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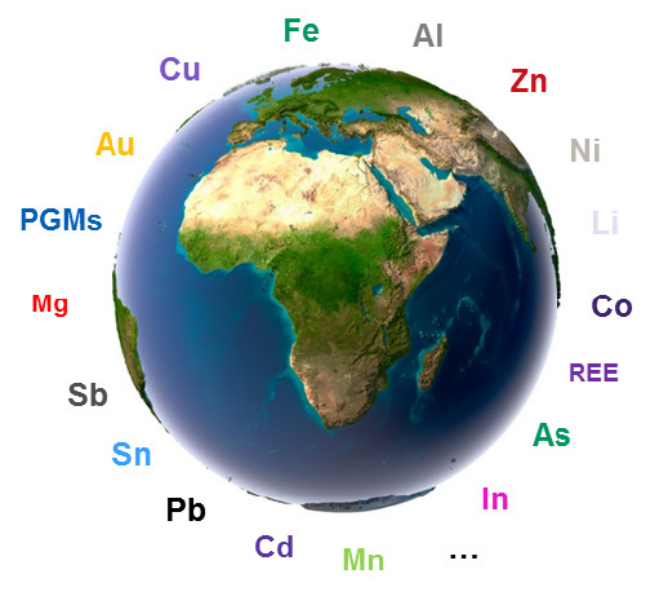

Advancing the Circular Economy of Metals

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Impact case study
Department of Chemical and Metallurgical Engineering 2018

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Field 3a: Chemical engineering and physics

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'We need a true Circular Economy of Metals'

1. Summary of the societal impact

The professors within these four research groups have provided an unprecedented increase in the volume of metal circular economy activities taking place in Finland—exceptionally these professors have provided a bridge between industry, policy-makers and academia that has led to the commitment of a wide range of different stakeholders to the Aalto's multifaceted activities. As a consequence, a broad cross-section of society (e.g., decisionmakers, media, industry, educators and the public) have an increased interest and understanding of Aalto's sustainability related activities. For example, Aalto University is the leading partner of the *Circular Metal Ecosystem – CMEco* project, with a €5m budget including 11 industrial and 5 research organisations.

The natural resources of metals are running out, and the only way to secure the continuously increasing need for metals is to change from the linear to circular economy of metals. Currently, the main obstacle is that end-of-life equipment is not recycled, although the technology for the separation of metals back to raw materials either already exists or can be developed. Consequently, this lack of awareness of all stakeholders, including key policy makers and citizens, must be addressed.

2. Underpinning research/artistic activity related to Aalto activities

The circular economy of metals is based on the expertise of the multidisciplinary research groups in the department that include *Minerals Processing and Recycling*, *Metallurgical Thermodynamics*, *Pyrometallurgy* and *Hydrometallurgy and Corrosion*. This combination of subject areas reflects the whole value chain found within both ferrous (iron/steel) and non-ferrous (copper, zinc, nickel, cobalt) metal industries. The chain requires in-depth knowledge of the key stages that range from methodologies for the preparation of feed materials from primary (mineral, ores) or secondary (wastes like dusts, fly ash or WEEE) resources, through novel processing methods based on both simulated and experimental work. The **final and most important stage** where the close interaction between the research groups has recently proved to be the most valuable is in 'closing the loop'. This has focused on broadening the industrial use of secondary resources using a holistic approach, carried out with companies, which addresses wide-ranging sustainability improvements in preparation methods (*Minerals Processing*) and processing techniques (*Thermodynamics, Pyrometallurgy, Hydrometallurgy*) to maximize critical metal recoveries for further re-use (*Minerals Recycling*).

