Life Long Learning Course: *HydroMetEC*

# *Hydrometallurgy in raw materials utilization*

An educational and communication programme

# Part II: International Seminar

Online

**5-6 November 2020**

# Book of Abstracts

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## Programme: International Seminar

| 5-11-2020 | Day 1 | |
|---|---|---|
| 09:00-09:15 | Welcome | **Jafar Safarian (NTNU)** |
| **Session 1** | **Recycling 1** | **Lena Sundqvist-Öqvist** |
| 09:15-10:00 | Recycling and circular economy in the non-ferrous field (Keynote) | Justin Salminen (Boliden Kokkola) |
| 10:00-10:30 | Resource recovery from EOL magnets: crystallization and precipitation processes. | Kerstin Forsberg (KTH) |
| **10:30-10:45** | **Break** | |
| 10:45-11:15 | Hydrometallurgy for vertical integration in lithium ion battery recycling- Challenges and possibilities | Mahmood Alemrajabi (Northvolt) |
| 11:15-11:45 | Keliber, lithium hydroxide process | Manu Myllymäki (Keliber) |
| 11:45-12:15 | Lithium battery recycling in Norway-current state and outlook | Sulalit Bandyopadhyay (NTNU) |
| **12:15-13:30** | **Lunch** | |
| **Session 2** | **Primary Raw Materials Processing** | **James Mwase** |
| 13:30-14:00 | A case for sustainable alumina production: The Pedersen process revisited | Michalis Vafeias (NTUA) |
| 14:00-14:30 | Recent progresses in the development of bioleaching processes-Overview of industrial applications in Europe | Anne-Gwenaelle Guezennec (BRGM) |
| **14:30-14:45** | **Photo & Break** | |
| **Session 3** | **Industrial Waste Valorization** | **James Mwase** |
| 14:45-15:15 | Recycled platinum group metals as a secondary raw material for producing new automotive catalytic converters. An integrated circular economy model based on hydrometallurgical leaching | Yakoumis Iakovos (Monilithos) |
| 15:15-15:45 | REEs extraction from bauxite residue | Efthymios Balomenos (NTUA/Mytilineos) |
| 15:45-16:00 | Closing of Day 1 | James Mwase |

| 6-11-2020 | Day 2 | |
|---|---|---|
| 08:50-09:00 | Opening of Day 2 | |
| **Session 4** | **Environmental & Safety** | **Jafar Safarian** |
| 09:00-09:30 | Simulation based life cycle assessment for hydrometallurgical processing | Heini Elomaa (Outotec Finland Oy) |
| 09:30-10.00 | Hydrometallurgical Treatment & Environmental challenges in aluminium dross & salt slag treatment | Fabian Azof (REAL Alloy) |
| **10:00-10:15** | **Break** | |
| **Session 5** | **Recycling 2** | **Maria Wallin** |
| 10:15-10:45 | Metal recovery from spent printed circuit boards (PCBs) by acidophilic bioleaching | Agathe Hubau (BRGM) |
| 10:45-11:15 | Optimized extractive metallurgy for spent nuclear fuel reprocessing | Stephane Bourg (CEA) |
| 11:15-11:45 | Recovering PGMs from secondary resources in the EU using innovative low cost and environmentally friendly technologies | Guillermo Pozo (TECNALIA) |
| 11:45-12:15 | Outotec lithium hydroxide process | Marika Tiihonen (Metso Outotec) |
| 12:15-12:30 | Closing of Seminar | Maria Wallin |

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# Recycling and circular economy in non-ferrous field

Dr. Justin Salminen, justin.salminen@boliden.com,
Boliden Kokkola, Boliden Smelters

Metals are vital part of our everyday life and enables the modern society. The demand of non-ferrous metals are increasing and both primary and secondary production are needed to achieve this. The increased consumption of metals require new resources, better recycling, looking for low-grade sources and wastes, and importantly clean energy. Carbon dioxide emissions can be tackled by developing new processes and improving efficiency. The European Union has previously committed to reducing its greenhouse gas emissions by at least 40 % by 2030, compared to 1990 levels. Electrification of processes, use of non-fossil reduction agents, and hydrometallurgy plays an important role to meet these targets.

