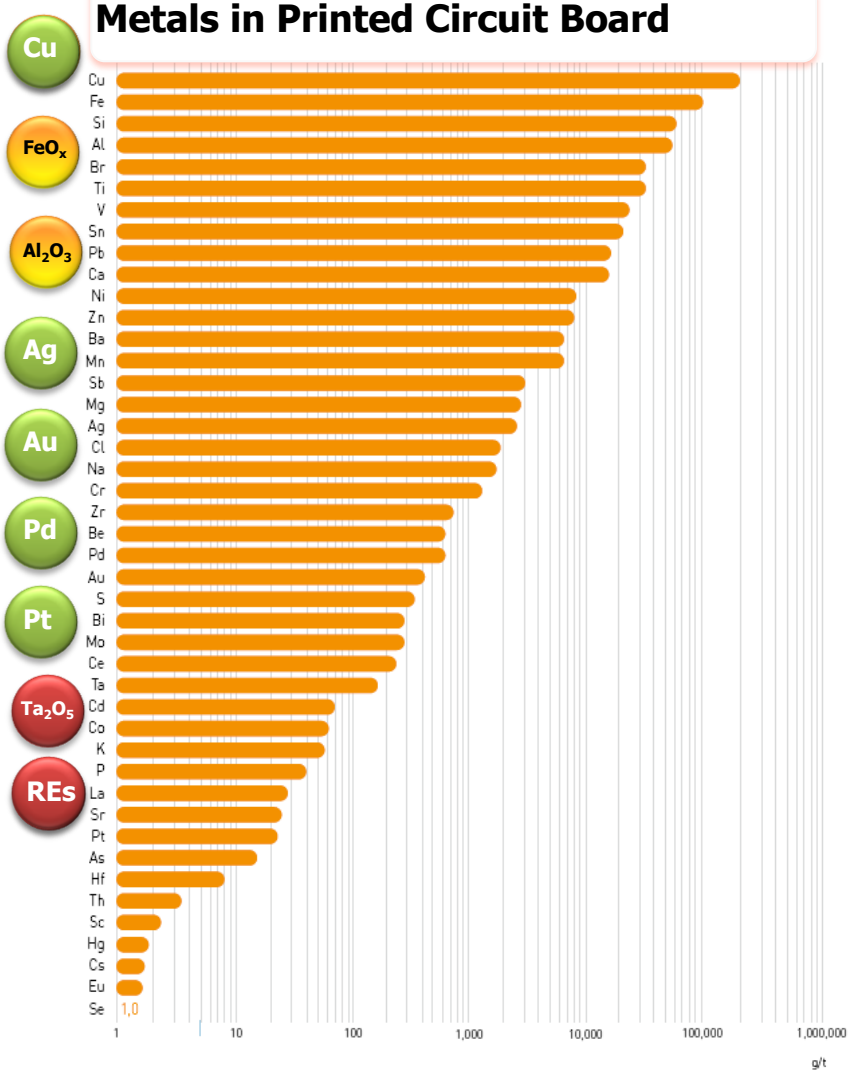
Slag, Slime, Speiss, Dust

Metal

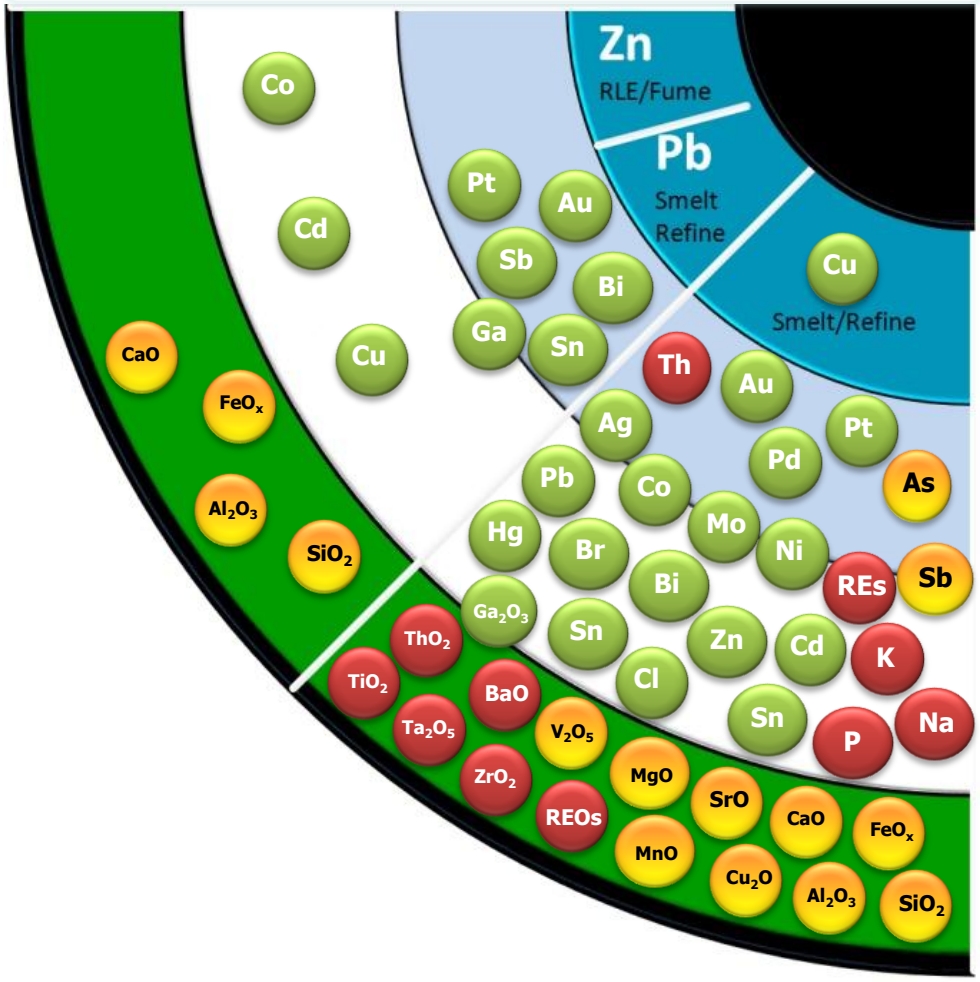
Guideline 7 : (In) compatibility of combined materials

