KU LEUVEN

Proceedings of the
THIRD INTERNATIONAL

SLAG VALORISATION SYMPOSIUM

THE TRANSITION TO SUSTAINABLE MATERIALS MANAGEMENT

19-20 March 2013
Leuven, Belgium

Editors Annelies Malfliet, Peter Tom Jones, Koen Binnemans, Özlem Cizer, Jan Fransaer, Pengcheng Yan, Yiannis Pontikes, Muxing Guo, Bart Blanpain

centre CR³ KU LEUVEN rare³ SMART-PRO²

VALORISATION OF CRITICAL METALS FROM HIGH TEMPERATURE RESIDUES AT UMICORE

Mieke CAMPFORTS[1], **Stijn FOERIER**[2], **Karolien VASSEUR**[1], **Christina MESKERS**[2]

[1] Umicore Group R&D, 2250 Olen, Belgium
[2] Umicore Precious Metals Refining, 2660 Hoboken, Belgium

mieke.campforts@eu.umicore.com, stijn.foerier@eu.umicore.com, karolien.vasseur@eu.umicore.com, christina.meskers@eu.umicore.com

Abstract

The current debate on material scarcity and metal supply risks indicates that a holistic, global system approach is needed to minimise material spillage over the whole product life cycle. Clearly, the set-up of an ecosystem between the different stakeholders along the whole value chain is essential to secure a sustainable material supply. Here, the assessment of the established partnership between mining, primary smelters and integrated smelters shows that metal value is and has been a sufficient driver for the manifestation of such an ecosystem as the three industries are aligned to optimise for maximal metal recovery from ores and recyclables entering the flow sheets.

Introduction

Today's society shows an increasing demand for multi-metal products as population grows and high standards of living are sought in developing and transition countries. This is directly reflected in an increase in metal demand, both in the volume of a specific metal and in the range of metals used today in products. This is more specifically for technology metals as they are key in providing the functionality of many clean- and high-tech applications.

To give an example, when comparing the primary production of technology metals with the volume needed in electric and electronic devices (Figure 1), 80% of the indium production and 65% of the ruthenium production are consumed in this application alone. Furthermore, these metals are subject to volatile metal prices and questions are posed concerning their supply security. As a result multiple organisations have performed a mapping of the supply risks of metals and materials based on a criticality methodology, see Figure 2 for the EU mapping where the economic importance is plotted as a function of the supply risk. Some mappings

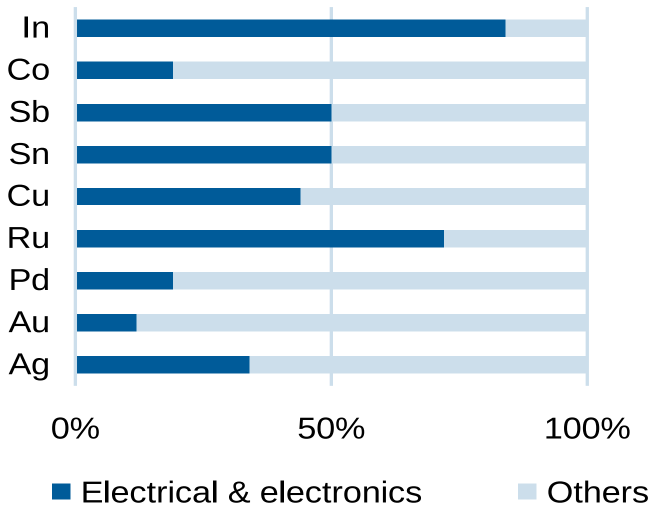

Figure 1: Overview of the fraction of primary mine production of technology metals that is used in electric and electronic devices

focus on the economy as a whole, others assess the risks for only a particular application. To study and provide sustainable access to the critical materials, a wide range of research and innovation programs are set up focussing at the different aspects and underlying factors that influence supply security. In this contribution a look will be taken at different scarcity concepts and challenges in the material supply. Then we will zoom in on the industrial network or eco-system between mining, primary smelters and integrated smelters and the role Umicore plays in this network. As conclusion ongoing efforts to further build and expand this eco-system are discussed.