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# Resource Recovery from EOL Magnets; Crystallization and Precipitation Processes

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Many of today's green and smart technologies require strong permanent magnets for use in *e.g.* sensors, motors and generators. Their higher strength allows the magnets to be smaller and the items lighter compared to when less strong magnets are used. Wind turbine generators, computer hard disc drives and motors in cordless tools are a few examples where strong permanent magnets are used. In a 3 MW wind generator 1.2 tons of magnet is needed and each computer hard disc drive contain 10- 20 g of magnets. The strongest types of permanent magnets in use today often contain the rare earth elements Nd and Dy. The European Commission has listed both the light (Nd) and the heavy (Dy) rare earth elements as critical raw materials for the EU in 2020. When the items containing the magnets reach their end of life (EOL) the magnets can either be directly reused, be recycled separately or be recycled together with other material. Crystallization and precipitation processes are important unit operations in hydrometallurgical processes for resource recovery from magnet containing waste. This presentation will focus on established and more novel crystallization and precipitation techniques of relevance for magnet recycling.

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# Hydrometallurgy for vertical integration in lithium ion battery recycling- Challenges and possibilities

Mahmood Alemrajabi-Lead Engineer of Recycling-Northvolt AB
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Recycling of valuable metals contained in batteries back into manufacturing flows offsets the need for mining raw materials, lowers the environmental impact of batteries and reduces battery costs. The key to achieve this goal is development of an industrial process for handling end-of-life batteries that is grounded in state-of-the-art recycling technologies and driven by environmental and industrial logic.

In recent years, several processes have been developed for recycling of lithium ion batteries in small-scale industrial/pilot plants in Europe, where the key focus has been on hydrometallurgical processes rather than pyrometallurgical.

Hydrometallurgical processes open great possibilities for vertical integration of battery manufacturing and recycling with high recovery rate for valuable metals and reduced amount of by-product, but on the hand these processes are technically and economically challenging.

Hydrometallurgical process for recovery of Ni, Co, Mn and Li from black mass is normally consisted of three key unit operations: leaching circuit, impurity removal circuit and recovery circuit. The design of these circuits is mainly dependent on level of impurity, Fluoride and total organic compound in the feed as well as final product specification and form.

However significant progress in industrial lithium ion batteries recycling has been achieved in the last few years, the developments are very dynamic and further development in many areas are required in the upcoming years.

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# Keliber, lithium hydroxide process

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**Abstract**

Keliber is a Finnish mining and chemical company with an aim of producing battery grade lithium hydroxide for the needs of the growing international lithium battery market. Lithium hydroxide can be used for the manufacturing of batteries intended for the increasingly electrifying traffic (electric and hybrid vehicles) as well as energy storage. Keliber goal is to be the first company in Europe to produce high-purity lithium chemicals from its own ore reserves.

This presentation includes a general update of lithium market and explains the increasing use of lithium. Background of Keliber lithium business case and basics numbers of project economics are presented. Whole production process starting from spodumene ore mining and ending to battery grade LiOH is briefly described as well as contents and results of piloting program which was executed in late 2019.

The main focus of presentation is to describe the heat treatment of lithium concentrate and hydrometallurgical process to produce battery grade LiOH. Spodumene concentrate which is called alpha-spodumene is fed in a high temperature rotary kiln where material is converted to beta-spodumene form. Heat treatment is followed by hydrometallurgical processes. The main process stages in the hydrometallurgical process are high pressure soda leaching, cold conversion, secondary conversion, ion exchange, LiOH chrystallization and mother liquor carbonation. Process flowsheet and main reactions are presented.

