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Lead Metallurgy is Fundamental to the Circular Economy

Metals are eminently recyclable, and by recycling and refining complex materials, the EU's interconnected metals sector is responding to the increasing scarcity of certain metals. In this way, we are delivering and recovering the technology and base metals for the EU's Circular Economy (CE). Moreover, metals are at the heart of the energy infrastructures that now run Circular Cities, and they will play an even greater part in the future. One of these metals is lead. With respect to this familiar metal, industry is fully aware that in order to keep on using it, the associated risks need to be well managed at all times. Importantly, lead is a key enabler in the CE, as it is capable of dissolving and carrying a multitude of technology elements. The recovery and recycling of several critical technology elements is based on refining them from lead through well-developed metallurgical processes in which the lead acts as a carrier metal. Limiting lead metallurgy would have a detrimental impact, not only on the lead industry itself, but on all the industries linked to it. It is therefore critical that we maintain and further develop the lead infrastructure and know-how in Europe. To put it simply, lead metallurgy is fundamental if the EU wants to retain its leading position in the global CE.

Executive Summary the 5 lessons learned:

- **Lesson 1:** Lead is frequently seen as a problematic metal that can be detrimental to human health; what is much less well known is its fundamental role in extractive metallurgy and how this is closely associated with the Circular Economy.
- **Lesson 2:** Molten lead has unique properties that means it can act as an efficient liquid carrier for critical raw materials such as In, Bi, Cd and Te.
- **Lesson 3:** Restricting lead metallurgy in the EU would not only have a detrimental impact on the lead industry, but also on all the industries linked to it that work with elements like Ag, Cu, Sb, Sn, Te, and Zn.
- **Lesson 4:** The focus must be on correctly and comprehensively minimising the risks of lead-containing materials for society and carefully managing them, rather than attempting to ban the use of lead.
- **Lesson 5:** An environmentally friendly and energy-efficient lead infrastructure together with the associated research and know-how in Europe is absolutely vital if the continent is to maintain its global leadership in the Circular Economy.



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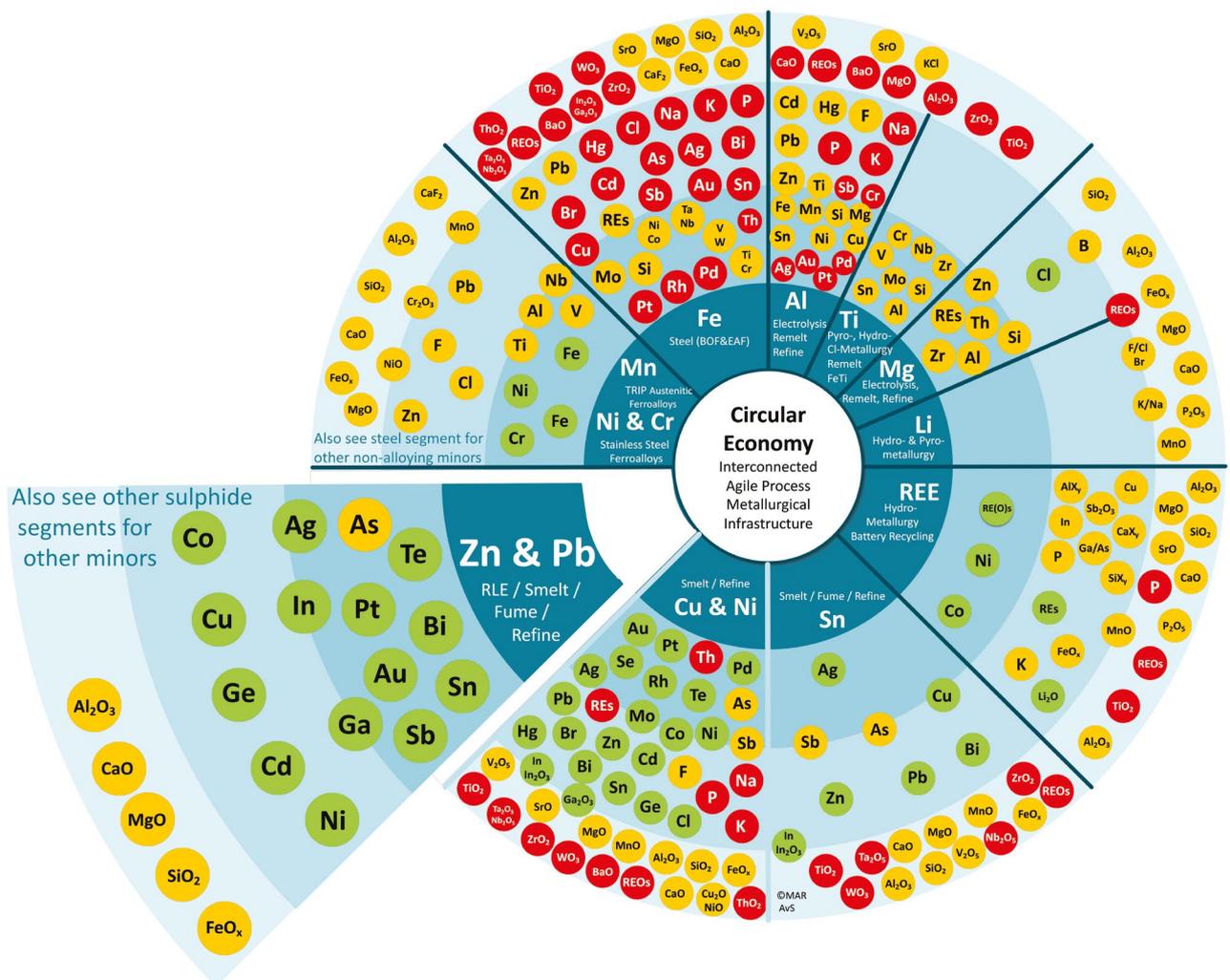
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Criticality of Lead for the Circular Economy

