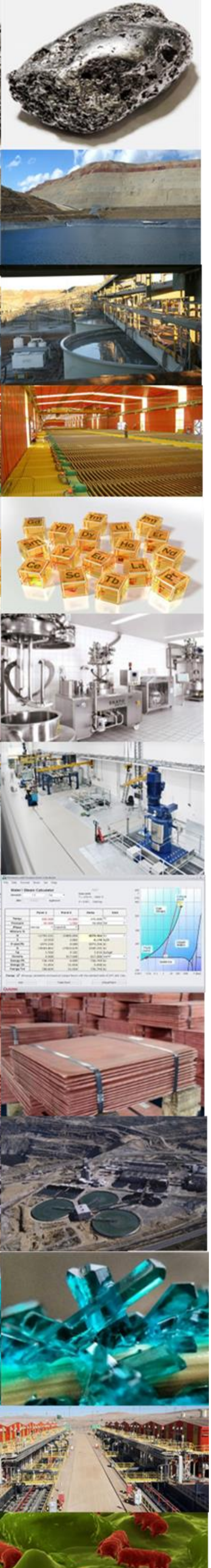

Life Long Learning Course: *HydroMetEC*

Hydrometallurgy in raw materials utilization

An educational and communication programme

Part: International Seminar

Online

16 January 2025

Book of Abstracts

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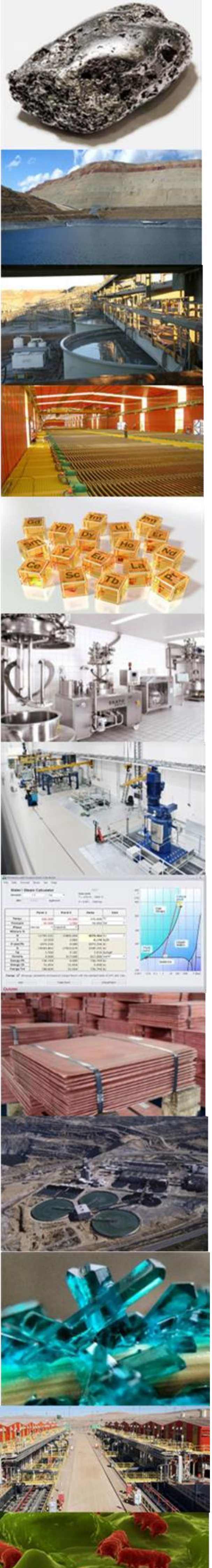

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HydroMetEC: International seminar 16 January 2025

Time, Central European Time (CET)	Title	Presenter
09:00-09:10	Welcome	NTNU
09:10-09:40	Sustainable recovery of critical raw materials	Iakovos Yakoumis (Monolithos, Greece)
09:40-10:10	Advances in understanding of synthesis of oxidic powders using of the ultrasonic spray pyrolysis from the water solution of metallic salts	Dusko Kostic, Srecko Stopic, Bernd Friedrich (RWTH Aachen, Germany)
10:10-10:40	Alkaline leaching of calcium aluminate slags and solution desiilication	Mengyi Zhu (NTNU, Norway)
10:40-11:00	Break	
11:00-11:30	Processing of industrial waste for the recovery of critical metals	Chinmaya Kumar Sarangi (CSIR-Institute of Minerals & Materials Technology, India)
11:30-12:00	Ex-Bauxite: The potential for recovery of CRMs from the bauxite processing value chain	Efthymios Balomenos, Metlen, Greece
12:00-13:00	Lunch	
13:00-13:30	Crystallization in battery recycling	Kerstin Forsberg (KTH Royal Institute of Technology, Sweden)
13:30-14:00	Novel research with domestic elements	Björn Martin Valldor (University of Oslo, Norway)
14:00-14:15	Break	
14:15-14:45	Non-aqueous leaching using acidic organic extractants: opportunities and challenges	Kurniawan (Argonne National Laboratory, USA)
14:45-15:15	HCl cookbook in Hydrometallurgy; some ideas for special cases	Guilherme M. D. M. Rubio, KON Chemical solutions e.U., Austria
15:15-15:20	Closing	NTNU