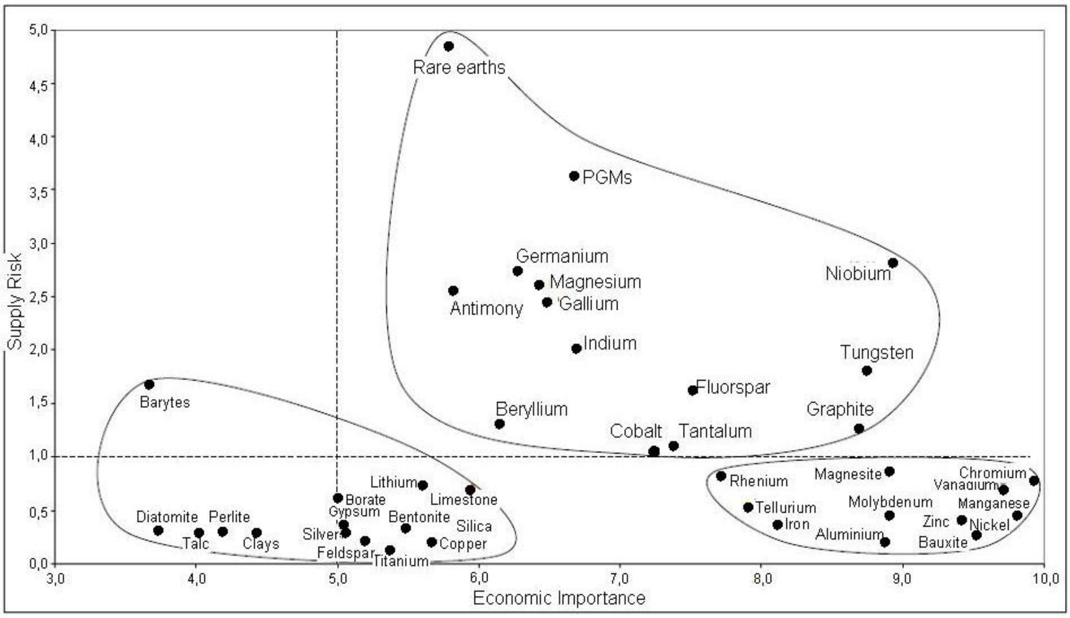

Figure 2: Criticality mapping of 41 raw materials as published by EU[1]

Scarcity concepts

The scarcity and supply security debate can be approached from two extreme positions, being the resource optimist or the believers in the market mechanisms to overcome the foreseen issues versus the resource pessimist who relies on the available numbers on ore resources and annual demand. A more realistic approach, however, is to evaluate three types of scarcity namely absolute, temporary and structural resource scarcity.

Absolute scarcity is equivalent to a depletion of mineable ore deposits and the total market demand for this metal exceeding the remaining mine output. This situation would result in extreme prices, drive substitution and in worst case severely impede further spread of technologies. This scenario is rather unlikely in the foreseeable future as rising metal prices drive further exploration such as deep sea mining, more difficult deposits or expansion of current mines and technological advances will enable innovative and more resource efficient technologies. The resource pessimists often use this type of scarcity.

Temporary or relative scarcity on the contrary has already been encountered. Here the metal demand is not met for a certain period of time because of multiple reasons going from new technological developments, to strong market growth of existing applications, to supply disruptions due to constraints in mining countries, transport issues or natural disasters. These risks increase when major mining or smelter operations are concentrated in a few and/or unstable regions/companies and when only a limited number of applications make use of a particular metal. The appearance of a new successful application increasing the demand can then result in temporary scarcity. Often the temporary scarcity is caused by a number of combined reasons.

Structural scarcity is the most severe type of shortage and most relevant for technology metals as extraction of these metals is often coupled to the extraction of major or carrier metals as is illustrated in Figure 3. The “by-product” metals are present in such a low concentrations in the ore compared to the carrier metals that their mining is driven by the demand for the carrier metal. The mining of the by-product metal on its own is not economically feasible, but as it comes along with a major metal the infrastructure is shared and mining and recovery is economically feasible. A strong increase in demand of the by-product metal will not necessarily lead to more primary production as an oversupply of the carrier metal will strongly affect its metal price.