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# Lithium Battery Recycling in Norway- Current State and Outlook

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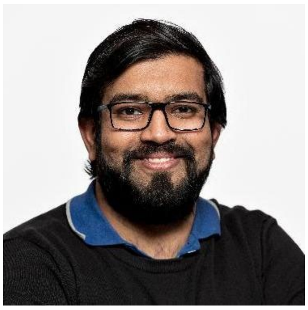
Lithium Ion Batteries (LIBs) are an indispensable part of modern-day technology – their uses ranging from electronic gadgets to passenger cars to industrial vehicles. One of the major drivers for the increasing demand in LIBs for electric vehicles (EVs) is to meet global targets for reductions in greenhouse gas emissions, whereby improving air quality in urban areas among other effects. A typical LIB is designed to have a lifetime of at least ten years, but eventually, these LIBs reach end of life, when waste management becomes an obvious necessity. Norway is in a special position in regards to EVs – it has the highest number of EVs per capita in the world, and an ambition to achieve zero-emission by 2025 for new passenger cars and light vans. In this regard, it is also in a position to develop and commercialize a next generation LIB recycling process.
Current recycling processes suffer from challenges such as low material recovery, high energy consumption, high manual labor intensity and almost no recovery of lithium. With the current low volumes of spent LIBs, the low recovery rate is not a significant problem, but when volumes increase dramatically in 7-10 years, much higher recovery rates will be required. Here, focus will be on our current efforts in LIB recycling with emphasis on hydrometallurgical routes to recover valuable metals from crushed battery powders. The aim in our work is to provide waste streams that can be directly fed into the metallurgical industries of Norway, whereby closing the loop.



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# A Case for Sustainable Alumina Production: The Pedersen Process Revisited

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Global primary aluminium production is totally depended on the uninterrupted flow of high-quality metallurgical alumina, which in turn is almost entirely produced by bauxite, through the Bayer Process. For more than a century, this dominant process inherited to our society all of its primary aluminium and along with it a complex web of environmental challenges. Among them, the handling of the solid residue of the process, termed Bauxite Residue (BR), is probably the most pressing of all. BR and alumina are produced in almost a 1:1 ratio, with huge amounts of the residue amassing in active disposal areas, as well as legacy sites.

As societies move to a circular economy model, the need for sustainable technologies grows and the case of the alumina industry is no exception. One lasting idea within the industry has been the possibility of a holistic utilization of both the Fe and Al content of bauxite. Historically, the only process that achieved this goal industrially was the Pedersen Process which produced cast iron and metallurgical alumina from bauxite. Moreover, the only residue of the process was an inert, $CaCO_3$ based, material.

So, could a 21st century modification of the Pedersen Process contribute to the industry's transformation to a more sustainable model? The goal of this speech is to introduce the audience to the fundamentals of the Pedersen process and the ongoing experimental work on its hydrometallurgical features, which differ substantially from the current state of the art, i.e. the Bayer Process.

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# Recent progresses in the development of bioleaching processes – Overview of industrial applications in Europe

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Bioleaching is a hydrometallurgical technique which uses the metabolic activity of lithotrophic microorganisms for the extraction of metals from sulfide ores. These microorganisms draw their energy from the oxidation of iron and/or reduced inorganic sulfur compounds, producing sulfuric acid and ferric iron. The result is a highly corrosive "bioleaching" solution that dissolves the sulfide minerals by oxidation, releasing the metals to solution. Bioleaching is a proven technology already industrially applied. Its main advantages over other processes are to be cost-effective and to provide the same duty in a simpler way in terms of operability. Bioleaching is also attractive insofar as it presents few environmental hazards. Although this technology remains a niche application, in the last decades it has garnered growing interest from both the academic community and the mining industry, who increasingly consider biomining to be an ecologically acceptable and economic alternative to conventional processes such as pyrometallurgy or conventional hydrometallurgy. This presentation will focus on current industrial applications of bioleaching as well as recent progresses in the development of this technology in Europe.