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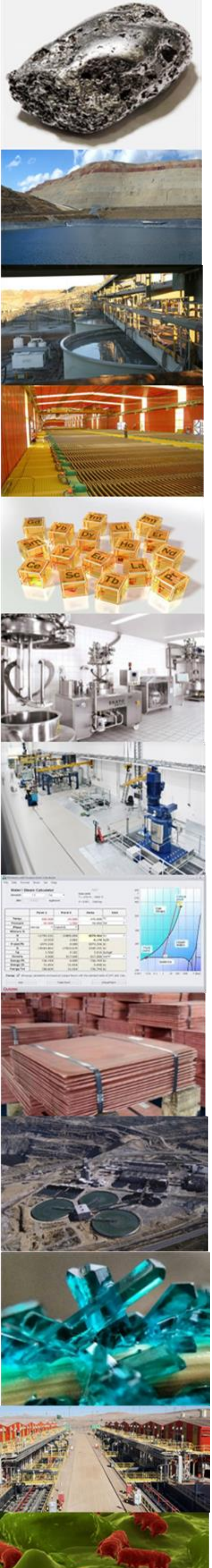

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Sustainable Recovery of Critical Raw Materials through Advanced Hydrometallurgical Recycling: MONOLITHOS's Pioneering Approach

Dr. Iakovos V. Yakoumis, CEO & Founder of MONOLITHOS
yakoumis@monolithos-catalysts.gr

MONOLITHOS is at the forefront of recycling innovation, focusing on the recovery of critical and strategic raw materials (CRMs) from end-of-life (EoL) devices and secondary sources. These sources include automotive catalytic converters, permanent magnets used in electric motors and wind turbines, fuel cells, electrolyzers, electric vehicle (EV) batteries, and a variety of industrial waste streams. A universal, low-cost hydrometallurgical process has been developed to selectively and efficiently extract CRMs, achieving exceptionally high recovery yields of platinum group metals (PGMs), rare earth elements (REEs), and other valuable strategic and critical raw materials. The innovative technology developed by MONOLITHOS, has been designed to minimize environmental impact, allows for sustainable and economically viable recovery of metals essential to high-demand sectors.

MONOLITHOS possesses the specialized expertise, facilities, and scaling capabilities required to process these materials effectively, making it possible to expand recycling operations and catalyst production as industry demands grow. By contributing in the establishment of a reliable supply of recovered CRMs, MONOLITHOS contributes to the stabilization of resource availability in critical sectors, while simultaneously reducing reliance on primary raw material extraction. The innovative recycling methodologies established by MONOLITHOS thus support the transition to a circular economy, reinforcing environmental responsibility and resource sustainability. This approach not only helps secure the supply of essential raw materials but also aligns with global objectives for sustainable development, positioning MONOLITHOS as a key player in advancing environmentally conscious, next-generation recycling technologies.

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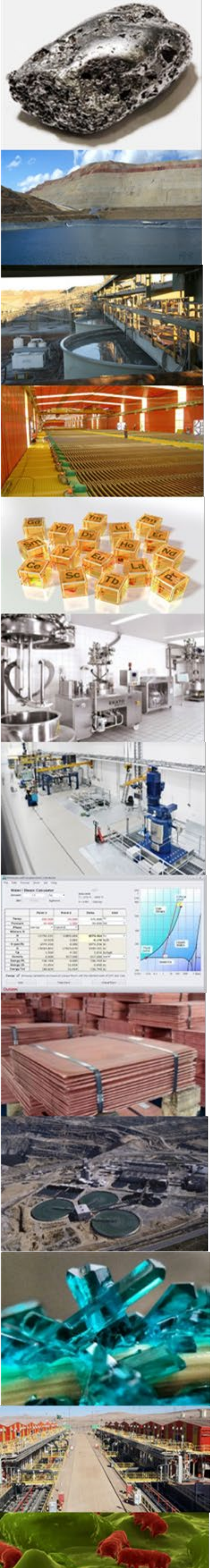