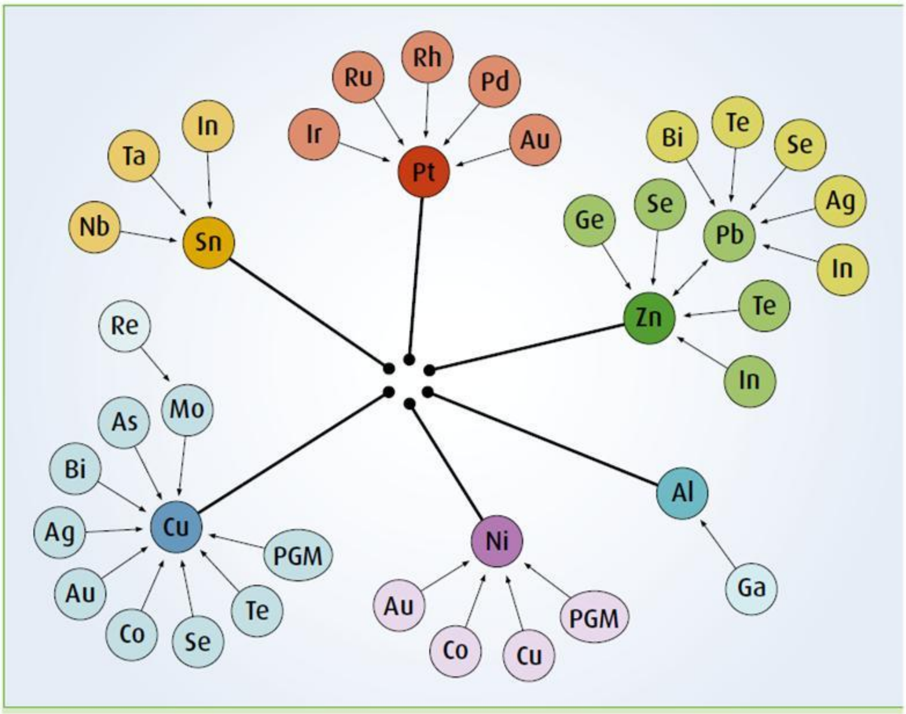

Figure 3: Illustration of the coupling of major and minor/technology metals. *E.g.* In is extracted as a by-product of Zn, Pb and Sn production[2]

Challenges in material supply security

In order to ascertain the supply chain of technology metals, it is essential to both avoid as much as possible spillage during each phase of the product life cycle (Figure 4) and provide a sufficient metal input to cope with the minimal losses and increasing demand. In addition it is necessary to recognise the fact that technology metals are associated with carrier metals in part of the life cycle. Figure 4 also illustrates this connection. In the ore and mining processes the by-product or minor metal is physically interlinked with the major or carrier metal. During primary metal production they are separated from each other and marketed as separate metals. During production minor and major metals are brought together again, but in different combinations and ratios than in natural ores. After use of the product the metals can be separated again physically in the end of life phase (for example via separating different components) and chemical separation into pure metals takes place in the raw materials production phase.

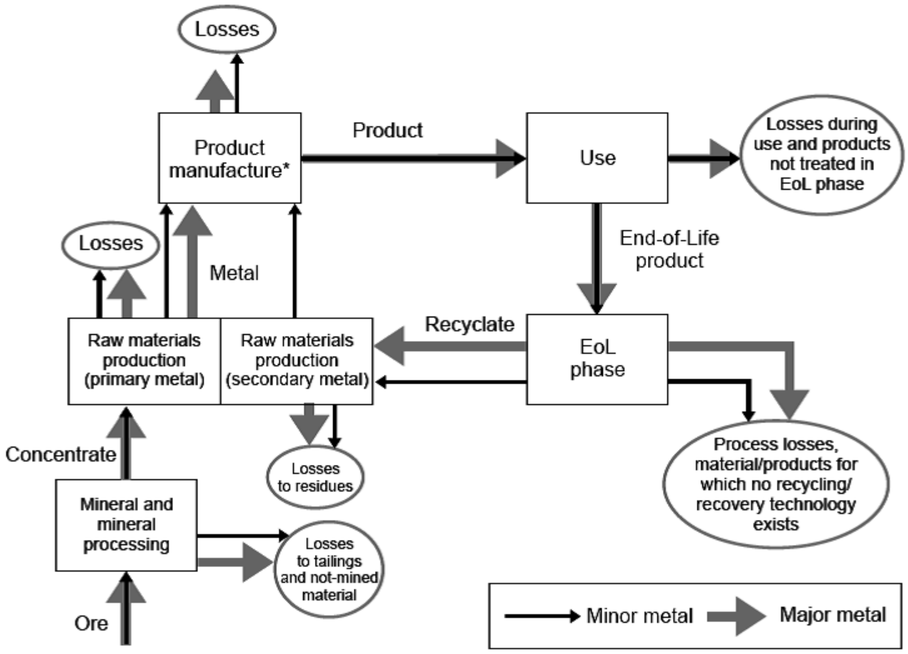

Figure 4: During the material life cycle losses occur systematically because of the thermodynamic laws[2]

As spillage can not be brought to zero due to the need for a certain metal grade, **access to and extraction of primary ores** cannot be excluded in the future. The decrease in ore grade and the increasingly difficult accessibility of ores, however, challenge the current primary metal supply as more and more energy, water and land is needed to provide new metals. New exploration and innovative technologies are necessary to access new resources and cope with the decreasing metal content in a sustainable manner.