Recovery&losses determined by quality and destination/processing route of recyclate/component

Metals in Printed Circuit Board



Destination (recovery/losses) of elements PCB



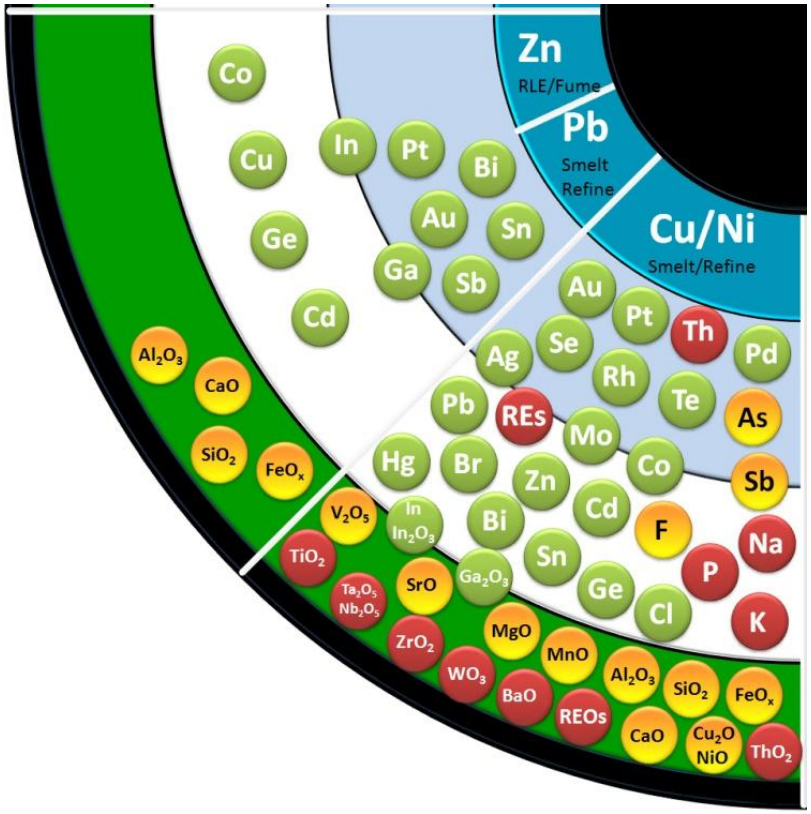
Guideline 7 (In) compatibility of combined materials

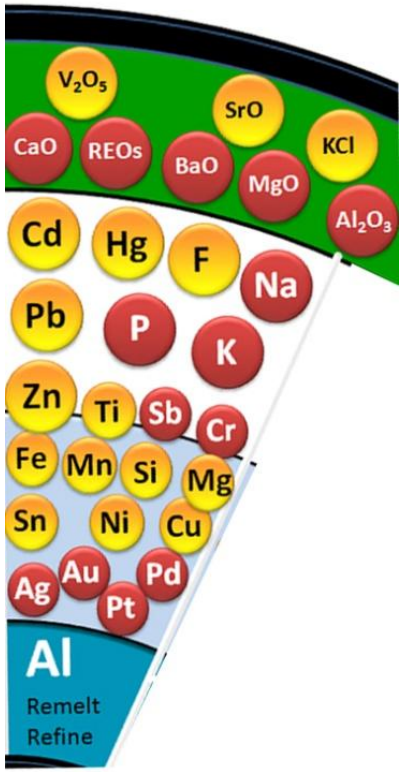
Compatibility tables for a first quick screening – based on Metal Wheel