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Advances in understanding of synthesis of oxidic powders using of the ultrasonic spray pyrolysis from the water solution of metallic salts

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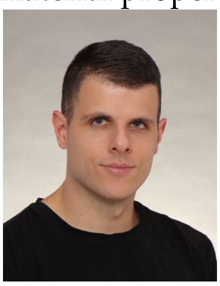
The synthesis of nanosized oxidic powders has become a very important in materials research due to their extensive applications across various industries. This study investigates the production of titanium-based nanoparticles through ultrasonic spray pyrolysis, an adaptable and efficient aerosol-based method. Using titanium oxy-sulfate as a precursor, we examined the influence of critical synthesis parameters in hydrogen and oxygen, including temperature, precursor concentration, and gas flow composition, to optimize particle formation. The transformation of titanium oxy-sulfate was studied over a broader temperature range, from 700°C to 1350°C in hydrogen atmoshere. The resulting powders displayed spherical morphology with particle sizes varying from nanometer to submicron scales, depending on the reaction conditions. Additionally, a comparative study was conducted in PRIZMA, Kragujevac, Serbia where a novel collection technique using electrostatic filters was employed in oxygen atmosphere, replacing the water bubbler system used in earlier experiments. This alternative method enhanced powder recovery efficiency. Moreover, precise control of oxygen content during synthesis was found to significantly impact the crystalline structure and morphology of the final powders. These results highlight the importance of process customization to achieve targeted material properties for advanced applications.



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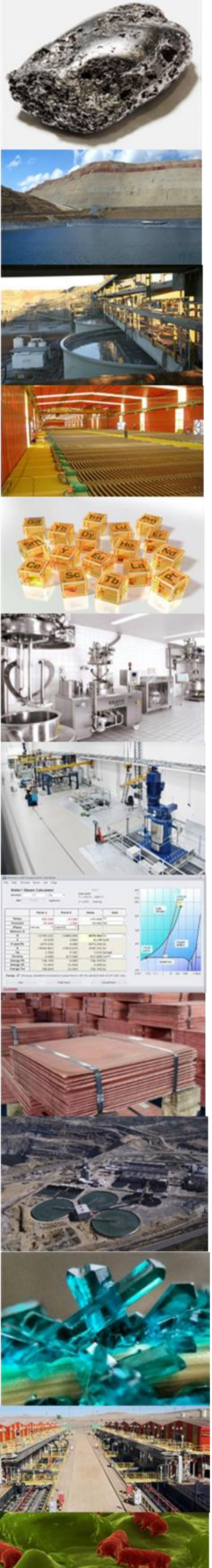

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Alkaline leaching of calcium aluminate slags and solution desilication

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In the current dominant method for alumina production, the Bayer process, substantial amounts of red mud are generated as a hazardous byproduct. This waste is difficult to recycle, posing significant environmental and economic challenges. To address this issue, this presentation introduces a novel hydrometallurgical approach for alumina production using calcium aluminate slags, which can be produced in a precursor pyrometallurgical step through the aluminothermic reduction of Al and CaO-SiO_2 slag, utilizing secondary materials from the aluminium and silicon industries as a novel industrial symbiosis. By treating the resulting CaO-Al_2O_3-based slags with Na_2CO_3 solutions, aluminium is effectively extracted while generating a recyclable $CaCO_3$-based grey mud, promoting a closed-loop material flow.

The presentation examines the effects of key process parameters, including impurity content and cooling rates, on slag mineralogy, impurity distribution, and leaching performance. Findings reveal that optimizing these parameters enhances alkaline leaching efficiency by regulating the formation of $CaCO_3$ isomorphs, thereby reducing passivation during alkaline leaching. In subsequent desilication studies, the hydration of unleached slag with alkaline leachates induces auto-desilication, forming Si-substituted katoite and significantly improving $Al(OH)_3$ purity through a cost-effective process. This innovative approach represents a transformative pathway for sustainable alumina production.

