Opportunities & Limits of Recycling
...and of a Circular Economy

Markus A. Reuter
[Dr. h.c., D. Eng., Dr. habil., PhD]
Circular Economy

Product Centric Recycling
Material Centric Recycling

Infrastructure
Criticality?
Metal Criticality
Circular Economy

Which of these lamps is better for a circular economy?

Infrastructure
Criticality?
Metal Criticality
Metals always a part of society, but complexity?

Recycling Index

Which is better to recycle?


Circular Economy: Simplicity vis-à-vis Complexity

Materials Production & Energy Infrastructure Linked
Circular Economy: Simplicity vis-à-vis Complexity

From base metals: Optimal link between energy infrastructure and metals

- **Energy savings relative to incandescent and halogen lamp**

<table>
<thead>
<tr>
<th>Energy Saving</th>
<th>43W Saving (Relative to 60W Incandescent)</th>
<th>15W CFL (60W Traditional)</th>
<th>15W CFL (43W Halogen)</th>
<th>12W LED (60W Traditional)</th>
<th>12W LED (43W Halogen)</th>
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Circular Economy: Product Centric Recycling
We have choices…
The Circle and Stochasim of Life
Metallurgy Block: Internet of Things (IoT)

**GEOLOGICAL MINE**
Geological Minerals

**URBAN MINE**
Designer "Minerals” and Functional Materials

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**Product Design**

**Physical Separation**

**Losses & Stocks**

**Unaccounted Losses & Theft**

**Particle Properties Controls**

**Losses**

**Multi-material Recyclate Grades**

**Complex Linkages/Connections**

**Metal & Energy Recovery (Pyro- & hydrometallurgy, Refining)**

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**Metals & their Minor Elements**

Enablers of a Circular Economy

Internet-of-Things
Web of Metals
Connected technologies
key to a Circular Economy

Metallurgical Infrastructure
Mineral & Product centric thinking
System Integrated Metal Production (SIMP)
Innovative Digitalization of the Internet of Things (IoT)

Maximize Recovery Pb, Zn & Minors
(Maximize resource efficiency of Web of Metal system)

Upper Limit
Less Resource Efficient System
Industry range

Lower Limit
More Resource Efficient System

Fundamental System Benchmark for Web of Metals
Technoeconomic based

Improved System Benchmark
Technology and Systemic Innovation

Driving the Web of Metals to its optimum

Present
Time (Years)
Digitalizing & optimizing metallurgical systems
Mineral/Product centric understanding

<table>
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<tr>
<th>Geological Minerals</th>
<th>Designer-Minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;15 Elements in gold minerals</td>
<td>&gt;40 Elements</td>
</tr>
</tbody>
</table>

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<tr>
<th>Geological Linkages</th>
<th>Designer-Linkages</th>
<th>Complex Recyclates</th>
<th>Metallurgical refining infrastructure</th>
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<tr>
<td>Functional Materials</td>
<td>Linkages</td>
<td>Recyclates</td>
<td></td>
</tr>
</tbody>
</table>

Secondary Feeds (low & high-grade Cu, circuit boards, metal containing residues, ASR etc.)

Raw / Anode Copper Fuel Air (Oxygen)

Discard Slag (Construction Material)

Reductant Flux

1-3 Stage TSL

Electrowinning & Refining
Recycle Slag

Digitalizing & optimizing metallurgical systems
Mineral/Product centric understanding

16-19 August 2015 | Markus A. Reuter | 6th Regional 3R Forum - Maldives
Recyclability Index → Enabling resource efficiency
Inform consumer in a simple manner of our industry to show its importance

<table>
<thead>
<tr>
<th>Recycling/Resources</th>
<th>LED lamp</th>
</tr>
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<tr>
<td><strong>Producer Model</strong></td>
<td><strong>ABC</strong></td>
</tr>
<tr>
<td><strong>Recycling/recovery rate</strong></td>
<td><strong>30-40 %</strong></td>
</tr>
<tr>
<td>Total weight based recycling/recovery rate of all materials/elements/compounds in the product after physical sorting and final treatment processing</td>
<td></td>
</tr>
<tr>
<td><strong>Environmental impact score of recycling</strong></td>
<td></td>
</tr>
<tr>
<td>- Recipe end-point indicator (type E - egalitarian weighting)</td>
<td>0.082</td>
</tr>
<tr>
<td>- GWG (Global warming potential)</td>
<td>0.66</td>
</tr>
<tr>
<td>- AP (Acidification potential)</td>
<td>3.13e-3</td>
</tr>
<tr>
<td>- EP (Eutrophication potential)</td>
<td>1.76e-4</td>
</tr>
<tr>
<td>- ODP (Ozone Layer Depletion Potential)</td>
<td>4.55e-10</td>
</tr>
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</table>

Recyclability Index → Enabling resource efficiency
Inform consumer in a simple manner of our industry to show its importance

So, which is better considering both energy and materials?
Quantifying the Circular Economy

Digitalizing
Linking web of
Energy & Materials

Internet of Things
Process metallurgical systems
key to circular economy
De-silo thinking and education

System Innovation
Simulation & Optimization
(linked to big data analysis)
Inform Policy & Consumer
Additional background sheets
Digitalization for Sustainability [2013-2015]

United Nations Environmental Programme - M.A. Reuter: Lead Author

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Background: http://scholar.google.co.uk/citations?user=5cLC8VEAAAAJ&hl=en&oi=ao
https://www.researchgate.net/profile/Markus_Reuter3?ev=prf_highl

• Industry
  • Director Technology Management: Technology Management, Outotec, Finland (2010→)
  • Chief Executive Technologist: Ausmelt-Outotec, Australia (2006-2010 - taken over by Outotec 2010)
  • Leader furnace control group: Mintek, South Africa (1994-1996)

• Academic
  • Dr. h.c.: Honorary Doctorate University of Liège (2015: Belgium)
  • Dr. habil.: RWTH Aachen (1995: Germany)
  • Adjunct Professor: Aalto University Helsinki (2012→)
  • Guest Professor: Central South University Changsha, PR China (2012→)
  • Professor and Professorial Fellow: University Melbourne, Australia (2005→)
  • Professor & emeritus: TU Delft, Netherlands (1996-2012)
  • Adjunct Professor: Stellenbosch, South Africa (1999-2007)

• Publications, Interests etc.
  • Lead author: UNEP report Metal Recycling: Opportunities, Limits, Infrastructure (2013)
  • Co-Editor and contributor: Handbook of Recycling (Elsevier 2014) (International Solid Waste Association 1st Prize-2014)
  • 2016 EPD Distinguished Lecture Award, TMS
  • Main author: The Metrics of Material and Metal Ecology (Elsevier 2005)
  • >400 Publications: Book / Chapters in Encyclopedias / Journal / Conference / Patents