Recycling of end-of-life (EoL) products and production scrap lowers the pressure on input of new materials in the product life cycle. Currently, recycling rates are far from optimal as the whole value chain from collection to pre-processing and final recycling is not well aligned. For closed product cycles, which are typical for industrially used products, recycling is already well established when the volume and/or the metal value makes recycling economically viable. Here products are well inventoried, changes in ownership are well documented and proper recycling routes are relatively well known. For open product cycles, being consumer goods, the recycling rates can be very low. First of all the consumer awareness of the metal value of these products (taking into account the volumes put on the market) is limited resulting in little awareness or actual behaviour to contribute to collection of these devices. Secondly, dissipation of the product often occurs as the product is stored in a drawer, disposed with household waste or ends up in improper recycling routes. Furthermore, the promotion of reuse results in poor tracking of material along the entire chain as products not only change from owner but often also from location (country). Effective collection and monitoring of EoL flows in a quantitative manner are necessary and proper knowledge of best available technologies is essential. Even when products end up in the best available routes, recycling remains a challenge as refining processes build further on the extraction of metals from ores that have a characteristic combination of metals. In a wide range of EoL products metals are combined in complex, man-made mixtures, a number of combinations pose new challenges for the established metal extraction processes.

Substitution depressurises metals scarcity further as it drives diversity in products. Substitution in itself can not bring the solution for the material scarcity issue. For clean-tech and high-tech applications namely the same group of metals are considered because of their specific unique properties, as is illustrated in Figure 5 for electronics and opto-electrics. Nevertheless, substitution can bring temporary relief if certain metal prices are high and can contribute to a steadier product flow. Substitution can also be driven by legislation such as the replacement of Pb in solders.

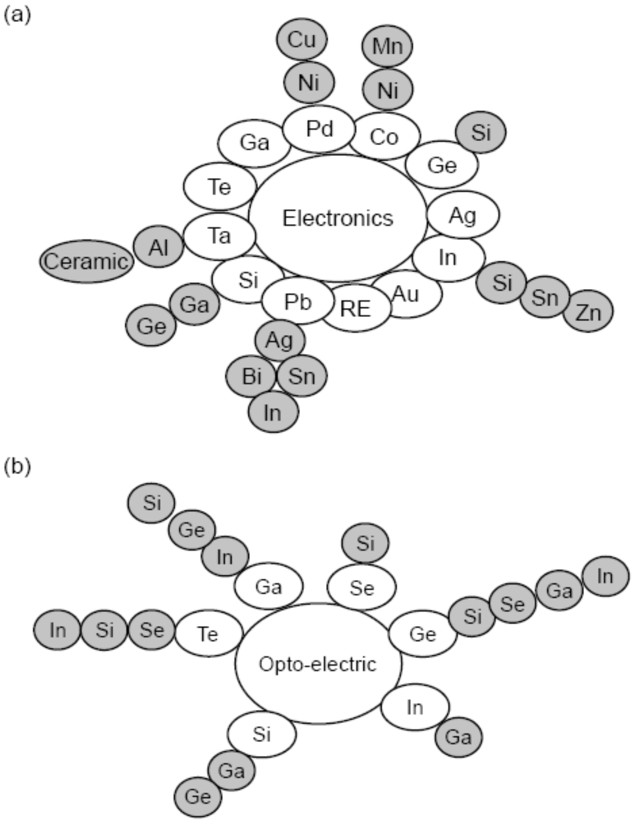

Figure 5: Illustration of how for clean- and high-tech products substitution focuses on the same group of metals. The substitution options for metals in electronics (a) and in opto-electric applications (b) both look at the metal groups[2]

When evaluating the material life cycle it is clear that material supply security will not be reached overnight. A holistic approach is needed to bring overall breakthroughs and not shifting to or accelerating issues in other parts of the material life cycle. It can be concluded that a large volume of work is waiting to be done. However, already today parts of solutions are in place. As an example the next paragraph describes the ecosystem that is already in place for metals extraction.

Ecosystem of metals extraction

When looking at the current mining, primary smelting and integrated smelter industry, it can be concluded that partnership between the three industries has led to the establishment of a symbiotic ecosystem in which each industry benefits from the others existence. The main driver for this establishment has been the strong increase in metal demands and concurrently the increase in metal prices.