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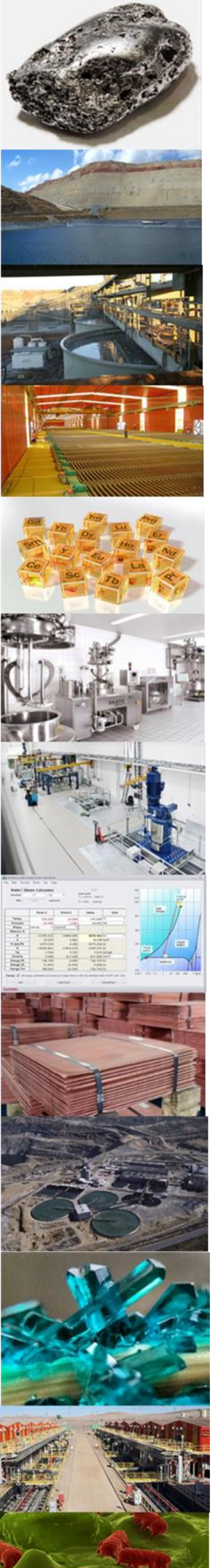

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Processing of Industrial Waste for the Recovery of Critical Metals

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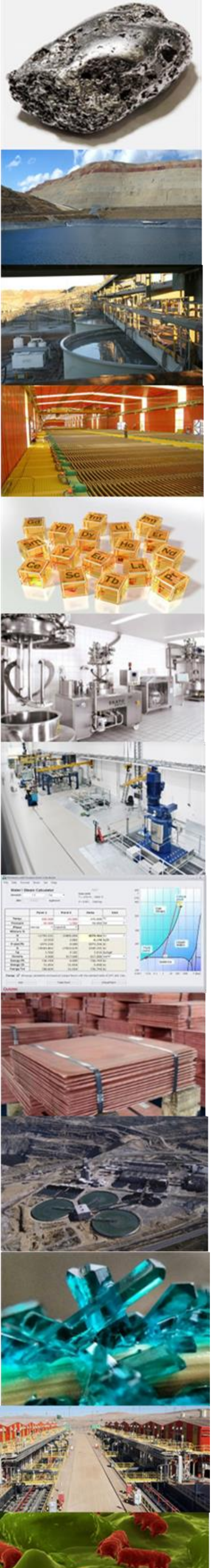
The industrial growth is generally associated with the problem of generating wastes and their safe disposal. Although many industries have been successful in avoiding air pollution through the implementation of pollution control technologies, the storage and utilization of the industrial wastes still remains a big challenge for the industries. Moreover, specific wastes or by-products generated by metallurgical industries such as alloy scrap turnings, refinery effluent, residues, slimes, red mud, etc. are found to be rich in valuable metals such as nickel, cobalt, copper, tellurium, rare earth elements (REEs), etc. which are critical for India as well as several European countries including Norway. Therefore, it is essential to develop suitable technologies, which can process such industrial wastes for the recovery of the abovementioned critical metals or production of value-added materials. It will not only assist in catering the need of critical metals for the nation but also will address the environmental issues associated with the disposal and utilization of the industrial wastes.

The present talk covers different processes and technologies, which have been developed by CSIR-Institute of Minerals and Materials Technology (CSIR-IMMT), for the recovery of critical metals from different industrial wastes. A technology has been developed for the processing of super alloy scrap turnings, which contain a significant amount of nickel and cobalt along with iron and molybdenum. Subsequent to the process development for the recovery of nickel and cobalt from alloy scrap, scale-up testing of flowsheet and basic engineering process package was also prepared. Furthermore, a process has been developed for the production of 99.9% pure cobalt metal from an impure residue containing impurities such as manganese, magnesium, iron and zinc. The bleed solution coming out of an Indian copper refinery contains substantial amount of nickel and copper. CSIR-IMMT has developed a process and tested the flowsheet in pilot scale for the recovery of nickel and copper metal values from the refinery effluent. The anode slime generated in the copper refinery unit contains a significant amount of copper, lead, tellurium, selenium along with a little amount of precious group metals such as gold and silver. A technology has been developed for the extraction of tellurium powder of 99.9% purity from copper refinery anode slimes, while producing copper and lead sulphide as the value-added products. In recent times, the development of suitable technologies for the extraction of REEs from valuable secondary resources has got attention considering their important applications and demand across the globe. Red mud, a solid waste generated by alumina refinery industry, is a potential source of metal values such as aluminium, titanium and most importantly, REEs. Considering the value-addition and mass utilization of red mud in a comprehensive manner, the recovery of REEs as well as iron and alumina from red mud has been accomplished.