The statement that lead is a “key enabler of the CE”¹ is explained here by the Metal Wheel (see Figure 1). The Metal Wheel visualizes the ability to recover base and technology metals from natural resources, residues and end-of-life products. This ability is based on the knowledge, science and technology established within the different base-met-

al processing infrastructures, each represented by a slice in the Metal Wheel. As such, each sector represents a carrier process metallurgy, including lead. The inner, dark-blue circle forms the backbone of the CE’s extractive-metallurgy and processing capacity, with the ability of the carrier to attract other elements, depending on their chemical and physical association. The green circles in the outer rings of the Metal Wheel indicate those elements that can be recovered through their extraction from the liquid carrier-metal phase or by collecting them as compounds (oxides, chlorides, sulphides), either in a refining infrastructure or elsewhere in connected

¹UNEP (2013) Metal Recycling: Opportunities, Limits, Infrastructure, A Report of the Working Group on the Global Metal Flows to the International Resource Panel. Reuter et al. (<http://www.resourcepanel.org/reports/metal-recycling>)



- Circular Economy’s Carrier Metals Processing Infrastructure
- Elements that dissolve in the carrier metal if metallic
- Elements that are collected as oxides/sulphates/chlorides/etc. in dust, slime, speiss
- Mainly going to lower-value building-material products and dissipative loss
- R Mainly recovered element
- R/L Recovered in alloy/compound or lost if in incorrect stream/scrap/module
- L Mainly lost element: not always compatible with carrier metal or product

Figure 1: The Metal Wheel, reflecting with the dark-blue ring the close interconnected symbiosis between the base-metal sectors that enable the CE. The metals for which the base metal of that segment can act as a carrier metal are indicated with green circles.