As most high grade ores have been mined through the years and ores with lower grades are economically viable to be processed, more and more complex ores are processed in the primary smelting routes. These flow sheets combine both pyro- and hydrometallurgical processes to obtain pure metal streams. Furthermore, primary smelters more and more introduce recyclables in their flow sheets giving further rise to impurities that need to be handled.

As the flow sheet focuses on the lean production of the main or carrier metals, minor metals that are not targeted in the process flow are purged and concentrated in by-products. These by-products often have a high metal value and are introduced in other primary smelters focusing on the production of the purged elements or integrated smelters specialised in producing a whole series of metals. The latter have as advantage that by combined recovery of metals, the more valuable metals pay for the recovery of interesting but less valuable metals.

Figure 6 visualises the role of Umicore’s integrated smelter within the material life cycle. Umicore is part of a larger eco-system that involves the manufacturing industry via the treatment of production wastes, and it is an integral part of the recycling chain by recovering metals from complex fractions from end of life consumer goods. Zooming in on the cooperation with copper – lead – nickel smelters, Umicore receives smelting and refining residues from the lead, copper, nickel, precious metals and platinum group metals smelters and refineries. These residues are complex and contain a wide range of the by-product metals indicated in Figure 4 that are associated with the major metal. Using three carrier metals in its own operations the by-product metals can be recovered efficiently.

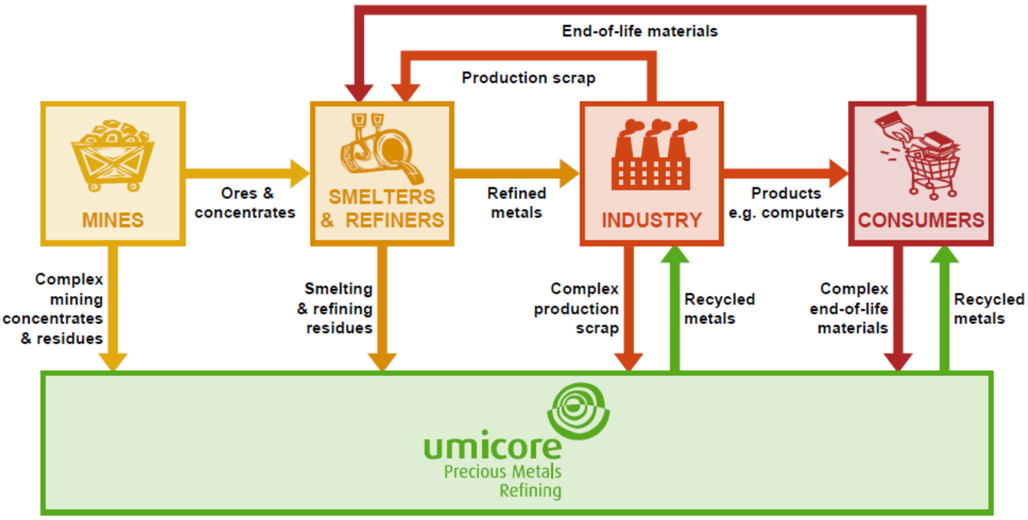

Figure 6: Example of the interaction between Umicore and the mining industry, smelters industry, product manufacturers and the consumer markets

This ecosystem between mining, primary smelters and integrated smelter is driven by the distribution of minor and technology metals between different base metals, therefore referred to as "carrier" metals (Figure 4). The distribution is driven by the physical laws of thermodynamics and, thus, by properly introducing minor and technology metals in the right flow sheet, a major part can be recovered. When considering a primary copper smelter for example a wide range of by-products