Keywords: Industrial waste, Critical metals, Value-addition, Process flowsheet, Pilot testing



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Ex-Bauxite: The potential for recovery of CRMs from the bauxite processing value chain

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Bauxite ore is the almost exclusive mineral resource used today to produce primary aluminium metal, first through the Bayer process (or alumina refining) for the hydrometallurgical extraction of aluminium oxide from the ore and then through the Hall-Héroult process (or aluminium smelting) for the molten salt electrolysis of the aluminium oxide and the production of primary aluminium metal. Bauxite hosts a high content of aluminium hydroxide phases (40-60% wt.) along with iron oxyhydroxides and hydroxides (20-30%) and minor clay minerals. It also hosts a significant amount of trace elements which include among other CRMs and strategic elements like: **Ga, V, Sc, Li and others**. During the processing of bauxite for the production of aluminium such trace elements are found as minor impurities in the final products and by-products, like the bauxite residue (BR) or *are up-concentrated at different side-streams throughout the production value chain*, such as the Spent Bayer liquor (SBL), i.e. the alkaline solution produced after leaching the aluminium bearing minerals from the bauxite ore in the Bayer process and the Spent Bath Salts (SBS), i.e. the molten fluoride salts which act as the electrolyte in the aluminium oxide electrolysis in the Hall-Héroult process. This lecture will provide insights into the bauxite exploitation chain and highlight potential hydrometallurgical options for the recovery of CRMs.

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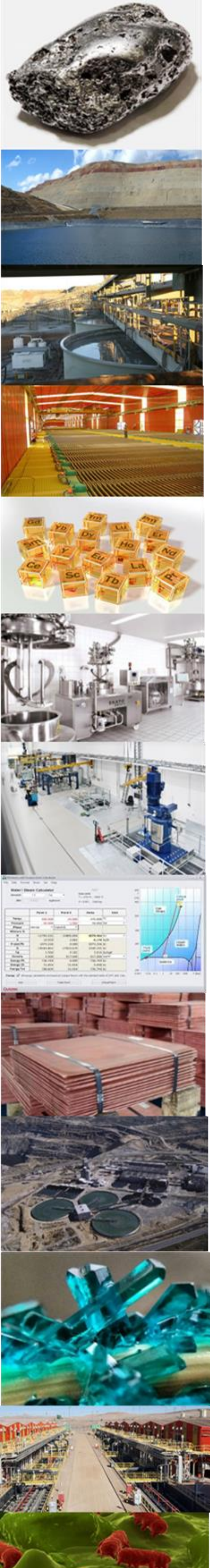

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Crystallization in battery recycling

Kerstin Forsberg, kerstino@kth.se and KTH Royal Institute of Technology

The transformation towards climate neutrality requires a number of key metals, which are essential for renewable energy production and storage. To support this industrial transformation developing the processing and synthesis of materials in the interface of process engineering and materials science is of key importance. Advancing the research and developing the understanding of these processes requires the knowledge and tools of industrial crystallization. This talk will highlight crystallization challenges in battery recycling and opportunities for circularity.

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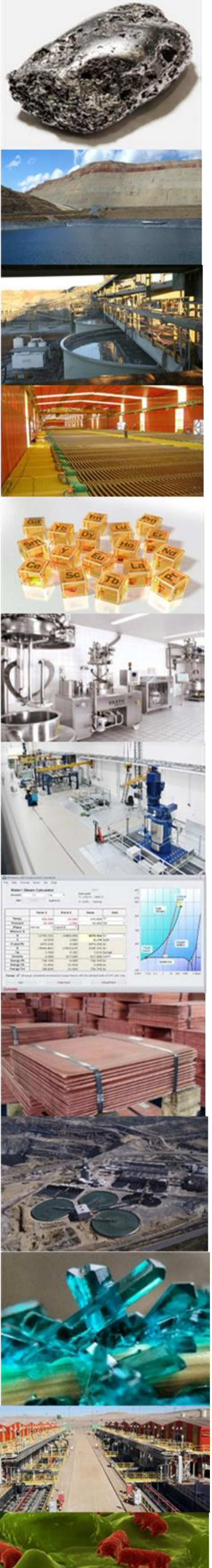