Materials in input streams (from WEEE materials)	**Society's Essential Carrier Metals: Primary Product** Extractive Metallurgy's Backbone (primary and recycling metallurgy)						
To Remelting, Smelting, Hydrometallurgy, Refining	**Fe** Steel (BOF&EAF)	**Al** Remelt/Refine	**Cu** Smelt/Refine	**Zn** RLE/Fume **Pb** Smelt/Refine	**Ni/Cr** Stainless Steel	**Rare Earths** Hydrometallurgy	**Rare Earths** Special Battery Recycling
PCBA (washing machine/LHHA)							
Ag							
Al							
Al_2O_3							
Au							
Bi							
Br							
Cl							
Cr							
Cu							
Cu_2O							
Fe							
FeO_x							
Ni							
Pb							
Pd							
Sb							
Sb_2O_3							
Si							
SiO_2							
Sn							
Zn							
Elastomers							
Thermosets							
Thermoplastics (flame retardants etc.)							
Epoxy							

Guideline 8 : Design matching with final treatment

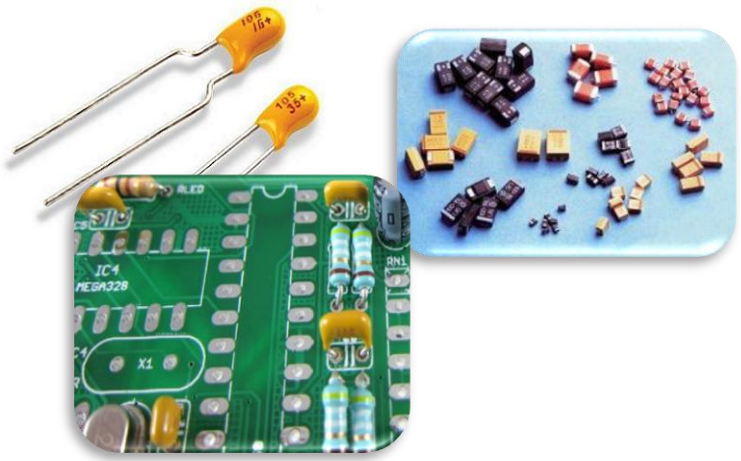
Design clusters or sub-units, which match with the final treatment recycling options (Metal Wheel) and that can be easily removed





Guideline 9 : Labelling/Sorting

Labelling and marking for Waste stream Sorting and (Automated) Disassembly & Sorting



Ta capacitors – color/identification based labelling & easy to break connections

CFL versus LED lamps

Compressors - Marking of tapping point

Standardisation of marking/identification (incl. position) of cooling liquid/gas for fluid system **and** foam

Guideline 10 : Design for Liberation

Avoid bolts/rivets of dissimilar materials (e.g. Fe bolts) as these produce generally a liberation problem therefore creates cross-contamination of the different recyclate fractions

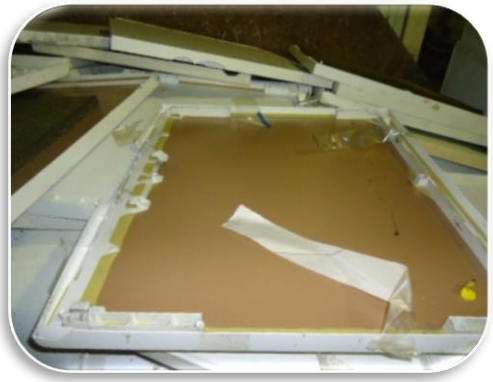
Guideline 10 : Design for Liberation

Minimize the use of non reversible adhesives for incompatible/undesired material combinations