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# Recycled Platinum Group Metals as a Secondary Raw Material for Producing New Automotive Catalytic Converters. An Integrated Circular Economy Model based on Hydrometallurgical Leaching


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In terms of critical raw materials (CRMs) sustainability, platinum group metals (PGMs) recovery is mandatory. The most concentrated secondary resource of PGMs (i.e. Pt, Pd, Rh) refers to spent catalytic converters (SCC) deriving from Light and Heavy Duty Vehicles (LDVs and HDVs); Hydrometallurgy is the mainstream process for recovering PGMs from SCCs.

A single step hydrometallurgical process has been developed by MONOLITHOS obtaining 100% Pt, 92% Pd and 60% Rh recovery yields without pre-treatment, under mild acidity conditions (3M HCl), low temperatures ($70^{o}C$) and high S/L ratio leached (0.7). A state-of-the-art leaching process has also been developed by TECNALIA, using Deep Eutectic Solvents (DES), where 86% Pd, 83%Pt and 43% Rh recovery yields are reached.

Due to remarkable recovery rates on LDVs, MONOLITHOS has extended the hydrometallurgical process on HDVs' feed, namely Diesel Oxidation Catalysts (DOCs) and Diesel Particulate Filters (DPFs), which are highly concentrated in Pt. High recovery yields of 95% and 75% of Pt from DOCs and DPFs, respectively, after thermal treatment have been reported. Thermal pre-treatment of the feed enhance the recovery rated by 40%, since C contaminations are removed.

The aforementioned recovery processes offer eco-, cost- efficiency, as well as potential for industrial upscaling; thus, it will be applied to CEBRA (Pr. *Nº 19148*) project. CEBRA upscaling project refers to an integrated model of sustainable circular economy, aiming to decouple Europe from PGM' imports, by manufacturing SCCs integrating 100% recycled PGMs, while simultaneously decreasing PGM' quantity via partial substitution copper.


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# REE Extraction form Bauxite Residue

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Bauxite Residue' (BR) refers to the insoluble solid material, generated during the extraction of alumina ($Al_2O_3$) from Bauxite ore using the Bayer process. When bauxite ore is treated with caustic soda, the aluminium hydroxides/oxides contained within, are solubilized, with approximately 50% of the bauxite mass being transferred to the liquid phase, while the remaining solid fraction constitutes the -bauxiteresidue. The primary aluminium industry has always focused on discovering potential applications for BR utilization. The vast amount of research and studies on BR utilisation is justified by more than 734 patents from 1964. Possible applications can broadly be broken down into various categories, such as cement and building materials production, iron production, trace element (Ga, REE,V,…) recovery, use as soil amelioration, landfill capping, acid mine drainage treatment and others. The recent REE crisis fueled significant research effort in recovering the REE that are found in some BRs in concentrations between 1 - 2 kg of total REE / t of BR . Given the large quantity of the annual BR production, the total amount of contained REE becomes significant and could cover part of the global REE demand. Furthermore, while the treatment of BR for the recovery of REEs does not solve the BR deposition problem, as the volume of the waste remains practically unaffected, it does help in the economic viability of holistic processing flowsheet seeking to achieve near zero-waste through multiple processing steps.

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# Simulation based life cycle assessment for hydrometallurgical processing

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The HSC-Sim module within HSC Chemistry software by Metso Outotec is used for simulation of whole processes and can be used to draw graphical flowsheets, and further to simulate processes for chemistry, metallurgy, mineralogy, etc. Simulations can be combined with life cycle assessment (LCA) in order to provide accurate and detailed data about metallurgical processes. The topic of this presentation is adaptation of simulation based life cycle assessment for hydrometallurgical processing, specifically gold processes.

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# Hydrometallurgical treatment and environmental challenges in aluminum dross and salt slag treatment

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The amount of aluminum (Al) which is produced by secondary production has been increasing for decades as the process requires only nearly 5% of the energy needed for primary production. The low-energy footprint has also reduced the carbon footprint in our environment, which is in line with the framework of EU climate and energy. However, the environmental challenges related to Al-dross and salt slag processing are apparent. A major problem of the salt slag treatment is it has high reactivity with water or even humidity in the air, leading to the formation of unpleasant odorous gases. REAL ALLOY NORWAY AS becomes one of the important facilities in maintaining the sustainability of Al secondary production in Europe as it has the biggest Al-dross and salt slag treatment facilities in Norway, which are located at Rød and Raudsand, Molde municipality.