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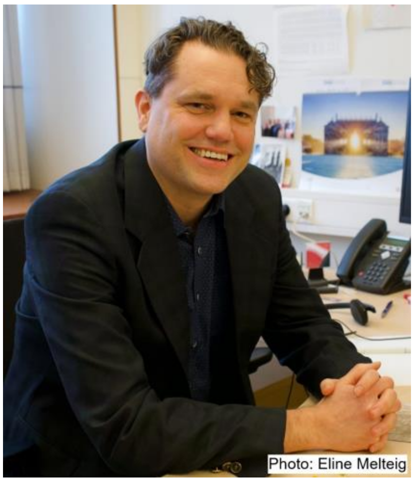
Novel research with domestic elements

Martin Valldor, b.m.valldor@kjemi.uio.no, Inorganic Materials Chemistry, Chemistry Department, University of Oslo

The geopolitical situation influences research, innovation, and technology, and it has been necessary to identify so-called "critical elements" that are essential for today's high-end applications. At all levels of research, an important question is: Why should we try to find novelties that will only benefit those who are in possession of critical elements and their mining sources? We should instead focus on finding novel materials that will only be based on domestic elements and minerals. By this strategy, it should be possible to increase the value of domestic sources. To bring this into a more general research concept, this seminar will give some inspiration to what we can do with metal like Sc and Be, which both are relatively common in Norway.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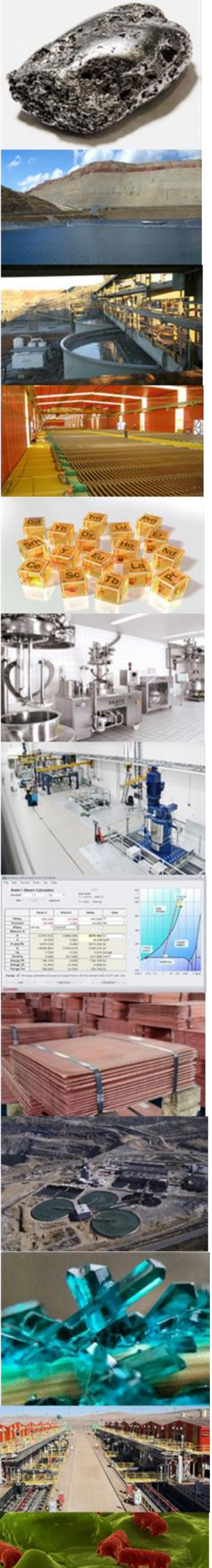

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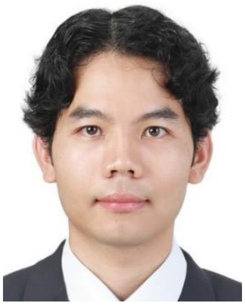
Non-aqueous leaching using acidic organic extractants: opportunities and challenges

Kurniawan
Materials Recycling Group, Applied Materials Division (AMD), Argonne National Laboratory, USA