Glass glued to steel mask

Shrink films

PUR glued to steel, Al, plastics



Glued wood/plastic

Sealed batteries

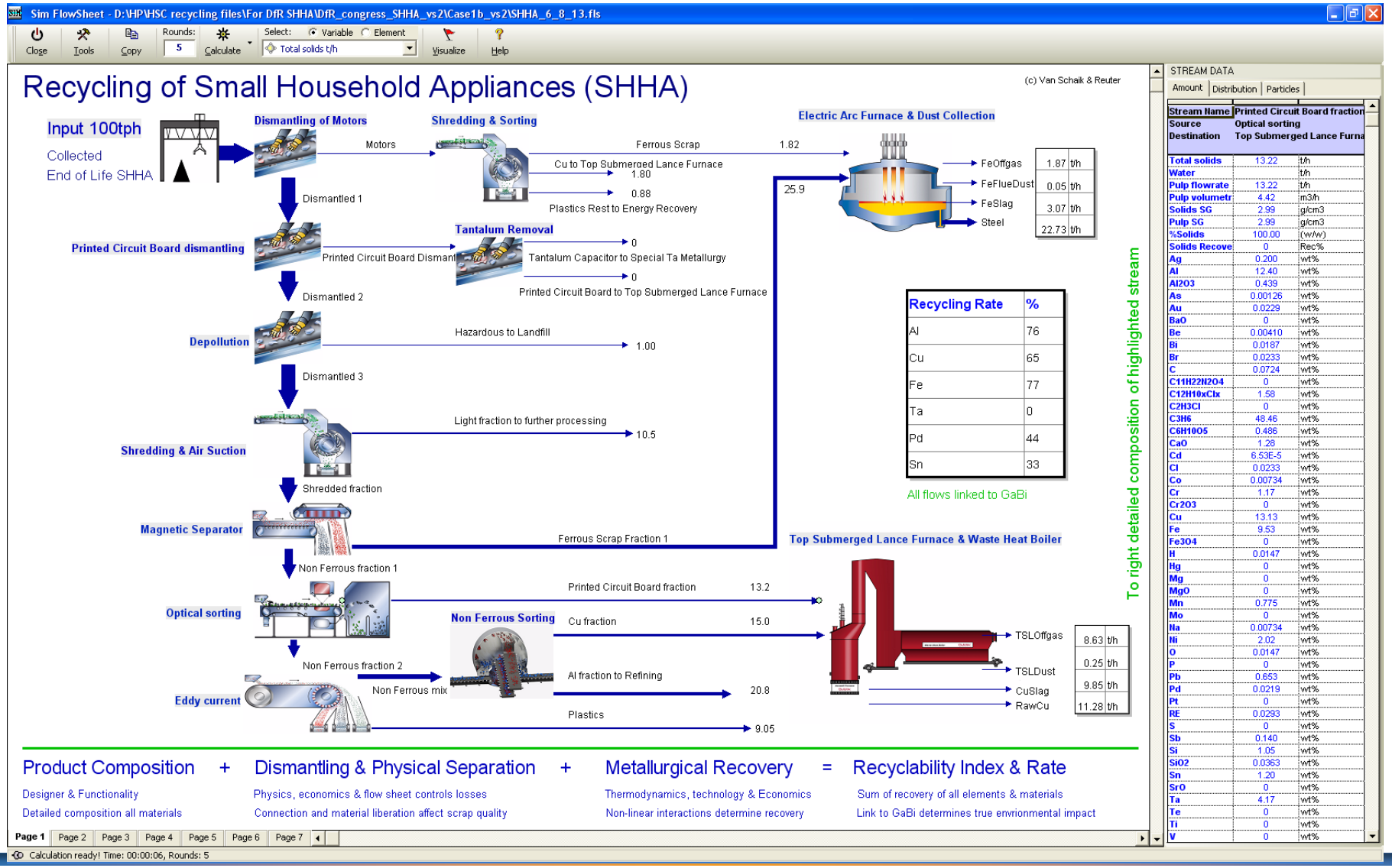
Guideline 10 : Design for Liberation

Particulate quality – an impression of