This approach is central to the wider Aalto University Strategy and makes up a vital part of the *Materials and Sustainable Use of Natural Resources* competence area within the *Advanced Energy Solutions* element of the multidisciplinary themes roadmap of Aalto. Consequently, professors from this research area have been particularly active in disseminating the need and benefits of circular economic thinking within the Aalto community, both through inter-School initiatives like the joint Sustainable Electronics Course, ELEC-E8714 (with ELEC) and more broadly campus-wide as part of Aalto's Sustainability Hub (with ENG, SCI, ELEC). This focus on metal sustainability issues has also led to the recognition of Aalto University as one of the dynamic players in this area on both the national and international stage, as exemplified by the levels of funding received over the last few years, which has included, amongst others: *METYK*, *NoWaste*, *DigiPyro*, *Closeloop*, *Mine-WEEE*, *FLEX*, *CMEco*. Additionally, researchers from the circular economy of metals area are members of a number of international strategy boards like the *IUPAC e-Waste task force*, *EIT-RawMaterials* and the *Raw Materials and Integrated Sustainable Cities Lighthouse*.

3. References to research / artistic activities

1. T. Tirronen, D. Sukhomlinov, H. O'Brien, P. Taskinen, M. Lundström 'Distributions of lithium-ion and nickel-metal hydride battery elements in copper converting', *J. Cleaner Production*, **2017** (168) 399-409. (*IPP=5.83*)
2. P. Halli J. Hamuyuni, H. Revitzer, M. Lundström 'Selection of leaching media for metal dissolution from electric arc furnace dust', *J. Cleaner Production*, **2017** (164) 265-276. (*IPP=5.83*)
3. P. Halli, H. Elomaa, B. P. Wilson, K. Yliniemi, M. Lundström 'Improved Metal Circular Economy-Selective Recovery of Minor Ag Concentrations from Zn Process Solutions' *ACS Sustainable Chem. Eng.*, **2017** (5) 10996–11004. (*IPP=5.92*)
4. A. Porvali, B. P. Wilson, M. Lundström, 'Lanthanide-alkali double sulfate precipitation from strong sulfuric acid NiMH battery waste leachate' *Waste Management*, **2018** (71), 381-389. (*IPP=4*)
5. M. Lundström, K. Yliniemi. **Invention disclosure number: IPD 1748** (*Sold to Outotec, 2015*) *International Application No: PCT/FI2016/050442;* ***Patent No: WO/2017/216417*** *(21.12.2017*)

4. Societal Impact, activities and roadmap for the case

The impact of the circular economy of metals is multidimensional; it has been involved in a wide spectrum of arenas (see below) with the overarching intention to have maximum impact on the *short-* (e.g., specialist conferences), *medium-* (e.g., joint industrial projects with a business focus–METYK/CMEco/FLEX) and *long-term* (e.g., teaching of MSc/PhDs; innovations related to new processes). More importantly, by engaging directly with schools, citizens and politicians, the circular economy of metals—along with others—is providing the necessary information required to ensure a **wider understanding of and positive legacy** for the 'Circular Economy in Society'.

Teaching: In addition to the teaching within Aalto University (highlighted above), faculty has been actively involved in teaching a number of specific courses that focus on the circular economy of metals to key stakeholders. This has been on both the national (*Jyväskylä Summer School 2017, POHTO Hydrometallurgy course 15-16 November 2017, Slags in metallurgy 11-12 April 2018*) and international scale: the regular Finno-Sino Metal Circular Economy Postgraduate School (with Central South University, China) and as part of the EIT Raw Materials KAVA funded *Circular Economy Entrepreneurship in System Integrated Metals Processing* (CEE SIMP) course 2016-2018 that includes partner institutions from across Europe. Furthermore, through active involvement in the Aalto LUMA ***Scientists in Schools*** programme, a generation of school-aged children have learned about the circular economy as a positive influence for the future.

Research: Groups associated with the circular economy of metals are very active within the wider research community, with over 100 papers in high-impact journals indexed in Scopus (2013-2017) as well as many international conference papers/meeting presentations (including over 15 invited/keynote speeches). Moreover, investigations on sustainability issues have led to 5 Innovation Notices (3 Patents Pending) and organisation of several related international conferences/seminars. In addition, a total of 40 Master's theses are complete, and currently 20 PhDs and 15 Master's thesis students are working in related projects.