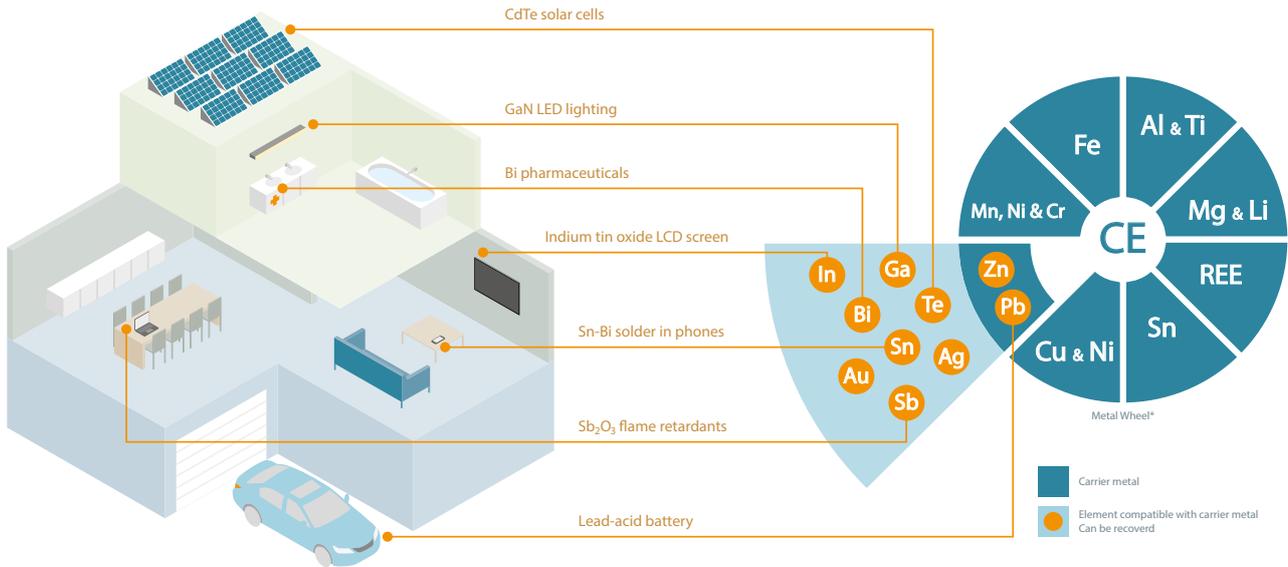


Figure 2: Simplified version in which only the elements that dissolve in the carrier metal in the metallic state and which can be recovered are shown.

metallurgical processing.

The positioning of lead in the Metal Wheel next to other base metals, such as Fe (steel alloys), Ni, Co, Zn, Cu, Sn and Al (alloys) is founded on the natural laws (thermodynamics, heat and mass transfer) involved in the metallurgical processes to recover and recycle several critical technology elements. Molten lead has unique properties (low melting point, intermediate oxidation potential, high difference in density with other typical materials streams) that enables it to act as an efficient liquid carrier for particular minor elements. Upon recycling complex residues and products (WEEE, cars and others), many technology elements, such as In, Bi, Cd and Te, will end up in the lead carrier phase (Figure 2), from where they must and can be recovered through pyro- or hydrometallurgical processes. As shown in Figure 2, the metals obtained through lead processing are present in many of our daily applications (mobile phones, laptops, pharmaceuticals, solar cells, etc.), from where they can be recycled again through an infrastructure involving lead metallurgy.

Metallurgical Processing Infrastructure Criticality – Lead’s enabling role

The metallurgy of primary and secondary materials is complex. A flexible industrial infrastructure is needed to cope with several groups of carrier metals and by-products (Figure 1). It is clear from the green dots (mainly recovered elements) that especially an interconnected Pb-Zn-Cu-Ni-Sn processing infrastructure is required to deliver technology elements from geological sources and also to recycle these elements from complex societal products and residues. Without this processing infrastructure, the realization of a CE is simply not possible.

While a linear economy focuses more on waste management and the recycling of bulk materials, each element in a product, residue or waste matters in a circular economy. New product designs and business models may play an important role in creating circularity, but the metallurgical infrastructure in its full technological sophistication

and economic reality will be essential. In the end, all new business models will in some way use technology elements associated with lead and will need lead to recover them again from complex products and residues¹.