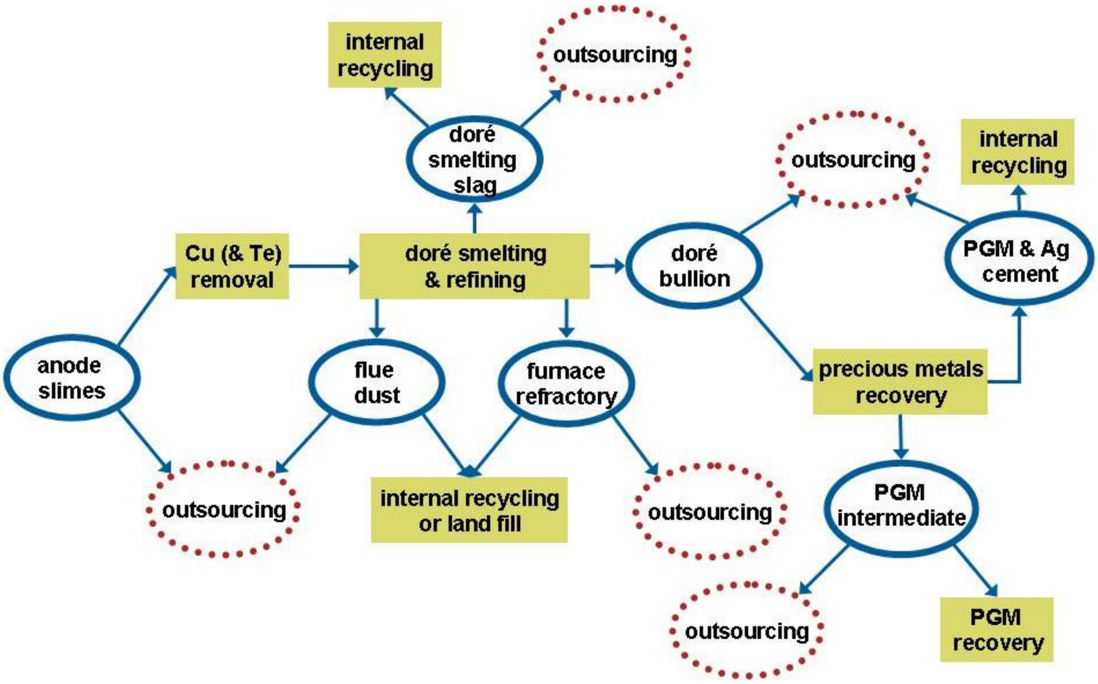

Figure 7: Overview of by-products that form during the processing of anode slimes and the options for further processing

results from the processing of copper ores. An example of such by-products is anode slimes which can be further processed in-house for the recovery of tellurium, precious metals and other metals (Figure 7). This will in turn generate other by-products with valuable metal content, including different types of slags. The outsourcing box indicates which fractions can all be processed by Umicore for the recovery of by-product elements. Similar Figures can be constructed for lead, zinc and precious metals flowsheets. Table 1 and 2 indicate which metals are recovered from the different by-products in a dedicated flowsheet. The advantage of treating the different by-products in one place is that the materials go in a flowsheet specialised for just that, and economies of scales can be applied.

Table 1: Overview of metals that can be recovered from a wide range of by-products from primary smelters

	As	Sb	Sn	Bi	Ni	Se	In	Te
Anode slimes (primary)	X	X	X	X		X		X
Anode slimes (secondary)	X		X	X		X		X
Dore slag	X	X	X	X				X
Dore flue dust	X	X		X		X		
Speiss (Pb)	X	X	X		X			
Matte (Pb)	X	X						
Refining dross (Pb)	X	X	X	X	X		X	

Umicore Precious Metals Refining has made its strength from mastering the metal distribution between Cu, Ni and Pb in order to recover 14 metals apart from the carrier metals Cu, Ni and Pb out of complex products as is illustrated in Figure 8.

Take for example Cu. During Cu smelting, precious metals are concentrated in the metal phase while elements such as Pb, Ni and Sn end up in slag. By further processing the Cu metal (typically electro refining) slimes containing the precious metals are produced while a rather pure Cu is obtained. As Cu here acts as "carrier" metal for the precious metals, the latter can finally be concentrated and further recovered. Similarly, further processing of the slag will lead to the recovery of Pb, Ni and Sn. However, when introducing the precious metals and Pb, Ni and Sn into a Fe smelting process, the precious metals and Sn are lost in the Fe or in dust and most likely also the Pb and Ni. Especially this last consideration is important when considering the recycling of fractions from end of life products, as it indicates the thermodynamic limitations of metallurgical processes, and thus of metal recovery.

Table 2: Overview of metals that can be recovered from a wide range of by-products from primary smelters, sequel

	PGM	Au	Ag	Cu	Pb
Anode slimes (primary)	X	X	X	X	X
Anode slimes (secondary)	X	X	X	X	X
Dore slag		X	X		X
Dore flue dust					X
Speiss (Pb)		X	X	X	
Matte (Pb)		X	X	X	X
Refining dross (Pb)		X	X	X	X