un-liberated & multi-material particles

SIMULATION EXAMPLE

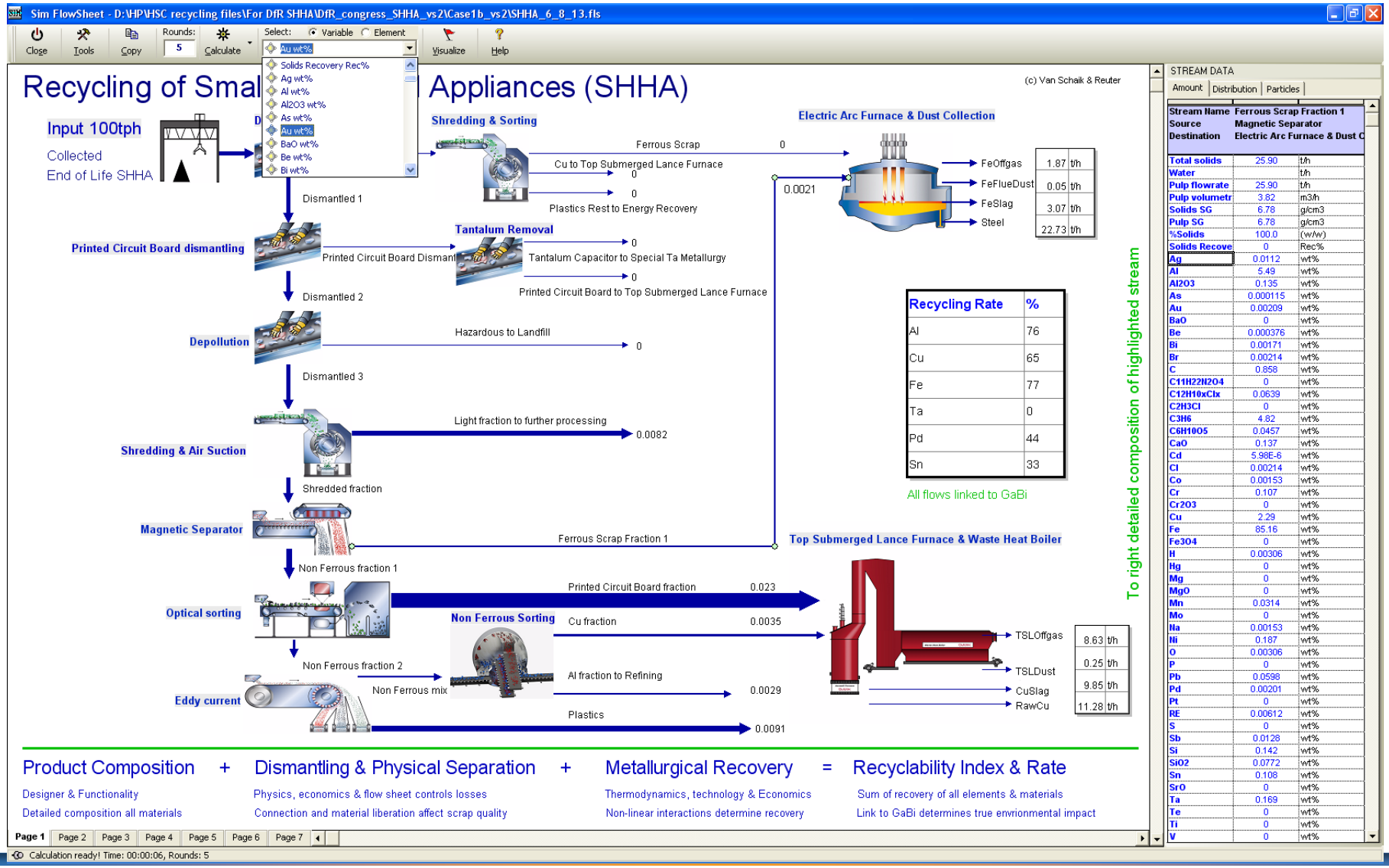
A Simulation Example : Quantification

Quantification of Recycling Rate, Mass flows and quality/composition of flows