Constraining lead metallurgy would have a detrimental impact, not only on the lead industry itself, but also on all the industries linked to it. Due to its interconnectivity with other metallurgies, companies active in other parts of the Metal Wheel would feel the impact. For example, the metallurgical processing of complex WEEE streams involves the use of both copper and lead as carrier metals. If lead processing were to be excluded, the technology elements normally going to the lead metal, would reside in the copper stream, thereby affecting the copper processing as well.

In addition, there would be a cascading effect on other parts of the supply chain, such as the EU manufacturing and recycling industries. This would drag the EU back by decades on the technological level, would create uncertain evolutions with respect to the circular economy for many elements and cause economic disadvantages with respect to the production of many metals (Ag, Cu, Sb, Sn, Te, Zn, and many more).

If the Metal Wheel is seriously disturbed by eliminating the critically important lead (connected to Zn and all its technology elements), this will lead to the end of the “CE ride” as illustrated by the bicycle in Figure 3. When the CE ride ends, materials that can no longer be treated in the EU will have to be incinerated, landfilled or exported to other regions, where the complete processing system reflected by the Metal Wheel is available. Either of these would result in a significant loss of value for the EU economy.

Lead is a key enabler of the CE due to its ability to attract and dissolve a multitude of technology elements, thereby allowing their efficient recovery. Furthermore, it is an integral part of the metallurgical infrastructure, as illustrated by the Metal Wheel, making it vital

to keep the wheels of the CE turning. The numerous complex mixtures of materials in sustainability-enabling technologies (energy-efficient electronics, renewable energy, electrical vehicles) makes it imperative that the web of the metallurgical processing infrastructure is as tight as it can be to recover at the highest resource efficiency of as many elements as possible. The bicycle shows that prohibiting any carrier metal (and lead is an important one) will cause a much wider impact than purely the removal of a sector. It will lead to the end of the “CE ride”, as the figure indicates.

Acknowledging the risks of lead

Of course, running the Metal Wheel at the highest operational sophistication and environmental compliance, requires managing the risks of lead for society. Industry is fully aware of the hazardous properties of lead and the fact that in order to keep on using it, the risks need to be well managed at all times.

Developing strategies, however, to avoid at all costs the presence of lead in any product or material stream would be fighting against nature. Many critical and valuable non-ferrous metals are associated with lead in natural ore bodies. For example, bismuth is mainly present in lead-based ores. Recycling some of these elements is already a challenge with lead metallurgy, but will be nearly economically impossible without it. And also for lead itself, it is widely spread throughout our natural resources in combination with other base metals (as co-elements, e.g., lead-zinc ores or as impurities). As long as society needs primary resources or the technology elements associated with lead (Figure 2), lead will be present in processing systems and will need a way out. Preventing lead from entering our society is unrealistic. Even if it might be technically feasible to remove lead from products and residues to an unquantifiably low level, such processes would require a lot of energy, which would directly impact the carbon footprint and various other indicators in a negative way.

The focus should, therefore, be on correctly and comprehensively assessing the risks of lead-containing materials for society and closely managing them, rather than striving to ban this element.

The circular economy can only be fully realized with lead in it^{1,2}. With the vision of Circular Cities operating on a Circular Economy basis, the generation of secondary raw materials is possible if there is a well-functioning interconnected metallurgical infrastructure, including lead metallurgy.

¹M.A. Reuter, R. Matuszewicz, A. van Schaik (2015): Lead, Zinc and their Minor Elements: Enablers of a Circular Economy, World of Metallurgy – ERZMETALL 68 (3), 132-146.

²Position statement – Lead REACH Consortium, 2018

¹A. Abadías Llamas, A. Valero Delgado, A. Valero Capilla, C. Torres Cuadra, M. Hultgren, M. Peltonmäki, A. Roine, M. Stelter, M.A. Reuter (2018): Simulation-based exergy, thermo-economic and environmental footprint analysis of primary copper production. Minerals Engineering 131 51–65.