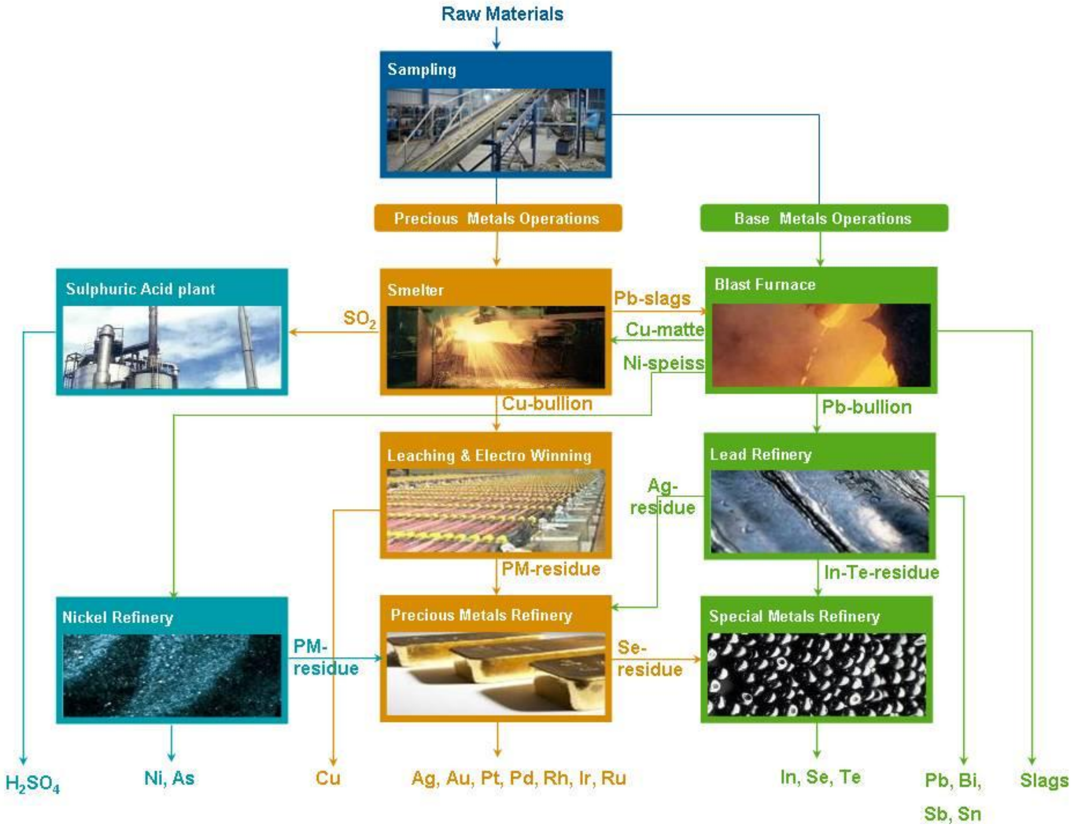

Figure 8: The integrated smelter of UPMR. By mastering the metal distribution between Cu, Pb and Ni a wide range of metals can be recovered

The established ecosystem has a huge potential to efficiently recover metals as long as the complex feed contains metal combinations similar to the ones found in nature and if the combination of metals has enough metal value to pay for the processing. However, in the case that other complex mixtures need to be treated, take for example high-tech materials containing both precious and rare earth metals, a trade-off has to be made as one of these metal groups will be lost during processing *e.g.* by dilution in the carrier metal or in the slag capturing impurities. Moreover, when the complex metal mixtures have low metal value and/or their composition is not compatible with the existing integrated smelters, the residues/EoL products containing these materials are not treated at the moment. An example of such a material is the high plastic residue from shreddering. These limits of the current ecosystem pose challenges for the treatment of low metal residues from mining, manufacturing wastes, EoL products, and slags containing low concentrations of precious metals.

Apart from the limitations associated with metal recovery from low value and strongly diluted materials, the limited market options for slags as valuable alternatives for natural resources in the building and construction industry, are a major challenge. Primary products are cheap, resulting in a limited economic drive to process slags. Furthermore, a good knowledge base of the impact of slag use in building and construction materials on the environment during first and second life is needed in order to provide input for good legislation. And finally, a partnership with the building and construction industry is gradually being built up. Here, further knowledge build-up of slag use in building and construction products while taking into account the whole life cycle of these products, will further facilitate the establishment of such partnerships.

Another aspect that is important in the discussion of industrial networks or ecosystems is that essentially the eco-system between integrated smelters and primary smelters is in essence an interaction between actors that all speak the same language, the language of metallurgy, that makes interactions easy. With the interactions in the recycling chain also a common language has developed between end-processors (metallurgy) and the pre-processors that do physical separation. On the other hand when considering the use of benign slags in for example construction applications, there is still a common language to be found. It is an ‘exploration’ into a new industry with its own language, way of working, policy actors and rules and regulations. Still if a closed loop is our aim different industries would have to take efforts to understand each other, to build up the eco-system and create common language and goals.