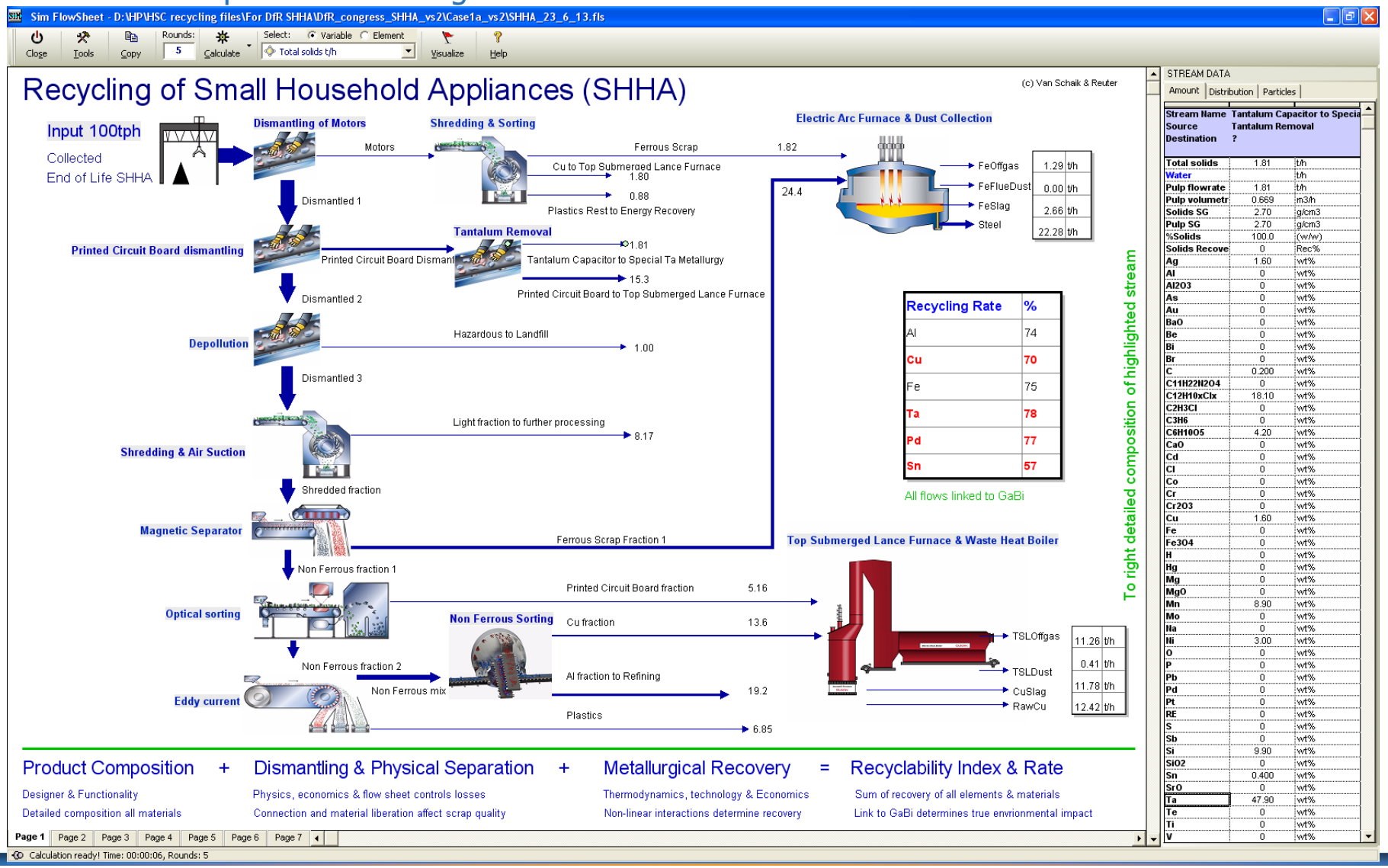
A Simulation Example : Quantification

Distribution/dispersion of elements/compounds can be traced – example on Gold



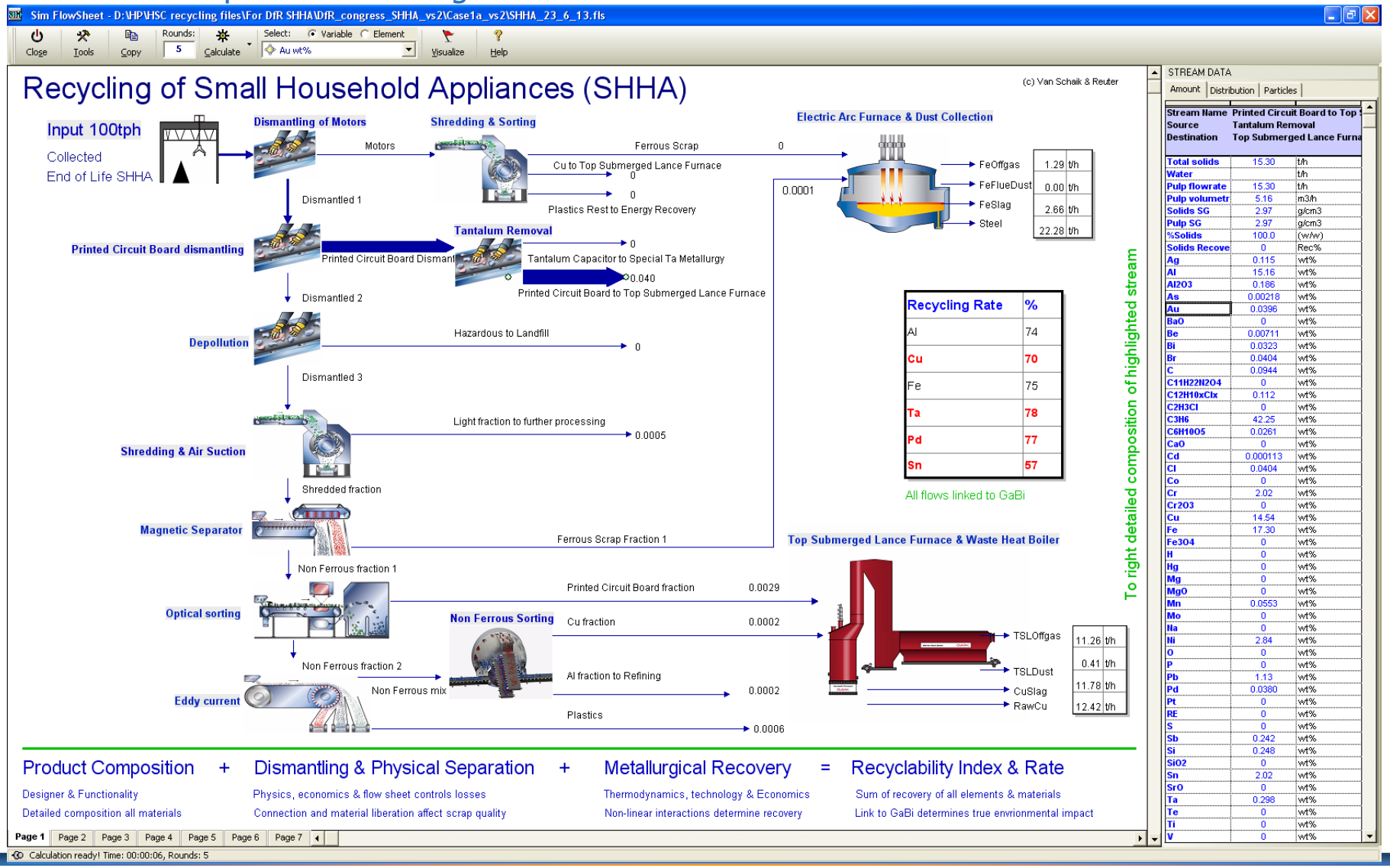
A Simulation Example : Redesign and recycling route