Abstract: Hydrometallurgical processes are often preferred due to factors such as (i) enhanced recovery yields, (ii) high selectivity, (iii) potential for total recovery of metals, (iv) applicability for treating low- and complex metal sources, (v) reduced energy consumption, and (vi) feasibility for small-scale operations. Indeed, these advantages are not uniformly applicable, as they vary by circumstances. Nonetheless, the primary issue in classical hydrometallurgical processes is the production of significant quantities of wastewater, with each unit operation of hydrometallurgy—such as leaching, metal separation/purification (predominantly via solvent extraction/SX), and metal recovery—contributing to this issue. Ongoing efforts are directed towards addressing this issue; a notable approach involves utilizing non-aqueous (organic) solvents as leaching agents. The utilization of non-aqueous solvents facilitates process intensification by integrating leaching and SX into a single stage. Additional advantages encompass enhanced selectivity (when appropriately chosen), improved solvent recyclability (as opposed to becoming wastewater), and minimized water use (leading to less wastewater generation). Numerous non-aqueous solvents demonstrate potential for this use, including acidic organic extractants that are extensively used in SX processes. This study reviews the potential application of acidic organic extractants as the leaching agents. The advantages of utilizing this class of solvents, compared to other non-aqueous solvents and classical mineral acids, are highlighted. Studies on the leaching of metals from various sources utilizing acidic organic extractants are subsequently presented to enhance discussion. Challenges concerning the use of acidic organic extractants as leaching agents, including efficiency, process economy, and safety, are identified, and future perspectives are discussed.



Dr. Kurniawan is a postdoctoral appointee at Materials Recycling Group, Applied Materials Division (AMD), Argonne National Laboratory, US. He received his PhD degree in Resources Recycling from University of Science and Technology (UST), KIGAM campus, Korea, in 2024, and his bachelor's degree in metallurgical engineering, Bandung Institute of Technology, Indonesia. His research interests are in extractive metallurgy, mostly based on hydrometallurgical processes, separation and purification of precious and energy critical metals/elements from both primary and secondary resources. He is also a regular reviewer for the reputable journal of Hydrometallurgy.

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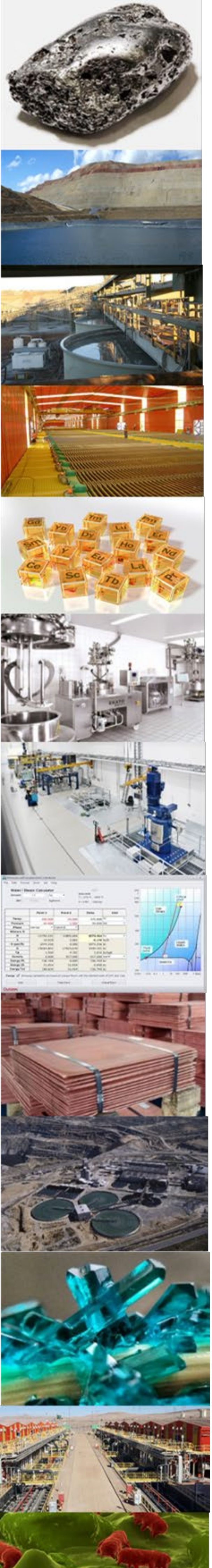

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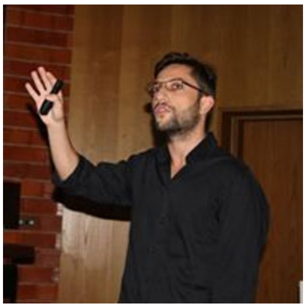
HCl cookbook in Hydrometallurgy; some ideas for special cases

Guilherme M. D. M. Rubio (guilherme.Rubio@kon-chem.com) & David Konlechner

KON Chemical Solutions e.U., Austria

Current industrial processes are scratched in stone, with only small changes occurring in long time spans. This follows the concept "if it works, don't change it". However, with the current energy crises, the CO_2 issues raised in the Paris agreement and various environmental concerns raised in the last decades, new ideas are essential. This presentation KON Chemical Solutions explores innovative applications of hydrochloric acid (HCl) in hydrometallurgy that have been developed and refined for the new era. We highlight its potential to enhance resource recovery and minimize waste. Key case studies include the alumina and magnesia industries, where traditional processes produce significant waste, such as red mud and CO_2 emissions. By leveraging HCl's versatility as a leaching agent, valuable materials like iron, rare earth elements, and high-purity silica can be recovered efficiently. Additionally, novel approaches, such as using non-magnesite sources for CO_2-neutral MgO production, underscore the environmental and economic benefits of closed-loop systems. These advancements exemplify sustainable progress in industrial chemical processes.



Guilherme Rubio

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