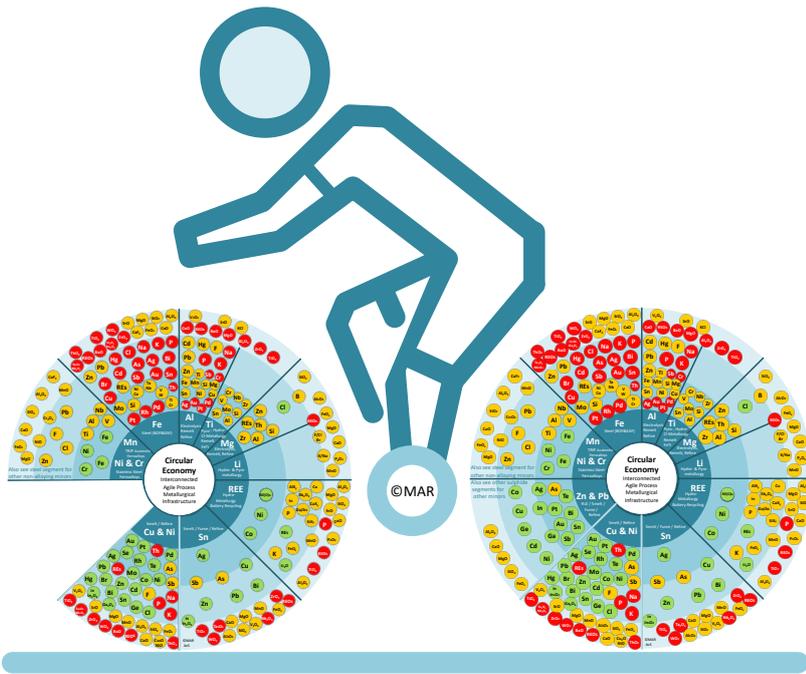


Figure 3: End of the “CE ride” in case of inhibited lead metallurgy

Lead processing infrastructure and know-how in Europe

The societal importance of lead metallurgy and the processing of its residues in the EU has been picked up by a concerned group of EU academics and scientists, working together on a project called SOCRATES, which is a Marie Skłodowska Curie European Training Network (ETN) that also includes 15 early-stage researchers². This ETN for the sustainable, zero-waste valorisation of critical-metal-containing industrial process residues targets ground-breaking metallurgical processes that can be integrated into environmentally friendly, (near-)zero-waste valorisation flow sheets. In particular, they are investigating the valorisation of the slag that is a by-product of the combined copper and lead-processing industry.

Over the years, the infrastructure and know-how on lead and base-metal metallurgy have been developed and applied EU-wide to treat Pb-containing primary ore bodies and residues and recycle complex end-of-life products and other wastes in accordance with the Metal Wheel. The connectivity of lead to the zinc-copper-nickel-tin processing infrastructure is, for example, reflected

in Flanders Metal Valley (FMV) (Figure 4), a world-leading region for high tech metal production, recovery and recycling, which has the following characteristics:

- **The know-how and technology to treat Pb-containing materials is in place.** The non-ferrous companies in the FMV have developed the technology and know-how to treat Pb-containing (usually also associated with zinc) material streams, thereby ensuring that their workers are protected against exposure, according to the regulations. The companies are global, best-in-class facilities with respect to environmental protection, health and safety.
- **Lead metallurgy is a well-developed process to recover technology elements.** The production of Ag, Bi, In, Pt, Rh, Sb, Sn and Te, many of which are on the EU list of Critical Raw Materials³ is based on the refining of these metals from lead metal in the FMV. The infrastructure and know-how to enable this through lead metallurgy has been built up over more than a century, but could be lost very quickly as a result of insensible policy. Once this system has been undone, it will be extremely difficult to reassemble it.

²SOCRATES European Training Network (Marie Curie) <https://etn-socrates.eu>

³http://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en



- Lead metallurgy is part of a complex, industrial symbiosis system to manage complex input material (e.g., WEEE or low-grade residues). Metal processing routes with either copper or lead as the carrier are connected between multiple company infrastructures as these routes start from many and complex input streams.