Removal/sorting of PCBs & Ta capacitors through design changes by e.g. labelling and identification options for sorting



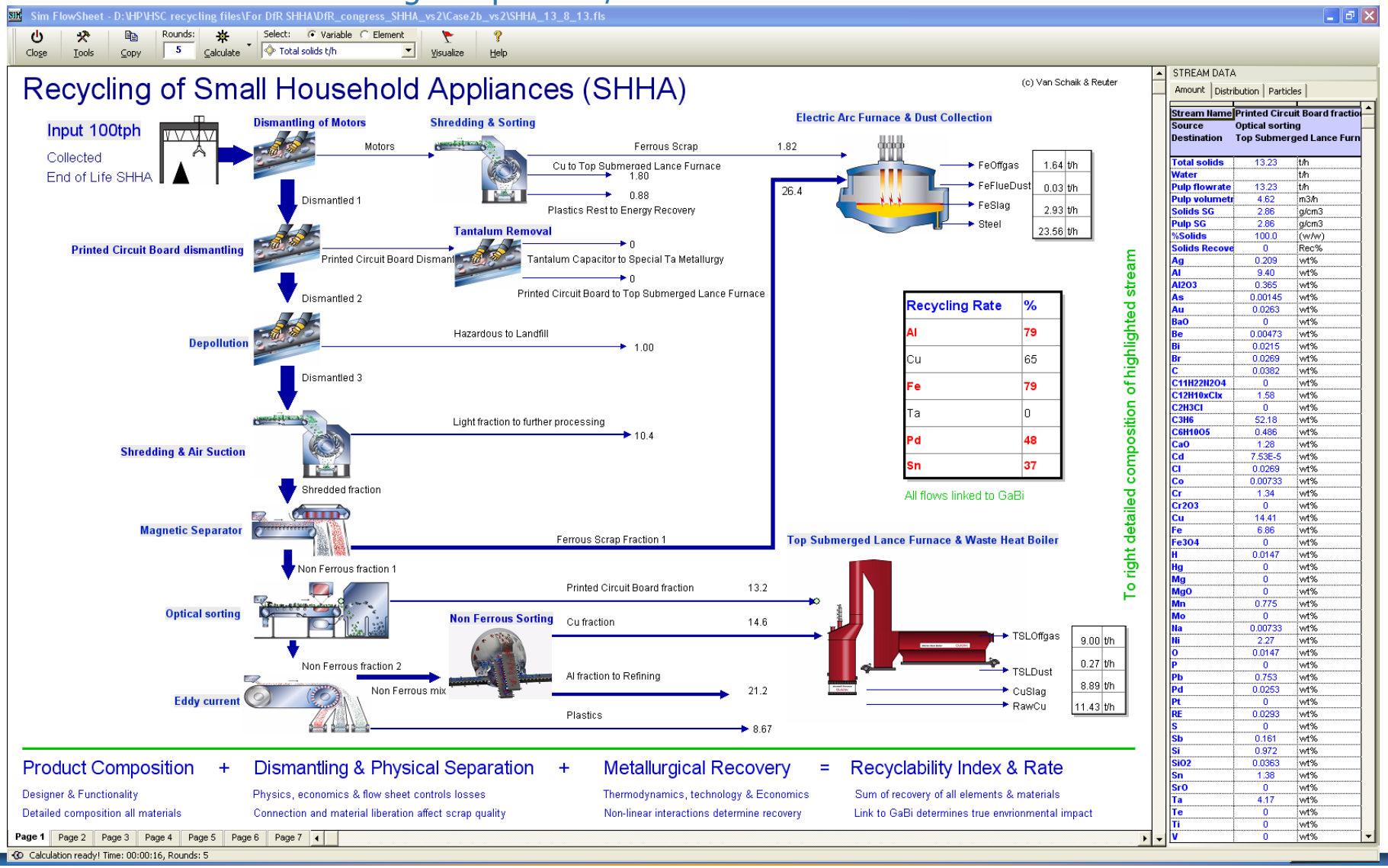
A Simulation Example : Redesign and recycling route

Removal/sorting of PCBs & Ta capacitors through design changes by e.g. labelling and identification options for sorting – distribution of Gold