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# Metal recovery from spent printed circuit boards (PCBs) by acidophilic bioleaching

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Given its compositions and the huge amounts produced every year, Waste Electrical and Electronic Equipment is a valuable resource. Spent printed circuit boards (PCBs) contain various metals, including precious and base metals, with concentrations that are generally higher than those found in primary resources. Today, the recovery of such metals is based on pyrometallurgy. However, this method presents several disadvantages (including high-energy consumption, toxic gas emissions, etc.). It is therefore necessary to develop new processes to overcome these limitations. Among the alternative technologies, bioleaching, i.e. microorganisms-assisted dissolution, could be combined with other hydrometallurgical techniques to recover metals. In bioleaching processes, the use of bacteria allows the dissolution of metals with markedly reduced amount of reagents and mild pressure and temperature conditions, compared to usual operating conditions. However, when applied to spent PCBs, bioleaching rates showed significant variations, due to the variability of spent PCBs, of microorganisms, the different operating conditions, etc. To reduce the toxicity of metals contained in PCBs towards bacteria, a new bioreactor was designed in BRGM. From the results of this study, new perspectives open up on the use of bioleaching for the recovery of some metals in e-wastes.

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# Optimised extractive metallurgy for spent nuclear fuel reprocessing

Stéphane Bourg, CEA-ISEC, stephane.bourg@cea.fr

For more than 40 years France has developed a global circular economy approach to manage its nuclear fuel cycle, from the uranium mine to the ultimate nuclear waste management, including uranium purification and enrichment, fuel fabrication, reactor construction and operation, spent fuel recycling with uranium/plutonium MOX fuel fabrication and waste conditioning.
Starting from a life cycle analysis of different nuclear fuel cycle management options, a focus will be made on the extractive metallurgical process allowing the efficient recovery and recycling of the valuable resources from the spent nuclear fuel, including the support brought by process modelling and simulation

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# Recovering PGMs from secondary resources in the EU using innovative low cost and environmentally friendly technologies

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The European Commission classifies platinum group metals (PGMs) since 2011 as Critical Raw Materials that are essential for the European economy but are at high supply risk. PGMs are mainly used in autocatalysts to cut dangerous NOx and SOx emissions and are also used in a wide range of industrial applications for which there are often no substitutes. The PLATIRUS project, funded by the European Commission under Horizon 2020, has developed an innovative, cost-effective, environmentally friendly, and compact technologies to recover PGMs from secondary resources in the EU.

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# Outotec Lithium Hydroxide Process

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**Abstract**

Outotec has developed a novel, patented Lithium refining technology: **Outotec Lithium Hydroxide Process**. The new technology offers a fast throughput, direct leach process for calcined spodumene concentrate to lithium hydroxide monohydrate product. The leach process is also environmentally sustainable: acid and sulfate free, with optimized reagents consumption. The process leach residue is neutralized & inert mineral residue.

The process concept is based on an alkaline leach process in two stages. Lithium is first extracted from the calcined spodumene mineral in a pressure leaching stage by soda ash. In the next stage, lithium is solubilized in a conversion reaction by hydrated lime, producing lithium hydroxide in solution and solid calcium carbonate, which will report to the mineral residues. The downstream process involves tailored solution polishing, product lithium hydroxide monohydrate crystallization and process solutions recycles.

During the past year Outotec merged with Metso to create a new company called Metso Outotec. At the same time, we have taken some very important steps forward in commercialization of our proprietary lithium technologies and come up with a total solution offering to a compact footprint plant supported by own equipment products.

Feasibility of the process has been tested and confirmed in several pilot campaigns and operation of a continuous demonstration plant campaign in January 2020. Tested spodumene concentrates cover a large range of lithium grades (4.5-6.6 % $Li_2O$) and impurities.

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