Running actions to further build up ecosystem

Taking sustainability at hearth, Umicore takes the lead in building up a material ecosystem. As the challenges are huge and need to be tackled in a holistic way, Umicore contributes at different levels to facilitate the paradigm shift. At the strategic level Umicore is involved in both worldwide[3], European[4] and local initiatives[5] in order to set-up a frame that enables the implementation and dissemination of innovative material solutions by bringing together all stakeholders (government, industry, university, research) across the whole value chain. Next to the strategic level, knowledge and technology development is essential to generate and implement material solutions. Here, well-aligned research efforts on pre-competitive and competitive level are essential in order to provide the knowledge base required to tackle the complex challenges faced[6]. For the implementation of the generated innovative sustainable solutions, entrepreneurship is key to accelerate the establishment of a sustainable society[7].

To stimulate entrepreneurial education, Umicore actively participates in the formation process of a Knowledge and Innovation Community (KIC) on raw materials. A KIC on raw materials will concentrate on fostering a knowledge hub on academic, technical and practical education and research in sustainable mining, material management, recycling technologies, material substitution and international trade in raw materials. Other than in research-based EU initiatives, the primary focus of the KIC is to develop the human capital and entrepreneurs that are key to drive the innovation. This initiative is tailored to enhance entrepreneurship along the entire value chain while managing an innovation program of strategic importance to EU industry. By doing so, it will create the landscape in which the gap between strategic objectives and the implementation of sustainable solutions is bridged.

The set-up of these collaborative networks with knowledge institutes, industries and public bodies demands for a long time vision, since a high level of trust between the stakeholders and a strong will to continuously improve, are key. Umicore therefore aims to create the right mindset to be open, share knowledge and look for overall solutions by taking at hearth the key values of openness, innovation, respect, teamwork and commitment. Openness stands for system thinking, interaction with stakeholders and a positive attitude towards constructive dialogues. Innovation represents the continuous search for better ways of doing things and creative solutions. Respect forms the base for the creation of win-win-win situations. Teamwork stands for bringing together stakeholders with multiple competences and multiple visions to deal with complex issues and hence increases the reliability when tackling shared goals. Commitment is interpreted as personal commitment to act as change agents within the organisation and the society as well as commitment to nourish long term partnerships allowing addressing large challenges and building on previous work.

Conclusions

The increased demand for metals has given rise to the debate on supply security and metal scarcity. A critical evaluation of the product life cycle shows that a holistic approach is needed when addressing the challenges in mining, reuse, recycling and product development to establish efficient use of materials. The assessment of the established partnership between mining, primary smelters and integrated smelters shows that by the current metal value already an ecosystem is arisen in which the material flows between existing flow sheets are optimised to maximise value and therefore metal recovery. This ecosystem indicates that although the challenges are still huge there is a societal base and an economic drive to tackle the issues encountered.

References

1. Critical Raw Materials for the EU – European Commission Enterprise & Industry, July 2010.
2. C. Hagelüken and C.E.M. Meskers, “Complex Life Cycles of Precious and Special Metals”, in *the Strüngmann Forum Report, Linkages of Sustainability (chapter 10)*. Edited by T.E. Graedel and E. van der Voet, Massachusetts Institute of Technology and the Frankfurt Institute for Advanced Studies, 2010.
3. The Second trilateral EU-Japan-US conference on critical raw materials, Tokyo, March 2012.
4. (a) COM(2008) 699 Communication “The raw materials initiative - meeting our critical needs for growth and jobs in Europe”, European Commission, Brussels, 2008.
   (b) COM(2011) 21 Communication “A resource-efficient Europe – Flagship initiative under the Europe 2020 Strategy”, European Commission, Brussels, 2011.
   (c) COM(2012) 82 Communication “Making raw materials available for Europe’s future wellbeing. Proposal for a European Innovation Partnership on raw materials”, European Commission, Brussels, 2012.
5. http://www.ovam.be/jahia/Jahia/pid/1684?lang=null (accessed on 26/02/2013)
6. CR^3: http://www.wpi.edu/academics/Research/CR3/index.html (accessed on 26/02/2013),
   SMaRT-Pro^2: http://smartpro2.eu/index.php (accessed on 26/02/2013),
   RARE^3 : http://www.kuleuven.rare3.eu/index.php (accessed on 26/02/2013)
7. EIT (2012), “Catalysing innovation in the knowledge triangle” (http://eit.europa.eu/fileadmin/Content/Downloads/PDF/Key_documents/EIT_publication_Final.pdf) (accessed on 26/02/2013)