A Simulation Example : Design for Liberation

Effect of construction/connections of Printed Wire Board in product – improved liberation of Al heat sinks and Fe containing components/bolts

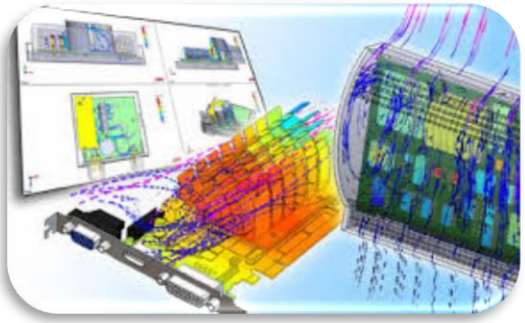


CONCLUDING REMARKS & RECOMMENDATIONS

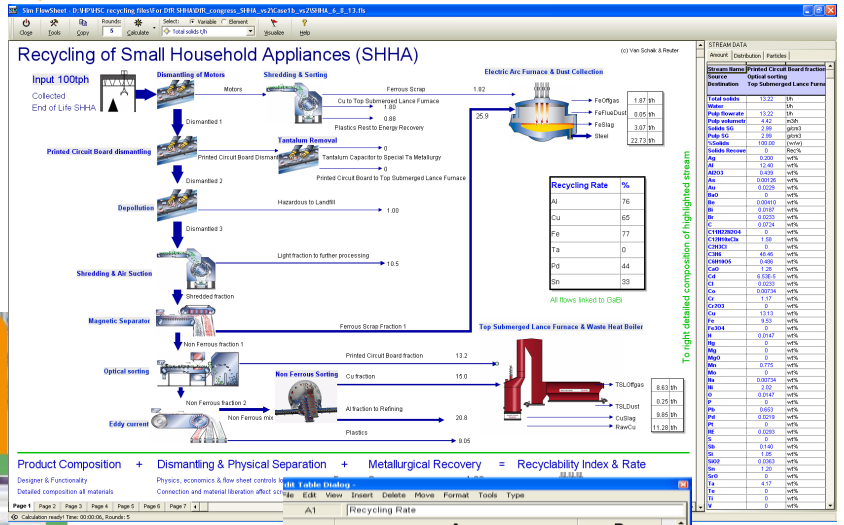
DfR Rule 4 & 5 : Recycling Simulation linked to Design

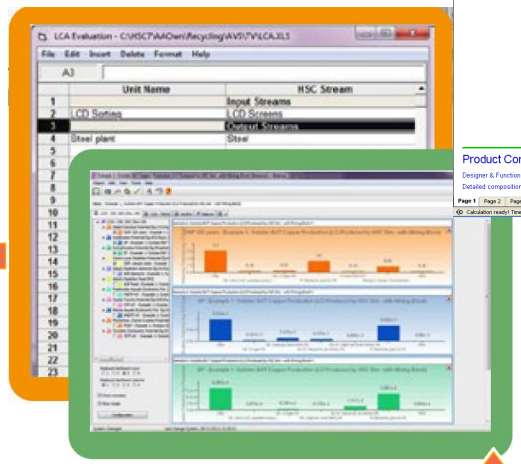
Recycling process simulation tools, including environmental footprint must be linked to CAD/Design tools to realise technology based, realistic and economically viable DfR & Ecodesign

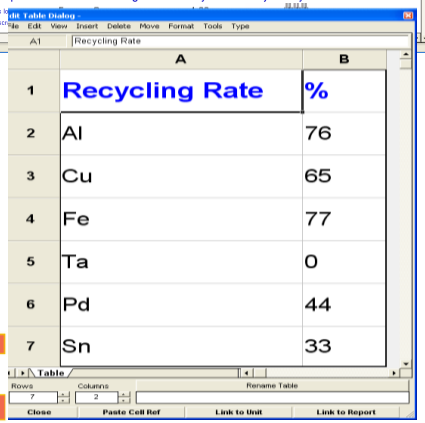
CAD/Design (BOM/FMD/etc)



Recycling system process simulation tools







	A	B
1	Recycling Rate	%
2	Al	76
3	Cu	65
4	Fe	77
5	Ta	0
6	Pd	44
7	Sn	33

Environmental Impact Analyses (Product /system specific)

Recycling & recovery rates + losses/emissions (Product and recycling system specific)

Recommendations

(Policy) targets for Recycling and Eco-design

- should remain within what is technologically (physically and thermodynamically) and economically possible and be based on recycling process simulation tools and knowledge;
- must be set in ways that account for the inevitable losses of materials due to mixing in products for product functional specifications;
- should stimulate Best Available Technology/Techniques (recycling and metallurgical infrastructures)
- should reflect the interest and expertise of all stakeholders in the product and recycling system and stimulate interaction;
- should respect the dynamic (time-varying) product characteristics and recycling profile over time.

Acknowledgements

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