Both for Flanders Metal Valley and the entire EU, primary resources will be needed in the foreseeable future to fulfil the societal needs towards for instance intelligent energy storage and communication. New technologies and products are driving a growing demand for a number of metals. Many of these metals are either not recycled or their demand is much greater than their availability from recycled sources. As many ore bodies of the technology elements are located outside of the EU, the focus for the EU should be on maintaining the capacity to treat these ores or to recover them from complex EOL products.

Summary: No smart future without lead metallurgy

Disrupting a basic metallurgy infrastructure in the EU will have far-reaching consequences and cause a knock-on effect for all the linked metals. The limitation on lead metallurgy will have a negative impact on the inflow, production, recycling, and therefore availability of many other metals. In this way, our future plans for energy storage, smart cities and clean technologies in the EU might be jeopardized. It is therefore key to keep and further develop the metals infrastructure and know-how in Europe to continue its global leadership role in the CE in the most environmentally friendly and energy-efficient manner.

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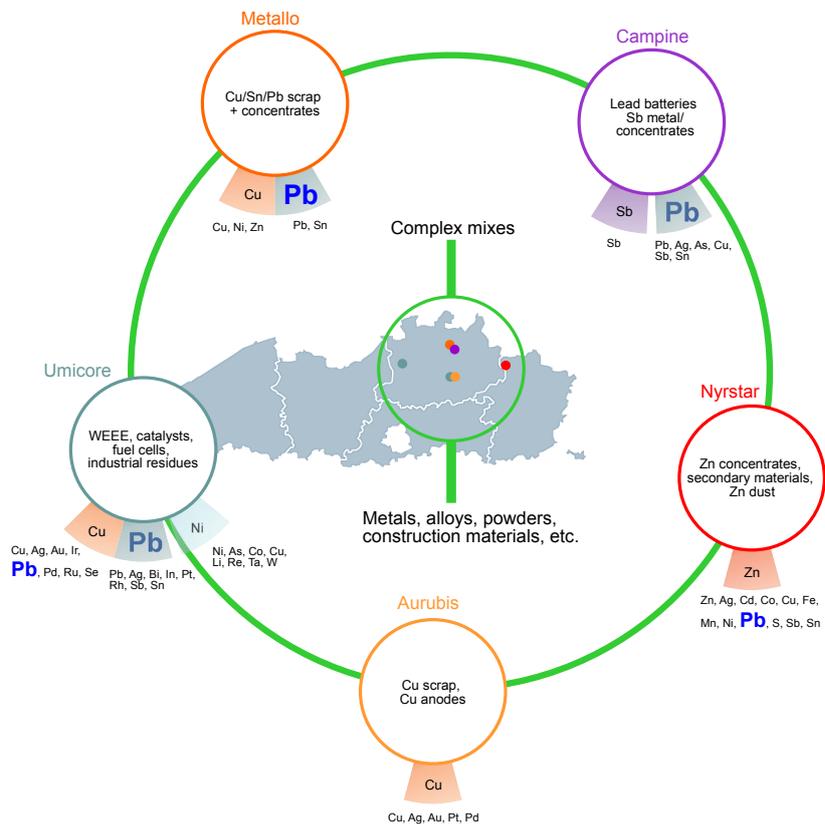


Figure 4: Flanders Metal Valley is a unique network of metal producers and supporting industries in Flanders, Belgium, which forms a pioneering region in recycling and is an industrial realization of the Metal Wheel. The lead metallurgy, in particular, is connected to the zinc and copper metallurgy due to their geological affinity in ores and therefore also in metallurgical intermediate products.



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Annelies Malfliet obtained in 2010 her PhD in the research group of “High Temperature Processes and Industrial Ecology” at the Department of Materials Engineering at the KU Leuven. She currently has the position of research expert at this department, with materials characterisation and vessel integrity as main expertise domains. She is copromotor of PhD students at the KU Leuven and at the University of Utrecht. She has more than ten years’ experience with research projects in close collaboration with both the ferrous and non-ferrous industry. She coordinates the Center of High Temperature Processes and Sustainable Materials Management, which is a cooperation between the research group and leading materials and recycling companies, including Aperam, Umicore, Metallo and Orbix. She is the organizer of the 2-yearly International Slag Valorisation Symposium, bringing together researchers, industrial actors and entrepreneurs to share knowledge and critically discuss the challenges and opportunities in the field of the valorisation of slags and other high temperature residues.