Academic-Industrial Partnerships: The circular economy of metals has generated upwards of €7m funding for related projects, which also include a high level (>30) of multinational industrial and small- and medium-sized enterprises' stakeholder engagement, either directly or as members of project steering groups. Of these, the flagship *CMEco* and *Flexible and Adaptive Operations in Metal Production(FLEX)* projects directly involve major companies, SMEs and research institutes, which shows the extent of the circular economy of metals' influence.

Political: Members of these research groups have had a number of meetings with key political stakeholders at both national and local government level, including the Ministry of Economic Affairs and Employment, National Commission on Sustainable Development, and Mayors of Pori City and Harjavalta Town councils. Additionally, we were part of the delegation that successfully lobbied for the first United Nations Technology Innovation Lab (UNTIL) that includes circular economy, to be set up in Espoo, Finland.

Non-academic: Aalto's circular economy of metals research has been in the media, including *El Pais* 'Metal Circular Economy' (Spain), and *Tuulilasi* 'Li Battery Recycling' and *Ahjo-lehti* 'Waste Heap Utilisation' (Finland). Additionally, public engagement has been achieved via 4 Open METYK-Seminars on battery recycling.

5. Additional sources to support the impact case (information and links)

- Organisers of international symposiums: Hydrometallurgy Symposium 2-3 November 2015, Process Metallurgy 7-8 November 2017 and the 6th Baltic Electrochemistry Conference, 15-17 June 2016.
- Invention disclosures: #IPID 2007 (Patent Application number 20175591); #IPID 1829 (Patent Application number 20165997); #IPID 1867 (03.05.2016); #IPID 1753 (01.09.2015).
- Host of the RawMatTERS Finland Infrastructure – Particle Characterisation Unit (RAMI-PCU) an international resource for academia and industry funded by the Academy of Finland.
- Partner in the EU ZeroWaste Cluster Networks of Infrastructure (NOI): Solvoflex, Electroflex.
- Meetings with Finnish government officials at the Ministry of Economic Affairs and Employment Director General (22.12.2016), Mika Aalto, Head of Division (8.12.2016); National Commission on Sustainable Development, Marja Innanen Deputy Secretary General (1.12.2016); Minister of Local Government and Public Reforms, Anu Vehviläinen (14.7.2016 and 13.7.2017).

6. Future goals

The strategy of the Department of Chemical and Metallurgical Engineering has one major goal, defined as 'processes based on hydro and pyrometallurgical phenomena and their optimization and digitalisation for enabling production of, especially, non-ferrous and critical metals, new products, and advancing circular economy of metals.' By definition, this requires active collaboration in European Union H2020 projects with partners across Europe (and beyond) whose complementary expertise add to in-house knowledge. Moreover, additional investments for the EIT Raw Materials Infrastructure (RawMatTERS, RAMI) are planned to further enhance its role as a dedicated resource to support the circular economy of metals vision. These investments include both equipment and personnel, for example, a recently appointed Staff Scientist role includes responsibility for future RAMI development. Such positive steps form the basis of the central target, which is to strengthen the long-term core expertise in Otaniemi (with Geological Survey of Finland and VTT) to position Finland among the world's elite research centres for the natural and new inorganic materials needed in the circular economy. Key focus areas to achieve this aim include the ability to process, characterize and recycle primary and secondary raw materials, and the capacity to lead the search for cutting-edge material replacements for future sustainable technologies, for example. In addition, major investment proposals 2018-2020 will be coordinated across the whole school via the CHEM infrastructure steering group to ensure appropriate and timely additions to infrastructure.

Furthermore, as a global centre of excellence, the professors intend to organise a biennial International Symposium on Process Metallurgy—Metallurgy as a tool for challenges in circular economy. This symposium series will focus on introducing the newest academic and industrial advances in recycling and recovery of metals—especially critical metals—from end-of-life equipment, the consumption of which is forecasted to exceed production capacity or known primary resources.