SOCRATES

EU MSCA-ETN

Key project information:

Project type: EU H2020 MSCA-ETN

Project duration: 4 years (2016-09-01 to 2020-08-31)

Website: <http://etn-socrates.eu/>

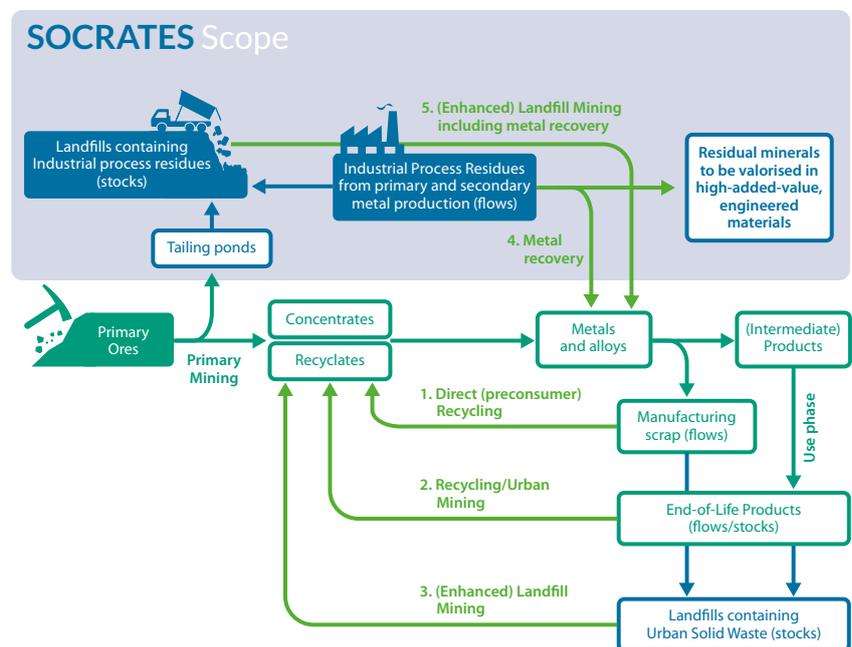
EU contribution: €3.86 m

Coordination: KU Leuven

The European Training Network for the Sustainable, zero-waste valorisation of critical-metal-containing industrial process residues (SOCRATES) targets ground-breaking metallurgical processes, incl. plasma-, bio-, solvo-, electro- and ionometallurgy, that can be integrated into environmentally friendly, (near-)zero-waste valorisation flow sheets. By unlocking the potential of these secondary raw materials, SOCRATES contributes to a more diversified and sustainable supply chain for critical metals (cf. Priority area 3 in EC Circular Economy Action Plan; COM(2015)614/2). The SOCRATES consortium brings together all the relevant stakeholders along the value chain, from metal extraction, to metal recovery, and to residual matrix valorisation in added-value applications, such as supplementary cementitious materials, inorganic polymers and catalysts. To maximise applicability, SOCRATES has selected four commonly available and chemically complementary residue families: (1) flotation tailings from primary Cu production, (2) Fe-rich slud-

ges from Zn production, (3) fayalitic slags from non-ferrous metallurgy, and (4) bottom ashes from incineration plants. As a basis for a concerted effort to strengthen the EU's critical-metal supply chain for Ge, In, Ga and Sb, SOCRATES trains 15 early-stage researchers (ESRs) in technological

innovation: metal extraction (WP1), metal recovery (WP2), residual matrix valorisation (WP3) and integrated assessment (WP4). By training the ESRs in scientific, technical and soft skills, they are the next generation of highly employable scientists and engineers in the raw-materials sector.



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